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COMPACT

EFFECTS OF PROJECTED YIELDS AND INITIAL INVENTORIES ON HARVEST SCHEDULES OF DOUGLAS-FIR

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INTRODUCTION

As demand for forest products increases and supply decreases, it becomes increasingly important that forest managers thoroughly understand harvest scheduling, the process by which harvest levels are planned over time in order to achieve an owner's objectives. Such plans have two parts: the short-run harvest (plans for when, how much, and where to cut during the first decade) and the long-run projection (the anticipated harvest levels from the end of the first decade to the end of the planning horizon and the anticipated condition of the forest over time). It should be noted that long-run projections are not prescriptions but estimates. As Beuter et al. (1976, p. viii) have pointed out,

> The projections are not intended to be forecasts of what will happen.... A projection simply indicates what would happen if its assumed set of conditions did indeed occur.

Ware and Clutter (1971) demonstrate the importance of harvest scheduling by noting that it controls growing-stock volume over time, growth rates, cash flows, the present net worth of the forest, and returns on investment made in the forest.

Because the timber resource is becoming increasingly valuable, forest managers should also realize how harvest scheduling is affected by uncertainties about measurements and future events. Uncertainty in harvest planning has often been ignored in the past, with only single values instead of ranges being reported in recommended harvest plans and in studies on public policy and timber supply. Among the uncertain parameters that affect harvest scheduling are the initial inventory (which is based on a sample), the predicted yields, regular and catastrophic mortality, anticipated levels of silvicultural activities, future utilization standards, and possible changes in (a) the land base, (b) environmental constraints, or (c) the inherent productive capacity of the forest (Davis 1966, Oregon State Forestry Department 1979).

This study seeks to determine the sensitivity of short-run and long-run harvest schedules for Douglas-fir in western Oregon to changes in two of these uncertain parameters: data on initial inventory and assumptions about future yield. Identifying how harvest schedules differ according to varying assumptions about these parameters should help forest managers recognize the gains or losses in harvest volume that may result from using necessarily uncertain data in their scheduling.

LITERATURE REVIEW

The U.S. Forest Service has conducted several major sensitivity analyses of various factors affecting harvest scheduling. Two of note are Bell (1976), and U.S. Department of Agriculture (1976). Using Timber RAM (Navon 1971) as the computational tool and nondeclining evenflow as the harvest policy, Bell (1976) examined how intensive management affects harvest yields. He found that, contrary to traditional thinking, it is possible for silvicultural activities that increase future yields to decrease the computed harvest levels, i.e., produce a negative allowable cut effect. Although this effect was observed on over half the situations tested, he observed no characteristics that might permit predicting such a result.

Concurrently, the U.S. Department of Agriculture (1976) compared nondeclining evenflow with alternative methods of planning harvests on National Forests. These alternatives included economic maximization, sequential evenflow under which harvest levels could change each period either up or down within preset bounds, harvest of a fixed percentage of available timber each period, and others. In addition to assessing the sensitivity of predicted harvest levels to the computational method used, this study also examined the effects of using different assumptions about future utilization standards, future management intensities, and the combination of planning areas, as well as comparing harvest schedules for high and low management intensities. Harvest levels for the first decade under highly intensive management were 25 to 30 percent higher than those projected under less intensive management. The rise predicted in harvests under increased management intensity is a function of the yield assumptions originally made. No attempt was made to verify the correctness of the assumed yields. However, as was noted (p. 47) in the study, the predicted

> harvest level is greatly influenced by the yield assumptions. Because the possible gain is quite large, the error introduced if the yield assumptions are incorrect is a source of concern.

In a study of the timber supply in Idaho, Hatch et al. (1976) used two different utilization standards and four alternative growth and mortality rates. Results showed that increases in timber supply through improved management were small in comparison with gains resulting from relaxation of multiple-use or environmental constraints.

Beuter et al. (1976) also used sensitivity analysis in making simulations to project Oregon's future timber harvests under various management intensities and harvest policies. Their results showed that under current policies and management levels, western Oregon will face a 22 percent decline in harvest levels by the year 2000. Furthermore, intensified management will have little effect on the decreased timber supply over the next 30 years. The authors suggest that the decline can best be prevented if harvest policies on publicly owned forests are shifted away from nondeclining evenflow and if nonindustrial private owners concentrate on maximizing volumes or revenues.

PROCEDURE

Within the last 15 years, several computer programs have been developed for harvest scheduling. Examples include SORAC (Chappelle and Sassaman 1968), SIMAC (Sassaman et al. 1972), and TREES (Tedder et al. 1980). A major benefit of these programs is that they permit rapid testing of a wide range of assumptions about input parameters. In the present study, TREES (Timber Resources Economic Estimation System) is used to conduct a sensitivity analysis of the effects of assumptions about initial inventory and future yield on harvest schedules.

Several different models are being used in the Pacific Northwest to predict future yields of Douglas-fir. Thus, one hypothesis tested in this study is that the predictions of short-run or long-run harvest schedules developed with these various models do not differ appreciably. Comparisons are made by holding all assumptions and other inputs constant except for information on yield and using TREES to simulate harvest schedules according to the various models.

The same technique is used to test the effects of using inaccurate inventory data. Inventory data are limited by the accuracy of the sample on which they are based, and a worst-possible-case inventory error is simulated by using the extremes of the confidence limits as defined by a desired level of precision.

The major steps in this study can be summarized as follows:

1. Obtain and standardize the yield predictions to be compared.
2. Obtain sample inventories and adjust them to simulate inaccurate inventory data.
3. Establish combinations to be compared.
4. Establish assumptions needed in the harvest scheduling model and make simulation runs.
5. Compare harvest levels resulting from appropriate combinations of assumptions.

YIELDS UNDER EXTENSIVE MANAGEMENT

The following predictors are used in the comparisons of yields under extensive management (which includes only planting and final harvest):

1. McArdle et al. (1961), commonly known as Bulletin 201
2. Bruce et al. (1977) and Reukema and Bruce (1977), commonly known as Douglas-fir Interim Tables (DFIT)
3. Chambers and Wilson (1972), commonly known as the DNR Empirical Yield Tables
4. Hoyer (1975), commonly known as Hoyer's Natural Stand Yields
5. Yields predicted by Bulletin 201 (McArdle et al. 1961) less 15 percent

Before legitimate comparisons could be made, it was necessary to standardize the utilization rule and log scale measurement for all yield predictors. This was done by using net live volume (not gross production) in total cubic feet, including top and stump, for all trees as the volume measure. An exception was that the DNR Empirical Yield Tables (Chambers and Wilson 1972) are based on trees greater than 7 inches d.b.h. as the standard rather than on all trees. The effect of this discrepancy should be minor because most trees are larger than 7 inches in diameter by the time harvesting occurs. Thus, DNR yields will be slightly lower for younger age classes than they would be if all trees were included.

Total cubic feet, including top and stump (CVTS), was selected as the volume measure for two reasons: it was available for all the yield predictors, and it eliminates the problem of guessing future utilization standards. Scribner board foot volume, which is still the most commonly used log rule for Douglas-fir in the Pacific Northwest, is not suitable for analytical use (Meyer 1930). Evidence indicates it is much more variable than cubic foot volumes, especially for young stands or those on poor sites. This variability can result in large, erratic differences between actual stand yields and those in yield tables. Cubic foot volume is a more consistent measure. In addition, the relation between percent normality for cubic foot volume and that for basal area is very regular (Meyer 1930; Chambers, personal communication, 1980).

There are disadvantages to using cubic feet rather than Scribner board feet. Cubic foot measure is not currently in widespread use operationally, though it is expected to be in the future. Moreover, the relative differences in harvest volumes reported in cubic feet are not necessarily the same as would be reported if Scribner volumes were used. Thus, predicted harvests in cubic feet would have to be converted to Scribner volume in order to implement them in the field.

This problem is compounded when management intensification in the form of commercial and precommercial thinning is considered. Use of Scribner measure with these practices results in increased merchantable volume through accelerated diameter growth, a benefit that use of cubic volume tends to hide.

Bulletin 201 was used as the base yield or standard of comparison for extensive management because it has been the most widely used yield information for Douglas-fir. Another reason for selecting it is that Beuter et al. (1976) reformulated it for use in harvest simulations with the TREES model.

Inventories were formulated for three levels of site class (100-year basis) according to the classification in Bulletin 201: low (indexes 80 to 110), medium (120 to 160), and high (170 to 200). Yield information from Bulletin 201 was supplemented with data from the U.S. Forest Service for ages 170 to 300. The yield-generating equations used for Douglas-fir in TREES were originally formulated by Beuter et al. (1976) to predict cubic foot yield as a function of age. In order to make all yield predictions conform to the same productivity classes, standardized site indexes were developed for both the 100-year base in Bulletin 201 and King's (1966) 50-year base.

The second predictor compared, DFIT, is a computerized single-stand simulator developed by U.S. Forest Service personnel at the Pacific Northwest Forest and Range Experiment Station. It has the capacity to simulate extensively or intensively managed stands. The DFIT yields for extensive management through age 125 were generated by substituting 100-year site indexes for various ages into equations 0-1 and 0-9 of Bruce et al. (1977) for natural stands:

$$A_B = A_T - 13.22 + 0.033S$$

$$\log V = 1.9628 - 12.4083/A_T - 1.7408/(A_B)^{0.25} + 1.3176 \log S$$

where:

A_B is age at breast height

A_T is total age

S is site index (100-year basis) from Bulletin 201

V is total cubic foot volume per acre

Beyond age 125 these equations gave unreasonably high volumes per acre, probably because of extrapolating beyond the data base. Yields for ages 135 through 305 were obtained by determining the difference between the yield for the age in question and that for the next lower age in Bulletin 201 and then adding that difference to the yield for the next lower age as given in DFIT. For example, to obtain the DFIT yield for age 135, the difference between the yields for ages 125 and 135 in Bulletin 201 was added to the DFIT yield for age 125.

The DNR Empirical Yield Tables, the third predictor compared, were developed for natural stands of Douglas-fir in western Washington. An empirical yield table is also called a variable-density yield table. As opposed to a normal yield table based on fully stocked stands, an empirical yield table is based on average stand conditions found in nature. The particular yields used for this study are for stands at 100 percent density (fully stocked) and are thus compatible with the other yield predictors.

As with the DFIT yields, the DNR yields were generated by using combinations of age and site index in the following equation from Chambers and Wilson (1972):

$$\begin{aligned} \mathrm{CVTS} = {} & -\,938.33423 \\ & + (2.01933 \times \mathrm{Age_B} \times \mathrm{Site} \times \mathrm{PNBA}) \\ & - (21.28009 \times \mathrm{Age_B} \times \mathrm{PNBA}) \\ & + (41.49121 \times \mathrm{Age_B}) \\ & - [(0.51870 \times (\mathrm{Age_B})^2] \\ & - (1567.56665 \times \mathrm{PNBA}) \end{aligned}$$

where:

CVTS is total cubic foot volume, top and stump

$\mathrm{Age_B}$ is age at breast height (total age minus 6 years for high sites, minus 8 years for medium sites, and minus 9 years for low sites)

Site is site index on King's (1966) 50-year basis

PNBA is percent normal basal area (in this case, always 1.0).

Yields from this equation were used for age classes up to and including 105 years. Yields for ages 115 to 305 were obtained in the same manner as were the DFIT yields for older age classes.

The fourth predictor compared, the normal yield tables for Douglas-fir (Hoyer 1975, Appendix Tables 14-A through 14-E), is based on 50-year site indexes. Yields from these tables were determined by linear interpolation in order to approximate the appropriate 50-year site index most closely. This source provided yields for age classes through age 95. Yields for ages beyond 95 were obtained by the method described earlier.

The final set of yields for extensive management are those of Bulletin 201 less 15 percent. A 15 percent reduction in yields was selected as the most likely direction and magnitude of error in yield predictions (Pacific Northwest Forest and Range Experiment Station 1963, Bruce 1977).

The five sets of yields used for extensive management in this study are shown in Table 1.

TABLE 1.
YIELDS PREDICTED FOR EXTENSIVELY MANAGED STANDS BY THE FIVE MODELS ACCORDING TO SITE CLASS AND AGE.

Site class and age (yr)	Yields (ft^3/acre) predicted by --				
	Bulletin 201	DFIT	DNR	Hoyer	Bulletin 201 less 15%
High					
25	3,309	4,545	3,868	4,000	2,812
35	5,916	7,204	6,586	7,150	5,029
45	8,303	9,438	9,070	9,809	7,058
55	10,480	11,297	11,339	11,988	8,908
65	12,456	13,075	13,644	14,232	10,588
75	14,241	14,676	15,745	16,282	12,105
85	15,845	16,163	17,900	18,419	13,468
95	17,277	17,650	19,734	20,401	14,686
105	18,548	19,136	21,719	21,672	15,766
115	19,668	20,552	23,135	22,791	16,718
125	20,645	21,772	24,355	23,769	17,549
135	21,491	22,648	25,231	24,615	18,268
145	22,215	23,342	25,925	25,338	18,883
155	22,826	23,952	26,536	25,950	19,402
165	23,334	24,462	27,045	26,458	19,835
175	23,751	24,878	27,461	26,874	20,188
185	24,084	25,211	27,794	27,207	20,472
195	24,344	25,471	28,054	27,468	20,693
205	24,541	25,668	28,251	27,665	20,860
215	24,684	25,811	28,394	27,808	20,982
225	24,784	25,911	28,494	27,908	21,067
235	24,851	25,977	28,560	27,974	21,124
245	24,893	26,019	28,602	28,106	21,160
255	24,921	26,047	28,630	28,044	21,184
265	24,932	26,057	28,640	28,054	21,193
275	24,932	26,057	28,640	28,054	21,193
285	24,932	26,057	28,640	28,054	21,193
295	24,932	26,057	28,640	28,054	21,193
305	24,932	26,057	28,640	28,054	21,193
Medium					
25	2,482	2,954	1,979	2,500	2,110
35	4,427	4,843	4,139	5,087	3,763
45	6,206	6,461	6,102	7,142	5,275
55	7,827	7,829	7,776	8,563	6,653
65	9,298	9,125	9,645	10,239	7,903
75	10,624	10,259	11,172	11,835	9,031
85	11,815	11,315	12,566	12,756	10,043
95	12,877	12,320	13,773	13,871	10,946
105	13,818	13,273	14,984	14,812	11,746
115	14,646	14,166	15,877	15,640	12,449
125	15,367	14,981	16,692	16,361	13,062
135	15,990	15,604	17,315	16,984	13,592

(Continued)

TABLE 1. (Continued)

Site class and age (yr)	Yields (ft^3/acre) predicted by --				
	Bulletin 201	DFIT	DNR	Hoyer	Bulletin 201 less 15%
Medium (continued)					
145	16,521	16,135	17,846	17,515	14,043
155	16,969	16,583	18,294	17,963	14,424
165	17,340	16,954	18,665	18,334	14,739
175	17,642	17,296	19,007	18,636	14,996
185	17,883	17,537	19,248	18,877	15,201
195	18,070	17,724	19,435	19,064	15,359
205	18,210	17,864	19,575	19,204	15,479
215	18,311	17,965	19,676	19,305	15,564
225	18,381	18,035	19,746	19,375	15,623
235	18,426	18,080	19,791	19,420	15,662
245	18,454	18,108	19,819	19,448	15,686
255	18,474	18.128	19,839	19,468	15,702
265	18,478	18,132	19,843	19,472	15,706
275	18,478	18,132	19,843	19,472	15,706
285	18,478	18,132	19,843	19,472	15,706
295	18,478	18,132	19,843	19,472	15,706
305	18,478	18,132	19,843	19,472	15,706
Low					
25	1,406	1,729	631	1,561	1,195
35	2,523	2,966	2,273	3,356	2,144
45	3,546	4,045	3,765	4,683	3,013
55	4,478	4,958	5,064	5,905	3,806
65	5,324	5,777	6,193	6,774	4,525
75	6,089	6,523	7,137	7,657	5,175
85	6,777	7,207	8,112	8,506	5,760
95	7,391	7,838	8,681	9,059	6,281
105	7,936	8,441	9,290	9,604	6,745
115	8,416	8,992	9 841	10,084	7,153
125	8,835	9,495	10,344	10,503	7,509
135	9,198	9,858	10,707	10,866	7,818
145	9,509	10,169	11,018	11,177	8,082
155	9,772	10,432	11,281	11,440	8,306
165	9,992	10,652	11,501	11,660	8,492
175	10,172	10,832	11,681	11,840	8,645
185	10,316	10,976	11,825	11,984	8,767
195	10,429	11,089	11,938	12,097	8,864
205	10,516	11,176	12,025	12,184	8,937
215	10,580	11,240	12,089	12,248	8,991
225	10,625	11,284	12,133	12,293	9,030
235	10,656	11,315	12,164	12,324	9,056
245	10,677	11,336	12,185	12,345	9,074
255	10,692	11,351	12,200	12,360	9,087
265	10,698	11,356	12,205	12,365	9,091
275	10,698	11,356	12,205	12,365	9,091
285	10,698	11,356	12,205	12,365	9,091
295	10,698	11,356	12,205	12,365	9,091
305	10,698	11,356	12,205	12,365	9,091

YIELDS UNDER INTENSIVE MANAGEMENT

Three predictors of yields under intensive management were compared: Bulletin 201 as modified by Beuter et al. (1976) for intensive management, DFIT, and the modified yields of Bulletin 201 less 15 percent.

Although intensified management includes commercial and precommercial thinning, the primary benefits of commercial thinning are not explicitly considered in this study except for better utilization of mortality. Because commercial thinning does not result in significant increases in total wood production, the yields used in the simulation with commercial thinning are the same as those for extensive management.

The effects of precommercial thinning are better represented in this study, although those associated with larger diameters are not considered. Both the modification of Bulletin 201 and DFIT show increases in total cubic foot yields from precommercial thinning. Yields derived from Bulletin 201 for this practice come from equations developed by Beuter et al. (1976). The equations for high and medium sites were developed by shifting the yields for extensive management so that they appear 5 years earlier in time, whereas a 10-year shift was made for low sites.

DFIT accounts for precommercial thinning by increasing the site index that is used in the yield equations of Bruce et al. (1977):

$$S_A = S[1 + (210 - S)^2/90000]$$

where:

S_A is the adjusted site index

S is the original site index

Adjusted site indexes were computed for each combination of age and site index (100-year basis) and were then used in equations 0-1 and 0-9 (see previous section) of Bruce et al. (1977) to approximate the expected yields after precommercial thinning. This method was used for generating DFIT yields under intensive management for ages up to 125 years. The technique outlined in the previous section was used for ages 135 to 305, with the intensive yields from Bulletin 201 serving as the base.

Yields per acre under intensive management are shown for the three yield predictors in Table 2.

TABLE 2.

YIELDS PREDICTED FOR INTENSIVELY MANAGED STANDS BY THE THREE MODELS ACCORDING TO SITE CLASS AND AGE.

Site class and age (yr)	Yields (ft^3/acre) predicted by --		
	Bulletin 201	DFIT	Bulletin 201 less 15%
High			
25	4,641	4,552	3,944
35	7,137	7,247	6,066
45	9,417	9,523	8,005
55	11,493	11,433	9,769
65	13,372	13,232	11,366
75	15,065	14,851	12,805
85	16,582	16,354	14,094
95	17,933	17,831	15,242
105	19,127	19,301	16,257
115	20,174	20,698	17,148
125	21,084	21,894	17,922
135	21,868	22,770	18,587
145	22,534	23,464	19,154
155	23,093	24,075	19,629
165	23,554	24,584	20,021
175	23,928	25,000	20,338
185	24,223	25,333	20,589
195	24,450	25,593	20,782
205	24,620	25,790	20,926
215	24,740	25,933	21,029
225	24,822	26,033	21,099
235	24,876	26,099	21,144
245	24,910	26,141	21,173
255	24,933	26,169	21,193
265	24,933	26,169	21,193
275	24,933	26,169	21,193
285	24,933	26,169	21,193
295	24,933	26,169	21,193
305	24,933	26,169	21,193
Medium			
25	3,476	3,132	2,954
35	5,337	5,175	4,536
45	7,036	6,937	5,981
55	8,581	8,431	7,293
65	9,978	9,822	8,481
75	11,236	11,039	9,550
85	12,362	12,159	10,507
95	13,362	13,218	11,358
105	14,246	14,207	12,109
115	15,019	15,127	12,766
125	15,690	15,975	13,336
135	16,267	16,598	13,826
145	16,755	17,129	14,241
155	17,164	17.577	14,588
165	17,499	17,948	14,874
175	17,770	18,290	15,105
185	17,983	18,531	15,285
195	18,145	18,718	15,423
205	18,265	18,858	15,524
215	18,350	18,959	15,596
225	18,406	19,029	15,644
235	18,442	19,074	15,674
245	18,465	19,112	15,694
255	18,478	19,132	15,705
265	18,478	19,136	15,705
275	18,478	19,136	15,705
285	18,478	19,136	15,705
295	18,478	19,136	15,705
305	18,478	19,136	15,705
Low			
25	2,523	2,053	2,144
35	3,546	3,517	3,013
45	4,478	4,799	3,806
55	5,324	5,889	4,525
65	6,089	6,866	5,175
75	6,777	7,736	5,760
85	7,391	8,539	6,281
95	7,936	9,266	6,745
105	8,416	9,966	7,153
115	8,835	10,592	7,509
125	9,198	11,163	7,818
135	9,509	11,526	8,082
145	9,772	11,837	8,306
155	9,992	12,100	8,492
165	10,172	12,320	8,645
175	10,316	12,500	8,767
185	10,429	12,644	8,864
195	10,516	12,757	8,937
205	10,580	12,844	8,991
215	10,625	12,908	9,030
225	10,656	12,952	9,056
235	10,677	12,983	9,074
245	10,692	13,004	9,087
255	10,698	13,019	9,091
265	10,698	13,024	9,091
275	10,698	13,024	9,091
285	10,698	13,024	9,091
295	10,698	13,024	9,091
305	10,698	13,024	9,091

APPROACH TO NORMALITY

The stocking level of an area is a measure of how fully that area is occupied by trees of the desired species. Although all yields used in the present study are net live volumes for normal or fully stocked stands, such stands are the exception in operational forests. It is the understocked or overstocked stands that are more common. Thus, yields must be modeled for multiple stocking levels, an operation for which the TREES model utilizes the concept of percent normality and approach to normality, with actual volume equal to the standard yield x percent normality. Approach to normality suggests that as stands grow through time, they become less overstocked or less understocked. While the normality concept has been criticized as being too imprecise and too subjective for use in stand projections (Nelson and Bennett 1965, Ware and Clutter 1971, Curtis 1972), it is a useful tool in simulations on the forest level and is a far better approach than ignoring the problem of multiple stocking levels.

Percent normality is computed by determining what percent of the volume listed in the standard yield table is in the stand. It can be computed for any utilization standard or measurement unit desired. In this study, percent normality is in terms of total cubic foot volume. This percent does not necessarily equal the percentages of normality for other parameters such as number of trees, basal area, or different measures of volume. Evidence does suggest, however, that for an unthinned stand, percent normality for total cubic foot yield is approximately equal to that for basal area (Meyer 1930; Chambers, personal communication, 1980). This supposition was assumed to be true and was a key assumption in the development of approach-to-normality functions for different yield predictors.

The TREES model uses a linear equation to model approach to normality, with percent normal in decimal form at time period t + 1 as a function of percent normal at time period t:

$$N_{t+1} = b_0 + b_1(N_t)$$

where:

b_0 and b_1 are empirical coefficients of the normality equation.

Because the approach-to-normality rate is a function of the yield predictor, a unique approach-to-normality equation was developed for each yield set.

The approach-to-normality equation developed by Beuter et al. (1976) was applied to the yields in Bulletin 201 and to the reduction of those yields by 15 percent. This equation generates a table of estimated increases in normality analogous to Table 28 in Bulletin 201. The same function is used for all three site levels and for extensive and intensive management regimes. The model allows specifying an age beyond which only half the computed approach to normality will apply and an age beyond which no approach to normality takes place. The two ages specified for yields from Bulletin 201 were 125 and 225, respectively. The approach-to-normality coefficients for Bulletin 201 and for the other yield predictors are shown in Table 3, as are the ages for full and half approach to normality. Computed values for full and half approach to normality for each of the four predictors are shown in Table 4.

TABLE 3.

COEFFICIENTS IN THE APPROACH-TO-NORMALITY EQUATION FOR FOUR YIELD PREDICTORS AND CORRESPONDING AGES FOR FULL AND HALF APPROACH TO NORMALITY. EQUATION IS OF THE FORM $N_{t+1} = b_0 + b_1N_t$.

Site productivity class and yield predictor	Coefficients b_0	Coefficients b_1	Full approach to normality up to age--	Half approach to normality up to age--
High site				
Bulletin 201	0.11	0.90	125	225
DFIT	.15	.8963	35	155
DNR Empirical	.085	.971	35	155
Hoyer's Natural Stand	.16	.8963	55	155
Medium site				
Bulletin 201	.11	.90	125	225
DFIT	.15	.8963	35	155
DNR Empirical	.083	.9634	35	155
Hoyer's Natural Stand	.15	.8963	45	155
Low site				
Bulletin 201	.11	.90	125	225
DFIT	.155	.8963	35	155
DNR Empirical	.061	.9699	35	155
Hoyer's Natural Stand	.14	.8963	35	155

The approach-to-normality function of DFIT was established by assuming that percentages of normality in terms of basal area and cubic feet are equal. This assumption was necessary because percent normality in the TREES model is defined in terms of cubic feet, whereas stocking in DFIT is defined in terms of basal area. Normal growth was defined as the difference between the yield at period t and that at period t + 1 as found in the DFIT column of Table 1. This growth was adjusted by using the growth-reduction multiplier from equation 2-3 of Bruce et al. (1977):

$$V_A = 1 - 16\ (G_z - 0.5)^4$$

where:

V_A is a growth-reduction multiplier

G_z is a measure of stocking level in terms of basal area.

It is set so that $G_z = 0.5$ or $V_A = 1.0$ if stocking is at the 100 percent level. (The

TABLE 4.

VALUES OF FULL AND HALF APPROACH TO NORMALITY FOR FOUR YIELD PREDICTORS. EQUATION IS OF THE FORM $N_{t+1} = b_0 + b_1N_t$.

Site productivity class and N_t value	N_{t+1}							
	Bulletin 201		DFIT		DNR Empirical		Hoyer's	
	Full (0-125 yr)	Half (135-225 yr)	Full (0-35 yr)	Half (45-155 yr)	Full (0-35 yr)	Half (45-155 yr)	Full (0-55 yr)	Half (65-155 yr)
High site								
0.10	0.20	0.15	0.24	0.171	0.182	0.141	0.25	0.175
.20	.29	.245	.332	.266	.279	.24	.339	.27
.30	.38	.34	.422	.361	.376	.338	.429	.364
.40	.47	.435	.512	.456	.473	.437	.519	.459
.50	.56	.53	.601	.551	.571	.535	.608	.554
.60	.65	.625	.691	.645	.668	.634	.698	.649
.70	.74	.72	.78	.74	.765	.732	.787	.744
.80	.83	.815	.87	.835	.862	.831	.877	.839
.90	.92	.91	.96	.93	.959	.929	.967	.933
1.00	1.01	1.005	1.049	1.025	1.056	1.028	1.056	1.028
1.10	1.10	1.10	1.139	1.119	1.153	1.127	1.146	1.123
1.20	1.19	1.195	1.229	1.214	1.250	1.225	1.236	1.218
1.30	1.28	1.29	1.318	1.309	1.347	1.324	1.325	1.313
Medium site								
0.10	0.20	0.15	0.24	0.171	0.179	0.14	0.24	0.17
.20	.29	.245	.332	.266	.276	.238	.329	.265
.30	.38	.34	.422	.361	.372	.336	.419	.359
.40	.47	.435	.512	.456	.468	.434	.509	.454
.50	.56	.53	.601	.551	.565	.532	.598	.549
.60	.65	.625	.691	.645	.661	.631	.688	.644
.70	.74	.72	.78	.74	.757	.729	.777	.739
.80	.83	.815	.87	.835	.854	.827	.867	.834
.90	.92	.91	.96	.93	.95	.925	.957	.928
1.00	1.01	1.005	1.049	1.025	1.046	1.023	1.046	1.023
1.10	1.10	1.10	1.139	1.119	1.143	1.121	1.136	1.118
1.20	1.19	1.195	1.229	1.214	1.239	1.220	1.226	1.213
1.30	1.28	1.29	1.318	1.309	1.335	1.318	1.315	1.308
Low site								
0.10	0.20	0.15	0.245	0.172	0.158	0.129	0.23	0.165
.20	.29	.245	.334	.267	.255	.227	.319	.26
.30	.38	.34	.424	.362	.352	.326	.409	.354
.40	.47	.435	.514	.457	.449	.424	.499	.449
.50	.56	.53	.603	.552	.546	.523	.588	.544
.60	.65	.625	.693	.646	.643	.621	.678	.639
.70	.74	.72	.782	.741	.74	.72	.767	.734
.80	.83	.815	.872	.836	.837	.818	.857	.829
.90	.92	.91	.962	.931	.934	.917	.947	.923
1.00	1.01	1.005	1.051	1.026	1.031	1.015	1.036	1.016
1.10	1.10	1.10	1.141	1.120	1.123	1.114	1.126	1.113
1.20	1.19	1.195	1.231	1.215	1.225	1.212	1.216	1.208
1.30	1.28	1.29	1.320	1.310	1.322	1.311	1.305	1.303

For each predictor, $N_{t+1} = N_t$ for ages older than those in the second column.

multiplier has little effect on growth of understocked or overstocked stands unless they are considerably different from normal, suggesting that stands over a wide range of densities have approximately the same total production levels in terms of cubic feet.) The adjusted growth was used to compute percent normality in period t + 1 for a beginning percent normality in period t. This computation was performed for ages 25 to 115, stocking levels of 10 to 95 percent, and all three site productivity classes.

Approach-to-normality equations for DNR Empirical Yields were developed similarly to those for DFIT. Pairs of normality values for the current and subsequent period were developed for ages 30 to 90, stocking at 35 to 115 percent, and all three site productivity classes. These values were based on growth tables (Chambers 1980) that correspond to the DNR Empirical Yield Tables (Chambers and Wilson 1972). Because site index seemed to influence the approach-to-normality rate, three slightly different equations were developed. As with DFIT, age also seemed to influence the rate, with age classes below 40 having somewhat higher rates than did older ones. The age-rate relationship was accounted for by developing equations that best fit the rate for younger age classes with full approach to normality while approximating the rate for older age classes with half the approach rate.

Approach-to-normality equations for Hoyer's Natural Stand Yields were developed by computing changes in basal area normality on the basis of the growing stock index curves from King (1970). These curves show basal area stocking levels through time. The normal basal area level came from the Natural Stand Tables 14A to 14E in Hoyer (1975). The DFIT equations for approach to normality fit the data from Hoyer with only minor differences and were used with only slight modification.

INVENTORIES

Eight sample inventories representing a spectrum of site classes, age classes, and stocking distributions were obtained: three were high sites, two were medium sites, and three were low sites. Each sample inventory was considered as a separate forest having only one site class. Detailed inventory descriptions appear in the Appendix. A survey of forest inventory personnel in the Pacific Northwest indicated that errors may be much higher with volume estimates than with estimates of acreage by age class. Reported standard errors of volume estimates ranged as high as 20 percent, while those for acreage estimates were no more than 5 percent with varying levels of confidence. Accordingly, each of the estimated volumes per acre for the 8 sample inventories was increased by 20 percent and each was decreased by 20 percent, resulting in 16 adjusted inventories. Although such adjustments reflect a bias rather than random sampling error, this technique best demonstrates the effects of a worst-possible-case error in inventorying.

SIMULATIONS

Table 5 shows the simulations that were compared for each inventory. The TREES model was used to make the simulations because its flexibility permitted standardizations necessary to make comparisons of inventories and yield predictions while holding other factors equal. The harvest scheduling method used was the sequential maximum evenflow of volume. First documented by Chappelle and Sassaman (1968) in the SORAC model, this method provides a relatively smooth transition of harvest levels from the current to a regulated forest structure while providing the flexibility to maximize those levels. The harvest level was allowed to vary from decade to decade, either up or down, in response to a changing forest inventory. No constraints were placed on how large the change from one period to the next could be, although such constraints are occasionally used with this method.

TABLE 5.

SIMULATIONS COMPARED FOR EACH INVENTORY.
BASE: INVENTORY UNDER CONSIDERATION IS ASSUMED TO BE UNDER EXTENSIVE MANAGEMENT WITH YIELDS ACCORDING TO BULLETIN 201.

Simulation	Compared with --
1. Inventory plus 20%, under extensive management with yields according to Bulletin 201	Base
2. Inventory less 20%, under extensive management with yields according to Bulletin 201	Base
3. Inventory under extensive management with yields according to DFIT	Base
4. Inventory under extensive management with yields according to DNR	Base
5. Inventory under extensive management with yields according to Hoyer	Base
6. Inventory under extensive management with yields according to Bulletin 201 less 15%	Base
7. Inventory under intensive management with yields according to Bulletin 201	Base
8. Inventory under intensive management with yields according to DFIT	3, 7
9. Inventory less 20%, under intensive management with yields according to Bulletin 201 less 15%	7
10. Inventory under extensive management with yields according to DFIT and approach-to-normal values from Bulletin 201	Base
11. Inventory under extensive management with yields according to Hoyer and approach-to-normal values from Bulletin 201	Base

The harvest for each decade was computed as if it were for the first period under evenflow of volume. The first-decade harvest was calculated as the maximum volume that can be sustained for a specified number of periods while ensuring that the constraints for the ending condition are met. The sustainability period was set at seven decades for all simulations. Changing the length of the sustainability period would affect the harvest levels, but the change would be in the same direction for all simulations--higher harvests if it were shortened and lower levels if it were lengthened.

After the first-decade harvest was established and simulated, the resulting inventory was assumed to be the available inventory for the beginning of the second decade. The harvest level for the second decade was established as being the maximum volume that could be sustained for seven full decades (i.e., decades 2 through 8). This procedure was repeated until a harvest was established for each period in the planning horizon. The planning horizon was set at 13 decades because that seemed to be the minimum time necessary for the sample forests to achieve an approximate equilibrium of long-run sustained yield. Changing this horizon would not affect harvest levels. Rotation length was set at 75 years.

Realistic values were set for lag time and success levels for regeneration, amount of mortality salvage, and the proportion of land scheduled for commercial and precommercial thinning. These values were standardized for all comparisons of simulations except those involving extensive vs. intensive management, where such values are vital in distinguishing the regimes. As noted by Johnson et al. (1975), several factors besides increased growth rates contribute to the higher yields of intensive management. These include shorter regeneration lags, better stocking densities after regeneration, less unsalvaged mortality, and faster rehabilitation of unstocked land. The assumed values for these and other factors under extensive and intensive management are shown in Table 6.

COMPARISONS

The simulations were compared in terms of relative differences (in percent) between comparable harvest volumes. Absolute differences are important to a forester planning a harvest for an actual forest, but they are unique to the initial inventory. Relative differences, on the other hand, reflect the general effects of uncertainty in the inventory and yield data used in a a projection. Relative differences were computed as follows:

$$\% \text{ Relative difference} = \frac{X_{2i} - X_{1i}}{X_{1i}} (100)$$

where:

X_{1i} = harvest volume for the i^{th} decade of the harvest schedule serving as the base or standard,

X_{2i} = harvest volume for the i^{th} decade of the harvest schedule being compared to the base.

For each comparison unless otherwise noted, the base consisted of the unadjusted inventory with yields from Bulletin 201 for extensive management.

TABLE 6.

ASSUMED VALUES OF VARIOUS FACTORS AFFECTING YIELDS UNDER EXTENSIVE AND INTENSIVE MANAGEMENT.

Factor	Extensive management[1]	Intensive management[1]	
		With commercial thinning	With precommercial thinning
1. Regeneration lag (yr)	2(3)	2	2
2. % cutover acres remaining unstocked	3(4)	2(3)	2
3. % cutover acres converted to well-stocked condition	55(50)	65(60)	85(80)
4. % cutover acres converted to medium stocking	30	25	10
5. % cutover acres converted to poor stocking	15(20)	10(15)	5(10)
6. % mortality available for salvage	50	75	75
7. Minimum mortality to permit salvage (ft^3/acre)	800	800	800
8. % regenerated acres placed under extensive management in first 50 years	100	10	10
9. % regenerated acres placed under extensive management after year 50	100	5	5
10. % regenerated acres subjected to commercial thinning in first 50 years	0	30	30
11. % regenerated acres subjected to commercial thinning after year 50	0	20	20
12. % regenerated acres subjected to precommercial thinning in first 50 years	0	0	60
13. % regenerated acres subjected to precommercial thinning after year 50	0	0	75

[1] Numbers in parentheses indicate differing values for low sites.

RESULTS AND DISCUSSION

Relative differences in harvest volume among the various simulations for the first and last decades of the planning horizon are shown in Tables 7 and 8. The results are averages for the sample inventories grouped by site class because this variable was usually related to the differences obtained. These differences were apparently unaffected by age class and stocking distribution, although such effects may have been masked by those of site class and other constraints. No generalizations are possible concerning the relationship between the reported differences and the initial inventory structure. Relative differences on a period-by-period basis are shown in the Appendix.

First-decade results are significant because they will be implemented immediately, whereas future harvests would probably be adjusted several times before their implementation. Nevertheless, the latter are important because long-range planning for capital investments in land and facilities partly depend on them. Furthermore, some harvest scheduling techniques link a periodic cut to what happens in future harvests, giving those future harvests more immediate importance. Relative differences in long-run sustained yield can be interpreted as differences in long-run equilibrium growth per acre per year as predicted by the different yield models.

TABLE 7.

PERCENTAGE OF RELATIVE DIFFERENCE IN HARVEST VOLUME AMONG VARIOUS SIMULATIONS FOR THE FIRST AND LAST DECADES UNDER EXTENSIVE MANAGEMENT.[1]

	Base (Bulletin 201) vs. - -											
	Base inventory + 20%		Base inventory - 20%		DFIT yields		DNR yields		Hoyer's yields		Base yields - 15%	
Site Class	First decade	Last decade	First decade	Last decade	First decade	Last decade	First decade	Last decade	First decade	Last decade	First decade	Last decade
High	14.0	1.5	-14.5	-1.4	-1.8	13.2	-0.2	17.5	6.5	35.3	-4.0	-13.5
Medium	14.2	1.3	-14.5	-1.3	-4.5	5.5	-5.0	8.6	-2.2	22.2	-4.2	-13.7
Low	15.4	1.3	-16.1	-1.6	-0.2	16.7	-0.6	8.8	-0.5	27.2	-2.9	-13.8

[1] For the first two simulations, initial inventories have been altered by 20 percent. For the last four simulations, the initial inventories are the same as that for the simulation based on Bulletin 201 but the yields are based on alternate models.

TABLE 8.

PERCENTAGE OF RELATIVE DIFFERENCE IN HARVEST VOLUMES AMONG VARIOUS SIMULATIONS FOR THE FIRST AND LAST DECADES UNDER INTENSIVE MANAGEMENT.

	Bulletin 201 under extensive mgmt. vs. Bulletin 201 under intensive mgmt.		DFIT under extensive mgmt. vs. DFIT under intensive mgmt.		Bulletin 201 under intensive mgmt. vs. DFIT under intensive mgmt.		Bulletin 201 under intensive mgmt. vs. Bulletin 201 under intensive mgmt. with inventories reduced by 20% and yields reduced by 15%	
Site class	First decade	Last decade	First decade	Last decade	First decade	Last decade	First decade	Last decade
High	3.9	0.9	11.0	-8.7	5.0	2.3	-18.4	-15.4
Medium	5.8	2.9	10.3	-1.4	-0.5	1.1	-18.1	-15.3
Low	6.1	9.3	8.5	8.6	2.0	15.9	-18.5	-15.2

IMPORTANCE OF ERRORS IN INITIAL INVENTORY

The effect of initial inventory errors on harvest volume can be seen by examining the results for an inventory overestimated by 20 percent on a high site, as shown in Table 7. Assume the base is the harvest schedule that would be developed under perfect knowledge of the forest condition. A forester who mistakenly thought the inventory volumes were 20 percent larger than they actually were would plan for a first-decade harvest that was 14.0 percent too large. This overcutting could lead to an undesirable distribution of age classes and to an offsetting reduction in harvests when better information becomes available. On the other hand, underestimating the inventory by 20 percent on a high site would result in a first-decade cut 14.5 percent smaller than would be planned if the forester knew the actual volume of the inventory, an under-utilization of available resources. If the error in initial inventory were half as large (10 percent), then both the first-period and last-period differences would also be halved. This response suggests that there is a linear relationship between error in initial inventory and the resulting change in harvest level, an hypothesis that will require further testing with other inventory structures, methods of harvest scheduling, and inventory adjustments.

This effect of under- or over-estimating initial inventory is most pronounced during the first decade and steadily dissipates over time, approaching a zero difference in harvest volumes by the last decade. Volume differences appear to be relatively independent of site class.

EXTENSIVE MANAGEMENT

Relative differences between first-period harvests in extensively managed forests as simulated with Bulletin 201 and other models are shown in Table 7. The differences among the simulated harvests are relatively small because first-decade harvests are dominated by the initial inventory instead of future yield predictions. Thus, the first-decade differences between the base and Bulletin 201 less 15 percent are small, ranging between 2.9 and 4.2 percent for the three site classes. Over time, however, the effects of the initial inventories are outweighed by those of the future yield predictions.

Except for volumes based on Hoyer's yields for high sites, first-period harvests based on the yields and approach-to-normality data in Bulletin 201 are larger than those based on the other models (as indicated by the negative values in Table 7). This larger volume occurs despite the fact that the predictions of volume per acre and approach to normality from Bulletin 201 are lower than those from other models. The disparity results from the interaction of initial volumes per acre, the yield predictions, and the approach-to-normality predictions used in the routine of the TREES model to compute growth. This routine for computing growth is based on percentage stocking levels combined with an approach-to-normality function. It is possible to compute less growth for a period by starting with a lower percentage stocking level.

An example will help clarify this point. Consider a 75-year-old stand on a high site, initially stocked at 80 percent of normality according to Bulletin 201. Ten-year growth for this stand according to Bulletin 201 and DFIT can be compared as follows:

	Bulletin 201	DFIT
A. Normal volume at age 75, ft^3/acre (from Table 1)	14,241	14,676
B. Actual volume at age 75, ft^3/acre (0.8 x 14,241)	11,393	11,393
C. Normality of actual stocking at age 75, N_t (B divided by A)	0.80	0.7763

D. N_t at age 85 (from equations in Table 3)	0.83	0.81105
E. Normal volume at age 85, ft^3/acre (from Table 1)	15,845	16,163
F. Actual volume at age 85, ft^3/acre (D x E)	13,151	13,109
G. 10-year-growth, (ft^3/acre) (F - B)	1,758	1,716

Thus, even though the normal volume at age 75 is larger under DFIT than under Bulletin 201, 10-year growth is less when computed on the basis of DFIT.

The relative differences in last-decade harvests according to the various models are also shown in Table 7. Harvests based on DFIT, DNR Empirical Yields, and Hoyer's Natural Stand Yields are substantially larger than those based on Bulletin 201, illustrating the fact that long-run harvests are dependent on the future yield predictions and that those of Bulletin 201 are relatively low. Differences between last-decade harvests based on Bulletin 201 and those with such yields reduced by 15 percent do not vary appreciably by site class and are approaching 15 percent as expected.

Trends in relative differences between the first and last decades are consistent and not erratic, as shown in the Appendix.

INTENSIVE MANAGEMENT

Table 8 presents relative differences in harvest volumes by site class for the intensively managed stands according to the various models. A comparison of the harvests predicted for extensive and intensive management by Bulletin 201 indicates that there are positive first-decade differences ranging from 3.9 percent for high sites to 6.1 percent for low sites. These short-term gains reflect the immediate availablity of harvests from commercial thinning and essentially represent an increase in initial inventory (Fight and Schweitzer 1974). This additional volume can be used to maintain harvest levels when shortages resulting from gaps in age classes would otherwise force decreases. Last-decade differences are related to the site class of the inventory, with high sites showing the smallest gains and low sites the largest. These results reflect the combined effects of different yields and management assumptions and of reductions in levels of growing stock as a result of commercial thinning.

This last factor moderates the effects of increased yields per acre and increased expectations of management activities. Relative differences in harvests would be larger if only these two factors were involved, but thinnings reduce the percent stocking levels and, therefore, total cubic volume growth. An example will clarify this point. Consider a 45-year-old stand on a medium site initially stocked at 95 percent of normality according to Bulletin 201. Ten-year-growth for unthinned and thinned stands of this description can be compared as follows:

	Unthinned	Thinned
A. Normal volume at age 45, ft^3/acre (from Table 1)	7,036	7,036
B. Actual volume at age 45, ft^3/acre (0.95 x 7,036)	6,684	6,684
C. Normality of actual stocking at age 45, N_t	0.95	0.95
D. Volume thinned, ft^3/acre	--	1,727
E. Volume after thinning, ft^3/acre (B - D)	6,684	4,957
F. N_t of stocking after thinning (E divided by A)	--	0.705
G. N_t at age 55 (from equation in Table 3)	0.965	0.7445
H. Normal volume at age 55, ft^3/acre (from Table 1)	8,581	8,581

I. Actual volume at age 55, ft^3/acre (G x H)	8,281	6,389
J. 10-year growth, ft^3/acre (I - E)	1,597	1,432

Thus, a reduction in the level of growing stock as a result of a commercial thinning causes 10-year growth to be less than if the stand had not been thinned.

Less cubic volume growth from thinned than from unthinned stands is also a factor causing last-decade differences to be negative on high and medium sites in the comparison of yields under extensive and intensive management as predicted by DFIT (Table 8). This result applies only to volumes measured in cubic feet and not necessarily to those in Scribner board feet or to any economic aspects of intensive management. For low sites, the 8.6 percent larger harvests during the last decade under intensive management reflect the sizeable increase in yield under this regime. As with the comparison based on Bulletin 201, the first-decade increases in harvests for all site classes demonstrate that the additional volume available from commercial thinning offsets shortages caused by gaps in age classes.

Harvest levels under intensive management as predicted by DFIT are generally slightly larger than those predicted by Bulletin 201 exept for the much larger harvest on low sites during the last decade. These results are not surprising because yield predictions from Bulletin 201 are only slightly lower than those from DFIT for high and medium sites but considerably lower for low sites.

A worst-possible case is also shown in Table 8 to demonstrate the combined effects of errors in initial inventory and in future yield predictions. Yields predicted by Bulletin 201 for intensive management are reduced by 15 percent and used with initial inventories reduced by 20 percent. Results for the various site classes are remarkably similar. On the basis of previously discussed simulations, it is likely that the 18+ percent differences for the first decade are primarly due to the errors in the initial inventory while the 15+ percent differences for the last decade are mainly the result of the underestimated yields. During the transition from the first to the last decade, the effect of one factor is gradually replaced by that of the other.

It should be borne in mind that this study was not an analysis of the benefits of intensive forest management; the only measure used for comparison was total cubic volume production, not saleable yield. The key to evaluating intensive management investments is to examine economic benefits, not biological gain.

APPROACH TO NORMALITY

Because of the uncertainty of the approach-to-normality rates developed for this study, tests were conducted to determine the effects of those rates on the relative differences reported in harvest levels. In these tests, harvests from simulations based on various models coupled with inherent approach-to-normality rates were compared with simulations based on such rates from Bulletin 201. Results shown in Table 9 suggest that the effects of approach-to-normality data on computed harvest levels are important.

TABLE 9.

PERCENTAGE OF RELATIVE DIFFERENCE IN HARVEST VOLUME AMONG SIMULATIONS BASED ON MODELS COUPLED WITH INHERENT APPROACH-TO-NORMALITY DATA OR WITH SUCH DATA FROM BULLETIN 201.

	Base (Bulletin 201) vs. --							
	Hoyer				DFIT			
	Approach-to-normality data from Bulletin 201		Approach-to-normality data from Hoyer		Approach-to-normality data from Bulletin 201		Approach-to-normality data from DFIT	
Site class	First decade	Last decade	First decade	Last decade	First decade	Last decade	First decade	Last decade
High	3.5	12.9	8.9	35.8	-2.9	2.3	-4.0	12.5
Medium	0.9	9.7	-1.5	23.3	--	--	--	--
Low	1.2	21.4	0	28.1	--	--	--	--

As shown in Table 9, when simulations based on yields and approach-to-normality rates from Bulletin 201 were compared with those based on yields and rates from DFIT, the relative difference increased from -4.0 percent on high sites for the first decade to 12.5 percent by the last decade. However, when the comparison was made between simulations based entirely on Bulletin 201 and those based on yields from DFIT coupled with approach-to-normality rates from Bulletin 201, relative differences lessened to -2.9 percent for the first decade and 2.3 percent for the last decade. Thus, substituting approach-to-normality rates from Bulletin 201 increased first-decade harvests based on DFIT by 1.1 percent but reduced long-term harvests by over 10 percent.

As shown in Table 7, last-decade differences between simulations based entirely on Bulletin 201 and those based entirely on Hoyer were the largest observed in this study. Table 9 shows that coupling Hoyer yields with approach-to-normality data from Bulletin 201 substantially reduced the size of the last-decade differences.

These results demonstrate that when growth is calculated as the difference between yields at two ages and those yields are computed as a percentage of a standard normal volume, then approach-to-normality predictions are as important as the yields themselves. Such predictions are an integral part of yield models when multiple stocking levels are considered.

APPLICATIONS

The responses of forest managers to the results of this study may vary, depending on their opinions about the importance of the reported differences in harvests with the various models and their attitudes toward risk. They might choose yield predictions and approach-to-normality data that are relatively low or, conversely, relatively high. They might feel compelled to intensify their inventory program despite the added cost, knowing that short-run harvest levels are more sensitive to such data than to long-run growth predictions. Or they might arbitrarily adjust harvest recommendations downward to provide a buffer against uncertainty.

Recently, Hamilton (1970, 1979) and Fight and Bell (1977) examined techniques for identifying how uncertainty affects forest management planning. They pointed out that if perfect knowledge were available, then an optimal harvest plan could be generated. Any deviation from this plan such as an adjustment in the cutting schedule because of imperfect knowledge should be considered a loss (Fight and Bell 1977). For example, an overestimate of initial inventory would cause initial harvests to be higher than if accurate data were available. Consequently, future harvests would have to be adjusted downward, resulting in economic disruptions and perhaps in an unbalanced distribution of age classes. On the other hand, an underestimate would result in undercutting and thus in missed opportunities.

Thus, one way to apply the results of the present study is to consider the relative differences in harvest volumes generated by various models as losses or deviation from an optimal harvest plan. The losses could then be used in developing loss functions for setting precision levels when designing inventories (Hamilton 1970, 1979). They could also be used in a less formal analysis by resource planners to decide if there is a need to intensify data collection (Fight and Bell 1977). After potential losses are identified, assumptions could be chosen that would minimize the chances of an adjustment having adverse consequences. Ware and Clutter (1971) describe the goal of this effort as the development of harvest plans that are relatively stable over a range of uncertain input. Hamilton (1970, 1979) describes this as the least-cost-plus-loss approach in which cost refers to that of improving the certainty of the input base, e.g., by more intensive sampling.

Finally, the reader should remember that biological and economic uncertainty abound in forestry because it is a long-term production process. An example is the question of whether volume differences resulting from changes in yield models or errors in initial inventory are biologically and economically significant in the face of uncertainty about other important factors affecting harvest schedules. Among the latter are shifting owner objectives, shifts in merchantability standards and utilization levels, site class determination, irregular mortality, changes in land base and in the economic value of the resource, and shifting environmental constraints. This study has established ranges of volume differences resulting from changes in yield model and inventory. It has not answered the questions about the biological and economic significance of those differences.

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APPENDIX

SAMPLE INVENTORIES

Inventory 1--High site; younger age classes; stocking distribution: well--0, medium--86.5 percent, poor--13.5 percent; 57,336 acres; 296,937,064 cubic feet.

Inventory 2--High site; wide range of age classes with small gaps between them; stocking distribution: well--41.3 percent, medium--58.2 percent, poor--0.5 percent; 233,007 acres; 2,121,113,874 cubic feet.

Inventory 3--Low site; younger age classes with gap to one older age class; stocking distribution: well--36.7 percent, medium--20.5 percent, poor--42.8 percent; 21,319 acres; 58,589,250 cubic feet.

Inventory 4--Medium site; range of age classes with gaps between them; stocking distribution: well--39.5 percent, medium--42.5 percent, poor--18 percent; 37,550 acres; 154,381,027 cubic feet.

Inventory 5--High site; younger age classes; stocking distribution: well--43.8 percent, medium--29.3 percent, poor--26.9 percent; 59,400 acres; 338,992,400 cubic feet.

Inventory 6--Low site; all age classes; stocking distribution: well--50.8 percent, medium--42.9 percent, poor--6.3 percent; 263,605 acres; 1,619,013,004 cubic feet.

Inventory 7--Medium site; range of age classes with gaps between the older ones; stocking distribution: well--12.2 percent, medium--53.2 percent, poor--34.6 percent; 109,934 acres; 703,191,140 cubic feet.

Inventory 8--Low site; all age classes; stocking distribution: well--25.7 percent, medium--47 percent, poor--27.3 percent; 263,995 acres; 1,098,414,015 cubic feet.

DESCRIPTION OF FIGURES DEPICTING DIFFERENCES IN HARVEST LEVELS

The following figures show relative differences in percent by decade for the entire 13-decade planning horizon used in the simulations. These figures correspond to the results presented in Tables 7, 8, and 9 in which only the first- and last-decade differences are shown. Relative difference in percent is computed as follows:

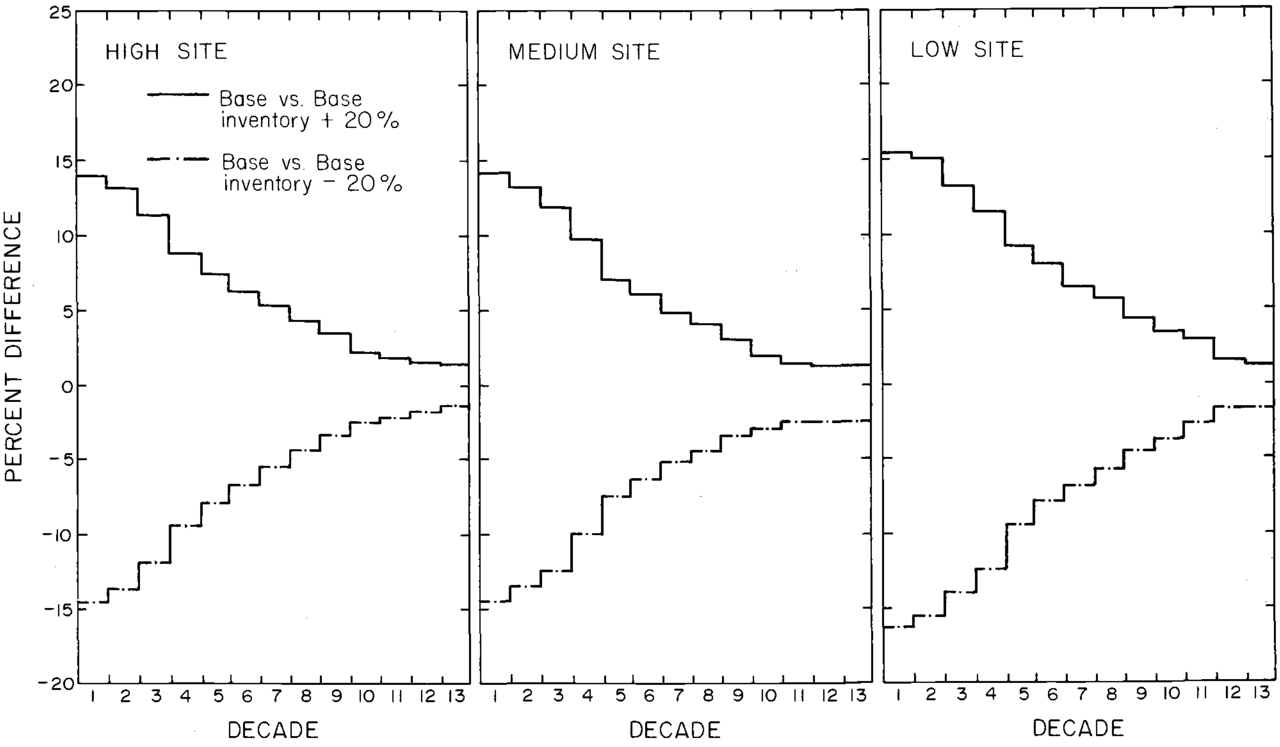
$$\% \text{ Relative difference} = \frac{X_{2i} - X_{1i}}{X_{1i}} (100)$$

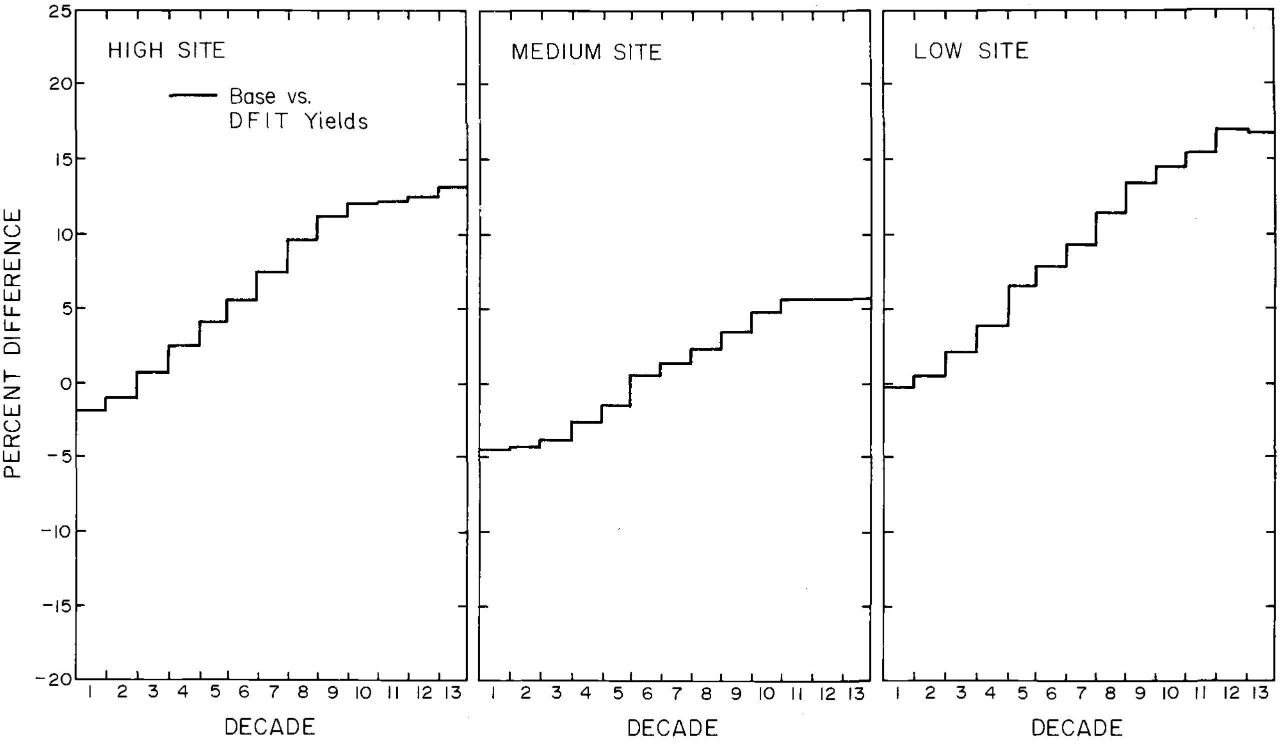
where:

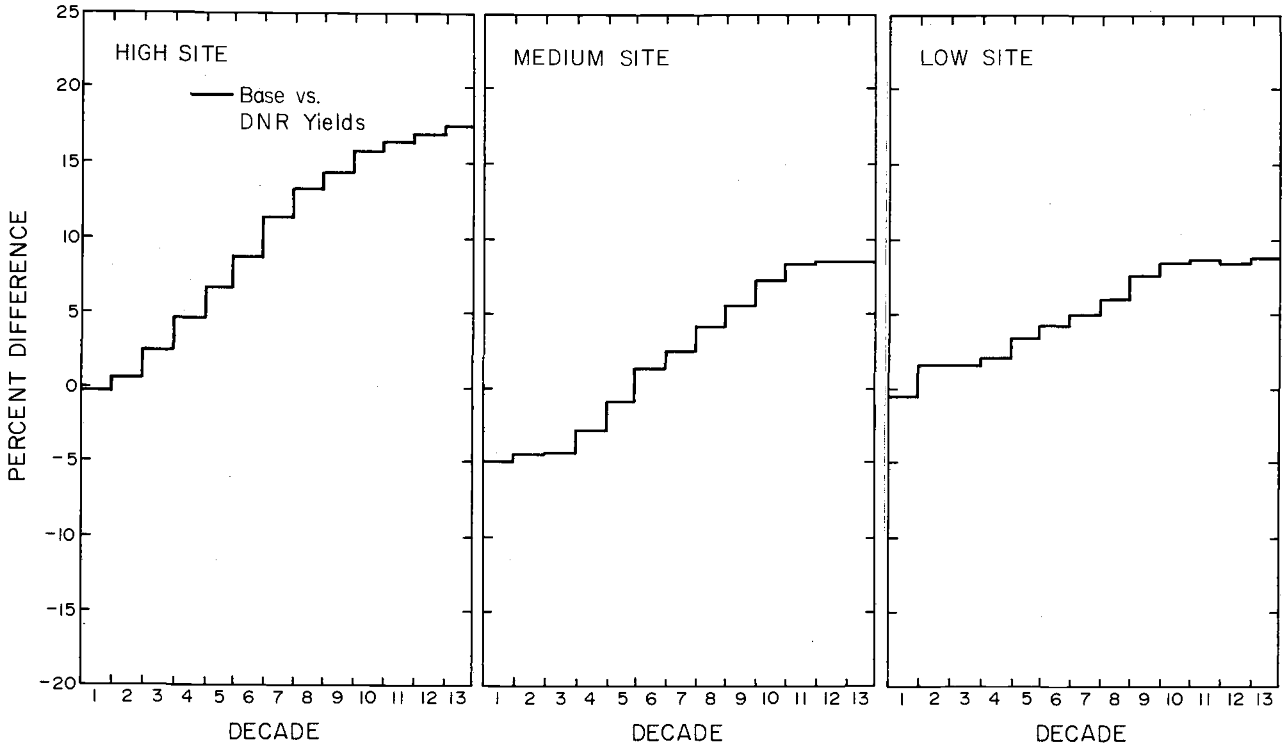
X_{1i} = harvest volume for the i^{th} decade of the simulation listed first in the figure heading (to the left of vs.)

X_{2i} = harvest volume for the i^{th} decade of the simulation listed second in the figure heading (to the right of vs.)

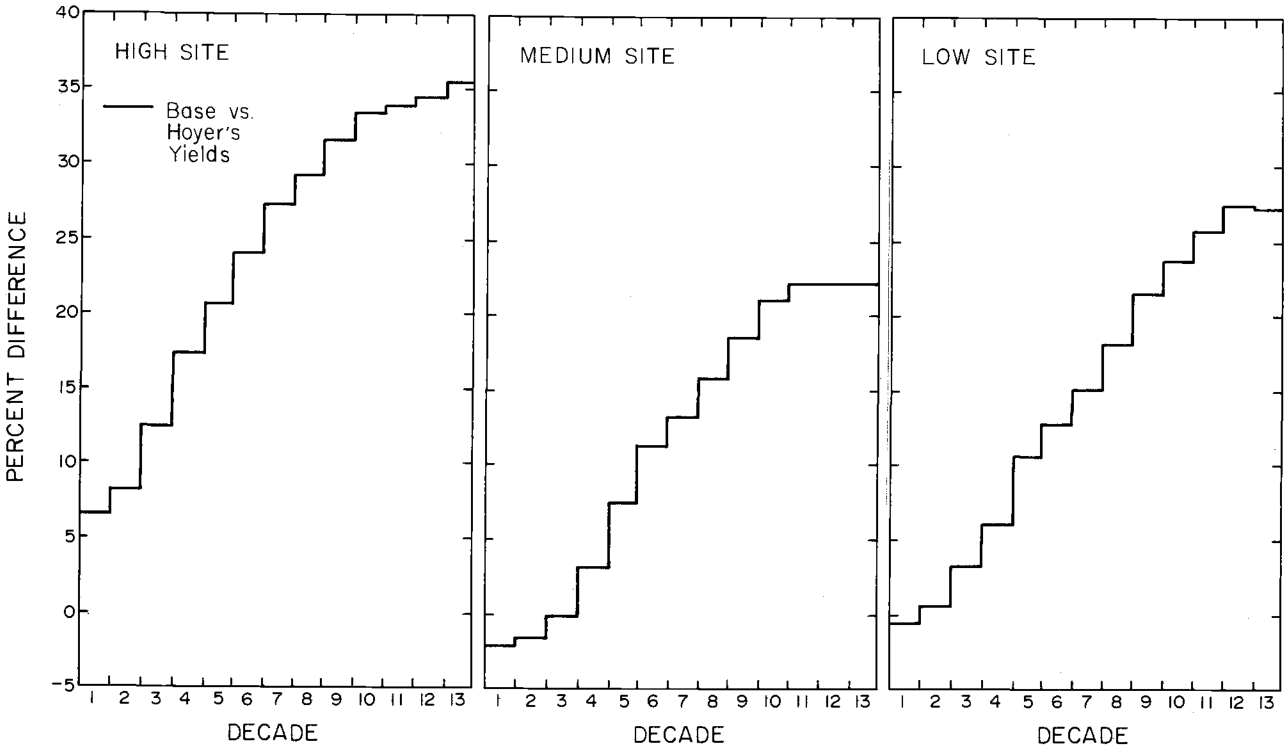
i = decade in the planning horizon; i.e., 1 to 13.


HIGH SITE
MEDIUM SITE
LOW SITE
Base vs. Base inventory + 20%
Base vs. Base inventory − 20%
PERCENT DIFFERENCE
25
20
15
10
5
0
-5
-10
-15
-20
1 2 3 4 5 6 7 8 9 10 11 12 13
DECADE

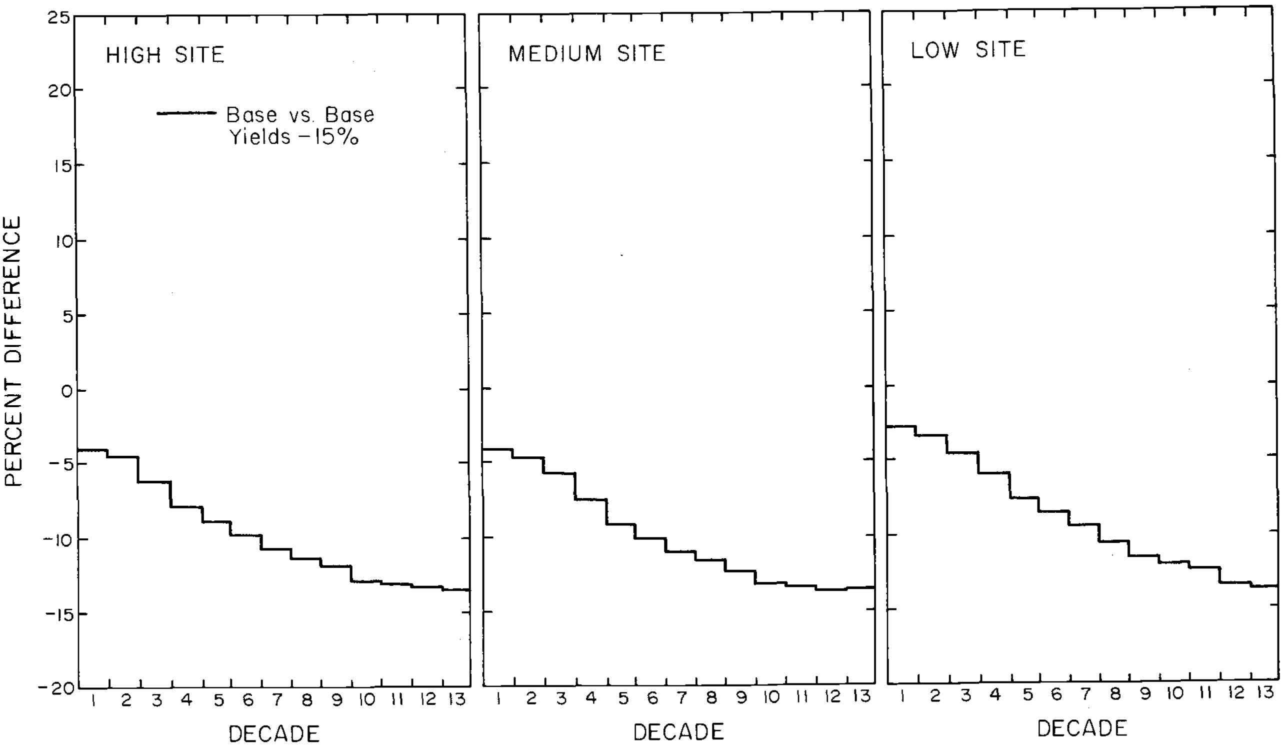

HIGH SITE
MEDIUM SITE
LOW SITE
Base vs. DFIT Yields
PERCENT DIFFERENCE
25
20
15
10
5
0
-5
-10
-15
-20
1 2 3 4 5 6 7 8 9 10 11 12 13
DECADE

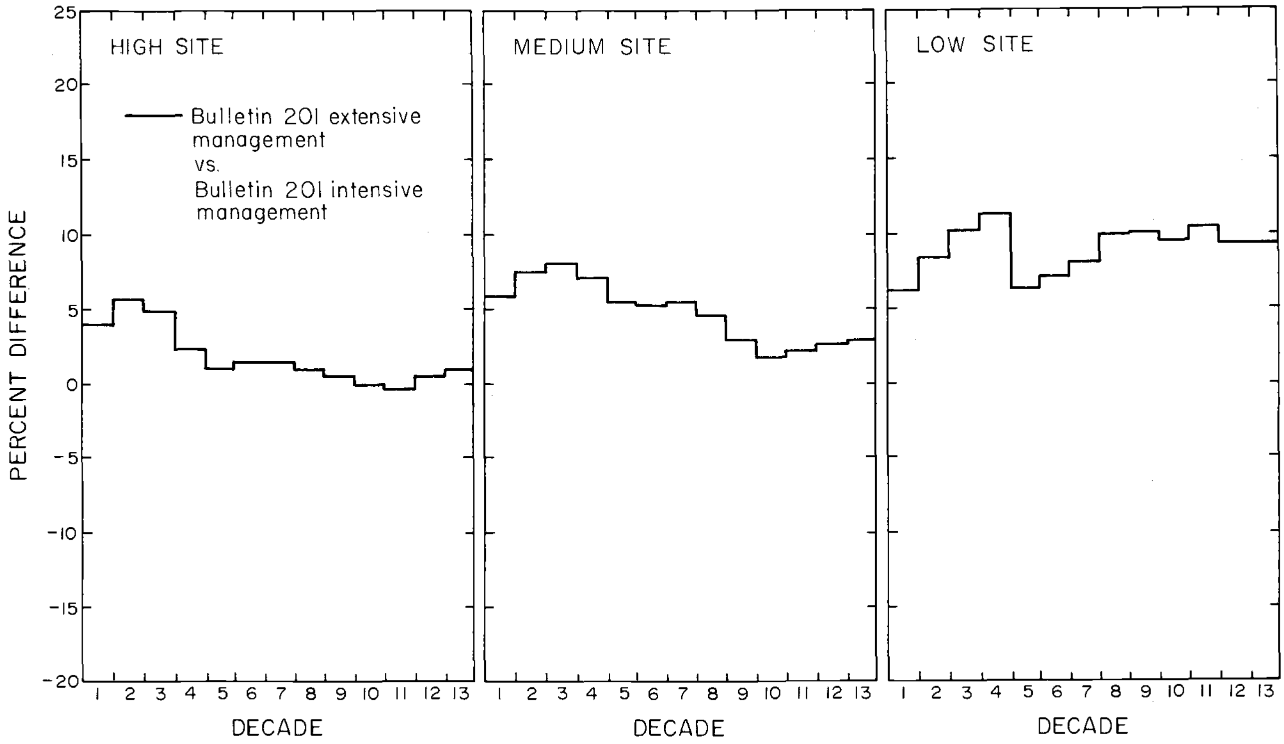


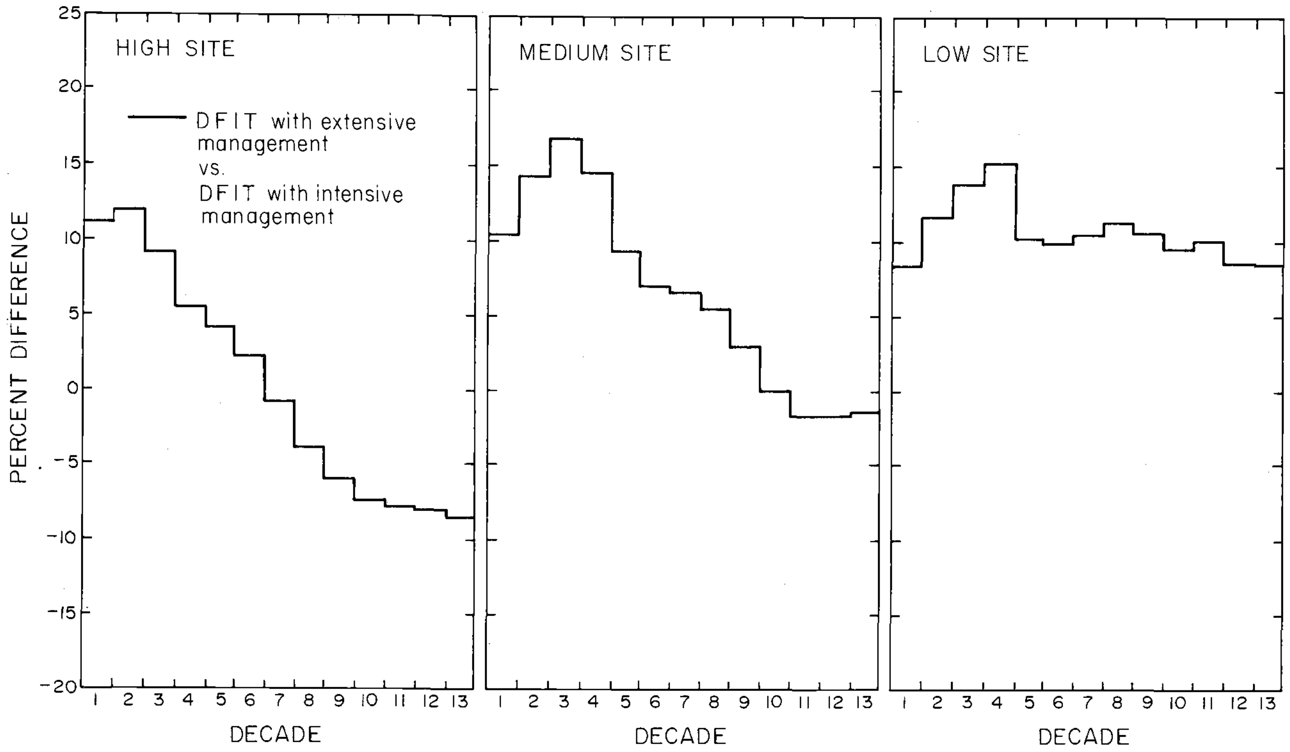
HIGH SITE
Base vs. DNR Yields
MEDIUM SITE
LOW SITE
PERCENT DIFFERENCE
25
20
15
10
5
0
-5
-10
-15
-20
1 2 3 4 5 6 7 8 9 10 11 12 13
DECADE

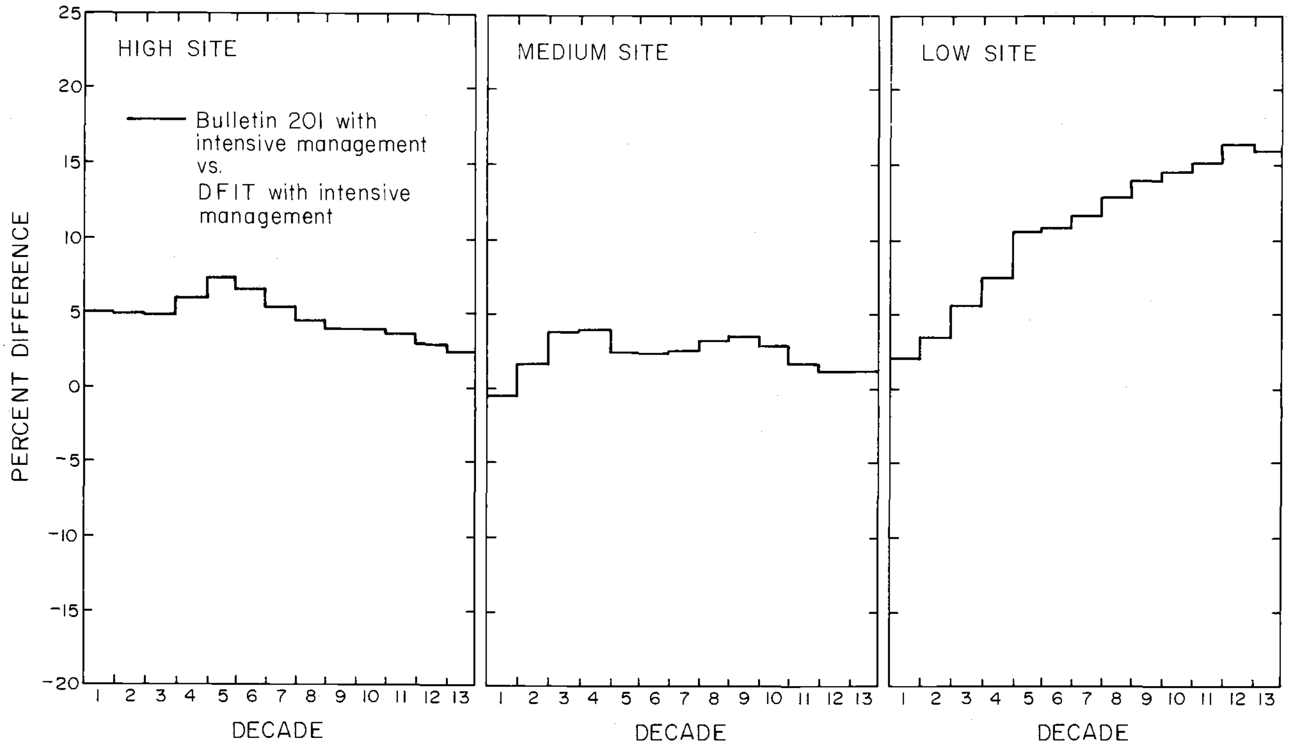


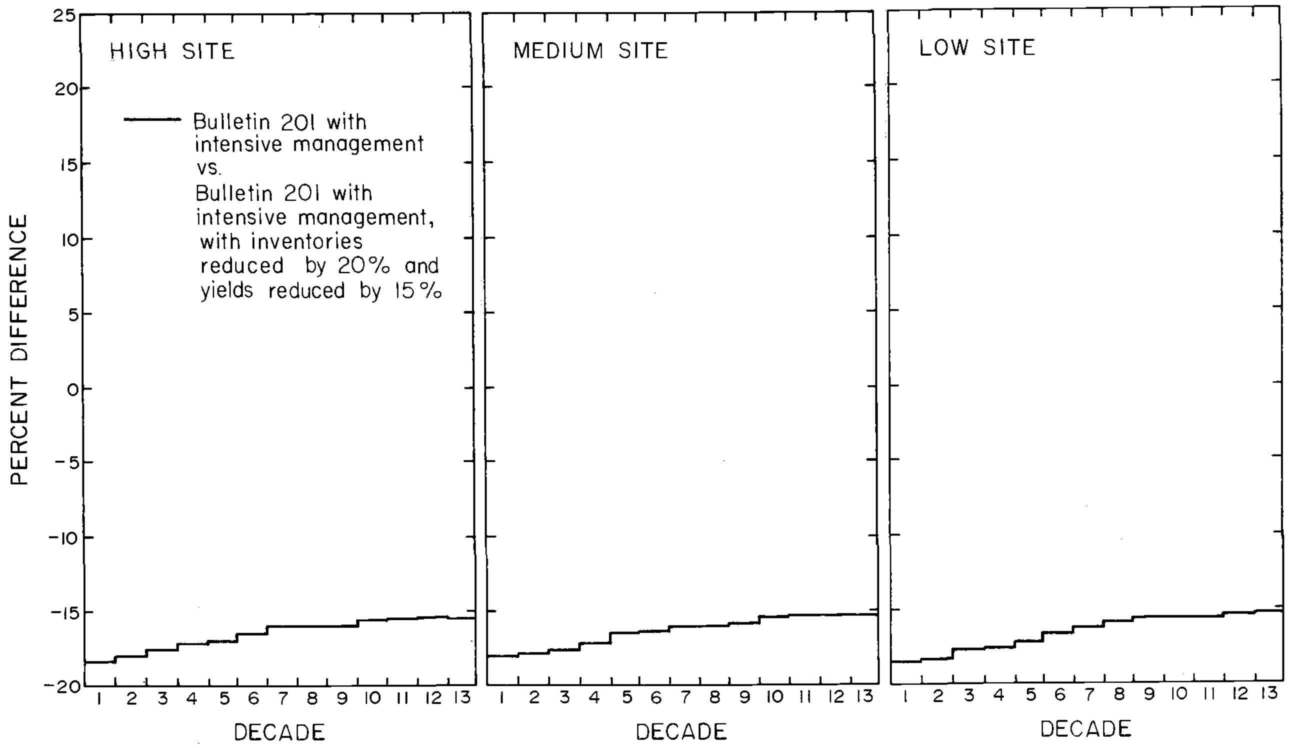
HIGH SITE
Base vs. Hoyer's Yields
MEDIUM SITE
LOW SITE
PERCENT DIFFERENCE
40
35
30
25
20
15
10
5
0
-5
1 2 3 4 5 6 7 8 9 10 11 12 13
DECADE

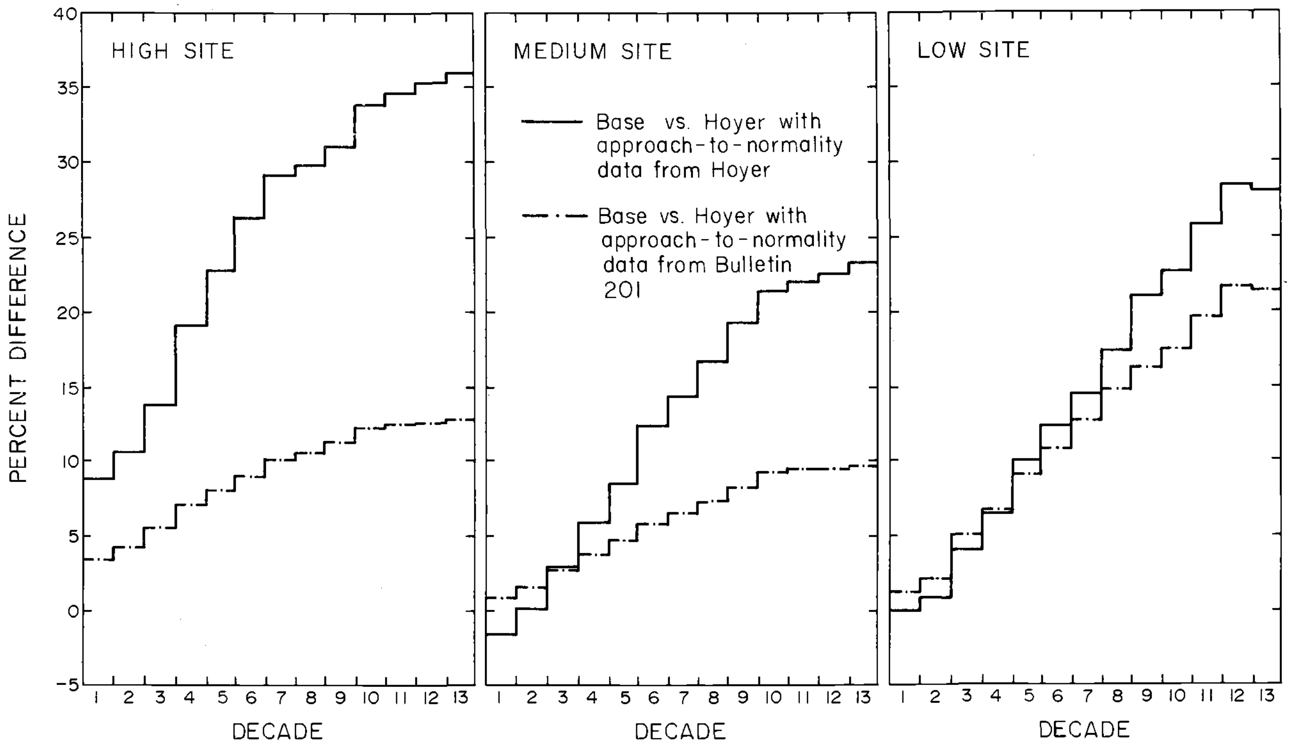

PERCENT DIFFERENCE
25
20
15
10
5
0
-5
-10
-15
-20
HIGH SITE
Base vs. Base Yields -15%
MEDIUM SITE
LOW SITE
1 2 3 4 5 6 7 8 9 10 11 12 13
DECADE
DECADE
DECADE

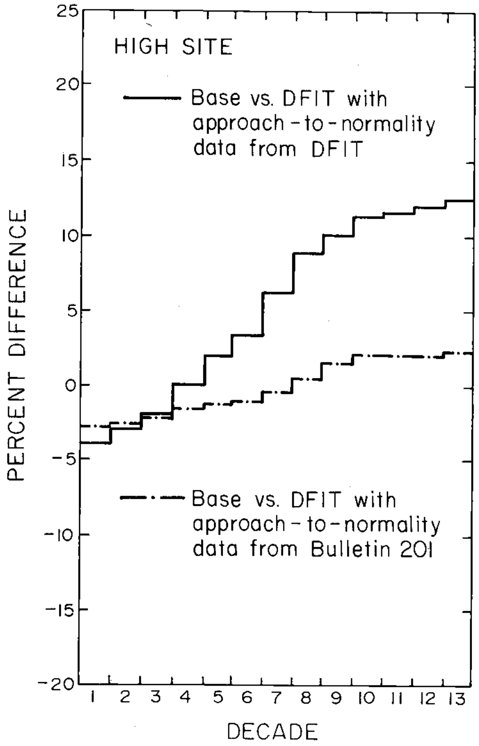

PERCENT DIFFERENCE
25
20
15
10
5
0
-5
-10
-15
-20
HIGH SITE
Bulletin 201 extensive management vs. Bulletin 201 intensive management
MEDIUM SITE
LOW SITE
1 2 3 4 5 6 7 8 9 10 11 12 13
DECADE
DECADE
DECADE


HIGH SITE
MEDIUM SITE
LOW SITE
DFIT with extensive management vs. DFIT with intensive management
PERCENT DIFFERENCE
25
20
15
10
5
0
-5
-10
-15
-20
DECADE
1 2 3 4 5 6 7 8 9 10 11 12 13


HIGH SITE
MEDIUM SITE
LOW SITE
Bulletin 201 with intensive management vs. DFIT with intensive management
PERCENT DIFFERENCE
25
20
15
10
5
0
-5
-10
-15
-20
DECADE
1 2 3 4 5 6 7 8 9 10 11 12 13


HIGH SITE
MEDIUM SITE
LOW SITE
Bulletin 201 with intensive management vs. Bulletin 201 with intensive management, with inventories reduced by 20% and yields reduced by 15%
PERCENT DIFFERENCE
25
20
15
10
5
0
-5
-10
-15
-20
1 2 3 4 5 6 7 8 9 10 11 12 13
DECADE


HIGH SITE
MEDIUM SITE
LOW SITE
Base vs. Hoyer with approach-to-normality data from Hoyer
Base vs. Hoyer with approach-to-normality data from Bulletin 201
PERCENT DIFFERENCE
40
35
30
25
20
15
10
5
0
-5
1 2 3 4 5 6 7 8 9 10 11 12 13
DECADE


HIGH SITE
Base vs. DFIT with approach-to-normality data from DFIT
Base vs. DFIT with approach-to-normality data from Bulletin 201
PERCENT DIFFERENCE
25
20
15
10
5
0
-5
-10
-15
-20
DECADE
1 2 3 4 5 6 7 8 9 10 11 12 13

Vomocil, Marc G., and Philip L. Tedder. 1983. EFFECTS OF PROJECTED YIELDS AND INITIAL INVENTORIES ON HARVEST SCHEDULES FOR DOUGLAS-FIR. Forest Research Laboratory, Oregon State University, Corvallis. Research Bulletin 44, 26 p.

Comparisons were made to determine how the uncertainy of initial inventories and projected yields affect harvest schedules for Douglas-fir. Results indicate that short-run harvests are most affected by errors in initial inventory, with the effect being less than the size of the error. Long-run harvests are most affected by yield projections and approach-to-normality predictions.

KEYWORDS: Harvest scheduling, uncertainty, inventory, yield model, approach to normality.

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