Managing Young Forests in the Douglas-Fir Region

Proceedings of a Symposium held June 11-13, 1974

Edited by

Alan B. Berg

Volume 5

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School of Forestry
Oregon State University

This is the fifth volume of a series of short courses by the School of Forestry on the management of young forests in the Douglas-fir region. The four preceding volumes are:

Management of Young-Growth Douglas-Fir and Western Hemlock. December 1970. 8½ x 11 inches. 145 p. Originally $5.00, now $4.00.

Managing Young Douglas-Fir and Western Hemlock—Economics, Yield Control, and Thinning. September 1971. 5½ x 8¼ inches. 175 p. $5.00.

Managing Young Forests in the Douglas-Fir Region. September 1972. 5½ x 8¼ inches. 224 p. $5.00.

Managing Young Forests in the Douglas-Fir Region. July 1974. 5½ x 8¼ inches. 234 p. $6.00.

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Alan B. Berg
Professor of Forest Management

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School of Forestry
Oregon State University
Corvallis, Oregon 97331

Cover Photograph: A dense stand of young trees in the Valsetz basin is rapidly replacing the old forest that has been harvested. Yields can be increased even on such already highly productive sites by cultural practices such as thinning and maintenance of nutrients in the soil.

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FOREWORD

These are the proceedings of the fifth short course in managing young forests in the Douglas-fir region, conducted by the School of Forestry, Oregon State University, June 11-13, 1973.

Knowledge and experience in the management of young forests continues to expand. The short courses are designed to keep pace with this expansion and to bring to the forester in the field information that will be useful to him. This volume, combined with the four previously published volumes, constitutes an up-to-date compilation of information about management of young forests in the Douglas-fir region.

New in this volume are discussions on opportunities for small forest landowners, the management of data for forest operations, and the impact of intensive management on fire hazard. More information on the levels-of-growing-stock study at Hoskins, cable thinning in young growth, and commercial thinning under sustainable harvest are included. Also, the importance of western hemlock continues to increase. Because of its silvicultural characteristics, hemlock must be managed differently and more carefully than Douglas-fir.

I thank my colleagues in the School of Forestry who participated as instructors. I especially thank the instructors from Harmon Tree Farms, Inc.; Georgia Pacific Corporation; Weyerhaeuser Company; Pacific Northwest Forest and Range Experiment Station; Oregon State Forestry Department; and the Department of Natural Resources, State of Washington. Without their help, this short course could not have been presented.

Alan Berg
Short Course Director

PROGRESS REPORT ON THE HOSKINS LEVELS-OF-GROWING-STOCK STUDY

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We are privileged to share this short course with you. Much is to be gained by meeting periodically and discussing young-growth management. The potential and the challenges are great. A shrinking forest-land base forces us to make the most from what we have. Each of us tends to have different objectives. Are you concerned with reaching a given size in a minimum time, finding maximum volume for a chosen utilization standard, obtaining maximum quantity of a given forest product, or achieving the highest ratio of growth to growing stock?

In our opinion, we do not have specific data yet to conclusively answer these questions. We now have an opportunity, however, to collect significant data through a regional levels-of-growing-stock study in Douglas-fir, which was established in the early 1960's (1). This regional study will not answer all your questions, but an examination of the results should point the way.

Forest industry, state and federal forestry agencies, and educational institutions are participating under the direction of the Pacific Northwest Forest and Range Experiment Stations. To date, nine study areas have been established in British Columbia (Vancouver Island (3)), western Washington, and western Oregon.

The objective of the study is not necessarily to pinpoint the optimum thinning schedule. It is, however, expected to show how the different schedules affect wood production, tree size, and the ratio of growth to growing stock. It will establish principles and factual data, which will enable the forester to formulate the thinning schedule that most profitably meets his objectives. These studies also will provide vital basic data for computer simulation programs.

The study consists of eight thinning regimes (Table 1) plus unthinned controls replicated three times, on 1/5-acre plots. The studies are established in young, vigorous stands from 20 to 40 feet tall with an average diameter of 6 inches or less.

The study plan includes rigorous specifications for a preparatory thinning of the 24 treated plots. The calibration period, the interval between the preparatory thinning and the first treatment thinning, serves to avoid differences among treatments because of differences in initial stand density. One of the specifications is that 16 crop trees per plot (80 trees per acre) be selected before the preparatory thinning.

Levels of growing stock to be tested will be determined by the gross increment of the unthinned plots, which is an integral part of the study, but not one of the recognized treatments. In this way, the "levels" will be keyed to growth conditions on the study area and will not be dependent on yield tables or other artificial criteria.

Thinnings will be made whenever crop trees on all treatments have increased their average height by 10 feet (to the nearest growing season) since the previous thinning. This will mean more frequent thinnings on higher rather than on lower sites, and at younger rather than at older ages.

The Hoskins Study is a cooperative project initiated by Oregon State University (2) about 22 miles west of Corvallis near Hoskins on land owned by T. J. and Bruce Starker. The study was established during the summer of 1963 in a 20-year-old stand. On the average, the stand contained more than 1,700 trees per acre at the time the project was established. The study area is site class II. The stand originated naturally after wildfires.

The calibration period lasted for three growing seasons as the average growth in height within that time was 9.8 feet for the crop trees. Mortality (windthrow) on the thinned plots was

TABLE 1. Treatment Schedule for Levels-of-Growing-Stock Study, Which Shows Percentage of Gross Basal Area Increment of Control Plot to Be Retained in Growing Stock.

Thinning	Treatment 1	2	3	4	5	6	7	8
	%	%	%	%	%	%	%	%
First	10	10	30	30	50	50	70	70
Second	10	20	30	40	50	40	70	60
Third	10	30	30	50	50	30	70	50
Fourth	10	40	30	50	50	20	70	40
Fifth	10	50	30	70	50	10	70	30

minimal and occurred primarily between the first and second growing seasons. Mortality on the control plots was caused by natural suppression and occurred throughout the calibration period.

The basal area per acre at the beginning of the calibration period for the 24 treatment plots ranged between 48.2 and 51.1 square feet, compared with 122.0 to 158.3 square feet for the three control plots. The number of trees per acre on the treatment plots ranged from 290 to 395 compared with 1,610 to 1,885 on the control plots. The basic data for treatments 1, 3, 5, and 7 for the calibration period are shown in Table 2.

Table 2 shows the uniformity among the treatments after the preparatory thinning and during the calibration period.

The basal area increment (Table 3) for the treated plots was about two-thirds of the control plots for the first growing season. Yet the basal area increment for the treated plots and the control plots was similar for the third growing season.

After the 3-year calibration period, the first thinning treatments were made between the growing seasons of 1966 and 1967. The average diameter by plot for trees removed ranged from 6.1 to 6.7 inches. The basal area per tree removed in

TABLE 2. Stand Data for All Trees per Acre for Calibration Period.[1]

Treatment	Trees[2]		Avg dbh[3]		Basal area	
	1963	1966	1963	1966	1963	1966
			In.	*In.*	*Sq ft*	*Sq ft*
1	353	352	5.1	6.7	49.3	85.5
3	343	342	5.1	6.8	49.0	85.5
5	365	363	5.0	6.6	49.2	86.0
7	328	328	5.3	6.9	50.1	85.9
Control	1,727	1,640	3.8	4.5	138.1	184.7

[1]Data were collected at the end of the growing season.
[2]Number is rounded to nearest whole tree.
[3]Diameter of tree of mean basal area.

thinning showed little variation by treatment. No mortality occurred on the thinned plots during the first treatment period. On the control plot, however, mortality increased each year.

Table 4 presents stand data for all trees for treatments 1, 3, 5, and 7 for the first period of treatment. The average diameter at breast height for the heaviest thinning at the end of the growing season of 1970 was 9.2 inches, but for the control was 5.7 inches.

TABLE 3. Basal Area Increment for All Trees per Acre for Calibration Period.[1]

Treatment	1964	1965	1966	Total
	Sq ft	*Sq ft*	*Sq ft*	*Sq ft*
1	12.1	12.7	11.4	36.2
3	12.6	12.3	11.2	36.1
5	12.3	12.3	12.2	36.8
7	11.7	12.5	11.2	35.4
Control	18.8	15.7	12.2	46.7

[1]Data were collected at the end of the growing season.

TABLE 4. Stand Data for All Trees per Acre for First Treatment Period.[1]

Treatment	Trees[2]		Avg dbh[3]		Basal area	
	1966	1970	1966	1970	1966	1970
			In.	*In.*	*Sq ft*	*Sq ft*
1	215	215	6.9	9.2	55.1	99.5
3	252	252	6.8	9.0	64.4	111.4
5	312	312	6.6	8.6	74.9	126.5
7	323	323	6.9	8.9	84.9	139.4
Control	1,640	1,272	4.5	5.7	184.7	228.6

[1]Data were collected at the end of the growing season.
[2]Number is rounded to the nearest whole tree.
[3]Diameter of tree of mean basal area.

For the growing season of 1967 (first growing season after treatment), the lighter the thinning the larger the basal area increment (Table 5). For the growing season of 1969, the net increment of basal area for each of the eight treatments was greater than that for the control. Yet, the most heavily thinned treatment (1) had about one-third the basal area of the control plots at the end of the growing season of 1968. The net increment of basal area for each of the treatments was nearly

TABLE 5. Basal Area Increment for All Trees per Acre for First Treatment Period.[1]

Treatment	1967	1968	1969	1970	Total
	Sq ft	*Sq ft*	*Sq ft*	*Sq ft*	*Sq ft*
1	10.6	11.3	10.8	11.7	44.4
3	11.4	12.3	11.0	12.3	47.0
5	13.1	13.7	11.9	12.9	51.6
7	15.1	14.7	11.2	13.3	54.5
Control	15.8	13.2	8.9	6.0	43.9

[1]Data were collected at the end of the growing season.

double that of the control for the growing season of 1970. The total net increment of basal area for the first treatment period was greater for each of the treatments than for the control.

Table 6 shows net increment of the basal area as a percentage of the basal area at the beginning of the period. The heaviest thinning produced the highest percentage for the first treatment period.

Table 7 presents stand data for all trees for the growing seasons of 1971 and 1972. The average diameter of treatment 1 at the end of the growing season of 1972 is 10.9 inches, compared to 6.3 inches for the control plots.

Table 8 shows the net increment of basal area for all trees for the growing seasons of 1971 and 1972. The average total basal area per acre for treatment 1 was 76.2 square feet at the end of the growing season of 1972, but the average total basal area per acre for the control plots was 246.7 square feet. Yet, the net increment of basal area for treatment 1 was 7.3 square feet per acre, compared to 7.5 square feet per acre for the control plants. The net increment for treatment 7 for the growing season of 1972 was 11.6 square feet per acre.

The total change of basal area from 1964 to 1972 per acre is shown in Table 9. Basal area increment, basal area of trees removed during treatment thinnings, and mortality for treatment 1 was 135.6 square feet, but basal area increment plus mortality was 130.1 square feet for the control plots.

TABLE 6. Increment as a Percentage of Beginning Basal Area.

Treatment	Calibration period	First treatment period
	%	%
1	73.4	80.6
3	73.7	73.0
5	74.8	68.9
7	70.7	64.2
Control	33.7	23.8

TABLE 7. Stand Data for All Trees per Acre for Growing Seasons of 1971 and 1972.[1]

Treatment	Trees[2]		Avg dbh[3]		Basal area	
	1971	1972	1971	1972	1971	1972
			In.	*In.*	*Sq ft*	*Sq ft*
1	119	119	10.3	10.9	68.9	76.2
3	175	175	9.8	10.3	91.8	100.6
5	249	249	9.2	9.7	115.6	125.8
7	287	287	9.4	9.8	137.6	149.2
Control	1,204	1,144	6.0	6.3	239.2	246.7

[1]Data were collected at the end of the growing season
[2]Number is rounded to the nearest whole tree.
[3]Diameter of tree of mean basal area.

The studies for regional levels of growing stock will not tell you specifically how to manage your stands. These initial results, however, emphasize our ability to control forest stands. They also provide basic data for other studies, which include simulation studies. The level of growing stock that is best for your stand will depend to a large extent on your objectives.

TABLE 8. Basal Area Increment for All Trees per Acre for Growing Seasons of 1971 and 1972.[1]

Treatment	1971	1972	Total
	Sq ft	*Sq ft*	*Sq ft*
1	8.5	7.3	15.8
3	10.2	8.9	19.1
5	12.0	10.3	22.3
7	13.1	11.6	24.7
Control	10.5	7.5	18.0

[1]Data were collected at the end of the growing season.

TABLE 9. Total Basal Area Change per Acre from 1964 to 1972.

	Treatment				
	1	3	5	7	Control
	Sq ft	*Sq ft*	*Sq ft*	*Sq ft*	*Sq ft*
Increment	96.4	102.1	110.7	114.6	108.5
Cut	39.1	29.8	22.9	14.9	---
Mortality	0.1	0.2	0.3	0.0	21.6
Total	135.6	132.1	133.9	129.5	130.1

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BRINGING FORESTRY TO THE SMALL LANDOWNER

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To the timber landowner, untrained in forestry, an aura of mystery exists about his forest that he does not understand. He often looks to any trained forester and expects to get the best word on how to handle his timber tract. The advice he gets can result in present and long-term financial returns, as well as a property that is a positive influence in the local environment.

If you are asked by one of these forest landowners for your opinion, can you answer him in words that he will understand, and are you prepared to look at his property with his welfare in mind, rather than the benefit of the company, agency, or institution that you represent? I think that all trained foresters should encourage the small landowner to practice good forestry, even if it means losing a timber sale or cutting less timber at the present time. By this kind of concerted action from trained foresters, the long-term benefits to the public, as well as the landowners, could be enormous.

Communicating with the small woodland owner with our forestry jargon presents problems. When I became a farm forester in Humboldt, Nebraska in 1945, I soon found that no one understood what I was talking about when I used customary technical forestry terms. Such words as reproduction, regeneration, and stumpage were foreign to their farming practices and terminology. By conscientious effort and much review with the secretary and coworkers, I converted my timber jargon to a language that could be understood by Nebraska farmers. Even in a timber country such as Oregon, we should talk and write in terms that are understood readily by the woodland owner, if we are to transmit our forestry knowledge.

Do not always accede immediately to the owner's stated wants, if you believe that his long-range benefits could be much better served by an alternate course. One Nebraska farmer owned a fine stand of black walnut, which he desired to liquidate. He asked me to advise the customary buyers on how much timber he had for sale. I did not want to be a party in clearcutting young walnut trees, so I marked only those trees 18 inches in diameter at breast height and larger, and estimated their value. I also counted and measured all of the salable trees from 14 to 18 inches. I gave this information to the owner, and he concluded that he would be foolish to liquidate smaller trees because of their low comparative value. By this method, I satisfied the owner, and he made the decision to save the young trees.

Foresters are often blessed with a vision for the future because of their training. This is contrasted with the current view held by most people. The small woodland owner can usually see the present value of immature timber, but has difficulty anticipating the potential of tree growth and future value. This is the area where you can be of most service.

Recently, I was asked to present a talk on forest dynamics to an association of small woodland owners, and chose to illustrate the growth potential of a typical leave tree in our 32-year-old stand, site II, horse-logging operation. In Figure 1, the tree on the left represents the measurements of a dominant tree, which was felled because of minor defect. The growth rates were projected for nearby dominants, which should continue to grow in height at 2 feet per year for the next 16 years.

One interesting thing to me is that the volume of the log, which is added to the tree volume at each 8-year interval, is contained in the butt log. Examples such as this can demonstrate more easily the growth potential of young timber to the untrained owner.

Since 1970, we have been managing our timber stands to produce as many large poles as possible on each acre. To me, this means removal of a greater proportion of nonpoles in the earlier cutting cycles, which are planned at 4- to 5-year intervals. This reserves the best dominants for large, high-value, polecrop trees to be cut when they reach a maximum value (Figure 2). Nonpole trees, however, will be used for final crop trees, if no poles are available in a given area.

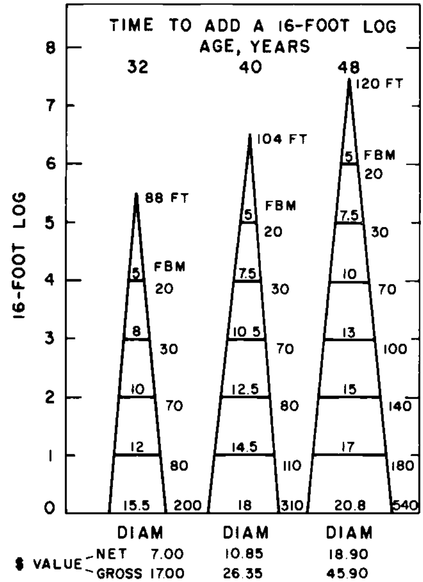

Figure 1. Growth potential in diameter (inches) and volume (board feet) of a typical leave tree in a 32-year-old stand, site II, horse-logging operation, at 8-year intervals.

To help analyze the pole potential, I converted the site II table in Table 2 of the Timber Stand Improvement Thinning Guidelines for Douglas-fir (1). I first presented this poletable in an article, Down To Earth Woodland Management (2).

Before proceeding with the discussion on the potential of this type of management, I must point out that this is only a target for management and that many hazards must be overcome to reach these financial goals. Some of these hazards are wind damage, fires, disease or insects, future markets, and wrong cutting practices at any cutting interval.

Table 1 is a modification of the original table and is useful in our pole management program. We have made the second cut in a 35-year-old stand and have been pleased with the results. Nonpoles will make up about 50 percent of the early commercial thinnings in many situations on our tree farms. Gradually, the percentage of poles should increase with this

Table 1. Theoretical Cutting Guide for Douglas-Fir on Site II per Acre.

Stand before cutting			Removed in thinning			Poles					
								Value delivered			
								Each pole		Total	
Age	No. trees	Volume[1] Scribner	No. trees	Dbh	Volume[1] Scribner	Cut	Avg length	1970	1973	1970	1973
Yr		*Fbm*		*In.*	*Fbm*	*%*	*Ft*	*$*	*$*	*$*	*$*
30	400	23,000	100	9.0	5,000	50	30	5.40	9.60	270	480
35	300	28,000	70	12.0	5,600	50	40	14.00	24.80	540	868
40	230	32,400	70	13.5	8,400	75	50	19.00	36.00	1,007	1,908
45	160	34,000	40	16.0	8,600	75	60	33.60	61.20	1,008	1,836
50	120	33,400	30	17.5	10,000	75	75	54.00	91.50	1,242	2,105
55	90	31,400	20	19.0	8,600	80	90	79.20	131.40	1,207	2,102
60	70	30,800	70	19.5-23.0	30,800	80	95-100	95.00	150.00	5,320	8,400

[1]Scribner log rule.

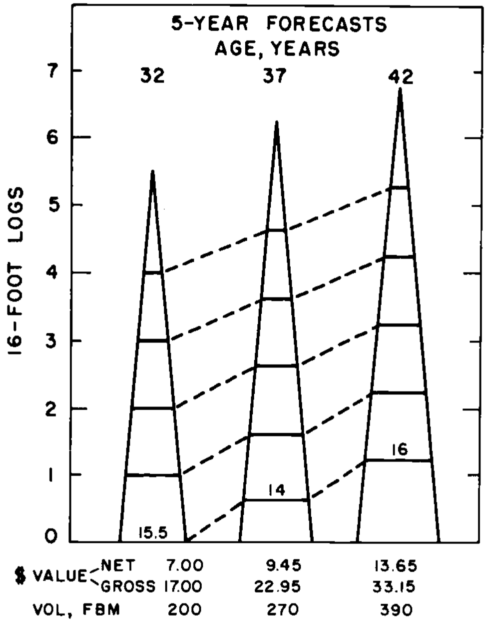

Figure 2. Value forecast for poles with the removal of nonpoles at 5-year intervals.

type of management and reach 80 percent at the end of the 55- to 60-year rotation.

Long poles, 90 feet and more in length, are difficult to fell without breakage and are time consuming to skid, whereas poles from 70 feet to 80 feet in length are relatively easy to log and may prove to be the most profitable to grow. I have been doing the pole cutting, and I hire a cat operator to do the skidding. We have worked in some 50-year-old stands, which produced several 90-foot poles.

Growing poles as a management objective is, in reality, producing the trees of straightest form with the least defect. Sometimes, fast-growing dominants are cut in early cutting cycles, because they have too much sweep or other minor defects, which disqualify them as future poles. This can result in some reduction in volume growth for that tree group. If the market for poles should disappear in the future, the potential pole trees are, in reality, the most desirable trees for other forest products and a management objective change would present no problem.

The pole prices of 1973 are a real incentive to hold 35-year-old timber for greater size. If a small timber owner, however, does not understand the growth dynamics of his timber, today's high prices may cause him to clearcut immature stands. This spring, many immature Douglas-fir stands were clearcut because of high timber prices. Some stands that I have observed were clearcut when about 40 years old. When one considers the growth potential of 40-year-old timber on site II and III land (Figure 3), we realize the great resources that have been lost. Another 30 years of growing will be required to produce another timber stand of minimum merchantable value at present-day standards. Before cutting, the young stands had the potential to produce high-value timber for many years, if

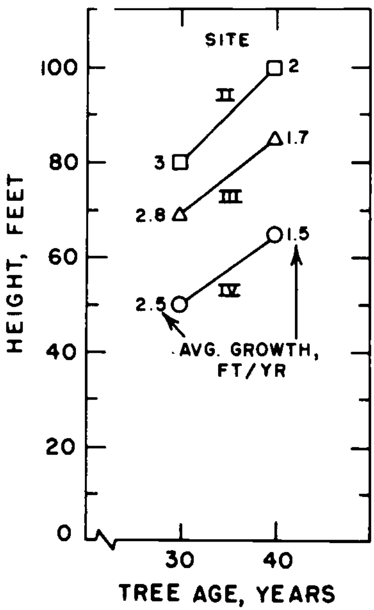

Figure 3. Growth potential of 40-year-old timber on site II and site III land.

managed on a thinning schedule. Liquidation at 40 years, however, ended this.

Today, we hear much against clearcutting. The public, however, is becoming aware of the need for clearcutting or shelterwood cutting, if Douglas-fir is to be reproduced on some sites. Little consideration or talk has been made about the growth potential of western redcedar, white fir, or hemlock as tolerant trees, which grow with and under Douglas-fir. We foresters know that a mixture of conifers is a safer gamble than growing only one species. Many of the timber areas owned by the small woodland owners support a variety of species. In fact, each tract of land varies in such features as tree composition, stocking, and age because of the differences in cutting and land use that have occurred up to the boundary. Here are many challenges for the skill of a silviculturist.

On tree farms that we have acquired, we have utilized all conifer species in precommercial thinning. Douglas-fir has been favored in the dominant position for fast growth of sawtimber and poles. We have carried on a supplemental stocking of 100 or more tolerant trees per acre in an understory position, however. Lower limbs have been pruned to a height of 6 to 8 feet in the thinning process, with power saws. We are producing as much clear cedar as possible, because I enjoy splitting cedar products.

One 80-acre tract, which we acquired in 1959, was cut about 20 years ago for all of the commercial Douglas-fir. It now is supporting a good stand of redcedar, as well as scattered Douglas-fir, hemlock, and grand fir. We have had this tract logged once for sawlogs and now have just completed a cut for Douglas-fir poles. In addition, we have cut large, sound redcedar into cedar rounds or stepping blocks as the highest financial return we can obtain and have most of the defective cedar split into posts and rails. By careful selection of the trees to be cut, practicing precommercial thinning, and cutting defective hardwoods into fuel, the property is rapidly accelerating in timber value and the appearance is more like a managed forest.

One of the practices we follow is to leave dogwood trees because of their springtime beauty. Unusual appearing bigleaf maple are reserved, and other hardwoods are retained in the stand. The understory, which is thinned and composed of tolerant trees, keeps this tract always in a forested appearance. Two stand openings, totaling about 10 acres, were planted to Douglas-fir 10 years ago. Now, small to large poles of excellent Douglas-fir are scattered over the balance of the tract.

As a small woodland owner, I am continually faced with the option of heavy cutting now or saving part of the tree group for greater size and value. The entire commercial stand could have been cut and sold 4 years ago when the previous high market existed. This would have left the tract in a similar condition to a nearby cutting with stumps, broken tops, and new brush patches.

We as foresters have a responsibility to encourage the small woodland owner in better stewardship of his land and timber resource. The farm forestry program was designed for this purpose, but to be successful more help is needed from all foresters. I would recommend that each of you acquire some of this forest land—1, 5, 10, or more acres—and practice good forestry on it. Your example can do much to sell good forestry to your neighbor. Also, the experience may help you to understand his problems.

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QUESTIONS

Audience What class of poles are you basing your prices on?

Harmon. The pole class is in 5-foot intervals, which start at 25 feet and extend to 100 feet. Prices are based on lineal-foot rates offered by the pole company for each length class. The poles are Douglas-fir "barkies" or unpeeled green trees. The poles must meet standards required by the company on such things as defects, sapwood, and knots.

Audience. Can you give us a price of dollars per thousand feet, board measure (*M* fbm) for these pole lengths?

Harmon. Yes. For example, at age 40 years in Table I, 70 trees should be cut. Their total scale is 8400 board feet, or 120 board feet per pole. The price per pole in 1970 was 19 dollars or \$19/120 bd ft = \$158 per *M* fbm. The pole price for 1973 was 36 dollars each or 300 dollars per *M* fbm.

Audience. Do you often get a sawlog off the butt, with the remainder making a pole?

Harmon. Not very often in our operation, as we are working in young age classes. This will depend, however, upon the age and size of the timber. I think that oversize timber could provide a sawlog on some butt cuts.

Audience. What is the total ownership you operate on?

Harmon. Currently, about 750 acres in and near Clackamas County.

CABLE THINNING IN YOUNG-GROWTH DOUGLAS-FIR–A CASE STUDY

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INTRODUCTION

As the attendance at this short course attests, young-growth management is becoming increasingly important in the Pacific Northwest. In recognition of this importance, the Department of Forest Engineering at Oregon State University recently started a research project that deals with harvesting systems for partially cutting timber less than 20 inches diameter, breast high (dbh).

This research is part of a continuing program of Forest Environmental Engineering research, and the thrust of our current effort in young-growth harvesting systems is toward developing economic alternatives to the commonly used ground-based systems. Ground-based systems, such as crawler tractors and rubber-tired skidders, generally are limited to gentle terrain, but much of the high site land is on steep slopes. As an example, over two-thirds of the Siuslaw National Forest is on slopes that are greater than 30 percent (3). Even on the more gradual slopes, tractors and rubber-tired skidders may cause unfavorable effects on soils through compaction and soil disturbance. Therefore, research into systems for logging young growth, which can be used on steep slopes and will have less impact on soils than ground systems, could be useful.

Toward this end, the Forest Engineering Department recently began a project on the development and analysis of aerial logging systems. The project focuses on small mobile skyline systems and has three purposes[1]: to develop reliable

[1] Froehlich, Henry A. Research Project Proposal: Skyline Logging Systems for Managing Young Stands. For. Res. Lab., Oregon State Univ., Corvallis. Unpubl. Rept. 9 p. 1972.

basic data on production rates and harvesting costs of skyline systems for land managers who plan to enter young stands in the future; to learn how the operating efficiency of skyline systems may be increased; and to determine the profitability of skyline and other logging systems when used to thin young stands under several topographic and marketing conditions.

THE CASE STUDY

With these objectives in mind, the Forest Engineering Department conducted a logging operation in the forest of Oregon State University in the summer of 1972. A Douglas-fir stand from 35 to 40 years old, on Site-III land, with trees that averaged about 10 inches dbh and a volume per acre of about 10,000 board feet, was thinned at three different intensities. Primary emphasis was placed on a time study of a basic slackline, skyline yarding system, with a Schield-Bantam 800-foot-reach skyline unit (Figure 1).

We designated six units, roughly 10 acres each, to be cable thinned on two different slopes of 0-20 percent and 20-60 percent (Figure 2). In each slope classification, three thinning regimes were designated. We used the number of trees with a dbh over 7 inches as our stocking control variable. On this basis, initial stocking ranged from 210 to 230 stems per acre. Each unit was designated to be thinned to one of the intensities shown in Table 1.

Selection of trees on any thinning unit was based on the following criteria: leave trees, listed by priority, were small

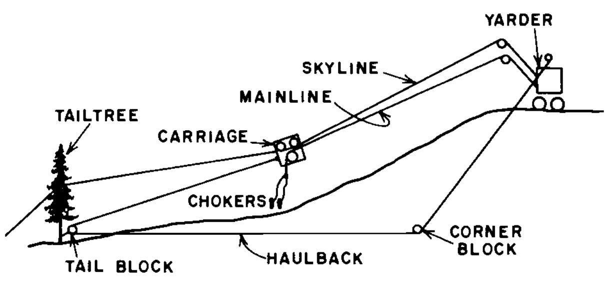

Figure 1. System configuration.

Table 1. Characteristics of Three Intensities of Thinning.

Intensity	Removal[1]	Residual stems per acre[1]	Spacing[1]
	Percent		*Feet*
Heavy	70	69	25 x 25
Medium	50	109	20 x 20
Light	20	170	16 x 16

[1]Exclusive of trees less than 7 inches dbh.

dominants, large codominants, and better intermediates to maintain spacing; and trees removed, listed by priority, were defective trees (crooks, sweep, and poor form), large limby dominants (wolf trees), merchantable intermediates and overtopped, and dominants and codominants to achieve spacing.

To compare the costs generated by the skyline system with those of a ground-based system, the high and low thinning intensities on the two slopes and the medium intensity on the steep slope were repeated with a John Deere 450 crawler tractor. Adding these five tractor units to the six skyline units gave a total of 11 thinning units (Figure 2).

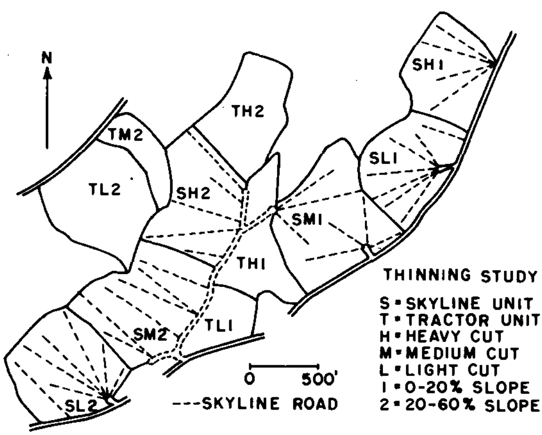

Figure 2. Thinning unit layout.

A coding system was devised for unit control and identification. It consisted of two letters followed by one numerical digit. The first letter signified whether the unit was skyline (S) or tractor (T) logged. The second identified the thinning intensity (H = heavy, M = medium, and L = light). The third digit separated the operation into slope classifications, with 1 referring to 0- to 20-percent slope and 2 referring to 20- to 60-percent slope.

Five products were considered as possible outlets for our thinnings: sawlogs, veneer logs, poles, posts, and pulpwood. Posts and pulpwood were eliminated quickly because the returns from these products were not sufficient to cover logging costs. During our logging, the mill price on sawlogs or veneer logs was about equal, but that on poles was about 40 percent higher. Therefore, trees harvested in the thinning were cut into poles, if they qualified. Otherwise, they were cut into sawlogs, because the sawlog mill was somewhat closer than the veneer mill. The poles went to a pole yard in Sheridan, Oregon, and the sawlogs went to a small log mill in Philomath, Oregon. If a pole were culled after arriving in Sheridan, it was sent to a veneer plant there, and we received a sawlog price for it.

A total of 95 acres was thinned in the 11 different units. Although objectives of the three thinning intensities were 70-, 50-, and 20-percent removal, the actual thinning intensities were closer to 60, 50, and 40 percent. The 95 acres yielded over 540,000 board feet, with four-fifths of the volume going as sawlogs and one-fifth going as poles. This volume came from 10,500 logs and 8,800 trees for an average volume of 51 board feet per log and 62 board feet per tree. The average dbh of these thinnings was 10.4 inches, with poles generally coming from larger diameter classes than sawlogs (Figure 3).

ANALYSIS

During the logging operation, information was collected on products removed, logging times, and costs associated with each

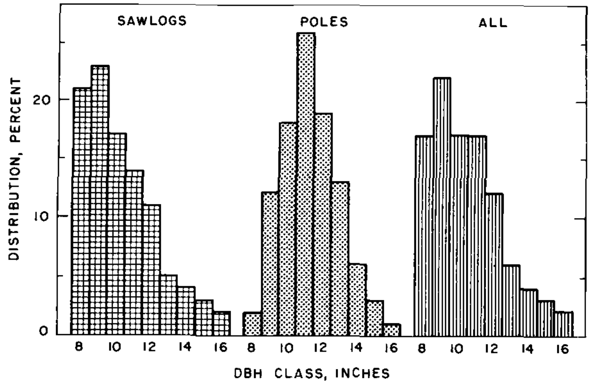

Figure 3. Diameter distribution of thinnings.

thinning unit. Reinventory of the stand is now in progress to determine residual stocking and damage during logging. We have divided our analysis of these data into three parts: production rates, logging costs, and comparison of costs and returns.

Production Analysis

Production analysis was broken in three parts: felling and bucking, yarding, and loading.

Felling and bucking

Time studies were made on the cutting operation in each thinning intensity (Table 2). The breakdown of activities, with the average time for each activity over all skyline units, is as follows:[2]

Tree selection. One of our original goals was to compare time spent felling in premarked stands with time generated by faller selection. This was not done. Initial treemarking in the dense stands was unsuccessful, and we went completely to faller

[2] Although the activity of eliminating hangups appears related to thinning intensity, total felling time for any one faller was about the same for the different intensities.

Table 2. Time for Cutting Operations on Each Tree in All Thinning Operations.

Activity	Avg time[1]	Total time
	Min	%
Selecting tree to cut	0.70	10.2
Moving to operation	0.43	6.3
Preparing site	0.16	2.3
Felling merchantable trees	1.07	15.6
Eliminating hangups	0.45	6.5
Bucking	1.51	21.8
Limbing	0.50	7.2
Collecting equipment	0.29	4.2
Assisting other faller	0.01	0.2
Felling nonmerchantable trees	0.64	9.2
Personal delay	0.42	6.1
Equipment delay	0.71	10.4
All	6.89	100.0

[1]For trees that averaged 10.4 inches in dbh, 62 board feet or 15 cubic feet in volume, and 1.2 logs.

selection. Because of density of the stand and the large amount of snow breakage, tree selection was easier after the stand had been opened.

Bucking. Results show that bucking is the major consumer of time, with over 20 percent of total time spent on this activity. This held true for all three thinning intensities. Thus, a logical candidate for system improvement would be to develop techniques to reduce bucking time. Tree-length yarding would be one solution, but we are not sure this is the answer in our operation. We would prefer to consider some manner of sawing the top off without taping the length. This could be done with the faller ocularly estimating top diameter. Pole quality and log grade may suffer, but such an alternative should be considered.

Also, bucking time was increased by the special bucking procedures required for poles. Poles required three additional cuts, plus a diameter measurement. One extra cut squares the bottom of the pole, and the two remaining cuts snipe the ends to indicate that it is a pole. The diameter measurement was necessary to determine the pole classification. These operations increased time per tree by 1 minute. Possibly, the measurements could be done at the landing, where the chaser may have some idle time. Also, if the decision of what product to make out of a log could be done at the landing, the snipe identification on both ends would be unnecessary.

Hangups. Time spent eliminating hangups was inversely proportional to the thinning intensity, with an increase of ½ minute per tree required as we moved from the heavy to light intensity. This is not surprising in a thick stand with small tree size and may not be a drawback. Ivar Samset (director, Norwegion Forest Research Institute, personal discussion, 1973) tells of a Norwegian practice in which fallers intentionally hang up trees to reduce damage when felling and yarding. Felling a tree completely, however, may be desirable, as this process removes large numbers of dead limbs on leave trees.

Delays. Delays were separated into two definable groups. The first, personal delays, included all delays not associated with equipment breakdown or maintenance. This covered rest breaks, discussions, and any work stoppage that could not be assigned to one of the other activities. The second delay dealt with equipment only. Any delay because of breakdown or servicing of equipment was included.

About 25 percent of total delay time was for equipment delays. The average equipment delay for all observations was 4.2 minutes. On the average, a personal delay was taken every 2.4 trees, and the average delay was 1.4 minutes.

Cutter variability. Several cutters were observed with some difference in cutting rate (Figure 4). The cutting-time pattern illustrated differences in worker experience. Workers 1 and 2 were both experienced, but worker 3 was an equipment operator, who cut during equipment breakdowns. This points

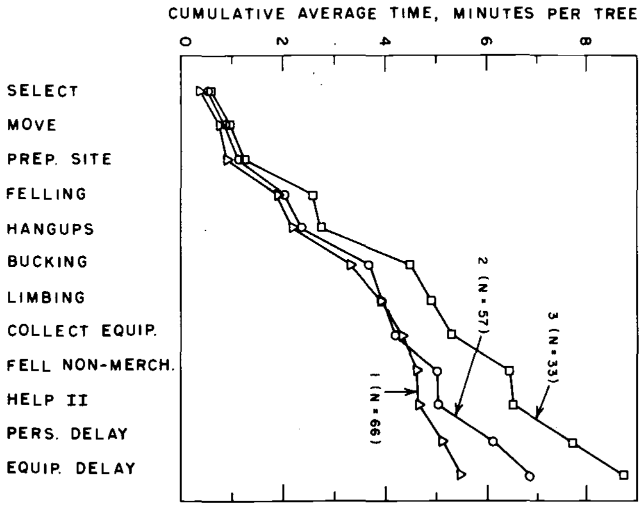

Figure 4. Cumulative time, by activity, for felling and bucking of workers for unit SH2.

out a condition that can happen in a small nonunion operation that has no rigid division of activities.

The amount of delay among operators differed considerably (Figure 4). Total accumulated time of two cutters was fairly uniform through the first ten activities. Then their time started to differ abruptly in the delays. Field observations suggested that one operator seemed more careful with his equipment and consequently suffered less time in equipment delay.

Another point of interest is the difference in the effort spent on felling nonmerchantable stems. Some of the workers cut nearly every stem while moving, but others severed only stems that would obstruct the felling process. Cutters who would switch back and forth with the rigging crew also severed high stumps from old loggings to reduce future hangups.

Although our statistical analysis of felling and bucking was not completed, some observations can be made on the felling and bucking operation that should be useful in future operations.

Yarding

Our project concentrated on study and evaluation of the skyline yarding system. The skyline roads were laid out by the operator. As the project proceeded from one unit to the next, the number of skyline roads per unit increased with a subsequent decrease in required lateral yarding distance over a comparable area. This is evident when units SH1 and SL1 are compared (Figure 2, Table 3).

An attempt was made to keep the maximum width of the skyline roads within the designated spacing of the residual trees. This means that the roads in a light-intensity stand could not exceed 16 feet. The location of random trees in sparse areas that fell in the skyline road, however, sometimes left large holes in the canopy. Actually, skyline roads averaged 15 feet in width, with the amount of the thinning unit in skyline roads ranging from 8 to 13 percent (Table 3).

Time studies were taken on the yarding operation to identify the predominant activities that affected the operation. The breakdown of activities was: carriage out, lateral out, hooking, lateral in, reset, carriage in, unhooking, and delay. Yarder moving time, skyline distance, lateral yarding distance, and number of logs per turn also were measured in the field during operations.

The first seven of these activities (Figure 5) follow the standard activities normally recognized as constituting a skyline operation (2). The reset activity was added to test whether the residual stand would influence the turn time. Lateral distance was measured as the angular distance and not the distance perpendicular to the skyline. As with felling and bucking, our analysis of the skyline yarding operation is not complete. Some interesting points, however, already are evident.

Moving. Takedown, moving, and rigging for the 36 road changes took about 1 hour each. The critical factor was whether a tail tree was required. If one over 10-12 feet were used, the tree had to be climbed, with an average increase of 30-45 minutes.

Lateral yarding. Because of the system configuration use, which required manual pulling of all slack in the mainline,

Table 3. Average Characteristics of Skyline Units.

Unit	Turns measured	Skyline distance	Lateral distance	Logs per turn	Maximum skyline	Maximum lateral	Sky-lines	Area in skyline roads
		Feet	*Feet*		*Feet*	*Feet*		*Percent*
SH1	148	290	46	2.3	540	200	4	8
SM1	71	195	47	2.4	390	180	7	8
SL1	65	158	41	2.7	420	140	7	10
SH2	270	257	47	2.0	620	250	5	8
SM2	76	474	50	2.9	650	130	6	10
SL2	55	490	66	2.9	620	170	7	13

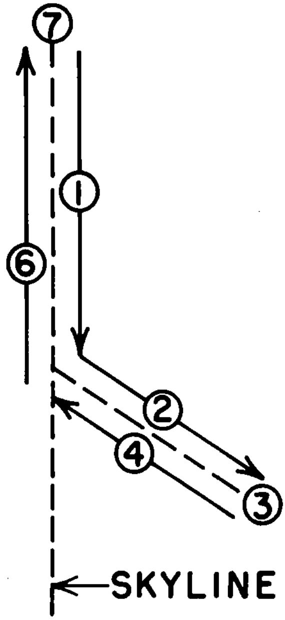

Figure 5. Primary activities that affect the yarding operation.

lateral distance would appear to have a large influence on yarding time. Lateral yarding time seems to account for almost 30 percent of total yarding time (Table 4). As expected, it is correlated strongly and positively with lateral yarding distance. Various approaches might be tried to reduce lateral yarding time. Among those considered are: easing the lateral yarding with a power slackpuller or by harvesting herringbone clearcut strips, which also would reduce resets and felling and bucking time; preyarding lateral turns to a position under the skyline with a low-cost "mini" yarder, which allows easier pickup at a later time; and providing closer skyline road spacing so that all trees felled would reach a skyline. The desirability of this would depend upon additional rigup costs for increased yarder moves and the resulting tradeoffs.

Hooking. The process of choking the logs seemed to have little correlation with any of the normally assumed independent variables, such as number of logs per turn. An interesting trend

Table 4. Average Skyline Yarding Time in Minutes per Turn.

Unit	Carriage out	Lateral out	Hook-ing	Lateral in	Reset	Carriage in	Un-hook	Delay	Total time
SH1	0.85	0.91	0.80	0.90	0.54	1.09	0.80	1.31	7.18
SM1	0.62	1.14	1.18	0.93	0.71	0.87	0.58	0.73	6.76
SL1	0.43	1.03	1.52	0.68	1.11	0.72	0.46	0.32	6.26
SH2	0.76	0.76	0.84	0.68	0.40	1.04	0.94	0.68	6.12
SM2	1.00	1.25	1.78	1.08	0.80	1.74	0.87	0.38	8.90
SL2	0.97	1.30	1.98	1.65	0.99	1.62	0.69	0.88	10.08

is evident (Table 4). On both slopes, the average hooking time increased as we went from heavy to light removal intensities. A possible explanation for this time is that the choker setters more quickly locate a turn of logs as the thinning intensity increases.

Resets. An inverse relation appears to exist between the intensity of thinning and the number of resets required in lateral yarding. This, of course, also can be influenced by the distance in which the turn moves laterally. Even under uniform lateral conditions as seen in Table 5, however, the rate increases with a decrease in stems removed (Figure 6). The importance of this variable on yarding cost can be seen when we consider the

Table 5. Yarding Costs per Hour.

Item	Cost
	Dollars
Schield Bantam	13.39
Yarder engineer	6.17
Choker setters (2)	12.72
Skidder	4.34
Skidder operator-chaser	6.56
Total	43.18

light thinning intensity where 57 percent of the turns required resets, and the average time of these 37 resets was almost 2 minutes. Considering the overall operational average time per turn, 18 percent of average total turn time was spent on resetting the chokers to get around trees. The importance of an experienced rigging crew who can observe the lay of a turn and select the most feasible removal path is evident. A multiple regression equation will not solve this problem.

Delay. Two categories of system interruptions were recognized in yarding, operational delays, and downtime. Operational delays were divided into two categories, equipment delays and other delays. An operational delay occurred about every fourth turn. Forty percent of these delays were equipment delays with an average length of 5.5 minutes. Other delays averaged 1.5 minutes.

Downtime is a system interruption serious enough to have the crew temporarily reassigned to other activities. It is associated chiefly with major equipment failures. Downtime is highly variable, and its impact on an operation is difficult to measure. We did not record downtime directly, but did consider it in calculating productive days per year for the yarder, which in turn influenced the yarder's calculated cost per hour.

A regression was run on a sample of our turn times. The skyline distance, lateral distance, number of logs per turn, and thinning intensity were regressed against total turn time, with the delays deleted. The resulting equation was

Time per turn = 7.3389 + 0.0039 skyline distance (feet) + 0.0174 lateral distance (feet) + 1.0247 logs per turn - 0.0917 thinning intensity

$n = 50 \qquad R = 0.70$

Thinning intensity shows up as a negative coefficient, which indicates that, as the percentage of trees removed increases, the average turn time for yarding decreases. The equation also indicates that per foot, lateral distance has a heavier impact on time than skyline distance.

Loading

Loading was done with a unit loader equipped with air tongs. Because most of our landings were on a slope, the limited reach capabilities prohibited loading during yarding. Originally, the loading operator sorted all decks to logs or poles. This did not work well, especially when the decks were high. Therefore, logs were swung away from the landing with a rubber-tired skidder and sorted along the road.

Only 12 loads were timed during the project. Of these, six included a complete breakdown of time spent on loading, sorting, moving, and delays. The average loading time was about 60 minutes, with 76 percent of the time actually spent loading.

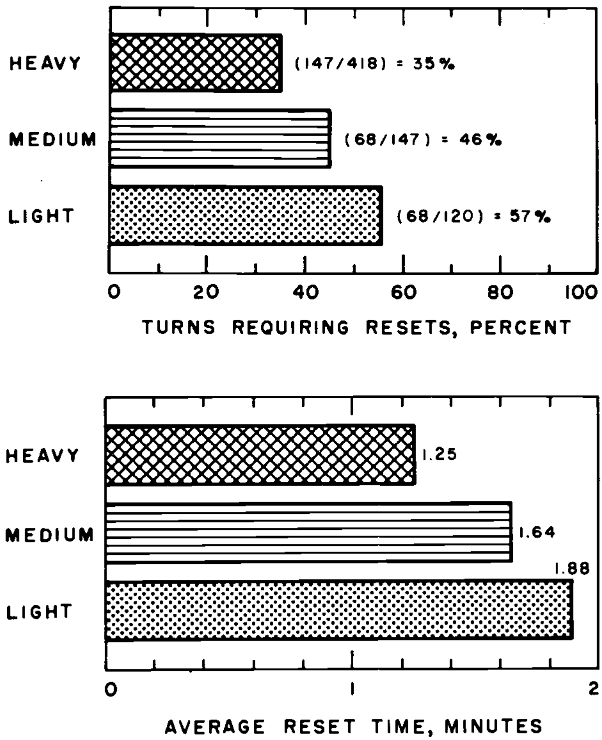

Figure 6. Resets as related to thinning intensity.

For 12 percent of the time, the loader was moving from deck to deck. This reflected the problem of small decking space and numerous landings.

The loads averaged 66 logs or 40 poles. With daily production less than 140 pieces, the loader obviously could not be kept busy.

Because of irregular production rates and decking problem, a self-loader would seem to solve high costs of loading. This, of course, would require decking space along existing roads and the utilization of a swing machine.

Cost Analysis

In this paper, we consider only what Adams (1) calls the "direct costs" of logging, such as felling and bucking, yarding, loading, and hauling. Excluded are the "fixed costs" of supervision, office overhead, road building, road maintenance, and slash disposal. Also, the costs of moving in and out and those of landing construction are ignored. These latter costs tend to vary considerably between firms and between settings, and thus were not considered here.

Felling and bucking

After removing the effect of faller variability, no significant differences were found in felling and bucking time per tree. Therefore, an average felling and bucking time of 7 minutes, which includes delays, was used for all units. At a felling and bucking rate of 7 minutes per tree and an average tree volume of 61.5 board feet, the production rate is 8.6 trees and 529 board feet per hour. With labor costs of $6.56 per hour and saw costs of $0.47 per hour, felling and bucking costs were $7.03 per hour, or $13.33 per thousand feet, board measure (*M* fbm).

Yarding

The basic production unit for the skyline operation consisted of the Bantam yarder, a yarding engineer, two choker setters, a chaser who doubled as a skidder operator, and a rubber-tired skidder to swing the logs from the landing to the loading deck with a total hourly cost of $43.18 (Table 5). With production rates ranging from 7.63 to 9.53 minutes per turn under the different thinning intensities, yarding costs ranged from $45.36 to $56.66 per *M* fbm yarded (Table 6). This compares to yarding costs on our tractor units of about $21.00 per *M* fbm and to yarding costs of $10.00 per *M* fbm reported by Adams (1) in his study on tractor logging.

Loading and Hauling

With loading taking about 1 hour per load, loading costs were about $5.00 per *M* fbm. According to the operator, hauling costs were about $45.00 per load. With an average load of 3,000 board feet, this gives an average hauling cost per *M* fbm of $15.00.

Table 6. Skyline Yarding Production and Cost.[1]

Thinning intensity	Turn time[2]	Logs per day[3]	Board feet per day[3]	Cost per *M* fbm[3]
	Minutes			*Dollars*
High	7.63	145	7614	45.36
Medium	8.58	131	6771	51.01
Low	9.53	118	6096	56.66

[1]Under average logging conditions of a 291-foot skyline distance, a 48-foot lateral distance, 2.35 logs per turn, a volume per log of 515 board feet or 12.3 cubic feet, and a cost of $345.44 per day.
[2]Includes delay (0.77 minute) and move time (0.71 minute).
[3]Assumes an 8-hour working day.

Total Direct Logging Costs

With poles part of the output, we found that total direct logging costs per *M* fbm ranged from $78.69 to $90.00 on the skyline units (Table 7). This compares to total direct logging costs on the tractor units of about $55.00 per *M* fbm and total direct logging costs in Adams' (1) tractor study of $40.00 per *M* fbm.

We estimate that poles cost about $10.00 per *M* fbm extra to log. This chiefly occurs because of longer bucking times and a lower volume per truck load that can be hauled. Without poles, the one-fifth of the volume formerly cut for poles would have a drop in logging cost of $10.00 per *M* fbm. Overall, costs would drop $2.00 per *M* fbm.

Comparison of Costs and Revenues

A major purpose of this study is to compare revenues and costs of thinning these stands under various thinning intensities

Table 7. Total Direct Logging Cost, in Dollars per *M* fbm, in Relation to Thinning Intensity.

Thinning intensity	Operation				
	Felling, bucking	Yarding	Loading	Hauling	All
Heavy	13.33	45.36	5.00	15.00	78.69
Medium	13.33	51.01	5.00	15.00	84.34
Light	13.33	56.67	5.00	15.00	90.00

and marketing conditions. Here, we will examine the net revenue per *M* fbm, under the three thinning intensities, with and without a pole market, and under prices that existed at the time of our operation and at current prices.

As mentioned, the thinnings yielded 540,000 board feet, with four-fifths of the volume going as sawlogs and one-fifth going as poles. Almost all of the sawlogs went as No. 3 and No. 4 because of their small size. The poles went in different grades, but most were in the 25- to 45-foot range (Table 8).

About 10 percent of the poles were culled when they arrived at the pole yard. For these logs, we were paid sawlog prices. At the time of thinning, we were receiving, at the mill, an average of $90.00 per *M* fbm for sawlogs and $140.00 per *M* fbm for poles. Since that time, as most of you know, log prices have risen spectacularly. Currently, we would receive $165.00 per *M* fbm for sawlogs and $190.00 per *M* fbm for poles. That is a 90-percent rise in sawlog prices and a 35-percent rise in pole prices.

Under the average logging conditions encountered in this study, the net stumpage return ranges from $2.00 to $91.33, depending on thinning intensity, products marketed, and prices received (Table 9). This return can accrue as stumpage return to stumpage owner or profit to the logger, or can be used to cover some of the fixed costs of the operation, such as road building.

Table 8. Poles Harvested, by Length and Grade.[1]

Length	Grade[2] C2 8.1	C3 7.5	C4 6.9	C5 6.2	C6 5.6	C7 5.0	All
Ft							
25	1	1	1	40	192	104	340
30	-	-	13	258	206	-	478
35	-	2	14	160	53	-	229
40	1	6	13	179	-	-	229
45	-	2	56	157	-	-	215
50	2	12	25	-	-	-	39
55	-	3	-	-	-	-	3
All							1,505

[1]After arrival at the pole yard, 149 poles were culled and sold as sawlogs.

[2]The number below each grade refers to minimum top diameter, in inches. For each length, there is also a minimum butt diameter, not shown.

CONCLUSIONS

As we begin to thin our steeper ground and more restrictions are placed on permitted logging techniques, aerial logging systems will become increasingly important in the Pacific Northwest. Conclusions concerning the use of one type of aerial logging system that can be drawn from our case study on partially cutting small timber with a skyline system are: skyline logging as conducted in our study is considerably more expensive than tractor logging; improvements seem possible in the yarding activities, such as lateral yarding, which can reduce substantially the cost of skyline yarding; improvements seem possible in the logging operation, such as log bucking, which can reduce substantially the overall cost of logging small timber; an experienced crew that understands the interaction of felling

Table 9. Net Return in Relation to Thinning Intensity and Marketing Conditions, in Dollars per *M* fbm.

Thinning intensity	Old market[1]		New market[1]	
	No poles[2]	With poles	No poles[2]	With poles
High	13.31	25.31	88.33	91.33
Medium	7.66	15.66	82.66	85.00
Low	2.00	10.00	77.00	80.00

[1]Revenue in old market:
No poles = $90 per *M* fbm
With poles = $100 per *M* fbm
Revenue in new market:
No poles = $165 per *M* fbm
With poles = $170 per *M* fbm

[2]Assuming an average $2.00 per *M* fbm increased logging cost when poles are produced.

pattern and yarding, in stands cut to varying intensity, is highly important in holding costs down; and market timing and product selection are crucial in determining the profitability of the operation. Here again, the interactions on the whole operation must be recognized. As an example, although poles may be a desired product on the market, their effect on logging costs may be sufficient to change the operation. Because of market variability and its effect on success or failure of a thinning operation, it must be monitored continuously.

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HARVEST CUTTINGS AND REGENERATION IN YOUNG-GROWTH WESTERN HEMLOCK

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ABSTRACT

Western hemlock may be regenerated by most of the standard harvest cutting systems—clearcut, seed tree, shelterwood, and selection—thereby providing the land manager wide latitude in writing silvicultural prescriptions. Harvest cutting objectives range from improving esthetic and recreational values to timber production at minimum logging cost. Clearcutting is the most common harvest cutting system, with regeneration generally satisfactory or in excess. Competing vegetation is a problem in some areas. Precommercial and commercial thinnings favor establishment of advance regeneration in the understory, and this increases opportunities for use of the shelterwood system.

INTRODUCTION

Most forest land managed specifically for production of western hemlock lies in the coastal areas of Oregon, Washington, British Columbia, and Alaska. Emphasis in this discussion will be on the Oregon-Washington portion, and the main focus will be on pure hemlock. Hemlock-Sitka spruce and hemlock–Douglas-fir mixtures also are mentioned because existing hemlock stands generally have at least a small portion of these species.

Southward along the coast, essentially pure stands of hemlock occupy only a narrow strip between hemlock-spruce forests near the coastline and hemlock–Douglas-fir forests inland. In places, pure hemlock is missing entirely. As you leave the coastline, spruce drops out, but may be replaced quickly by Douglas-fir. Northward, the hemlock belt widens to several miles in Tillamook County, Oregon, and continues north as a fairly wide and extremely productive strip of forest land. Pacific silver fir becomes an important associate in Washington and northward into British Columbia.

Western hemlock is the climax species over a vastly broader area—an area encompassing most of what is referred to as the Douglas-fir region (2). Historically in the broad area, Douglas-fir has been favored by repeated wildfire; clearcutting and broadcast burning continue to favor it. Even in the existing hemlock belt, landowners may clearcut hemlock, then plant or seed Douglas-fir to obtain mixed Douglas-fir–hemlock. Man, therefore, continues nature's bias, which favors Douglas-fir over hemlock.

Changing times may find us extending hemlock eastward rather than Douglas-fir westward. Comparison of yield tables shows that hemlock produces considerably more volume than Douglas-fir. This yield-table comparison generally is accepted as valid even though yield-table data were taken on different sites. Many foresters agree that, on many sites, hemlock is more productive than Douglas-fir. Much of the rationale for establishing Douglas-fir on these sites has been that higher log prices will more than compensate for hemlock's greater productivity. Recent increases in hemlock log prices make this prediction more tenuous than in the past. The idea is gaining acceptance that the species to plant on a particular area is the one that will produce the most wood fiber on that acre. Often this species will be western hemlock.

Landowners who are regenerating a mixture of western hemlock and Douglas-fir may be in a favorable position. The mixture should produce more than pure Douglas-fir, at least on sites where light rather than moisture is a principal limiting factor. The hemlock usually assumes a subordinate position in the canopy, where it utilizes light that filters through the Douglas-fir canopy. It produces usable wood fiber that otherwise would be lost or go on understory vegetation. Whether the mixture will produce more than pure hemlock is an unanswered question. In any event, the forester must be able to prescribe harvest cutting systems that will control species composition in the new stand, whether it be pure hemlock or a particular species mix.

Clearcutting is by far the most common harvest cutting system, with nearly all regeneration cuts made by this method. The seed tree system will work, but rarely is used because many seed trees blow down during storm winds. Shelterwood cutting has been used successfully in even-aged stands. Silviculture of uneven-aged stands by the selection system has not been tested formally, but general observations and the fact that western hemlock is the shade-tolerant climax species indicate this system also will be successful in obtaining hemlock regeneration. Various combinations of these four basic systems also may be used. Biologically speaking, the forester managing western hemlock has wide latitude in selection of a harvest cutting system.

OBJECTIVES OF HARVEST CUTTINGS

The silvicultural prescription for a given area depends on the objectives of the landowner and local environmental conditions. If the landowner is managing intensively, he usually has several objectives. If not, the primary one often becomes minimum logging cost. Frequently, a major objective is regeneration, probably pure hemlock, but perhaps hemlock with a component of other species. Perhaps the area is to be regenerated by planting. Then an objective of the harvest cutting is to open the area to facilitate planting.

A common problem in regeneration of hemlock is overtopping by competing vegetation such as red alder and salmonberry brush; therefore, a harvest cutting objective may be destruction of this vegetation and creation of conditions that favor tree seedlings over their competition.

Often regeneration is already established. Then the objective is to protect it. Advanced regeneration, however, may be too dense. Then the objective may be a complicated one of destroying some of it during the logging operation, but leaving the area fully stocked with well-spaced seedlings. A variation may be to leave less than desired stocking, then fill in with another species.

Blowdown is a major problem in hemlock forests, and the need to leave windfirm borders is always present. If only part of the stand will be removed, the trees left need to be as windfirm as possible. To maintain or improve the scenic beauty of the forest is an increasingly important objective. Another objective that has been with us through the years is protecting the soil resource by minimizing disturbance, exposure of unstable soils, and soil compaction. Protecting the wildlife resource is an important consideration in many areas. An objective that increases in importance southward and inland is to minimize fire danger that results from logging. Another objective may be to furnish particular log grades and sizes; this may require taking only parts of the timber stand. Mistletoe control is a common objective, particularly when older trees are present.

Probably, by now you have thought of additional objectives, but I will not try to cover them all. Two main points should be made. The first is that objectives of a proposed harvest cutting should be understood clearly, because only then can you select the best harvesting system or combination of systems. The second is that objectives invariably will be multiple, and your job will be to write the silvicultural prescription that will provide the best overall results. Trade-offs will have to be made. Now let us take a closer look at some of these objectives and consider how western hemlock best may be harvested to meet them.

Minimizing Logging Costs

Clearcutting best minimizes logging costs, the seed tree system next, then shelterwood cutting, and finally the selection system. This priority is not based on actual cost comparisons between harvesting systems, because they are not available, but on the hypothesis that costs are lowest when fixed costs are spread over large volumes per acre. Also, protecting residual trees increases costs when partial cutting systems are used. Cost surely is a major reason for most harvest cuts in western hemlock being clearcuttings. Of course, clearcutting may not meet other objectives, which may be more important than current logging cost.

Establishment of Regeneration

Production and dissemination of western hemlock seed generally are adequate for seedling establishment. In Oregon and

Washington, hemlock produces a heavy cone crop every 3 to 4 years, with light crops intervening. Only occasionally is there a complete failure. Seed dissemination occurs from October to May.

Rate of fall is 2.6 feet per second, compared with 3.1 feet for Sitka spruce, 4.4 for Douglas-fir, 4.95 for Pacific silver fir, and 5.1 for western redcedar (12). Western hemlock seed released 200 feet above a snowfield during a 12.5-mile-per-hour wind landed up to 3,800 feet from the point of release. Heaviest seedfall was at 2,000 feet. Seed flight was considerably greater than for Douglas-fir under similar conditions (6). Therefore, in the reseeding of large clearcuttings, hemlock is superior to associated species because its seed will reach farther out into the area.

Regeneration on large continuous clearcuttings made by early-day loggers confirms the excellent seeding capability of hemlock. These large areas now support dense natural stands of western hemlock and associated species. A recent study on a mile-square clearcutting in Alaska showed adequate seed dispersal throughout the area. A regeneration survey taken eight growing seasons after logging generally showed adequate natural regeneration. Nonstocked areas were judged to be caused not by lack of seed, but by competing vegetation or subsequent disturbance (3). In the Oregon Coast Ranges, we measured seed fall near the center of an 81-acre clearcutting. Hemlock seed fall over a 4-year period averaged 128,000 sound seeds per acre; spruce seed averaged 115,000 seeds per acre (10). Too much regeneration became established, and the area had to be precommercially thinned. I think we may conclude that hemlock seed fall seldom is limiting for natural regeneration.

One qualification that should be mentioned concerns use of adjacent stands for the seed source. General observations show that opening of cones and dissemination of seed occur during periods of dry weather. This was confirmed by Harris (4) at Juneau. He found that after cones matured, the scales opened and closed in response to dry and wet atmospheric conditions with much flexing of cone scales during the season. Winds that blew when cone scales were open were helpful in dislodging the seed. Dry winds in Oregon and Washington normally blow from north and east. These winds cause cones to open and disseminate most seed to the south and west. Some seed is disseminated by moist southwest winds. For example, when moist winds begin, a lag occurs before cone scales are closed. If moist southwest winds are strong during this period, and they often are, they carry seed considerable distances. We noted one season in coastal Oregon when no dry periods occurred after October seed maturation. This eliminated that burst of seed fall expected with the first dry wind. Seed fall stretched over a long period, and dissemination was to the north and east. In general, dry winds do occur, and a seed source located north and east of a clearcutting probably is more effective than one in another direction.

The selection of a harvest cutting system has a major effect on species composition of the new crop. Under the shade of the forest canopy, the very tolerant hemlock has an advantage over tolerant spruce, also over Douglas-fir and red alder, which are classed as intermediate in tolerance. Leaving some canopy (as in shelterwood cutting) or almost all of it (as in selection cutting) should favor regeneration of hemlock over its competitors. Differences in tolerance may be used to advantage by controlling the intensity of solar radiation that reaches the forest floor. Possibly, we could permit hemlock regeneration, but minimize spruce, or permit hemlock and spruce regeneration, but minimize Douglas-fir and red alder.

We experimented with effects of canopy density on first-season growth of hemlock, spruce, Douglas-fir, and red alder on mineral soil. Four strips were thinned, a heavy thinning at one end that progressed gradually to no thinning at the other (9). The idea was to have solar radiation that reached the forest floor range from too much to too little along the strips and, by measuring seedling germination and growth, to determine the optimum for each species.

After 1-milacre, scarified plots were established, seedlings were measured on 1-square-foot subplots, identified by wooden frames or circular screens. Some subplots on the thinned strips received only natural seed fall; others were seeded with all four species. Some had hardware cloth placed over them during seed germination to keep out rodents. Radiation intensities on the plots ranged from less than 10 percent to almost 70 percent of radiation in the open. This was estimated to bracket the optimum for hemlock and spruce. Similar plots were located in an adjacent clearcutting in full sunlight.

The first seed fall after plot establishment was a poor crop of only 16,000 sound hemlock and 120,000 sound spruce seed per acre. About 4,000 alder seed per acre drifted in from adjacent stands. The next cone crop produced 1.3 million hemlock, about 1 million spruce, 5,000 fir, and 7,000 alder seed per acre. This crop resulted in enough seedlings for some analyses of radiation effects. The best comparisons, however, came from plots that were seeded directly with about equal numbers of all four species.

From our discussion of adequate regeneration even on large clearcuttings, it follows that with shelterwood cutting there is no danger of getting the overstory so light that seed fall will be limiting. Except for an occasional cone crop failure, environmental factors rather than lack of seed are likely to control seedling establishment.

Seedling establishment on mineral soil was much better under the shelterwood canopy than in the clearcutting (Table 1). The hemlock seed fall of 1.3 million sound seeds per acre under the canopy led to establishment of 206,000 seedlings per acre on the subplots. On the clearcutting, the subplots were about 300 feet west of the timber edge, but still received ample seed. Some seedlings germinated, but none survived the summer. On the subplots seeded directly on the clearcutting, some seedlings did survive. But here, the seed had been covered with about 3 millimeters of mineral soil. Hardware cloth was placed over the seed spot during germination, and this provided about 25-percent shade until it was removed on May 19. We may conclude that, even in the moist hemlock belt, all the species, including Douglas-fir and red alder, benefit from shade during the season of establishment. Excellent regeneration obtained on clearcuttings generally occurs when the microsite is shaded in some way—by logging slash, vegetation, or perhaps no more than an irregularity in the surface that shades individual seeds during germination. Seedlings also may get started during a wet spring, which gives them time to get their radicles down far enough to keep up with

Table 1. Average Number of Seedlings on Mineral Soil Plots by Species, Seed Source, Treatment, and Area, September 1965.

Species	Natural seed fall[1]				Direct seeding in 1965, screened spots[2]	
	Open seed spots		Screened seed spots, 1964			
	Shelter-wood	Clear-cutting	Shelter-wood	Clear-cutting	Shelter-wood	Clear-cutting
Sitka spruce	96,300	0	110,000	0	5.0	1.4
Western hemlock	206,100	0	267,410	0	3.0	0.6
Douglas-fir	1,800	0	38,625	0	2.8	0.8
Red alder	9,000	0	0	0	0.3	0

[1]Seedlings per acre.
[2]Seedlings per plot.

receding moisture levels when dry weather arrives. Northward in the hemlock belt, less shade is needed because dry periods are less common.

The 10- to 70-percent radiation reaching the forest floor under the shelterwood stand had little effect on numbers of seedlings that survived the growing season—that is, on seedling establishment. No significant relations between radiation and numbers of seedlings were found for hemlock. Some were found for spruce and fir, but they accounted for only a small percentage of the variation among the plots.

An important result measured on the mineral soil seed beds under the forest canopy was the high ratio of seeds to seedlings for red alder. It took 47 red alder seeds to produce an established seedling; depending on species, only from 4 to 10 conifer seeds were required.

Solar radiation played a much more important role in first-season growth than it did in numbers of seedlings established (Figure 1). Western hemlock and Sitka spruce were almost parallel in their response to radiation, with no significant differences in total weight. Hemlock, however, was significantly taller. An important difference between species was the greater weight and size of Douglas-fir seed, which presumably has a greater nutrient capital. But Douglas-fir and the other species differed significantly in response to radiation, as illustrated by the shape of the regression lines. Douglas-fir growth continued upward, compared with reduced growth of hemlock and spruce at the high radiation levels.

Reduced growth of hemlock and spruce probably was a result of increasing soil moisture tension rather than a direct result of radiation. This probability was indicated by close correlations between soil moisture percentage and radiation. Either the increasing radiation, decreasing soil moisture, or some combination could have caused reduced growth. That moisture was the probable limiting factor was confirmed by a study of shading conducted concurrently, in which water was provided and growth reductions did not occur.

Optimum levels of radiation calculated here for hemlock and spruce are valid only for the study area in 1965. In a drier year, I would expect soil moisture tension to be more limiting and the optimum radiation level to be less. In a wet year, simulated by watering of seedlings, the optimum would be higher. From this and other data, we probably can conclude safely that, in general, for first-season seedling establishment on mineral soil, low levels of radiation (a moderately dense forest canopy) will favor hemlock and spruce, and a higher level of radiation (a more open canopy) will favor Douglas-fir. But mineral soil usually makes up only a small portion of the seed bed and, of course, we are interested in more than just initial establishment. Therefore, these

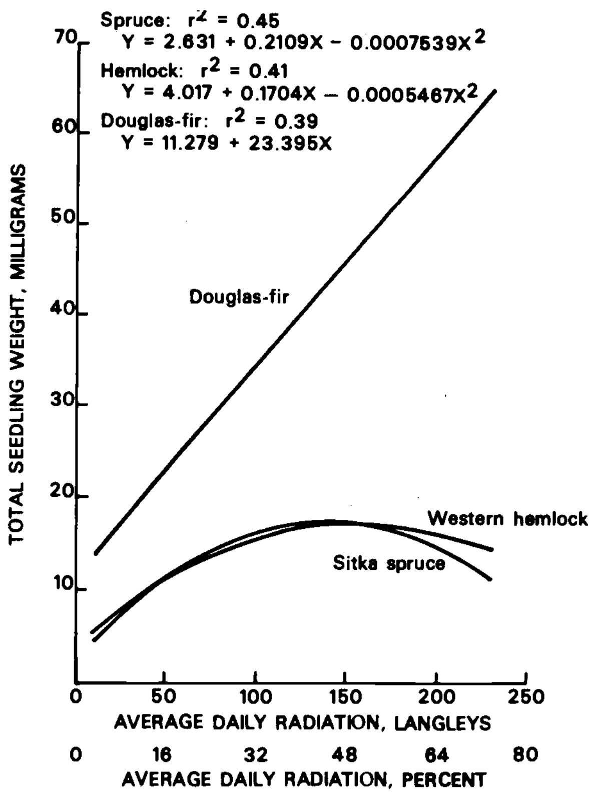

Figure 1. Regressions of total seedling weight on average daily radiation by species, in a shelterwood area, on screened seed spots in 1965.

data are just small pieces in a much bigger puzzle. The main point I want to make is that basic differences do exist in the ecology of species and that we must learn to utilize these differences in obtaining the species of forest regeneration we want.

I think consensus among practicing foresters is that Douglas-fir, red alder, and even Sitka spruce do not do as well on the general run of seed beds found on the forest floor as they do on mineral soil. For example, under the same timber stand, we observed regeneration on clusters of four 1-milacre plots, located by measuring out 3 meters in each direction from each scarified plot. We counted only seedlings that germinated the first and second year after the thinned strips had been established, so we knew about how much radiation they had been getting. There were 12,680 hemlock and 4,213 spruce seedlings per acre. But seedling establishment was highly variable and, interestingly enough, was not related significantly to radiation. When variability among normal seed beds was left in the data, radiation effects in the 10- to 70-percent range just were not strong enough to be significant.

Not a single Douglas-fir or red alder seedling was found on the plot clusters, although 5,000 fir and 7,000 alder seed per acre had fallen. We looked for seedlings. They were there, but almost exclusively on mineral soil; the plot cluster seed beds were mostly organic.

On the other hand, Minore (7) showed that, in the growth chamber, Douglas-fir and red alder grew on both duff and rotten wood, growth being significantly better on the more nutritious duff. He also made some observations on growth under natural conditions in the forest. In the deep forest, with less than 10 percent of the sunlight reaching the forest floor, seedlings, which were almost always hemlock, were found on rotten logs, but not on the duff-covered forest floor. With 10 to 40 percent sunlight, both hemlock and spruce grew on logs and the forest floor, but they were taller on the logs. With 40 to 60 percent sunlight, both logs and the forest floor were excellent seed beds. In full sunlight, both were unsatisfactory seed beds. But if well established in the shade, some hemlock seedlings survive subsequent exposure during the yarding operation and go on to form the nucleus of the new stand.

Considering research results and general experience, I think we safely can say that we favor hemlock regeneration by maintaining a dense to moderate overstory and organic rather than mineral soil seed beds. A moderately dense overstory will encourage spruce along with the hemlock. A light overstory and certainly a clearcutting will encourage the addition of Douglas-fir and red alder. Under a light overstory and in a clearcutting, organic seed beds often get too hot and dry even in the coastal climate. Mineral soil seed beds, preferably with some microsite shade such as light slash, are better when the seed bed will be exposed to the sun. More specific statements can be made as we learn more about species-seed bed interactions and effects of light, moisture, and nutrients.

Control of species composition also may be accomplished by controlling the seed source. For example, you may wish to favor hemlock over Sitka spruce regeneration in an area where spruce saplings would be damaged badly by the Sitka spruce weevil. You could use the shelterwood system and thin spruce from the overstory during the seed cut, thereby eliminating the seed supply. Seed will drift laterally within a stand, however, and a wide buffer strip will need to be treated.

A common problem with western hemlock is that too much regeneration leads to a costly precommercial thinning job. This being true, perhaps we should get away from the philosophy that we should create the best possible environment for establishment of regeneration. A better objective may be to create an environment that will lead to the establishment of just the right amount of regeneration, neither too much nor too little. Maybe you want to provide for a little extra, just as insurance, or perhaps to encourage natural selection of the best of several seedlings through competition. Or maybe you want to strive for just the right amount, and if you do not get it, fill in by planting. In any event, we should be able to do better than establish thousands of seedlings per acre, then pay out about 60 dollars per acre to thin them to 250-350 per acre.

A promising approach for limiting natural regeneration is through control of the seed bed. With clearcutting, for example, a yarding method may be selected that minimizes disturbance and leaves a high proportion of the area as organic seed bed. Subsequent seedling establishment would be concentrated on more limited mineral soil seed beds.

Control of Competing Vegetation

Western hemlock is a slow starter, and young seedlings are overtopped easily by competing vegetation. Salmonberry (*Rubus spectabilis*) and thimbleberry (*R. parviflorus*) are major competitors, particularly in creek bottoms and other wet areas. When exposed to full sunlight after clearcutting, these brush species tend to form dense thickets and exclude hemlock regeneration. Even when damaged by logging and burned back by fire, they sprout quickly and tend to dominate the site. The sprouts may grow from 1 to 2 feet by the end of the first growing season when hemlock seedlings may be only 1 inch tall. This brush is deciduous, and fallen leaves tend to smother the small tree seedlings at the end of their first season.

Two basic approaches to brush control are to prescribe treatments that will, first, destroy or at least retard growth of brush plants and, second, speed establishment and growth of hemlock seedlings. Areas threatened by brush should be identified in advance of logging, brush control plans developed, and the logging operation designed to facilitate control work. For example, yarding may be arranged to drag logs through brush patches, thus destroying much of the aerial portions of the plants. Tree tops may be felled into the brush and burned. These treatments tend to kill the plants back to ground level and clear the area for planting. Tractor scarification is an alternative technique that is being used successfully, but care must be taken to avoid stream siltation and protect the fish habitat.

Whatever means are used to destroy the brush, the treated area needs to be planted as soon as practicable with the largest and most vigorous planting stock available. Even so, planted seedlings may be overtopped by brush sprouts. If this appears imminent, chemical brush control should be considered to retard the brush until the seedlings gain dominance. Chemicals also may be substituted for the mechanical methods just mentioned. I prefer using the harvesting operation to accomplish as much brush control as possible, limiting use of approved herbicides to follow-up treatments where needed.

The following herbicide-research findings come from Ron Stewart, in brushfield reclamation research for the Pacific Northwest Forest and Range Experiment Station. The research reported was for aerial applications. The pesticides reported on and recommended here were registered for uses at the time this paper was presented. As registration of pesticides is under constant review by federal and state authorities, a responsible state agency should be consulted as to the current status of these pesticides before they are applied in the field.

Salmonberry often is treated with an early foliar application of Amitrol-T, using 2 pounds active ingredient per acre plus enough water carrier to make 10 gallons per acre. An application with Amitrol-T is better than Amitrol alone, because the addition of ammonium thiocyanate adds to the effectiveness. The best time for application begins when at least three-fourths of the leaves on the salmonberry plants are fully developed. It ends when new growth on the conifers is 2 inches long. Only a short period remains when salmonberry foliage is developed sufficiently, but before tree seedlings become too vulnerable to the treatment. Treatments are effective on salmonberry at this time because foliage is growing actively, and plant food is being translocated to the root system. Of course, the same is true for intermingled conifers. The hope is that, at time of application, most hemlock shoots will be protected by a canopy of brush foliage. Timing of application should be geared to stage of development of the plants. As this varies from year to year, tying the treatment to a particular calendar date may get you into difficulties. Amitrol-T is not very effective on thimbleberry and is not an appropriate treatment when this species is intermingled with salmonberry.

Salmonberry also is treated during midsummer with from 2 to 3 pounds acid equivalent of 2,4,5-T per acre in an oil-water emulsion. The oil is added to improve penetration into leaf surfaces, which by this time have more cutin on the surface and perhaps a coating of dust. Use no more than one-half gallon of oil. More causes too much penetration into conifer foliage. Enough water carrier is added to make a total application of 10 gallons per acre. The treatment period begins after conifer buds are set and growth essentially stops. It should end about 1 month before leaf abscission on salmonberry. Usually, the treatment period is from mid-July to mid-August, but it will vary somewhat from year to year, depending mostly on moisture conditions. In midsummer, bush plants are not so susceptible as earlier in the season, but chance of damage to the conifers is less. Timing is not so critical as with an early foliar application.

I should mention that, in general, western hemlock is more susceptible to damage by herbicides than is Douglas-fir, and both are more susceptible than Sitka spruce. Extra care must be taken when working with hemlock.

Red alder is another competing species that overtops western hemlock seedlings. Like the brush species, it frequents wet areas. But alder also invades well-drained soils and quickly can dominate large cutover areas. It favors bare mineral soil, and scarification for brush control or soil disturbance from logging will encourage alder. You often see alder 10 feet tall over hemlock seedlings less than 1 foot tall, and both may be the same age. Yet alder, on rotations currently considered practicable, produces must less wood volume than hemlock; and the unit value is less. Some landowners have designated certain wet areas for alder production, but the policy of most is to control alder as necessary for regeneration of conifers.

Red alder is controlled readily with herbicides, and control has become standard practice on many ownerships. Treatments are most effective when alder is only a few feet tall; otherwise, to get spray to penetrate the lower portions of the trees is difficult. Spray treatments may be applied to stems in spring or to foliage in summer.

In the spring, alder bud burst normally begins while conifer buds remain dormant. A common treatment applied in Douglas-fir areas during this period is 1 pound acid equivalent each of 2,4-D and 2,4,5-T per acre, plus enough diesel oil carrier to make 10 gallons per acre. Control comes from absorption of oil and herbicide through the alder stems. Treatments should be stopped when conifer buds begin to swell or when alder leaves become large enough to shield the stems from the spray. This treatment often is extended to mixed Douglas-fir and hemlock areas, but it does damage hemlock seedlings. As hemlock becomes the major species, spraying of stems in the spring usually is abandoned in favor of an early foliar treatment.

The early foliar application uses 2 pounds acid equivalent of 2,4-D, plus enough water to make 10 gallons per acre. If hemlock seedlings are exposed, there is danger of some damage to them. A midsummer foliar application also is effective on alder, and danger of damage to the hemlock is less. The usual treatment is from 2 to 3 pounds acid equivalent of 2,4-D per acre in an oil-water emulsion to make 10 gallons per acre. Use no more than one-half gallon of oil. Damage to hemlock seedlings from these treatments probably will be less than loss of growth from an extra year of suppression.

If salmonberry or other brush species cover part of the area, substitution of 2,4,5-T will be more effective on the brush and also should control the alder. If brush species are under the alder, and this is often the situation, they will be protected by the alder canopy, then released as the alders die. Further treatments often are needed to control the brush species.

Herbicides also may be used for site preparation as an alternative to yarding logs through brush areas or tractor scarification. When no conifers are present, apply about 3 pounds acid equivalent of 2,4,5-T per acre in an oil-water emulsion, with three-fourths gallon of diesel oil, plus water to make 10 gallons per acre. If the brushfield is well established, increasing the carrier to make 15 gallons per acre is advisable. Time of application should be from the early foliar period until early July.

In the past, some clearcut areas were left untreated and regenerated with a mixture of species. Almost always this included red alder, a few hemlock, and perhaps other conifers, plus lots of brush, both under the alder and in thickets. Many such areas now are being rehabilitated by an alder conversion operation. A common approach is high-lead logging to remove merchantable logs and knock down the alder and brush, broadcast burning, prompt planting, and herbicide spraying as needed. Some areas are scarified with tractors, and the debris is pushed into windrows, which may be burned or left to decay naturally.

The shelterwood system of harvest cutting is another means of accomplishing alder control and favoring hemlock. Enough overstory is left to shade out the alder, then the overstory can be removed after the hemlock is well established. This system, however, has been little used to date. Most alder control is with herbicides.

A preburn spray often is applied to alder conversion areas, also to other areas with severe brush problems. This spray has a twofold purpose: one, to kill alder and brush and, two, to defoliate the vegetation so underlying logging slash will dry out and fire will run broadcast across the area. Brush plants quickly overtop and shade logging slash, particularly on north slopes. This prevents the slash from drying out enough to carry the fire. The preburn spray kills the brush foliage, thereby adding some light-weight, flashy fuel, and lets the sun through to dry out the slash. The fire usually destroys the brush plants to ground level and cleans up the area for planting hemlock or other conifers. The same formulation described for site preparation may be used, 3 pounds acid equivalent of 2,4,5-T per acre in an oil-water emulsion.

Protection of Advanced Regeneration

When hemlock seedlings become established in the understory before harvest cutting, the overstory needs to be removed without destroying too many seedlings. Under even very dense stands, you find hemlock on the ridges; you find it under thinned stands; and of course, you find it under stands managed by the shelterwood system. As we increase our precommercial and commercial thinnings, it will become more common. Consequently, we have situations with new stands already established or partly established. The problem is to remove the overstory and leave an adequate stocking of hemlock. You may want to destroy some seedlings, thereby reducing the cost of precommercial thinning later. If your standard is from 250 to 350 trees per acre, you will want healthy hemlock seedlings on about a 12- by 12-foot spacing. I think we do not know how to do this overstory removal job very well. Mostly, it is a problem of logging techniques.

Some years ago, we started an exploratory study just to see whether the shelterwood system would work at all. All yarding was with crawler tractors. A 104-year-old stand had been thinned about 20 percent, which left about 76,000 board feet per acre. We had no thought of regeneration, but hemlock and some spruce seedlings promptly became established. This regeneration gave us the idea of going ahead with a shelterwood harvest system.

The spruce seedlings began to die out, and hemlock growth slowed down. The canopy had closed considerably 9 years after the thinning. Milacre plots were established and were 51 percent stocked. Then we removed 27,000 board feet per acre, leaving a shelterwood canopy made up of the best trees. Crown closure was about 60 percent. This logging reduced milacre stocking to 35 percent. During the next three growing seasons, stocking increased to 60 percent. Then we split the area into two parts with similar topography and aspect.

On the north half, three more seasons brought stocking up to 94 percent with seedlings up to 8 feet tall. There were thousands of seedlings per acre. The entire overstory was removed. This logging reduced stocking to 55 percent, still a lot of trees per acre. The overstory removal was a failure, however, in the sense that we had too many seedlings in most areas and no seedlings in some badly disturbed areas. Released seedlings had poor vigor and a yellow appearance the first year, apparently from abrupt exposure to the sun. The area looked like a normal clearcutting, with little of the esthetic value often claimed for the shelterwood system.

On the south half, three additional growing seasons brought stocking up to 73 percent, with seedlings up to 8 feet tall. Here, we prescribed a two-stage removal and started by taking 63 percent of the overstory. This reduced stocking only a little, from 73 to 67 percent. The remainder of the overstory is still there, along with lots of seedlings in the understory now up to 15 feet tall. We still have the challenge of removing the remainder of this overstory and ending with desirable spacing in the understory. We hope we can keep the area looking better than would have been possible with the clearcutting system.

Conclusions from this study so far are: one, the shelterwood system indeed will work in hemlock; and two, removing a heavy overstory all at once makes a proper distribution of remaining seedlings difficult, and the seedlings suffer some shock from abrupt exposure to the elements.

In another shelterwood study, the overstory was removed after seedlings were established in the understory. This stand was younger and pure hemlock. Cutting began when the stand was about 60 years old. No previous thinnings had occurred. The first cutting had the objective of stimulating seed production, although subsequent measurements showed seed fall to be more than adequate. Twelve intensities of cutting left basal areas that ranged from 234 square feet per acre to only 38 square feet (5). Seedling counts 4 years later revealed that not only had seed been produced, but seedlings had become established, which ranged from 1,100 to 24,400 per acre. The next treatment removed half the overstory and left basal areas ranging from 117 to only 19 square feet. This damaged some seedlings, but all treatment areas remained overstocked. Seedlings increased in number and height by the time the overstory was removed 4 years later. After the overstory was removed by rubber-tired skidder, the average per acre was 16,900 seedlings. After 2 years, the average was 18,700, with the dominants averaging about 6 feet tall. Even these large numbers of seedlings per acre are low, because when more than 10 seedlings occurred on a quarter milacre, they were recorded as 10 without trying to count all of them.

The plot that had the least basal area, first 38 and then 19 square feet, had fewer seedlings, probably because of more exposure to the sun, as in a clearcutting. There were 6,500 seedlings per acre right after the overstory had been cut back to 19 square feet. Six years later, there were 11,650. Dominant seedlings ranged from 6 to 15 feet tall.

The second study confirms that the shelterwood system will work well in hemlock and apparently with almost any overstory density. With younger timber and less volume per acre, removal of the overstory did not leave any nonstocked areas. Overstocking was the problem.

The next step that needs to be taken in developing the shelterwood system for hemlock is to work out harvesting techniques that will, one, avoid nonstocked areas as we found in the first study and, two, minimize overstocking.

Minimizing Blowdown

Blowdown probably is our most serious problem in managing hemlock forests. Major storms, such as the Olympic blowdown in 1921, the storm of December 4, 1951, on the Oregon coast, the Columbus Day storm in 1962, and many smaller storms have taken a heavy toll.

On several tree farms, wind dictates the harvesting plan. It works this way. The forestry staff labors over a detailed management plan that calls for particular stands to be harvested at particular times. Maybe they run it through a computer and select the best of hundreds of alternatives. Along comes a windstorm, and the carefully prepared plan has to be held in abeyance and all efforts directed to salvage operations. About the time salvage is complete and the plan is dusted off, along comes another storm.

Most silvicultural practices to minimize wind damage depend on knowing the direction from which storm winds can be expected. It is quite easy to tell for a particular storm, simply by viewing blowdown from the air or from some vantage point and taking a compass reading on the average direction of fall. During the Oregon coast storm of 1951, direction of fall averaged north 30 degrees east. During the Columbus Day storm, most trees fell to the north. Recently, some east wind blowdown has occurred, which caused trees to fall westward. Average direction of fall for an area should be based on several storms over a period of years. Wind direction during previous storms can be determined by observing old blowdown in the forest. Compass readings on many down trees should be taken and averaged, because some trees are knocked down by others on their way down. They may fall in several directions, but probably not back into the wind. Historical records of wind direction are present in the forest in the form of humps and depressions in the soil. When a tree uproots, the root system takes some soil with it, which leaves a depression. When the roots decay, this soil is left as a hump on the downwind side of the depression.

Windfirmness of a forest tree is a mechanical matter determined mainly by force of wind on the crown, tree height, and inertia of the soil mass gripped by the root system. Wind velocity and, therefore, the force on the crown, is influenced by topography; many studies show a relation between wind damage and topography. Observations made after the storm in 1951 on the Oregon coast showed that in the uncut stand, blowdown usually began near the lee side of a ridgetop and extended down the lee slope (11). If the lee slope was steep, over 70 percent in the Oregon study, the lee windflow apparently did not adhere to it, and little damage occurred. Some blowdown occurred on small ridges in the lee of a high main ridge or on flats in the lee of long steep slopes. Winds tend to funnel up or down a valley, especially one with steep sides. The Columbia Gorge is a typical example. An opening in the timber created by cutting a right-of-way between two clearcuttings creates a small but similar "valley," and wind damage sometimes occurs. The basic principle seems to be that damage may be expected wherever airflow is constricted and velocity, therefore, increased.

Wind damage also is related to soil conditions, particularly any that restricts rooting depth (1). Often in the moist hemlock area, this is a high water table, but it may be an impermeable layer in the soil, or simply shallow soil underlain with bedrock. If root rots are active in the area, trees become more susceptible to uprooting by wind.

Wind damage also is related to harvest cutting practices. Wind dips into clearcut areas and hits trees on the lee side with full force. After the storm in 1951 on the Oregon coast, with winds from south 30 degrees west, we found 93 percent of the blowdown along the north and east boundaries of the clearcuttings. Only 7 percent was along the south and west boundaries, which were still protected by trees to windward. If an exposed northeast forest edge was on a lee slope, it seemed to suffer more damage than it would on a windward (southwest) slope. Cutting lines may funnel wind into a corner, which causes wind damage at the apex. Although not determined conclusively in the study, I think that wind damage is related to the length of exposed cutting line—the more exposed line, the greater the risk. This is a point in favor of large rather than small openings. For example, a mile-square clearcutting leaves 4 miles of cutting line exposed to storm winds. Cutting sixteen 40-acre units leaves 16 miles of cutting line, four times as much.

Trees exposed to storm winds tend to build up windfirmness; hemlock does this by developing enlarged prop roots on the lee side. Buildup takes several years. Therefore, if storms are frequent, a newly exposed tree may be lost before it has time to develop adequate resistance. Results of study after the storm in 1951 indicated that Sitka spruce and Douglas-fir were more windfirm than western hemlock, that dominant trees were more windfirm than other crown classes, and that individual conifers sticking up out of alder stands, although exposed, suffered little damage. This is the basis of the recommendation often made by European foresters, but restricted to mineral soils with good drainage, for early thinnings to increase windfirmness of timber stands (8).

Arrangement of harvest cuttings is a promising approach for reducing wind damage in hemlock stands. Progressive strip clearcutting into the wind (13) has been recommended for European forests. This system, using strips about the width of a high-lead setting, seems to have application for hemlock stands here. A demonstration of the method has been started on the Cascade Head Experimental Forest near the Oregon coast (Figure 2). Cutover and pasture lands along a main stream form the northeast boundary of the management unit. The first cut was made windward of this boundary and perpendicular to southwest storm winds. The cutting area has regenerated; and a second strip may be harvested to windward, again perpendicular to the storm winds. Additional strips should be harvested at a rate that will cover the entire management unit by the end of the rotation. Note that no northeast boundary ever becomes exposed to storm winds. The same method may be used with

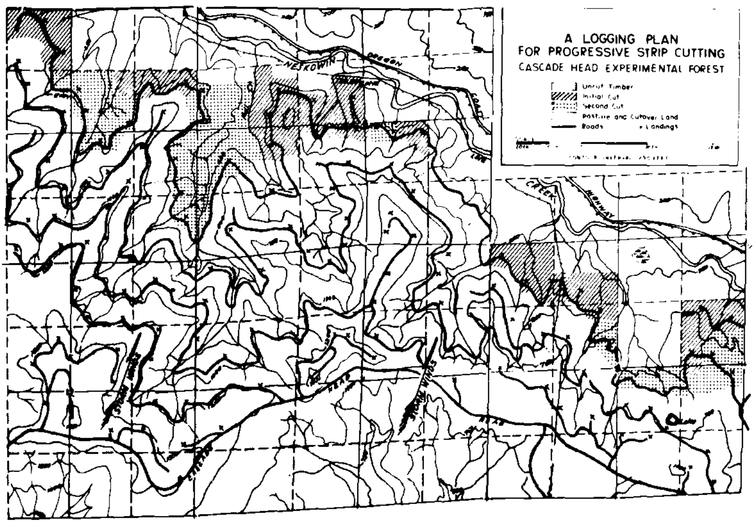

Figure 2. A logging plan for progressive strip cutting to lessen damage by storm winds on the Cascade Head Experimental Forest.

the shelterwood system by making a shelterwood cut in the first strip. After regeneration is established, the overstory is removed from this strip, and a shelterwood cut is made in the second strip; and so on across the management unit (11).

At the end of the rotation, the age-class distribution would be rotation-age trees on the first strip along the northeast boundary and a stepwise progression of younger age classes and shorter trees to windward. Storm winds would be lifted up over the canopy with no exposed cutting lines (Figure 3). The second rotation would begin by again harvesting the first strip along the northeast boundary and again cutting progressive strips into the wind.

Windthrow-susceptible areas require special attention in location of cutting boundaries. Running a boundary through a swampy area will, after cutting, leave an exposed stand border of wind-susceptible trees. To either harvest or leave the entire area is better. If the entire area is left, a buffer strip of more deeply rooted trees to windward should be retained to protect it. An exposed cutting boundary should be more windfirm on a

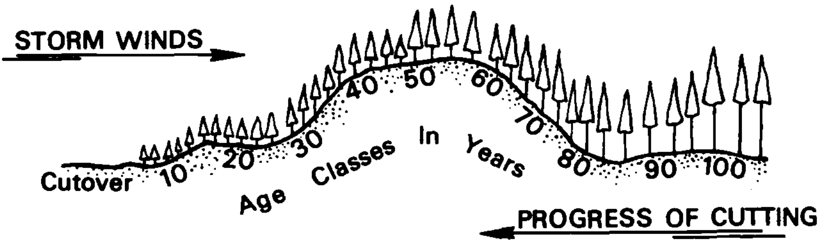

Figure 3. Progressive strip cutting could result in this distribution of age classes at the end of the first rotation.

windward (usually southwest) than on a leeward (usually northeast) slope. Hardwoods or mixed conifers and hardwoods make a more stable stand border than pure conifers. Young stands make windfirm stand borders because the trees are not tall and less leverage is on the root system. Young, rapidly growing trees may be better able than older trees to build up windfirmness.

Wind damage may be reduced by careful selection of trees to be left along the cutting boundary. Usually, dominant hemlocks are more windfirm than lower crown classes. Leaving trees with any indication of root or stem rot should be avoided. If other species are in mixture, dominant trees of the most windfirm species should be left along the immediate cutting line.

Wind damage is destined to be less of a problem in hemlock silviculture. As older stands are harvested, foresters will be managing younger and, therefore, shorter trees, and less leverage will be on the root systems. Precommercial and commercial thinning in areas of moderate to deep soil should increase windfirmness of trees by exposing them to more wind while they are young, which permits them to build wind resistance as they grow.

Improving the Appearance of the Forest

Use of the selection system and uneven-age management will maintain a forest cover at all times and, therefore, in the eyes of most people, a forest more pleasing in appearance. Hemlock, a climax species, can be managed this way without converting to a different species.

Currently, the selection system is used only in special situations. Mostly, these are scenic strips of hemlock left along main roads and around public use areas. Timber production may be limited to salvage of mortality and removal of trees considered a safety hazard. Most of the stands are well past rotation age. More information is needed about managing these stands. The esthetic appeal of an uneven-age stand managed for timber production on a normal rotation also needs to be evaluated.

The shelterwood system is next best from the esthetic viewpoint because the new stand is established before the overstory is removed. I was disappointed, however, in the appearance of experimental shelterwoods because, right after overstory removal, they looked like clearcuttings. Their appearance could be improved by allowing the seedlings to grow taller before removing the overstory, removing the overstory in several steps, and taking special precautions to avoid damage to seedlings. Shelterwood cutting leads to overstocking and need for precommercial thinning, which in turn, has some esthetic disadvantages. One definite advantage of shelterwood cutting over clearcutting is the absence of delay in seedling establishment. The area greens up much faster.

Most of the landscape management efforts in hemlock go into designing clearcut boundaries to blend in with the landscape.

Reducing Fire Danger and Residue Management

Fire danger generally is low in hemlock forests because of the moist climate. It does vary within the type, however, with drier conditions prevailing southward and inland, and wetter conditions northward and seaward.

Fire danger increases with the increasing volume of logging residue. Logging defective old-growth stands can leave huge volumes of residue compared with almost defect-free young stands, which leave little residue. Another important variable is the amount of advance regeneration that may be present. Residue treatments largely determine the fate of this regeneration.

After logging, rapid growth of herbs, shrubs, and red alder may form a closed canopy over forest residues and keep them too moist for broadcast burning, even on warm summer days. This is the reason for the preburn spray mentioned earlier. This spray often is used on areas where burning is needed as part of the brush control plan.

Residues have favorable effects in that they protect soil from exposure to the elements, serve as a storehouse for part of the nutrient capital of the site, and provide shade needed for seedling establishment. They tend to keep cattle and big game away from seedlings.

Residues have unfavorable effects in that the threat of wildfire is increased; they are an unsatisfactory seed bed when exposed to the sun; and they provide a physical obstruction to seeding and planting. They also obstruct intensive management of the new stand. They provide shelter for small forest mammals that may damage seedlings and consume seed, which some years is in short supply.

Broadcast burning of hemlock residues destroys most tree seedlings that may be present and creates conditions that temporarily favor Douglas-fir and red alder over the hemlock. Sitka spruce is intermediate. Burning cleans up the area and facilitates planting and, therefore, is often favored by land managers who intend to plant Douglas-fir to obtain a mixture of Douglas-fir and hemlock. The red alder that comes in as a result of burning usually is treated with herbicides.

The general trend in hemlock management is away from broadcast burning. Surely this trend will continue as utilization standards improve and harvesting operations complete the shift, already well underway, from defective old growth to intensively managed young growth. I believe we can say that most broadcast burning already is limited to special situations. One, of course, is where a huge accumulation of residues constitutes a fire hazard and obstructs regeneration and intensive management. Burning should be considered here—probably a one-time treatment with intensive management of the new stand, which would prevent huge accumulations of residue in the future.

Burning should be avoided on steep slopes and shallow soils where the mantle of forest floor material and logging residues is needed to protect the soil. Burning is a valuable treatment when seedlings and saplings are infected with mistletoe and need to be destroyed. When genetically superior hemlock seedlings become available, burning may be used to destroy natural seedlings before planting the superior stock. Fire is helpful in rehabilitation of brushy areas; burning brush plants to ground level facilitates planting and favors planted seedlings in keeping ahead of the brush sprouts.

Other Objectives

Time does not permit full discussion of harvesting systems to meet other objectives, but at least two points need mentioning. For mistletoe control, the source of infection needs to be removed, and generally this means clearcutting. Removing infected trees and leaving healthy ones is difficult, because the infections are not seen easily from the ground. Regarding wildlife, clearcutting generally favors big game, because the cutting area provides browse plants, and the surrounding timber provides shelter. Small forest mammals and birds may be affected by clearcutting either favorably or unfavorably, depending on the species and habitat requirements.

SELECTING THE HARVEST CUTTING SYSTEM

Having talked about several of the objectives you may have for harvesting operations in hemlock and described how various harvest cutting systems meet these objectives, I wish I could provide you a written framework for evaluating the alternatives. A computer program would be better yet. You could plug in all the factors, and the computer would print out the best harvesting method. Perhaps this can be done in the future. For now, I know of nothing better than your own evaluation.

I will conclude by mentioning some of the trends taking place. These trends result from many decisions by managers who, hopefully, evaluated most if not all of the factors mentioned here today.

Just mentioned is the trend away from broadcast burning of logging residues, which probably will continue. Another is the increased emphasis on protecting basic soil, water, and wildlife resources. The new Oregon Forest Practices Act has provided added motivation for this. Another trend is landscape management—a response to public pressure to make the forest look better.

Clearcutting continues to be the chief harvest cutting system, but there is some trend toward shelterwood cutting. This system should be considered as an alternative whenever harvesting operations are planned, particularly in rotation-age stands.

With rapid expansion of precommercial and commercial thinning in hemlock, we will get natural regeneration in the understory. When the time comes for a harvest cut, the new stand may be there already. I expect the cutting we now think of as the last commercial thinning of the rotation may be considered a shelterwood cut with regeneration as a main objective. An exception to this, of course, will be in mistletoe-infested areas where shelterwood cutting will perpetuate the parasite. Steep ground, as we learned from the discussion of cable thinning earlier in this symposium, probably will not preclude shelterwood cutting. Perhaps, with little change in the intensity of the last commercial thinning, some special care in making the final removal cut, and some control of type of seed bed, we will abandon clearcutting in favor of shelterwood cutting. Hopefully, we will alleviate some alder, brush, and esthetic problems and provide a head start on the next rotation by such practices.

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QUESTIONS

Audience. Where do you get western hemlock seedlings to plant?

Ruth. The Industrial Forestry Association at their Colonel W. B. Greeley Nursery near Olympia, Washington, is producing hemlock. Some of the large companies also are producing hemlock in their own nurseries. The British Columbia Forest Service has been producing hemlock at their Duncan Nursery for a long time and, I believe, now at a nursery on the mainland. They are increasing production and are switching from bare root stock to growing hemlock in styrofoam blocks. Some container hemlock also is grown in Oregon. The Siuslaw National Forest is one example. We need to encourage more nurseries to produce hemlock. Wildling stock also is available in many areas.

Audience. What problems occur with wood rots and root rots in hemlock thinnings? Is scarring of residuals and root damage in a thinned hemlock stand nullifying much of the release potential of the thinning?

Ruth. We have a study underway on stem damage. The planned approach was to identify a large number of tree wounds, treat part of them with chemicals in an attempt to prevent infection, and leave some untreated for a check. The wounds turned out to be extremely variable in size and shape, and some were in contact with the soil and others not. Finally, we decided to make our own wounds to cut down on the variability. We did this, making knife cuts around a rectangle about 4 inches wide by 1 foot long and peeling the bark off the enclosed area. An examination at about 5 years showed little indication of decay, even with the untreated wounds. By now, it must be about 10 years since we made the wounds. We will examine the trees this summer and see whether it is time to fell them and measure kind and extent of decay. The fact that we did not have enough decay after 5 years to justify stem analysis of the trees indicates decay may not be too serious. Trees that do have decay can be removed in a subsequent thinning and, probably, this will be soon enough to avoid serious loss in volume. It will require marking of trees that, were it not for the decay, might be left as final crop trees. Basal wounds in contact with the soil may decay faster than the stem wounds studied.

The most common organism of decay that attacks hemlock logging wounds is *Fomes annosus*. To my knowledge, this has not caused serious volume losses in the time that would elapse between thinnings, even with many of the wounds in contact with the soil.

There is considerable concern that *Fomes annosus* will infect stumps left by thinning operations and the infection will spread to live trees. Charlie Driver at the University of Washington is working on this, but I have not heard whether he has shown actual spread in this manner. Are any of you up to date on this?

Audience. I think he has demonstrated spread to live trees.

Audience. Have reports been published on the shelterwood studies you referred to, especially in 60-year-old stands?

Ruth. The first study referred to was in a 118-year-old stand on the Cascade Head Experimental Forest, and the results are available in my Ph.D. thesis (9). The second study in the 60-year-old stand was conducted at the Hemlock Experimental Forest near Hoquiam, Washington. A progress report was published after the initial cut (5).The final report, which will have the regeneration data in it, is now in preparation.

Audience. What is the expected lag and loss of yield that accompanies shelterwood cutting of hemlock?

Ruth. I do not know that there is any. You are still getting growth on many of the crop trees while regeneration is becoming established, and I think of this as getting a head start on the next rotation. A complete analysis of shelterwood cutting compared to clearcutting needs to be made that considers both volume growth and economics. I think that yield will be greater from the shelterwood system, because it largely avoids the period, right after clearcutting, when the site is not fully occupied for timber production.

Audience. I have seen progressive strip cutting going up the ridge into the prevailing wind that ran into a venturi effect from the wind, which came over the ridge, swirled under and blew down border trees from behind. Is this common, and is there any way to predict this?

Ruth. I doubt that it really happened this way. The possibility always exists that an easterly wind came along later and caused the damage. Wind patterns indeed are more turbulent and erratic on lee slopes, but the uprooted trees we have seen over the years have their tops pointed downwind in line with the general airflow. Winds blowing over a bluff sometimes do form a large, stationary roll eddy with surface winds below the bluff actually blowing upslope. So far, we have found no instance of such winds causing blowdown. I would like to visit the particular area you have in mind.

Audience. What is the status of tree improvement work in western hemlock?

Ruth. The main effort in hemlock genetics is at the Pacific Forest Research Centre at Victoria, B.C., under the direction of Dick Piesch. They have made "plus-tree" selections from several stands and have made outplantings in five areas. Scientists and others interested in hemlock genetics have met informally both in the Pacific Northwest and in British Columbia. The next meeting will be June 19-20, 1973, at Victoria. Considerable interest exists in a practical tree improvement program similar to the program in Douglas-fir. The Pacific Northwest Forest and Range Experiment Station, ITT Rayonier, and Crown Zellerbach are cooperating on a study of family differences. Oregon

State University has some research started under the direction of Helge Irgens-Moller.

Audience. Has planting of hemlock had extensive success? If not, why?

Ruth. In general, planting success has been variable with examples of good survival and numerous examples of poor survival. More needs to be known about handling and planting techniques for hemlock seedlings. The trend now is to grow hemlock in styrofoam blocks, and planting success is expected to be much better.

Audience. We have planted many thousands of hemlock seedlings with good success. The problem is with nursery production, which has been difficult.

Audience. How limiting is animal damage on the spread of hemlock reproduction? What animal species damage or browse, or both, hemlock?

Ruth. Not much animal damage has occurred in the stands I have worked with, and I doubt that it is a serious problem. Deer generally seem to prefer other species. I have seen serious rabbit damage on some planted hemlock seedlings.

Audience. Does it appear to be worthwhile in terms of increased production to thin a 40-year-old hemlock stand that is infected with mistletoe?

Ruth. I don't know the answer to this one. Both the trees and the mistletoe would respond to the increased growing space, and the answer would depend on the relative response of the two. A research work unit at our Forestry Sciences Laboratory at Corvallis is working on the mistletoe problem, and they may be able to answer this question.

Audience. Would it be advisable to plant hemlock on high-quality sites at low elevations that we know are problem reforestation areas for Douglas-fir because of brush? I am referring to clearcut areas.

Audience. On what sites would we prefer hemlock over Douglas-fir?

Ruth. Answering the last question first, I do not think we can predict relative stumpage prices a rotation ahead. For example, 60 to 70 years from now hemlock may be just as valuable as Douglas-fir. If you accept this premise, then you should select the species that will produce the most wood fiber on the site in question. The problem is to know which species this is. In the case of hemlock compared to Douglas-fir in natural stands, you can determine the site index and refer to yield tables. But surely the coming rotation will be managed intensively, and we do not have adequate information on yield of managed stands. To complicate the question further, perhaps a combination of species will be more productive than a pure stand.

Regarding the first question, hemlock is more shade tolerant than Douglas-fir and, once established, may be able to come up through overtopping brush better than fir. The presence of brush, however, should not dictate the species to be grown for the new rotation. To control the brush and then plant the tree species you want would be far better.

PROGRAMMING AND DATA MANAGEMENT IN FORESTRY

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Much confusion surrounds the roles of a statistician and a programmer in research and management. We want to explain the views of Gourley, as a data management programmer, and the views of Overton, as the statistical consultant and data management coordinator, in the Forest Management Department at Oregon State University.

First, we will show a diagram of the research process, with forestry research as the example (Figure 1). We will identify the management problem associated with the research field, in this case, forest management. We will describe the activities of the statistician and the programmer within this process.

The outer circle of this diagram represents the activities pursued in forestry research. We start with a body of accumulated knowledge about forests. The scientist draws from this body of knowledge and poses questions about the forest. He takes his questions to the statistician to rephrase them as formal hypotheses and to work out an experimental design formulated to test the hypotheses (answer the questions). The scientist, conducting a field observation of the forest, collects data from the real world system. He analyzes these data with the help of a programmer, synthesizes information, and adds to the body of accumulated knowledge. New questions occur to him during the research process, and the cycle continues.

The forest management problem fits into the center of this cycle. A forest manager draws upon the body of knowledge to develop a set of procedures for managing his forest. He, like the scientist, has questions to ask, questions not considered by the scientist, questions incompletely answered, or questions with a

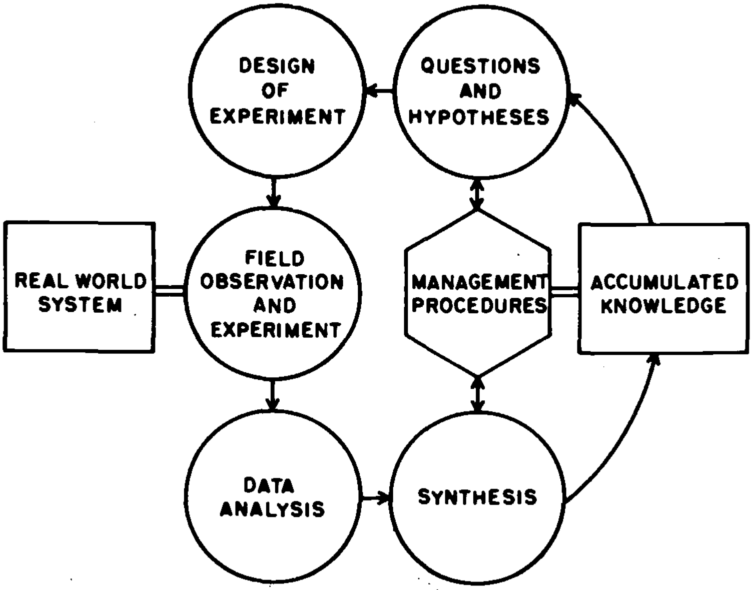

Figure 1. A diagram of the process of research.

doubtful answer. The forest manager uses the same process in answering his questions that the scientist uses, and the roles of the statistician and the programmer are similar. The forest manager should select a statistician and a programmer who are oriented toward research problems in forestry or a related field. The appropriate selection is critical to an effective process.

During the question and hypothesis phase, the forest manager discusses with the statistician what is known and what questions are asked. The statistician helps him to rephrase the original questions into hypotheses and to design a field observation or experiment to test the hypotheses within the available methods and resources.

I want to emphasize that the activities we are discussing do not have to be complicated and that the forest manager does not need a large problem to justify the formal statement of his problem. This same process can be used by a forester and a statistician to design a data form and a set of procedures, which require no computer work at all. A recent example is the Regeneration Survey Form, designed by Eugene Mannock of the Oregon State Department of Forestry and W. Scott Overton. This form with its instructions describes methods to estimate tree stocking levels and to determine if the estimated levels meet state stocking requirements. One of the methods described allows the observer to judge in the field when his sample is sufficient. Data are collected and analyzed by the field observer.

If a forest management problem is large, a computer may be used for data analysis. If a computer will be used, some additional items need formal specification during the design phase. After the hypotheses, the experimental design, and the preliminary analyses are specified, the forest manager meets with a data management programmer. A data management programmer deals with field collection, data transfer, quality control, and analysis problems. As the first step in computer data management, the forest manager and the programmer record the experiment in a form similar to the abstract of a paper. This data abstract lists the experimental design, the field procedures, and the analyses specified by the forest manager and the statistician. The data abstract is useful for communication among the people working on the project and for retrieving information about available data. The data abstract should include all pertinent information. We list title, investigator, initial and final dates, variables and their units, taxonomy, geographic description, and description of the experiment, which includes information such as purpose, methods, tools, and instruments. This list could be expanded or condensed to suit the needs of the forest manager, but should be detailed enough to reconstruct the experiment.

Next, the forest manager and the programmer plan a field data form, which is mutually convenient to the field data collection and to keypunching. Often, we notice that a form designed to facilitate keypunching also is used easily by the field observer. A part of the field form design is the identification of variables that are groups or classes rather than direct measurements. Crown class, tree form, and evaluation of damage are examples. A coding system for recording these classifications is required. The programmer can supply a coding system that will facilitate later computer processing. Usually, the desired analysis must be specified before this can be done.

Quality control in data management starts at the design phase. Criteria for impossible or unlikely data values are established. These criteria will be used in computer screening of field data. Examples of impossible values are class 45 when only 44 classes have been defined or a height of -30 feet. Sometimes, a combination of values forms an impossible observation, for example, a dead tree that subsequently grew. Unlikely values are those that may be correct, but are uncommon. An annual height growth of more than 5 feet is routinely reexamined at the Forest Research Laboratory, because actual growth of that amount is uncommon in our data.

Armed with all these forms, lists, and specifications, the forest manager makes his field observations. Problems with any phase of data collection should be referred to the programmer. Additional classifications may be needed or a criterion may need changing. The sooner the programmer knows about the changes, the better he can handle the data. Also, he may be able to determine if the statistician should be consulted.

The first records should be returned to the programmer as soon as possible, to check the data analysis procedures. The programmer designs a data form, generally a punched card, supervises keypunching, and makes a computer list of the data. The procedure of checking data cards is greatly simplified by using the computer to print values in a form that closely resembles the field collection form. We call this a facsimile listing. The facsimile listing has an additional feature: the computer can print a special mark to call attention to any unlikely or impossible values. The facsimile listing is returned to the forest manager for proofreading. Each value should be checked against the original record, changes should be marked, and unlikely values that are correct should be initialed. We recommend that two people associated with the field work do the proofreading. Their familiarity with the field observations can unravel knotty questions quickly, and their sense of the importance of the data makes their work thorough.

Any required changes are made in the data cards, and the programmer selects a storage form from the data. He records the location of each data item, the field records, the punched cards, and the facsimile listings.

The preliminary analysis runs are made next. These are the analyses specified during the design of the experiment. The analyses are given to the forest manager for his synthesis. Unexpected results can bring the forest manager to the statistician for a secondary analysis and more computer runs.

The forest manager makes his synthesis, which includes management decisions and also adds to the body of accumulated knowledge.

QUESTION

Audience. What is the demand for statisticians and programmers trained in the biological sciences? Is this demand being met?

Gourley. The demand is for statisticians and programmers, regardless of their associated training. Few of the statisticiams and programmers I know have training in the biological sciences. I received no particular encouragement to develop skills in programming from my biology instructors and in biological problems from my mathematics instructors. I feel this lack of demand is especially unfortunate for those trained in biology who need statistical and programming help.

Audience. Are computer services available for the operator of a small forest? What is the cost of these services?

Gourley. Some companies and universities offer computer services by contract. The operator must decide what he wants, get an estimate of the cost involved, and decide whether the job is worth the money. Contact the local university or a local business with computer billing for information in your area. I am not familiar with costs, which obviously vary according to the job. The more complete and more accurate the job description, the better the cost estimates will be.

Audience. Can you give some information about the "table top" computers?

Gourley. Several calculators with data analysis programs are sold. I am not familiar with their operation. Contact companies that sell desk calculators.

Audience. I do not want to do research, but I do want to know if my cruising and sampling are adequate to give the answer I need to manage my forest. Will you comment on this?

Gourley. I recommend that you write out the assumptions and facts you have assembled about your forest, the management questions you have, and take all this to a statistician. He needs this information to judge how adequate your cruising and sampling are. A programmer cannot give you this statistical help.

Audience. If, as a manager, I know I need a data management system, how do I go about getting one set up?

Gourley. Assemble and organize the material you know. Locate a consultant. Most large companies and universities have data processing centers. Request information about consulting either from their group or from a group they know.

Audience. What are the model name and size of your big computer?

Gourley. Our computer is a Control Data Corporation model 3300 with 92K words for the entire system. This is a time-sharing machine with card reader, line printer, four tape units, a large desk unit, a couple of small desk units, and an extensive remote terminal system, which includes teletypes, cathode ray tubes (CRT's), techtronic terminals, Data 100 terminal, and Hazelton terminals. Our operating system, OS-3, was written at Oregon State University. This system was recently purchased by Control Data Corporation.

Audience. Are you acquainted with the computer memory bank portrayed in the television program Star Trek? Is any effort being made in this direction to store, collate, and make available masses of forestry data for the whole community to use?

Gourley. I have seen the computer on the Star Trek series a couple of times and saw HAL, in "2001: A Space Odyssey." The types of programs needed to command such a computer would be incredibly complex, and I know of no current development anywhere near that. The federal government is the only organization I know that has the manpower and computers to write that kind of system, as computations in their Internal Revenue Service and space program seem to indicate. The level of data retrieval, which I think is within the grasp of a large company or university, would be the storage of abstracts, either data abstracts or abstracts of papers and articles, identification of keywords in the abstract or title, and retrieval of abstracts based on the keywords, the authors, the date, or some combination thereof. I know of no actual data retrieval system in forestry.

THE INFLUENCE OF INTENSIVE MANAGEMENT ON FIRE HAZARD

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INTRODUCTION

The forester must understand the relation of fire to the development of forest plant communities to be able to evaluate the results of his actions.

Forests develop with the three components of flora, fauna, and fire. A natural Douglas-fir forest will progress through a fuel cycle, from a bareground state through stand maturity. Maximum fuel loading occurs at 50 years and again at stand maturity.

Man's activity in a stand will cause variations in this fuel loading with his intensive management, the variations depending upon treatment given. Precommercial thinnings will increase hazard, but commercial thinning will lessen hazard. Intensive management generally will lessen fire hazard during most phases of the management cycle.

DISCUSSION

The forest environment long has existed and developed with the basic components of flora, fauna, and fire. Each of these components has influenced the others through the ages. A natural relation has developed. Indeed, a readily recognized natural interdependence among these components has developed.

We long have recognized the relation of Douglas-fir and fire. The same is true of lodgepole pine, ceanothus, pine grass, and a host of other species that, for the most part, depend upon fire to regenerate naturally. We need not travel far in the forest to see the effect fire has had upon plant succession and the development of plant communities.

Fire also has a dramatic effect upon fauna. The animal population explosion in burned areas is proof of the effect of fire upon fauna.

We could spend considerable time elaborating this eternal triangle of flora, fauna, and fire, and how each influences the others. We will not take more time on the matter, except to emphasize that fire always has been a factor with considerable impact on the forest environment. It is a natural phenomenon. It always has been and always will be part of the forest complex. Man has had, and will have in the future, some influence on the part fire plays in forest development.

Before we can begin to examine the effect we, as forest managers, might have upon this natural phenomenon, we must recognize existing natural forest conditions and how they affect fire. We must realize that whatever happens will depend greatly upon the fuels present. Then, we can begin to analyze the results of our management actions upon fire hazard.

The natural forest is a complex of fuels in a variety of arrangements. Quantity and arrangement of fuel vary considerably, depending upon the stand density, age, and particular plant community involved. Fire intensity and behavior in forest fuels is dependent upon the quantity of fuel and its arrangement and, as we shall see later, upon other factors also.

The fuel quantity in a natural forest that is predominately Douglas-fir goes through a cycle during the life of the stand. Fuels vary considerably from the time a stand begins after a natural burn until it reaches maturity or approaches climax.

As Figure 1 shows,[1] the weight of available fuel in tons per acre ranges from a small amount at age 1 year to a maximum at about 50 years. After 50 years, available fuel decreases for about 70-80 years. It then begins to climb gradually, until it reaches the 50-year quantity again at about 400 years.

A brief analysis of stand composition at a few points along these curves tell us why this occurs.

[1]George Fahnestock. Fuel Succession in the Pasayten and Mt. Jefferson wilderness areas.

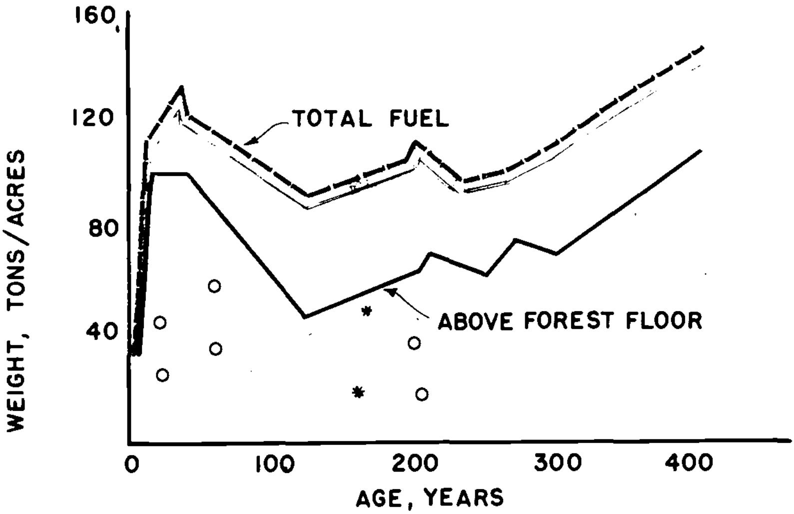

Figure 1. Fuel weight compared to stand age in the Pasayten wilderness area.

The first few years produce little fuel in terms of weight. New growth, consisting of trees, brush, grasses, and forbs, does add up to considerable fuel, which is available because it is close to the ground. As the fully stocked stand develops, ground cover changes to the dominant species. At 50 years, much of the aerial fuel is still available and considerable ground fuels are present (Figure 2). The ground fuels are brush that succumbed to shade, limbs that were shed from the stand by self-pruning, and suppressed trees that died and fell to the ground. Available aerial fuels are tree foliage and small limbs.

George Fahnestock measured an average of 130-140 tons of available fuels in such stands in his studies in the Pasayten wilderness area.

The available aerial fuels in this stand at 50 years include most of the tree tops, even though the tops are a considerable distance from the ground fuels. To understand this, we must digress for a moment and explore fire behavior in this situation.

Ground fuels are generally small in diameter and burn readily, so they produce a hot fire. These fuels burn under a

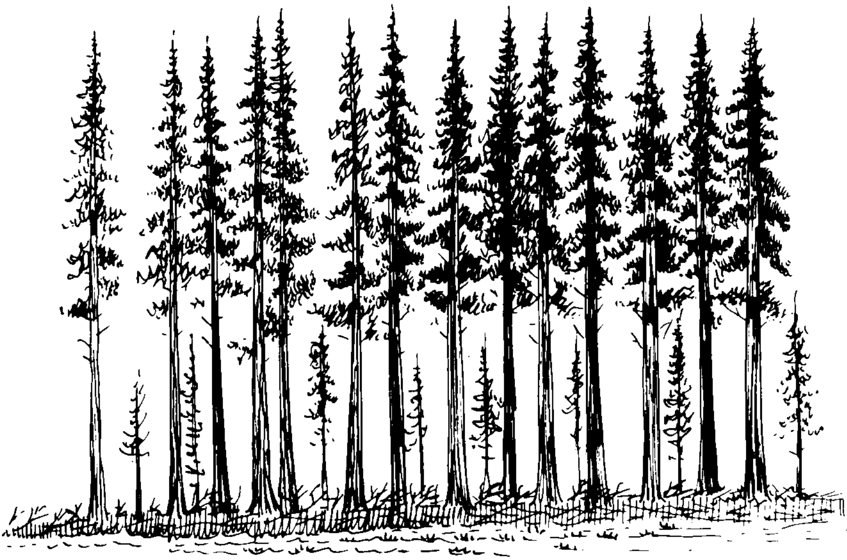

Figure 2. A 50-year-old stand with aerial and ground fuels present.

solid canopy, which greatly restricts convection of heat. The trapped heat causes intensified burning of ground fuels, drying of aerial fuels, and running of fire up tree trunks and understory trees into the stand canopy. This phenomenon gives firefighters cause to reflect upon their choice of occupation and newspaper reporters some spectacular photographs.

As a stand develops and grows taller, the aerial fuel decreases because of the distance of the canopy from the ground and less dense crown layer, which produces less entrapment of radiated heat from ground fuels (Figure 3). Ground fuels diminish as natural pruning and mortality of suppressed trees decline. This situation continues for 100 more years or so until the stand matures and starts downhill.

Trees in a mature stand succumb to insects, disease, and wind (Figure 4). Dead trees provide more ground fuel by shedding bark and limbs. Snags provide available aerial fuels. As the stand opens up with age, new trees grow underneath, which increases the fuel load and provides a ladder for fire to climb into the crowns. If considerable moss is present in the crowns,

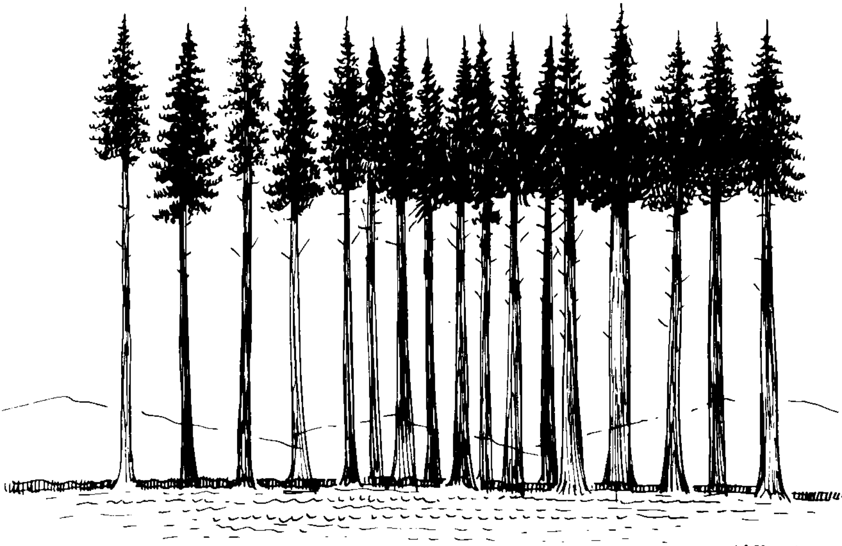

Figure 3. A stand that has developed and grown taller with less aerial fuel present.

Figure 4. A mature stand that has succumbed to insects, disease, and wind to provide more ground fuel.

the problem is compounded, and the firefighter again is given cause to reflect upon his choice of occupation.

Development of the fuel cycle in the pine forest type is interesting, but time does not permit us to follow it here. The basic pattern is similar to that of the Douglas-fir forest type, except that fires occur naturally much more frequently. The fuel cycle plays a much more important role in the pine country, and man's intervention with fire protection has created some interesting and challenging situations with fuel buildup.

Let us move a forester into this Douglas-fir timber stand and look at what he produces with his textbook, ax, and saw. To add consistency, let us start this forest manager out on some bare ground, just as we did the natural stand.

The first job he will do is plant 500 or 600 trees per acre on the site. These trees probably will be joined by a few hundred more natural seedlings and a variety of brush, grass, and weeds. The result may be a rapid transition from bare ground to a dog-hair patch with 2,000 or 3,000 stems per acre. Now we have a fuel problem. Many limbs are shed, and many suppressed stems add to the fuel on the ground. All fuels on the site are available for fire.

As the stand grows slowly and the canopy is solid, the forest manager soon decides the stand needs thinning. He instructs the thinning crew to reduce the stems per acre or basal area to an established standard. In doing this, the thinning crew cuts a few hundred stems per acre and leaves them where they fall. This process drastically increases the fuel on this site.

Much of the fuel now has become ground fuel. It is lying where it fell in a crisscross pattern. It can dry readily and has lots of air spaces to provide an oxygen supply. It is close enough to maximize radiant heat between individual pieces of fuel. To add to the problem, the canopy has been opened to let in the sun to speed drying and increase fuel temperatures. It all adds up to an ideal situation for an intense fire. And the fuel will be there a long time, because rotting is slow on well-ventilated materials.

Few actions of a forester create a more explosive situation than this. He has created a mass of kindling, which will support a hot, fast-moving fire. Resistance to control is high because of the high temperatures produced and because of the difficulty in fireline construction.

Most precommercial thinning has about this effect, although it may not be so dramatic. Thinning stands by stages and leaving stems standing spread the effect over a longer period, although about the same amount of fuel will reach the ground within a few years. Hack-and-squirt methods of applying herbicides speed the natural process by accelerating ground-fuel buildup, but lessen the 50-year fuel peak somewhat because of earlier decomposition of some of the potential fuel load. Generally, any precommercial thinning will create an earlier maximum fuel loading, which likely will have somewhat less tonnage per acre than a natural stand, but will be highly explosive for a few years.

Fuel treatments, such as tomahawking and rolling, commonly practiced in pine types, will compact fuels close to the ground. Compaction reduces burning temperature, slows drying, and increases the rate of decomposition. Most forest types west of the Cascade Mountains do not lend themselves to such treatment, however.

To proceed, let us assume that nothing has started a fire in this stand, and that it has reached the size for commercial thinning. Generally, the result in fuel production will be about the same for any marking or tree-selection method.

Commercial thinning will remove considerable fuel by removing trees that would have become fuel by way of natural mortality. We will have added some tops to the ground fuels.

Yarding will break up some fuel concentrations and generally will compact natural and thinning ground fuels. Yarding roads will provide small fuel breaks throughout the stand. Opening up the crowns will let in more light to speed drying of fuels. The more open canopy will provide far greater convection of heat from ground fire, which in turn will lower the ground-fire intensity. Crown fires generally will not occur in commercially thinned stands because of more open canopy and fewer understory trees to provide a ladder to carry the fire into the crowns. Development of yarding roads also will let motorcycles into the stand, which will help keep the yarding roads clear of debris. You may wish to regard some of these activities as hazards, although they are risks rather than hazards.

Generally, the effect of commercial thinning will be to reduce total natural fuel loading, although an increase of short duration will occur at the time of thinning. The overall effect is to reduce hazards the first year or two after cutting.

The forester may manage the stand into a shelterwood program. Shelterwood stands usually contain a variety of fuels, which consist of reproduction, brush, grasses, and weeds. Debris from harvesting also will be present in some quantity. Fuel temperatures will be fairly high, depending upon overstory density.

Generally, fuel loading will start to increase as the new stand develops. The fuel loading will not increase as rapidly if stocking levels are controlled at an early age.

Clearcutting will add immediately from 40 to 180 tons or more of available fuels per acre, depending upon the nature of the stand before cutting.

A mature, healthy, young-growth stand, where breakage is minimal and utilization is good, may produce as little as 40 tons per acre after logging. An over-mature, old-growth stand may leave as much as 180 tons of fuel per acre after logging.

Young-growth logging slash will deteriorate fairly rapidly because much of the material left is sapwood. Most of the hazard will not be gone, however, by the time the new crop of trees begins to generate considerable additional fuel load. Even light, unburned, young-growth slash will create a fuel situation much heavier than normal during the first 20-30 years of a stand's development.

As the amount of slash present at the beginning of a new stand increases, the length of time it will affect the total fuel will increase also. Heavy, old-growth slash will increase loading well into the next management cycle. Indeed, it probably will last through a rotation of 80-100 years. Heavier slash loadings present impossible barriers to fireline construction. Also, they greatly intensify total energy release from a fire.

Some managers have chosen to leave heavy, old-growth slash unburned. The problem this creates for fire control is obvious. The barriers this debris will represent to intensive management of young-growth stands will be severe in many areas. Young-growth managers are going to face some real challenges in finding ways to remove commercial thinnings through this material.

CONCLUSION

I want to remind you again that fire has played a key role in the development of forest stands. In the pine country, fires occurred naturally about every 15 years. This resulted in the development of plant communities unique to this environment. Fuel buildup was seldom great enough to sustain more than light ground fire. Catastrophic fires seldom occurred.

Fires occurred on a much longer cycle in the Douglas-fir country, with wide areas burned occasionally. Nature wiped the slate fairly clean of fuel when this happened. Fuel amounts increased rapidly after these fires for about 50 years, gradually reduced for the next 100 years or so, and then began to climb slowly as stands reached maturity.

Most activities in natural stands will change the natural fuel cycle in some way. We must be aware of the hazards we are creating. We also must be aware that fire control is difficult in some of the fuel conditions we create. Fire in heavy fuel areas will run its course, for the most part, with firefighters concentrating efforts at natural or manmade fuel breaks. This will be true until we learn to manage the dead materials as well as we manage the live trees.

QUESTIONS

Audience. Would you comment on the effectiveness of buffer strips along roads, breaking up thinning units to avoid continuous slash areas, and other ideas you may have to reduce hazards and risk of fire on precommercial thinning?

Wilson. Buffer strips are effective along roads. Every day we have a given number of potential sources of fire ignition. Fortunately, most of them occur in an environment unfavorable to ignition of forest fuels. Thinning slash is an ideal environment for fire. A buffer strip tends to isolate the fuel from potential sources of ignition. An added advantage is that the obvious fire potential is hidden from the occasional firebug who might be prompted to light a match, if exposed to an obviously explosive situation.

Audience. Does removing the crown by clearcutting or reducing the crown by a commercial thinning increase or decrease the decay on the forest floor?

Wilson. Generally, opening a crown canopy will decrease or slow decay. Dry fuels decay slower than wet fuels. An open canopy lets in more sun and air, which dries ground fuels faster.

Audience. In horse logging in a young commercial thinning, do you think the extra cost of cutting up tops and large branches would be justified? The goal would be to get fuels on the ground.

Wilson. The difference is not great, because yarding roads and the logging process will have reduced fuel hazard somewhat. Risk might be the deciding factor. Areas where fire risk is high might warrant treatment. Low-risk areas might not justify the cost.

Audience. Would you comment on the Park Service's new philosophy that fire, a natural phenomenon, should be allowed to burn itself out naturally within limits, in areas that are consistent with their "natural, untouched" philosophy?

Wilson. We must accept the fact that fire always has been part of the natural development of plant communities in our forests. We have created some unique problems in much of the pine forest types by keeping out fire. The Wenatchee fires were the result of severe fuel buildup in stands that were protected from fire for many years. Over the centuries, frequent low-intensity fires had prevented fuel buildup. Massive fuel buildup in the protected forest made this catastrophic fire possible. Allowing some fires to burn under low-intensity conditions may prevent catastrophic fires in these areas and tend to maximize the potential for all uses, which include those of man. This program is in the testing stage and must be supported, if we are to learn from it.

Audience. How would you evaluate hazard in a thinning done by chipping or chopping with mechanical equipment?

Wilson. This certainly will reduce hazard. Fuels are compacted, which will reduce burning intensity and speed decay. The process is expensive and, therefore, limited to high-risk areas.

Audience. Compare the fire hazards in hemlock and Douglas-fir, which are precommercially thinned mechanically, such as with a power saw, or precommercially thinned with chemicals.

Wilson. Mechanical thinning puts all the fuel on the ground at the same time. This creates a maximum fuel loading for a short duration. Chemical thinning will increase fuel loading somewhat, but will put fuel on the ground over a longer period. If fuel loading made a difference in making a choice, I would certainly go with chemicals.

Audience. Do you feel 8 feet or so of pruning of heavy dead branches will pay in reduced fire hazard in stands from 25 to 35 years old?

Wilson. A stand from 25 to 35 years old with heavy, dead branches within 8 feet of the ground is pretty open. Chances are that little ground fuel other than needles exists to carry fire under this stand. I think such pruning would add considerably to ground fuel hazard, and limbs would still be close enough to the ground to carry fire into the crowns. Risk might be the deciding factor. Higher pruning would help some, but if the crown is closed, the added ground fuel creates a problem anyway. If fire risk is high, you are gambling. If risk is low, it is a good gamble.

Audience. What is your opinion of yarding old-growth slash as opposed to slash pruning? Do you think it sufficiently removes the hazard?

Wilson. "Yum" yarding, which is yarding unusable material, does not change the amount of available fuel greatly the first year or two. The additional yarding compacts the finer fuel somewhat and buries some of it. This helps considerably. The material that would increase fuel over the long term is removed, and this change is considerable. The reduction in hazard does not equal that of slash burning, but it is still considerable. Yum yarding does have the advantage of removing logs that would be a severe obstacle to intensive management of new stands during their first 50 years or so.

Audience. You mentioned the "ladder effect" within a stand from 35 to 50 years old. We have decreased this effect by removing the suppressed and intermediate trees in a thinning, but have increased ground fuel. Present guidelines and trends indicate we will leave snags in this situation for ecological reasons. Would you comment about the fire hazard problems of this and the ladder effect of these snags?

Wilson. I recently issued a directive to State Forestry people, which indicated that snags are to be left in some places to provide habitat for birds and animals. This question may be a subtle jibe. Snags have always been a real fire problem when they are close to fire-control lines. The primary problem is firebrands, which may travel considerable distances. Snags in thinning areas that are lower than the crown canopy are not a great problem. The crowns intercept firebrands and reduce this problem. Thinned stands have reduced crown density, so crown fires or crown burnout is not generally much of a problem in these stands. Our decisions as forest managers have considerable impact on the total forest environment. We are concerned with preserving as much of the total environment as is reasonably possible and still taking from the forest those things we need. Leaving some snags is a trade-off. We will have some increased fire problems occasionally, but the maintenance of wildlife values demands that we take this risk.

DOES COMMERCIAL THINNING PAY UNDER SUSTAINABLE HARVEST?

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INTRODUCTION

For the last 20 years, much has been said and written about biological and economic gains from commercial thinning.

Silvicultural work done in the 1950's and early 1960's by Barnes (1), Staebler (12), Heiberg and Haddock (5), and others dealt mainly with applying European theory and case studies to the management of Douglas-fir in the Pacific Northwest. The European concept then had not been adequately tested for Douglas-fir; thus, studies were established in the Pacific Northwest to test it.

The results of these studies indicate that biological gains from commercial thinning are not as optimistic as first thought 20 years ago. Reukema (8) shows less than a 2-percent increase in cubic-foot yields on a present 56-year-old stand at Voight Creek Experimental Forest. Work by Hoyer (6), using new data on basal-area growth in a stand-simulation program, shows that the increase (Scribner volume to a 6-inch top) over unthinned stands was less than 1 percent at 60 years, 2 percent at 70 years, and 3.8 percent at 80 years, all on site III. Also Reukema and Pienaar (9) indicated that on site II at McCleary Experimental Forest, after 20 years of thinning on a Douglas-fir stand now 70 years old, the usable cubic-foot increase for thinned stands was from 2 to 4.5 percent greater than for unthinned stands.

[1] R. N. Pierson is now with Weyerhaeuser Company, Tacoma, Washington.

Worthington and Fedkiw (16), Heiberg and Haddock (5), and others studied the economics of commercial thinning in the 1950's and 1960's, using the theory of per-acre analysis. In the late 1960's, forest economists began analyzing forest management practices, such as commercial thinning , precommercial thinning, fertilization, genetic programs, and others, by applying the theory of allowable-cut effect (10), which takes into account the effect of the additional growth by accelerating today's harvest of timber that is over rotation age.

From the studies of the 1950's and 1960's, the conclusions generally agreed upon as results that most foresters could expect from thinning were: growth is redistributed from many trees to fewer trees—thus, average diameter breast height (dbh) at harvest is greater than in unthinned stands; mortality is salvaged, thus increasing usable yield, which is not to say that total gross growth is increased; and, economically, thinning is sound because it produces income before final harvest.

THE STUDY

Today, with the availability of data on actual growth and the theory of allowable-cut effect, commercial thinning obviously should be reviewed for those situations that come under the following assumptions: stands that have no treatment before first commercial thinning and that are fully stocked (normally, stands from 40 to 80 years old); and ownerships that are under constraint of sustainable harvest and have an abundance of timber over rotation age.

A theoretical forest model was developed to compare commercial thinning with no commercial thinning on those areas that met these assumptions.

The Department of Natural Resource's 635,000 acres in Grants-and-Fee ownerships, which are similar to the model, could have been used. Because of the complexity of the number of age classes being thinned, different sites, and zones with two species, however, a simpler model was selected to keep the effect of the interaction of these parameters as small as possible.

Model and Management Assumptions

The forest model used consists of 24-percent old growth (100 years plus) and 76-percent young growth[1], all Douglas-fir, on site III, with three regimes of forest management. Management Regime 1, **Natural Stand Management** (plant, spray, and clearcut), and Management Regime 2, **Intensive Management** (precommercial thinning at 15 years and 3 fertilizations at 15, 25, and 35 years) were held constant for all cut calculations. Regime 3 had two variations, 3A and 3B. The acreage distribution by age class and other input assumptions are shown in the appendix, along with activities in the two variations. Because of their importance to this study, the two variations of Regime 3 are further discussed.

Regime 3A. This regime represents 115,000 acres that will be **thinned at age 40 years** for the first time (Table 1). The present 40-year age class accounts for 70,000 acres; the 30-year age class, for the other 45,000 acres. The harvest schedule will be a 10-year cycle, thinning from below (avg diameter of thinnings/avg diameter left = 0.9) with 65 percent of normal ["normal" based on Table 1 of Empirical Yield Tables for the Douglas Fir Zone (3)] that remains after each cut. This regime

Table 1. Yields for Regime 3A: 40-Year-Old Stands, 100-Percent Stocked, with No Prior Treatment, but with Commercial Thinning from Age 40 Until Clearcut.

Age	Volume[1]			Avg dbh	
	Thinning	Clearcutting	Total	Thinning	Clearcutting
Yr	*Fbm*	*Fbm*	*Fbm*	*In.*	*In.*
40	5,098	15,207	15,207	10.5	11.7
50	4,406	22,264	27,362	13.9	15.4
60	4,575	30,769	40,273	16.7	18.5
70	4,560	39,020	53,099	19.1	21.2
80	0	46,051	64,690	0	23.6

[1]Scribner, board feet per acre.

was developed by using Hoyer's equation for basal-area growth for thinned stands and the Department's stand-simulation program (6). The initial input data of basal area, trees per acre, and dbh for each of the two variations were held constant and referenced from the empirical yield tables (3), 100-percent stocking, site index 110, and total age 40 years.

Regime 3B. With the same acreage, the timber is allowed to grow until final harvest with **no thinning** (Table 2). This regime was developed with Hoyer's equation for basal-area growth (5) for unthinned stands and the Department's stand-simulation program. Staebler's Table 2 (11) was used to simulate mortality.

Comparison of Regimes 3A and 3B. Comparing thinned Regime 3A to unthinned Regime 3B at 60 years, a 2.7-percent increase in usable yield is obtained by thinning; at 70 years, a 4.9-percent increase; and at 80 years, a 7.2-percent increase. The usable yield increase of 7.2 percent is similar to the cubic-foot increase that Reukema and Pienaar (9) estimate the thinned stands at Voight Creek will produce at 80 years of age (about the year 1995).

Williamson and Price (15) stated that recovery of 100 percent of the observed mortality, as assumed in our study, is

Table 2. Yields for Regime 3B: 40-Year-Old Stands, 100-Percent Stocked, Clearcut with No Previous Commercial Thinning.

Age	Volume per acre[1]	Average dbh
Yr	*Fbm*	*In.*
40	15,027	11.7
50	27,037	13.7
60	39,202	15.3
70	50,610	16.6
80	60,302	17.8

[1]Scribner.

optimistic. Though the figure is arbitrary, they indicated that only 80 percent of the observed mortality can be recovered under most thinning schedules.

Comparison of the average diameters of Regimes 3A and 3B should be interpreted with caution. At the time of clearcutting, average dbh of 3A (thinned) is 23.6 inches, and for 3B (unthinned), 17.8 inches. This is not to say that because of thinning, the average dbh is 5.8 inches greater. Hawley and Smith (4) point out that comparing averages is appropriate as long as comparisons are made between average diameters of equal numbers of crop trees. A stand average is increased automatically merely by removing some of the smaller trees. Thus, in this study, we were unable to determine the effect of thinning on the rate of growth in dbh. Groman (7) found that growth of the dominant and codominant trees on thinned plots was significantly greater than on unthinned plots. On the other hand, Reukema (8) found at Voight Creek that growth on the 40 largest trees was slightly, but not significantly, greater in thinned than in unthinned stands.

Biological Results of Allowable-Cut Calculations

Tables 3 and 4 show the results of the two allowable-cut calculations, with the two variations of Regime 3.

As expected, the average harvest of an 80-year period for the thinning regime 3A was 7.0 million board feet (*MM* fbm) per year higher than for 3B. A difference that should be noted between 3A and 3B is the increased amount of the higher value, old-growth timber that can be cut in the first decade by not thinning commercially. Again, old-growth volume can be substituted for thinning volume only under the assumption of the allowable-cut effect.

The standing inventory at the end of the eighth decade is 272 *MM* fbm (7,937 *MM* - 7,665 *MM* = 272 *MM*) greater for Regime 3B (unthinned) than for 3A (thinned). This is what might be expected, because the increase in the old-growth cut in the first decade would convert acres without growth to intensively managed, young-growth acres sooner than in the thinned stands.

The larger inventory indicates that if the allowable cut had been calculated for a longer time, such as 12 or 16 decades, the difference between the two regimes might have been less.

The average dbh for 8 decades for the young-growth stands was larger when the allowable-cut calculation was under Regime 3A, 18.1 inches compared to 17.6 inches under Regime 3B. The reasons for this are: the cut calculation under 3A as outlined has an average dbh 5.8 inches greater than under 3B, which weights the total average higher; and the calculation under Regime 3B cuts more rapidly through the age classes and,

Table 3. Allowable Cut in Millions of Board Feet Based on a Commercial Thinning Program of the 115,000 Acres of Regime 3A.

Decade	Clearcutting		Commercial thinning				Harvest volume
			No prior treatment		Prior[1] treatment		
	Volume	Avg dbh	Volume	Avg dbh	Volume	Avg dbh	
		In.		*In.*		*In.*	
1	751.3	--[2]	35.7	10.5	0	0	787.0
2	470.7	--[2]					
	251.2	18.5	53.8	12.6	11.3	10.2	787.0
3	694.4	18.0	51.9	15.7	40.7	12.8	787.0
4	662.3	17.9	45.2	18.2	78.6	12.8	786.1
5	642.4	20.6	14.8	19.1	129.8	13.7	787.0
6	630.0	19.9	--	--	157.5	15.0	787.5
7	633.4	18.3	--	--	130.4	14.8	784.8
8	694.5	18.0	--	--	92.5	13.4	787.0

[1]Prior treatment of 1 precommercial thinning and 3 fertilizations.

[2]Old growth.

by the eighth decade, is still harvesting, on the average, younger timber, which gives a smaller average dbh.

Economic Analysis

An economic analysis of present net worth was made on each model with its respective variation in commercial thinning assumptions (Regime 3A or 3B). Cash flows over an 80-year period were discounted to the present by interest rates of 5 and 10 percent to account for the cost of capital. Five percent could represent the opportunity cost of the Federal government, and

Table 4. Allowable Cut in Millions of Board Feet Based on a Clearcutting Harvesting Program of the 115,000 Acres of Regime 3B.

Decade	Clearcutting		Commercial thinning[1]		Harvest volume
	Volume	Avg dbh	Volume	Avg dbh	
		In.		*In.*	
1	780.0	--[2]	0	0	780.0
2	439.8	--[2]			
	328.8	18.9	11.3	10.2	780.0
3	739.3	17.6	40.7	12.8	780.0
4	702.3	17.0	77.7	12.8	780.0
5	647.6	17.3	132.4	13.9	780.0
6	624.4	18.7	156.5	14.9	780.9
7	649.5	17.7	129.7	14.7	779.2
8	677.4	16.6	99.8	13.4	777.2

[1]All commercial thinning volume from one precommercial thinning and three fertilizations, Regime 2.
[2]Old growth.

the 10-percent rate might be more typical of a private corporation. Cash flows were assumed to occur at the midpoint of each decade (fifth year).

Negative cash flows or costs were assigned for reforestation, fertilization, precommercial thinning, and timber sales as quantities of these activities changed with the thinning assumption. Costs per acre for these activities were assumed to be \$58.32 for reforestation, \$23.52 for fertilization, and \$48.86 for precommercial thinning. All costs were based on data used in the budget analysis of the Department of Natural Resources for fiscal year 1973. Annual administration costs for fire protection, research, and inventory were not included, as they were assumed to be the same, regardless of the thinning assumption. Timber-sales costs for presales, administration, and compliance were estimated for old-growth clearcutting, young-growth clearcutting, and young-growth sales, as precise data of timber-sales costs for these types of sales were unavailable. The average cost for these timber-sales activities was \$4.18 per *M* fbm sold in fiscal year 1971. Two sets of assumptions for timber-sales cost were analyzed (Table 5).

Positive cash flows or incomes were accounted for by sales of clearcut old growth, clearcut young growth, and young growth thinnings. Weighted average of the Department of Natural Resources for Douglas-fir in fiscal year 1971 formed the basis for value estimate, which was \$28.22 per *M* fbm for thinning sales. In addition, prices for second-growth thinning and clearcutting were estimated by use of an equation devel-

Table 5. Assumptions as to Costs, in Dollars per Thousand Board Feet, of Making Sales for Three Categories of Timber.

	Assumption set	
Kind of timber	1	2
Old-growth clearcutting	3	3
Young-growth clearcutting	4	6
Young-growth thinnings	5	9

oped from the above data, which related price to diameter. The objective in using such a relation was to account for value changes in average stand diameter, which resulted from modifications of the basic commercial thinning assumptions. The equation was:

Price (\$/*M* fbm) = 14.05 + 1.34 x avg dbh.

Results of Economic Analysis

Results of a present-net-worth analysis of each allowable cut model is presented in Tables 6 and 7. Table 6 presents the analysis with current prices and costs as outlined throughout the 80-year period of evaluation. Table 6 is modified to demonstrate the effect of assuming that prices will increase by 4 percent per year and costs by 2 percent per year above the outlined current values. The price estimate is based on a supply-and-demand-equilibrium analysis of data in The Outlook

Table 6. Allowable-Cut Model Evaluation with Current Prices and Costs. Income, Costs, and Net Worth Are Discounted to the Present in Millions of Dollars.

Assumptions		Regime 3B[1]			Regime 3A[1]		
Timber sales cost	Discount rate	Income	Costs	Net worth	Income	Costs	Net worth
$[2]	%						
AVERAGE PRICE							
3,4,5	5	752	-86	666	747	-87	660
3,4,5	10	408	-40	368	405	-41	364
3,6,9	5	752	-102	650	747	-105	642
3,6,9	10	408	-44	364	405	-46	359
PRICE-DBH EQUATION							
3,4,5	5	738	-86	652	743	-87	656
3,4,5	10	405	-40	365	403	-41	362
3,6,9	5	738	-102	636	743	-105	638
3,6,9	10	405	-44	361	403	-46	357

[1]Regime 3A, commercial thinning then clearcutting; Regime 3B, clearcutting only.

[2]Sales costs in dollars per *M* fbm for clearcut old and young growth and thinnings, respectively.

Table 7. Allowable-Cut Model Evaluation with Yearly Increase of 2 Percent in Costs and 4 Percent in Price. Income, Costs, and Net Worth Are Discounted to the Present in Millions of Dollars.

Assumptions		Regime 3B[1]			Regime 3A[1]		
Timber sales costs	Discount rate	Income	Costs	Net worth	Income	Costs	Net worth
$[2]	%						
AVERAGE PRICE							
3,4,5	5	2,034	-142	1,892	2,025	-143	1,882
3,4,5	10	667	-53	614	661	-53	608
3,6,9	5	2,034	-176	1,858	2,025	-179	1,846
3,6,9	10	667	-60	607	661	-62	599
PRICE-DBH EQUATION							
3,4,5	5	1,953	-142	1,811	1,999	-143	1,856
3,4,5	10	655	-53	602	658	-53	605
3,6,9	5	1,953	-176	1,777	1,999	-179	1,820
3,6,9	10	655	-60	595	658	-62	596

[1]Regime 3A, commercial thinning then clearcutting; Regime 3B, clearcutting only.
[2]Sales costs in dollars per *M* fbm for clearcut old and young growth and thinnings, respectively.

for Timber in the United States (13). Cost estimates closely approximate the historical trend of the Wholesale Prices and Price Indexes (14) from 1926-1971.

Both Tables 6 and 7 present discounted incomes (positive cash flows), costs (negative cash flows), and net worths (positive less negative cash flows). In Table 6 and, in particular, the allowable cut model for Regime 3B (clearcutting only in stands currently 40 years old with prior treatment), the discounted income amounts to 752 million dollars, and discount costs are 86 million dollars for a net worth of 666 million dollars, using the average price assumption; timber-sales costs of 3, 4, or 5 dollars per *M* fbm for old-growth clearcuttings, young-growth clearcuttings, and thinnings, respectively; and a 5-percent discount rate. Increasing the discount rate from 5 percent to 10 percent about halves the discounted values. Increasing timber-sales cost to 3, 6, or 9 dollars per *M* fbm for the respective categories of old-growth clearcuttings, young-growth clearcuttings, and thinnings results in sizable increases in total costs, especially at the 5-percent discount rate. Utilizing the price-dbh equation, instead of the average price assumption, results in decreased discounted incomes because the dbh's of the large volume of young-growth clearcuttings are generally less (Tables 3 and 4) than needed to achieve the average price, which is realized at an average dbh of 19.6 inches.

Similar results can be observed from Table 7 in reference to evaluating the model for the allowable cut that contains the commercial thinning and the clearcutting assumption 3A. Here, discounted incomes are not reduced as much as in the clearcut-only model when the price-dbh equation is used in comparison to the average price assumption. This is because average dbh's for clearcut volumes are more nearly equal to the average-price dbh of 19.6 inches in the commercially thinned model than are dbh's for the clearcut-only model (Tables 3 and 4). The model thus shows the commercially thinned timber as having a greater present net worth than the allowable cut model without commercial thinning at the 5-percent discount rate. Commercial thinning is greater than no commercial thinning, but the 10-percent discount rate reverses this by putting greater emphasis on the higher value clearcut volumes in the first few decades in the unthinned model than the lowered value thinnings of the thinning-regime model.

Table 6 generally presents results similar to those in Table 7, using the assumption of increases per year of 2 percent for costs and 4 percent for prices, although the magnitudes of the discounted values are considerably higher. With the price-dbh equation and a 10-percent discount rate, however, the commercial-thinning model is slightly greater than the no-commercial-thinning model. This can be explained in that the price increase of 4 percent per year shifts the emphasis from the early decades of the models where the high-value clearcut volume of the no-commercial-thinning model predominated under the current-price assumption to the latter decades, which gives the commercially thinned model a slight advantage.

Table 8 outlines the present-net-worth contribution to the allowable cut of beginning commercial thinning in 40-year-old stands without prior treatment. This is the difference between the thinned model and the nonthinned model. As can be observed, under all conditions of the average price assumption, thinning results in a negative contribution. In other words, the no-commercial-thinning, clearcut-only model has higher discounted net worths, as can be seen in Tables 6 and 7. A policy of pursuing thinning in stands without prior treatment under these average price assumptions would result in a reduction in present net worth in comparison to not thinning. The magnitudes of loss because of

Table 8. Present-Net-Worth Contribution in Millions of Dollars to Allowable Cut of Beginning Commercial Thinning in 40-Year-Old Stands Without Prior Treatment.

Assumptions		Prices and costs	
Timber sales cost	Discount rate	Current	Annual increase[1]
$[2]	%		
AVERAGE PRICE			
3,4,5	5	-6 (0.9)[3]	-10 (0.5)
3,4,5	10	-4 (1.1)	- 6 (1.0)
3,6,9	5	-8 (1.2	-12 (0.6)
3,6,9	10	-5 (1.4)	- 8 (1.3)
PRICE-DBH EQUATION			
3,4,5	5	+4 (0.6)	+45 (2.4)
3,4,5	10	-3 (0.8)	+ 3 (0.5)
3,6,9	5	+2 (0.3)	+43 (2.4)
3,6,9	10	-4 (1.1)	+ 1 (0.2)

[1]Annual increases of 2 percent in cost and 4 percent in price.
[2]Sales costs in dollars per *M* fbm for clearcut old and young growth and thinnings, respectively.
[3]Values in parentheses are percentages.

commercial thinning range from 4 to 12 million dollars of discounted net worth, or as a percentage of the thinned model, a loss of 0.5 to 1.4 percent. As the discount rate goes from 5 to 10 percent, the losses, because of thinning, are reduced in absolute terms, although the percentage of the commercially thinned model is increased because of its smaller base at 10-percent discount rate as compared to 5 percent. At price increases of 2 percent for costs and 4 percent for prices per year, the magnitudes of the losses are greater than under the assumption of current price and cost, because of the large present-value figures caused by the price increase, although as a percentage of the commercially thinned model, they are smaller than under the assumption of the current cost and price.

Placing a premium on larger commercially thinned stands, however, by use of the price-dbh relation results in a positive net-worth contribution for commercial thinning as compared to no commercial thinning under most assumptions of timber-sales costs and discount rates. Only under the conditions of a 10-percent discount rate and current prices and costs does the commercial thinning model not increase discounted net worths over the nonthinned model by use of the price-dbh relation. This is because of the high emphasis current prices and a 10-percent discount rate placed on income in the early decades of the analysis, which contains greater amounts of high-value clearcut volumes in the nonthinned model as compared to the thinned model.

Economic

In conclusion, we found that the impact of regulated commercial thinnings (beginning in 40-year-plus stands that have not received prior treatment in an allowable-cut model containing old-growth inventories) have only a minor impact in terms of absolute (- \$12 to \$45 million) or relative (- 1.4 to + 2.4 percent) contributions over a range of price and cost assumptions. Only when an economic premium is placed on increased stand diameters by a price-dbh relation does commercial thinning make a positive contribution to present net worth. Other costs that should be included in the decisionmaking framework for commercial thinning include the capital costs of road building, increased reforestation costs associated with brush control, and disease losses.

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QUESTIONS

Audience. Do you have any data on the economics of precommercial thinning?

Speaker. Yes. The Department's Sustainable Harvest Report Number 5, which will be out in the middle of June 1973, has both yield and economic data on precommercial thinning. Also, information is available in Precommercial Thinning Coastal and Intermountain Forests in the Pacific Northwest (2).

Audience. Would earlier commercial thinning, for example, 25-30 years, change the yields and economic projections of the old-growth and young-growth situation you presented?

Speaker. Yes, but I am not sure what the answer would be. In our present 20- to 30-year-old stands that have had no prior treatment, I do not think we could get enough board-foot volume to put up a sale. In general, we precommercially thin somewhere between 10 and 25 years. Thus, most of our 25- to 35-year-old timber will not have any prior treatment and will have a commercial thinning at around 40 to 50 years.

Audience. Have you worked out a thinning comparison for strictly young-growth forest?

Speaker. If you have abundance of young-growth timber over rotation age, for example, 60-year rotation, with 20 percent of your inventory in 70-, 80-, and 90-year-old timber, you will get nearly the same answer as in our present model. If you have little, if any, over rotation age, you are forced into a per-acre analysis.

Audience. In the cost analysis, you used the "present net worth" or liquidation value of a firm. Does the same cost analysis hold when the "going concern" value is used, for example, where marketing changes, utilization standards, and social values are projected and considered.?

Speaker. The net-worth analysis could consider other assumptions about marketing changes, utilization standards, and social values.

Audience. What effect would you expect on your outcome, if you had no old growth, but all young growth to manage?

Speaker. If volumes of young growth over rotation age were available, similar results could be expected, although the magnitude probably would be less.

Audience. Are your commercial thinning returns (stumpage) based on cat or high-lead costs?

Speaker. Rubber-tired skiddings and cat operations.

Audience. Have you included necessary road development, such as cost in commercial thinning and its impact on productive area loss?

Speaker. Road development has been considered as a cost to commercial thinning to the extent that it has been included in the timber-sale appraisal. The biological impact on growth has not been included in the analysis.

Audience. Is it not worth something to get income now instead of waiting for uncertain future values?

Speaker. Yes, it is worth something to get the income now, and the discounting process recognizes this by placing less emphasis on the values the further out in time they occur.

APPENDIX

Management Data Assumptions

1. All Douglas-fir on site III.
2. Acreage distribution by age class as tabulated below.
3. No reforestation lag.
4. Rotation of 60 years with minimum cutting age of 55 years.
5. Evenflow.
6. Fifty percent of the natural stand management regime at time of clearcutting will go to the fertilization regime; 100 percent of Regime 3 will go the fertilization regime.
7. Cut the oldest first.
8. Acres of activities by decade for Regimes 3A and 3B, as tabulated below.

Acreage By Age Class

Age class	Management regime: 1 No management	2 Precommercial thinning plus three fertilizations	3 Commercial thinning at age 40[1]
Yr	*Acres*	*Acres*	*Acres*
160	200,000		
100-159	40,000		
90	10,000		
80	30,000		
70	70,000		
60	60,000		
50	110,000		
40	60,000		70,000
30	45,000		45,000
20	40,000	40,000	
10	40,000	30,000	
0	40,000	70,000	

[1]Commercial thinning, 3A; no commercial thinning, clearcut only, 3B.

Acres of Activities by Decade for Regime 3

Decade	Planting	Precommercial thinning	Fertilization
REGIME 3A, Commercial Thinning and Clearcutting			
1	110,000	70,000	70,000
2	150,000	110,000	180,000
3	129,607	75,130	255,130
4	127,535	64,803	249,933
5	138,464	63,767	203,700
6	136,919	76,196	204,766
7	143,386	104,691	244,654
8	181,358	107,319	288,206
REGIME 3B, Clearcut Only			
1	110,000	70,000	70,000
2	156,000	110,000	180,000
3	137,984	78,000	258,000
4	141,196	68,992	256,992
5	143,081	70,598	217,590
6	122,184	87,227	226,817
7	144,113	93,021	250,846
8	186,574	104,682	284,930

COMMERCIAL THINNING AS AN INCOME OPPORTUNITY FOR SMALL WOODLAND OWNERS

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ABSTRACT

Small woodland owners base their management decisions on both financial and nonfinancial objectives. This paper demonstrates how information related to decisions on commercial thinning and based on a landowner's financial objectives can be developed and used in conjunction with nonfinancial objectives to influence stand management.

COMMERCIAL THINNING AND THE SMALL WOODLAND OWNER

Young-growth timber is an increasingly important source of wood products in the Douglas-fir region. Accordingly, forest-land owners are becoming aware of the values represented by their young-growth holdings and showing more interest in the silvicultural and economic alternatives that might be available in managing these resources. In this paper, commercial thinning is examined as one of the alternatives available to owners of young-growth Douglas-fir stands. Focus is especially on the management situation encountered by nonindustrial and small woodland owners. According to Fight and Gedney (1), forest-land owners in the "other private" (nonindustrial) category account for 2,704,000 acres, or 19 percent of 14,348,000 acres of all conifer stands in western Washington and western Oregon. In terms of acreage available for commercial thinning, nonindustrial owners account for 17 percent, or 212,000 acres out of 1,250,000 acres in all ownership classes of timber at ages 35-75 with normal basal area stocking of 70 percent or greater.

Considerations such as sustained yield, allowable cuts, and old-growth conversion are generally of far less importance to small woodland owners than are these same considerations on industrial or public forests. Thus, the small woodland owner may have more freedom in deciding which, if any, management practices will be applied to the stand and when the stand will be liquidated. The course of action chosen will depend in large part on owner objectives, which are varied and difficult to generalize. The forester who would offer advice to landowners on forest-management problems needs to recognize, not only the diversity of objectives among landowners, but also that particular individuals can have diverse and even conflicting objectives. To be most effective in outlining forest-management alternatives, the advising forester should be able to provide the landowner with information on possible impacts of those alternatives on the landowner's objectives.

AN ECONOMIC APPROACH TO EVALUATING COMMERCIAL THINNING

A convenient way of viewing objectives is to divide them into two categories, financial and nonfinancial. Financial objectives are those that can be expressed in dollars. In this paper, I will demonstrate an approach by which financial information can be developed for decisions on commercial thinning in existing Douglas-fir stands of age 75 and under. Specifically, information on the dollar returns that can be expected from thinning will be developed and compared with dollar returns from alternatives such as immediate stand liquidation or retaining the stand without thinning. Although the information developed will relate directly to financial objectives of landowners, it is recognized that nonfinancial objectives can influence and override financial objectives in stand-management decisions. I will argue, however, that financial criteria can be valuable even when the primary objectives of an owner are nonfinancial. I also will demonstrate how changes in discount rates can influence the management of a stand.

Availability of Yield Data

Although much work remains to be done in obtaining information on the response of Douglas-fir to thinning, sufficient data have been collected and analyzed for interim approximations of the yields that can be expected from thinning Douglas-fir. In fact, estimates of interim yield are being prepared for publication as managed-stand yield tables by scientists at the Pacific Northwest Range and Experiment Station. The economic approach presented in this paper is based on these yield tables.

The economic approach to be presented is part of a larger study in which managed-stand yield tables will be used as the basis for developing economic guides for the determination of the best timing and intensity of thinning. The first phase of this study has been to develop an economic framework that can be used to determine the financial returns expected from a given regime of thinning in a Douglas-fir stand of a given age and site class.

Defining Thinning Opportunities

Commercial thinning opportunities are assumed to exist when the average diameter at breast height (dbh) of cut trees is 9 inches or larger. Thinning opportunities are defined further in terms of site class and the age at which thinning first takes place. Site classes were represented by the following site indexes:

Site class	100-year site index
I	200
II	170
III	140
IV	110
V	80

Thinning could be initiated at any time along the continuum of ages in the life of a stand; however, only a few discrete points in the stand's life were chosen for analysis. For example, in stands of site class I, commercial thinning was evaluated at ages 30, 40, 50, and 60. Table 1 summarizes the ages at which the effects of commercial thinning were evaluated for each site.

Defining Thinning Regimes

The managed-stand yield tables used in this study are based on the assumption that once commercial thinning is begun, a specific regime of thinning will follow during the remainder of the stand's life culminating in a final harvest. Several important assumptions concerning the manner in which thinning will be carried out are:

> Commercial thinnings will start when average dbh of cut trees is 9 inches or larger, and subsequent thinnings will follow at 10-year intervals.
>
> At the time of initial thinning, stands are about "normal" by Bulletin 201 (2) standards—in terms of average dbh and number of trees and volume per acre.
>
> Commercial thinnings plus expected unsalvable mortality reduce the cubic-foot volume to either two-thirds of prethinning volume or 60 percent of normal by age and site, whichever is greater.
>
> Size of cut trees relative to average dbh before thinning (d/D) varies with age. Early commercial thinnings remove trees larger than average, and later thinnings remove trees smaller than average. Maximum d/D is 1.2; minimum, 0.8.

Evaluating Thinning Opportunities

Once a thinning regime and a time for final harvest have been established, volumes, stumpage prices, and costs expected at each harvesting entry must be estimated. Net revenue then can be calculated for each entry; these values are discounted to

Table 1. Stands Eligible for Commercial Thinning by Site Class and Stand Age at Which Thinning Is Begun.

Site class	Stand ages
I	30, 40, 50, 60
II	35, 45, 55, 65
III	40, 50, 60, 70
IV	55, 65, 75
V	None

the present and summed to obtain the discounted net revenue of the stand with thinning. A similar procedure minus the thinning regime can be used to evaluate the discounted net revenue of a stand without thinning. The difference between the discounted net revenue of the thinned stand and the discounted net revenue of the unthinned stand is the net gain or loss that can be attributed directly to thinning.

In the following section, the economic approach described above is used to evaluate thinning and no-thinning alternatives in a Douglas-fir stand on site II at age 45. The stumpage values used at each entry to derive net returns are assumed to be representative of average prices on the west side of the Cascade Mountains during 1970-1971, minus relevant costs. These stumpage values are assumed to be $22.50 for thinnings and $30 for mature young growth; that is, thinning stumpage prices are about 75 percent of stumpage prices for the mature final harvest. Estimates of future prices are assumed to be constant real prices, meaning that, even with general inflation, prices of factors of production and commodities will maintain present relations, therefore not changing the results of the analysis.

A discount rate tells us the highest rate of return the landowner could earn aside from the investments being considered. It is used to adjust for time differences in the occurrence of costs and revenues so that a correct comparison of investment projects can be made. In this evaluation, a 6-percent discount rate was used, but only for purposes of illustrating the approach. The actual rate of return for evaluating forestry investments would vary depending on the situation of each small woodland owner.

EVALUATING COMMERCIAL THINNING ON A STAND BASIS

An evaluation of one stand will demonstrate the procedure used on each combination of age and site class. Using a site-II, age-45 stand as an example, Table 2 shows the volume yield expected. The table shows accumulated total production as well as the condition of the stand before and after thinning. Compared with a no-thinning regime in the same stand, total production at age 75 or at age 90 is not especially impressive. At age 90, total production in the thinned stand is 96,000 board feet Scribner, and total yield of final harvest in the unthinned stand is 94,200 board feet Scribner. The gain from thinning amounts to less than 2 percent. At age 75, total production in the thinned stand is 75,100 board feet Scribner, and total yield at final harvest in the unthinned stand is 75,400 board feet, seemingly a loss of production as a result of thinning. The meager improvement at age 90 and the loss at age 75 result in part from use of the Scribner log scale, however. In terms of cubic-foot log scale, gains from thinning are about 5 percent at age 75 and 7 percent at age 90.

In terms of financial returns, the evaluation presented in Table 3 gives a more encouraging picture of commercial thinning than physical yields alone would indicate. Table 3 shows the volume data presented in Table 2 converted to economic data. The undiscounted net revenues are derived by multiplying volume yields from Table 2 by net stumpage values of \$22.50 per *M* fbm (thousand board feet) for thinning and \$30 per *M* fbm for final harvest.

The example shown in Table 3 is for a 90-year rotation and a 6-percent discount rate. Notice that net revenues in the

Table 2. Yields per Acre with Commercial Thinning to a 5-Inch Top in a Stand of Douglas-Fir, Beginning at Age 45 on Site-II Land (Volumes by Scribner Scale).

Age	Before		Thinned		Residual		Total Volumes
	Dbh	Volume	Dbh	Volume	Dbh	Volume	
	In.	*M fbm*	*In.*	*M fbm*	*In.*	*M fbm*	*M fbm*
45	10.6	31.4	10.8	9.0	10.5	22.4	31.4
55	13.1	36.6	12.0	6.3	13.4	30.3	45.6
65	15.8	45.7	13.4	4.9	16.3	40.8	61.0
75	--	--	--	--	18.2	55.1	75.3
90	--	--	--	--	20.6	75.8	96.0

thinned stand are $481, but net revenues from letting the stand grow unthinned are $205, a net improvement of $276 directly attributable to thinning. This difference amounts to about 135-percent increase in dollar value from thinning the stand. If

Table 3. Amount of Volume (Scribner Scale) and Net Revenues in Dollars per Acre from Thinning and No-Thinning Alternatives in a Stand of Douglas-Fir at Age 45 on Site-II Land.

Time interval	Thinning			No thinning		
	Volume	Net revenues: Undiscounted	Net revenues: Discounted at 6%	Volume	Net revenues: Undiscounted	Net revenues: Discounted at 6%
Yr	*M fbm*	*$*	*$*	*M fbm*	*$*	*$*
0	9.0	203	203	--	--	--
10	6.3	142	79	--	--	--
20	4.9	110	34	--	--	--
45	75.8	2,274	165	94.2	2,826	205
	96.0	2,729	481	94.2	2,826	205

we were to use a 75-year rotation as an example, discounted net revenues in the thinned stand would be $604, but discounted net revenues from the unthinned stand would approximate $394, a net increase of $210 or 53 percent.

Table 4 shows the discounted net revenues directly attributable to thinning; that is, the difference between revenues from the thinned and unthinned stands shown in Table 1. These stands were evaluated by use of the same basic assumptions and procedures that were used to evaluate the site-II, Douglas-fir stand at age 45. The information in Table 4 could be used to establish thinning priorities based on the highest revenues obtainable from thinning, if an owner had several stands in which to thin and thinning them all in the same year was not desirable. Keep in mind that the information shown in Table 4 is based on specific assumptions. Changes in these assumptions could change the level of revenues and even priorities among stands.

INFLUENCE OF OBJECTIVES AND DISCOUNT RATES ON STAND EVALUATION AND CHOICE OF ALTERNATIVES

From the example given in the preceding section, one might wonder what would motivate a small woodland owner to hold timber to age 90. Would not a shorter rotation be more realistic? Moreover, if the owner is determined to hold onto the stand, can he be induced to thin it? The owner's objectives and financial situation are crucial in answering these questions. Some landowners might be quite willing to hold timber stands to 90 years, or even more, because their primary purpose in owning timber may be recreational or esthetic. Thinning might be considered if the primary values are not harmed. Likewise, other landowners may view timber as part of an estate to be passed on to their children and thus may not consider final harvest of the stand an acceptable alternative, although thinning might be. Still other landowners, strongly motivated by financial objectives, may clearcut stands that might be considered ideal for thinning.

Table 4. Increase in Discounted Net Revenue per Acre, in Dollars, from Thinning Douglas-Fir Stands by Age and Site Class.[1]

Age	Site class I	Site class II	Site class III	Site class IV
30-35	220	197	--	--
40-45	337	276	155	--
50-55	431	319	205	127
60-65	351	286	228	142
70-75	--	--	209	131

[1]Values shown are based on specific assumptions concerning stumpage prices, thinning yields, rotations, and so on. Changes in these assumptions could change the magnitudes of values as well as priorities among stands.

In the previous section, one alternative not considered was that of clearcutting the site-II, Douglas-fir stand at age 45. Table 5 shows the results of clearcutting at age 45 compared with carrying the stand to various rotation ages. To evaluate clearcutting at age 45, a net stumpage value of $26 per *M* fbm was used rather than the stumpage value of $22.50 per *M* fbm assumed for thinnings. Lowered harvesting costs for clearcutting are assumed to account for the difference. The land also is assumed to remain in timber production indefinitely, no matter which alternative is followed. Therefore, revenues expected from future rotations are estimated, discounted to the present, and added to discounted net revenues from the present rotation. Thus, the discounted net revenues for each alternative shown in Table 5 represent a perpetual series of rotations.

Table 5 shows that if a 6-percent discount rate is appropriate and a net value for stumpage of $26 per *M* fbm prevails, clearcutting the stands generates the highest discounted net revenues of all alternatives presented. To the extent that a landowner was guided by such a financial criterion, he would be influenced to liquidate the stand. On the other hand, if a

Table 5. Net Revenue, in Dollars per Acre at Selected Discount Rates, from Various Management Alternatives in a Stand of Douglas-Fir at Age 45 on Site-II Land.

Management alternative	Discount rate	
	6 percent	3 percent
Clear cut at age 45	843	1,174
Thin at 45, final harvest at age 55	824	1,285
Thin at 45, 55; final harvest at age 65	711	1,252
Thin at 45, 55, 65; final harvest at age 75	604	1,178
Thin at 45, 55, 65; final harvest at age 90	481	1,047

3-percent discount were appropriate, the landowner would be better off financially to thin the stand and then hold it to a final harvest at age 55.

As can be seen from Table 5, the impact of changing discount rates can be dramatic. Although at 6 percent, little justification can be found (using solely the information in Table 5) for holding the stand, at 3 percent one can justify managing the stand for up to 30 more years rather than clearcutting it. Again, I stress that the objectives and financial situation of the landowner would determine how much influence an analysis of this kind would have. Some landowners with predominant financial objectives might liquidate the stand on the basis of the results at 6 percent. Others with predominant nonfinancial objectives might refuse to consider any harvesting in spite of the analysis. Others with more balanced financial and nonfinancial objectives might be persuaded to thin, even without plans to clearcut in the future.

CONCLUSION

The preceding analysis may help explain why some landowners liquidate young age classes that seem just right for thinning, but others hold on to such stands without applying any form of management. The relative weight of financial and nonfinancial objectives combined with the financial situation of the landowner can have greater influence on management decisions than the actual condition of the timber itself.

The economic approach shown in this paper can help the landowner realize the financial consequences of alternative decisions that concern the management of stands. Although such information may lead sometimes to stand liquidation, at other times the information may reveal previously unknown income opportunities that lead to cultural practices that increase stand productivity.

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QUESTIONS

Audience. With regard to the last chart (Table 5) on returns for various cutting times, have you taken into consideration any expected increase in stumpage price over the rotation period? I believe Pierson used a 4-percent compound rate (to inflate future prices).

Randall. I assume constant real prices, which means that even with inflation, all prices and costs will inflate proportionally to maintain present relations. I have evaluated thinning opportunities at higher price levels and have found that the choice among alternatives and rankings among stands remain unchanged. The critical price assumption in this paper is that thinning stumpage prices are 75 percent of final harvest prices.

The effect on the choice among alternatives of changing this assumption is being studied and will be discussed in a forthcoming research note from the Pacific Northwest Range and Experiment Station.

Audience. If you are using the small owner as an example, and a 6-percent alternative rate, your figures serve to emphasize the importance of early returns from thinning. The one crop is the only one he will have to work with. Thinning with periodic returns or bare land are the owner's only alternatives in his short life.

Randall. Although clearcutting leaves the landowner without the option of periodic income from thinning until another commercial-size stand is grown—perhaps not in his lifetime—we should not overlook the investment opportunities outside of forestry that are available as alternatives to holding timber capital. In fact, with respect to comparing alternative investments, use of a discount rate (for example, 6 percent) that leads to a decision to clearcut presumes that the owner has alternative investment opportunities that would earn him that rate of return. If such opportunities do not exist, then a lower rate is called for.

Audience. Landowners are not motivated by money alone. Of what value is a purely financial analysis?

Randall. As I pointed out in my talk, an individual landowner can be motivated by various objectives, financial as well as nonfinancial. I think that a forester advising a landowner should provide his client with the best information available that concerns both financial and nonfinancial objectives. I do not suggest that the landowner base his decisions solely on financial criteria, but only that he be given information that will help him correctly assess the financial consequences of management alternatives open to him. The value of such information will depend on the relative importance attached to financial objectives by the landowner in question.

Audience. Were taxes considered in your analysis?

Randall. Because of the wide variation in the tax situation of individual landowners, no attempt was made to determine after-tax values. The discounted net revenues presented are before-tax estimates. Adjustments would have to be made to these values to derive after-tax values. The magnitude of adjustment would, of course, depend upon the particular tax situation of the landowner.

Field Trips

The field trip (Figure 1) on June 12, 1973 was arranged and directed by Steve Woodard, District Forester for the Industrial Forestry Association. Acting as hosts were George Bradshaw, Chief Forester, Springfield Division, Georgia-Pacific Corporation; Bert Hockett, Extension Forester, Oregon State University; and Jim Rombach, Regional Forest Engineer, Weyerhaeuser Company.

In addition to thinning young stands, the rehabilitation of unstocked, clumpy, and scattered stands were observed. The forester must decide whether he will retain small patches or isolated scattered trees in the rehabilitation process. These problem areas are a part of young-growth management.

PRUNE HILL REHABILITATION

George Bradshaw

The Prune Hill area (Figure 1) was visited to illustrate rehabilitation work in understocked stands and brush areas.

Figure 2 shows the location of areas visited in the Prune Hill ownership of the Georgia Pacific Corporation.

In area A, the summer and late fall of 1972, the mixed, scattered old-growth and large young-growth Douglas-fir were logged. After logging, the residual stand consisted of hardwoods, brush patches, and some well-stocked, young Douglas-fir patches. The hardwoods and brush patches were brush bladed into piles and burned. Patches of young Douglas-fir were saved. The area was then planted to large bare-rooted Douglas-fir seedlings. If necessary, the area will be aerial sprayed next spring for brush control.

Area B was a fully stocked Douglas-fir stand from 60 to 65 years old, that was thinned during the winter of 1969 and clearcut in 1972-1973. The remaining scattered, suppressed Douglas-fir, hardwood trees, and brush were brush bladed into piles and burned. The area was planted with Douglas-fir plugs. Aerial spray will be applied later to control brush if necessary.

Area C was high-graded before and during World War II and relogged from 1959-1968. Residual vegetation is grass with patches of brush and Douglas-fir reproduction. The area was scarified with a tractor, and the brush piled and burned where necessary–about one-third of the area. Large barerooted Douglas-fir seedlings were planted, and the area sprayed the following spring to control grass and brush.

Area D was high-graded at the turn of the century. Final logging occurred during 1969-1972. The suppressed Douglas-fir

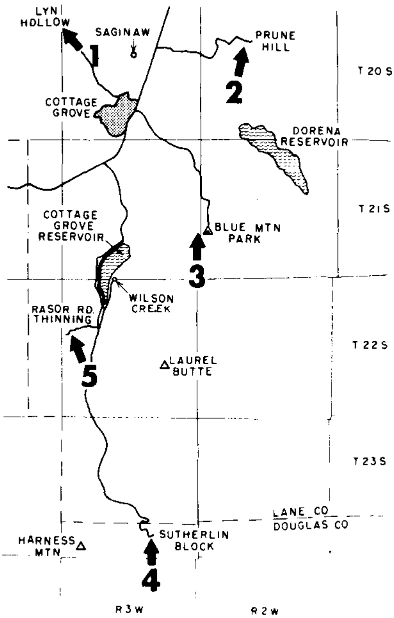

Figure 1. Location of areas visited on field trip on June 12, 1973.

and brush (salal and vine maple) were piled by tractor in the summer of 1972, burned during the fall of 1972, and seeded to Douglas-fir south of the mainline during the winter of 1972-1973. The area north of the mainline will be planted with Douglas-fir seedlings during the winter of 1973-1974. If necessary, the area will be sprayed in the spring of 1974.

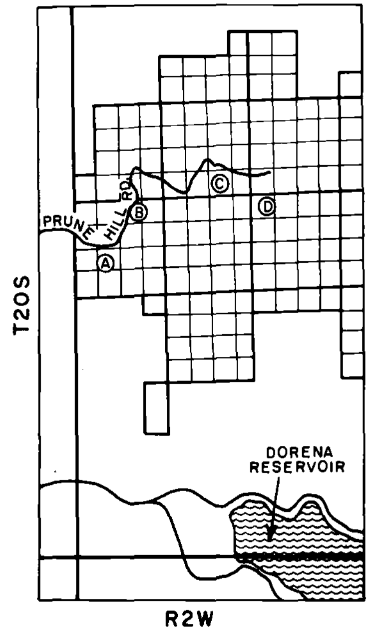

Figure 2. Location of areas visited in the Prune Hill ownership of the Georgia Pacific Coporation.

LANE COUNTY

BLUE MOUNTAIN DEMONSTRATION FOREST

Bert Hockett

The 275-acre Blue Mountain Demonstration Forest (Figures 1, 3) is owned by Lane County and managed by Oregon State University Extension Service as a demonstration of forest practices that can be applied to local small woodlands.

A Second Precommercial Thinning

A 38-year-old Douglas-fir stand on Nekia soil, low site III (Figure 4) was thinned to spacings from 4 feet by 4 feet to 8 feet by 8 feet at age 26 years. The measurable response in dbh

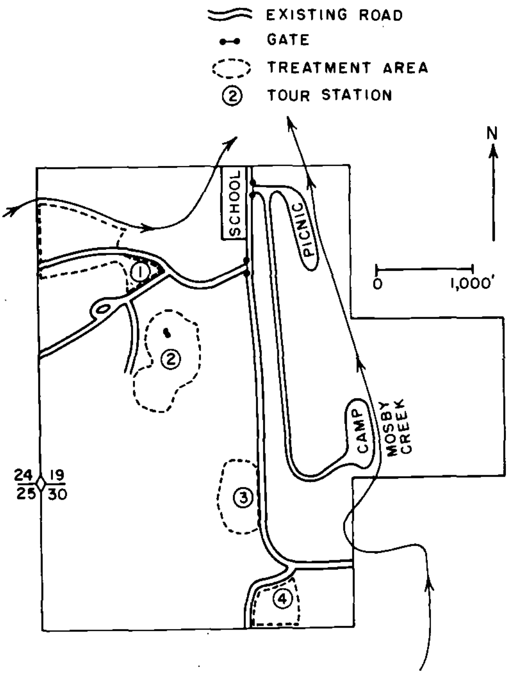

Figure 3. Lane County Blue Mountain Tract.

(diameter breast height) to this thinning lasted for about 2 years.

The stand was thinned a second time in 1971. Posts and corral poles were removed. To avoid this situation, an early thinning to a 12-foot by 12-foot spacing is recommended.

Shelterwood Cutting

In March 1972, a shelterwood cutting left 50 of the best trees on each acre of a 70-year-old Douglas-fir stand on Nekia soil, medium site III (Table 1, Figure 5). The logging removed 9,000 board feet per acre, which represented 33 percent of the volume and 65 percent of the trees.

A stocking survey in May 1973 showed that 73 percent of the area is stocked with seedlings at least 1 year old.

Figure 4. Second precommercial thinning.

Table 1. Average Tree, Shelterwood Cutting.

	Dbh	Volume
	In.	*Fbm*
Before cutting	15	200
Remove in cutting	14	160
Residual shelterwood	17	320

Third Commercial Thinning

A 60-year-old Douglas-fir stand on Willakenzie soil, low site II (Figure 6) has 97 trees and 36,500 board feet that remain on each acre. A normal unmanaged stand on this site, according to Bulletin 201[1], would have 137 trees and 36,200 board feet

[1]McARDLE, R. E., W. H. MEYER, and D. BRUCE. The Yield of Douglas-Fir in the Pacific Southwest. U.S. Dept. of Agric. Tech. Bull. 201. 74 p. 1961.

Figure 5. Shelterwood cutting.

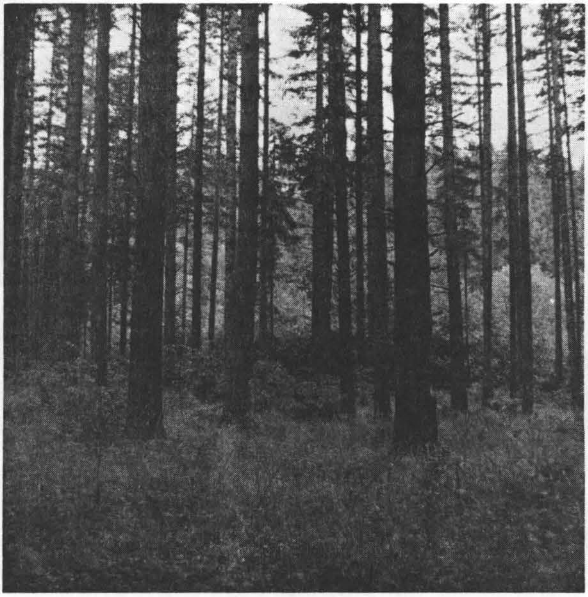

Figure 6. Third commercial cutting.

per acre. Table 2 shows the yields from each of the three thinnings.

Growth has averaged 1,420 board feet per acre per year since the first thinning. The light, infrequent thinnings salvaged mortality and maintained a vigorous stand. Both average tree size and yield have increased over that of an unmanaged stand.

Table 2. Yield, per Acre, from Thinning.

Year	Trees	Volume
		Fbm
1956	27	2,050
1959	33	3,650
1972	42	6,800
Total	102	12,500

Commercial Thinning

A 40-year-old Douglas-fir stand on Willakenzie soil, medium site III (Figure 7) was thinned precommercially in 1962 to release dominant trees. A commercial thinning in 1972 removed 1,500 board feet per acre. The residual stand has 140 trees per acre, 8 inches dbh and larger.

LYN HOLLOW REHABILITATION CONVERSION

Jim Rombach

The Lyn Hollow area was an example of brush conversion, low intensity logging, regeneration, vegetation control, animal damage, and precommercial thinning (Figures 1, 8).

An abandoned farm area (Figure 1) was acquired in the late 1960's and contained scattered residual trees from the previous logging. The primary brush species was vine maple. Site was averge III, with a southerly exposure. Big game and rodent levels were high.

In the spring of 1972, 60 acres of heavy vine maple brush were sprayed during the dormant period. In August, the residual

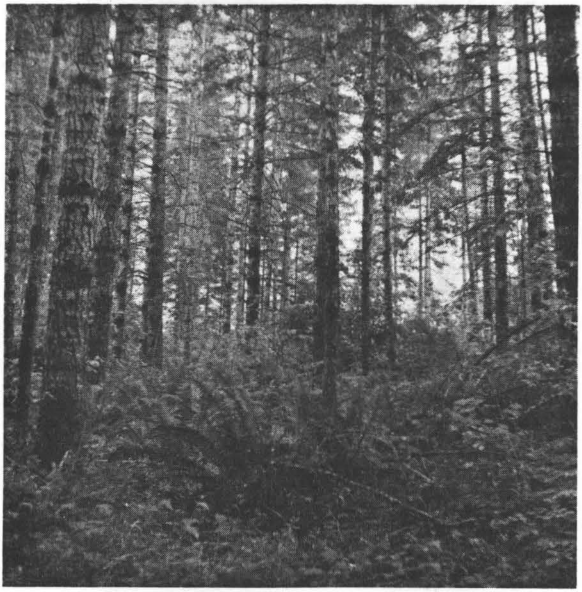

Figure 7. Commercial thinning.

Figure 8. Lyn Hollow rehabilitation conversion.

Figure 9. The Sutherlin block.

Figure 10. Rasor road thinning.

trees on 430 acres were logged with tractors and skidders. A road system to facilitate management of the entire area was developed concurrent with logging. After logging, the site, which included the 60 acres previously sprayed, was prepared for planting by scattering and dispersing brush with brush blades to create planting spots. About 1.3 acres were prepared per hour.

During the 1972-1973 planting season, an area was planted with 2-1 Douglas-fir on a spacing of 8 feet by 8 feet. In the spring of 1973, 4 pounds of Atrazine and 4 pounds of Dowpan were aerially applied for the control of grass on 98 acres. In May 1973, after the new leader growth had reached 1 inch in length, all seedlings were treated by hand with a big-game repellent developed by Weyerhaeuser Company. The application was timed with the occurrences of browse locally. The same treatment will be repeated in 1974. Seedling survival is 98 percent.

Eighty acres of naturally established Douglas-fir trees, from 15 to 20 years old, were thinned to a spacing of 10 feet by 10 feet in 1972.

Sutherlin Block

The Sutherlin block is a large cutover that is stocked with natural Douglas-fir trees (Figures 1, 9). The area was thinned precommercially to spacings of 9 feet by 9 feet and 10 feet by 10 feet. Roads and heliports have been built and maintained in strategic locations for management purposes. The area, part of a 30,000 acre block, will be fertilized in the fall of 1972. Effects on the environment have been assessed.

Table 3 details the treatments applied to the area that was visible during the field trip.

Rasor Road Thinning

A 45-year-old Douglas-fir stand was scheduled for commercial thinning in June 1973 (Figure 10). The tree crowns have closed throughout the stand, but the stems per acre vary from open growth to dense. Soil is Nekia series, sites II and III. The stand was fertilized in the fall of 1972.

Table 3. Treatments Applied by Acre to the Area Visible During the Field Trip.

Period	Logged	Area treated Regenerated					Release (sprayed)	Thinned	Fertilized
		Natural	Seeded	Planted	Reseeded	Replanted			
1960-1964	445	275	300	5	80	325			
1965-1970	530	25	150	45	65	160	338		
1970-1971								730	
1971	50			120	45		422		
1972				50					
1973									800
Total	1,025	300	450	220	190	485	760	730	800

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