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Much forest land in Western Oregon has been lost to production due to brush competition. As the demand for forest products increases, more attention should be paid to the reclamation of these unproductive lands.

Chemical herbicides have been proven an efficient tool for brush control from the physiological viewpoint. This study uses the internal rate of return and benefit-cost ratio analyses for the economic evaluation of herbicidal brush control for decision-making under certainty. A general sensitivity analysis is conducted and discussed in terms of the changes in stumpage price and interest rate. The internal rates of return and benefit-cost ratios are given as guidelines to forest managers in decision-making. The possibility of using decision-making under uncertainty has been explored and explained. The maximum expected value was used as a criterion in decision-making process.

An Economic Analysis of the Cost of Chemical Brush Control in Western Oregon

by

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AN ECONOMIC ANALYSIS OF THE COST OF CHEMICAL BRUSH CONTROL IN WESTERN OREGON

I. INTRODUCTION

General Background

The consumption of forest products increases as the population grows and as per capita income increases. According to the projection reported in Timber Trends in the United States (23), there will be a 100 percent rise in pulpwood consumption from the years 1970 to 2000. Consumption of veneer logs will increase 78 percent and lumber consumption will increase 35 percent. In order to meet this demand, the supply can increase either by boosting domestic production, or by encouraging net imports, or perhaps by both. But from the viewpoint of reliability of material supply and the utilization of resources, it may be best to increase domestic production.

Domestic production can be increased in two ways. First, by intensifying management to produce more per unit of forest land, either by shortening the rotation with the same present level of timber output, or with the present rotation length but obtaining more timber output per acre. A second way is to expand forest production by reclaiming those areas occupied by brush or undesired species. Chemical brush control seems to offer a good method for reclaiming brushfields and increasing per acre timber production by obtaining regeneration success as quickly as possible after timber harvest.

Since Oregon, mainly western Oregon, produces one fourth of the total forest products in the United States, it is very important to consider production problems in the state. In western Oregon, it is estimated that there are 15,082,000 acres of total commercial forest land, of which 9,483,000 acres are sawtimber stands, and 731,000 acres are non-stocked areas (Table 1). However, even among "stocked stands", 40 percent of them are really "understocked". Most of these understocked stands are poletimber, sapling and seedling stands (6). Obviously, production will be lower in understocked stands. Although it is unfair to say that all understocked forest lands are caused by brush, it is true that most of the understocked forest lands have a bad brush problem. Brush not only increases the production cost and reduces the timber output from the present crop of trees, but also increases the cost of future regeneration and reduces future production.

Since herbicides, such as 2,4-D and 2,4,5-T, offer a method for brush control on a forest operation, a lot of experiments have been conducted using these herbicides. There are three advantages of chemical brush control herbicides. These are:

1) Chemicals can be sprayed by aircraft, thereby making rough terrain easily accessible.
2) Application of chemical sprays is time-saving compared to previous methods of brush eradication.
3) Herbicides are selective. (I.e., they kill certain plant species, therefore can be applied to get rid of undesirable species without damaging crop trees.)

Table 1. Area of commercial forestland, by stocking level of growing-stock trees and by stand-size classes in western Oregon.

Stocking level	All stands (M acres)	(%)	Sawtimber stands (M acres)	Poletimber stands (M acres)	Sapling & seedling stands (M acres)	Nonstocked stands (M acres)
70% or more	8,640	57	6,818	860	862	-
40 to 70%	3,382	22	1,823	320	1,239	-
10 to 40%	2,329	16	842	288	1,199	-
Less than 10%	731	5	0			731
All stocking levels	15,082	100	9,483	1,468	3,400	731

Note: Fully stocked stands have 70% or better stocking. Less than 70% stocking is considered understocked.

Date source: Forest Survey, PNW, 1964 (6).

These reasons tend to reinforce the use of herbicides in brush control in forest management. Up to now, most of the experiments have emphasized the physiological and ecological viewpoint. These experiments have shown that chemical control is technically feasible. But due to budget constraints, an operation is possible only if it is both technically and economically feasible. I have attempted in this research to develop a model and some criteria for evaluation of economic feasibility.

The Brush Problem in Western Oregon

Brush is considered in a broad sense in this paper. Any species which competes with the crop trees shall be considered brush, i.e., grasses, shrubs and even some undesirable coniferous and hardwood species. The appearance of brush on forest land creates many problems - biotic, edaphic and economic (4, 13).

The availability of factors affecting tree growth is limited. With brush competition, factors like moisture, sunlight, and nutrients, may become very critical for survival and growth of the crop trees. Immediately after planting, seedlings are very weak and are unable to compete with brush for these factors affecting growth. They are easily overtopped by brush. Without cultural treatments, the planting area will become a brush field. Some planting areas may become unsuitable for crop tree production ecologically. Further regeneration without brush control may be impossible. This is both a biotic and an edaphic problem.

Economic losses are losses in terms of money. They are felt through delayed stocking, understocking and reduced growth of trees at all ages. Brush can easily overtop the crop trees in the beginning period of regeneration - the first five years being the critical brush control period (4, 14). Brush competition will increase the mortality of seedlings, delay stocking, and even turn the productive forest land into chaparral - a densely brush-covered forest land which produces no timber.

According to the definition of brush, there are four general and typical classes of brush development. The first class is composed of fast-growing hardwoods such as alder, willow, bitter cherry and bigleaf maple. These species grow so fast and occur so soon after a major disturbance such as forest fire and clear cutting, that the establishment of crop trees is almost impossible.

The second class is the intermediate class of brush developed from sprouts following clear cutting. It is composed of vine maple, salmonberry and madrone. This type of brush will cause seedling mortality if it invades the area before or at the time of planting.

The third class is composed of slow-growing shrubs that normally follow the burning of slash on relatively dry sites. The main species in this class are snowbrush, ceanothus, manzanita, and other evergreen shrubs. Many seeds of these species are stored in the duff and slowly develop into dense stands following burning. They do not cause an appreciable amount of damage to seedlings if they germinate after the seedlings are established. However, they will become a formidable obstacle to regeneration if the seedlings are not successful concurrently with the brush (4, 13).

The fourth class is one composed of herbaceous plants, mainly perennial species such as grass. This type of brush grows fast and overtops seedlings in a short time. Furthermore, it is very efficient in transpiring moisture and depleting it from the soil in the root zone of young crop trees. Young Douglas-fir seedlings either die in the first season or struggle for several months to survive under moisture stress (4, 13).

The distribution of these four types of brush in western Oregon varies according to the climatic and topographical condition. Density and degree of competition differ from species to species, and from area to area. There are hundreds of brush species in western Oregon. It is hard to separate the effect of one brush species from the total effect of all brush species. In order to apply herbicides effectively from site preparation and to release crop trees from brush competition, one must classify brush into different brush types according to their dominance. From Table 2 (26, 27), the main or dominant brush species, the associated crop tree species by geographic area, and the correct chemical herbicides and their estimated cost can be obtained.

Chemical Brush Control in Western Oregon

The history of chemical brush control in forest operations is quite short. The whole process of chemical brush control is as yet

Table 2. Chemical dosage by brush type, regional distribution and crop trees.

Brush Type	Region	Crop Trees	Herbicide Dosage
1. Red Alder	Coast Range	Douglas-fir, Grand Fir, Hemlock & Redwood	2 lbs 2,4-D (4 or 6 lbs/gal), water, 1 pint to 1 quart of surfactant per 100 gals of spray (8 to 10 gals of spray per acre)
2. Maple & Alder Hardwood & brush vine maple in combination with red alder & big leaf maple	Coast & Cascade Ranges	Douglas-fir	1 lb 2,4-D & 1 lb 2,4,5-T (4 or 6 lbs/gal) oil (No. 2 burner fuel) (8-10 gals of spray per acre)
3. Salmonberry	Coast & Cascade Ranges	Douglas-fir, Hemlock, Sitka Spruce	2 lbs Amitrole T .5-1.0 pint surfactant per 100 gals (10 gals of spray per acre)
4. Ceanothus, Blue-Blossom, Snowbrush & Varnishleaf	Coast & Cascade Ranges	Douglas-fir, Hemlock, True Fir, Redwood	2 lbs 2,4,5-T, water, No. 2 diesel oil (8 gals of spray per acre)
5. Vine Maple	Coast & Cascade Ranges	Douglas-fir	2 lbs 2,4,5-T .5 pint to 1 quart of surfactant per 100 gals of spray solution (8 gals of spray per acre)

Table 2. (continued)

Brush Type	Region	Crop Trees	Herbicide Dosage
6. Tanoak-Madrone Tanoak, canyon, live oak, madrone & manzanita	Southwest Oregon	Douglas-fir, Hemlock, Grand Fir, Red Fir & Redwood	3 lbs 2,4-D (6 lbs per gal), water, or No. 2 diesel oil
7. Deciduous oak California black oak, Oregon white oak	Southwest Oregon	Douglas-fir, Ponderosa Pine, Sugar Pine	2 lbs 2,4,5-T (6 lbs per gallon) water, No. 2 diesel oil (8 gals of spray per acre)
8. Rhododendron	Coast Range	Douglas-fir	2 lbs 2,4-D or 2 lbs 2,4,5-T (6 lbs per gal), water, No. 2 diesel oil (8 gals per acre)
9. Broadleaf Evergreens Ceanothus Tanoak, chinkapin, canyon line oak, madrone, mountain white thorn ceanothus, snowbrush ceanothus	Southwest Oregon	Pine and Associated Conifers	2 lbs 2,4,5-T (6 lbs per gal) (8 gals per acre)
10. Red Alder or Deerbrush Ceanothus	Southwest Oregon Coast Range	Douglas-fir	2 lbs 2,4-D (6 lbs per gal) No. 2 diesel oil (8 gals of spray per acre)

Table 2. (continued)

Brush Type	Region	Crop Trees	Herbicide Dosage
11. Ceanothus	Cascade Range (Mt. Hood Area)	Douglas-fir, Noble Fir & Hemlock	.5 lb 2,4-D and .5 lb 2,4,5-T (6 lbs per gal), water & .5 gal diesel oil (8 gals of spray per acre)
12. Willow & Cherry	Cascade Mountains (Gifford-Pinchot)	Douglas-fir	1 lb 2,4-D (6 lbs per gal) & .5 lb 2,4,5-T (6 lbs per gal) 1/3 gal diesel oil
13. Grasses	Willamette Valley, Coast Range (Other Region 6 Areas Having Spring Rain)	Douglas-fir	4 lbs Atrazine (5 lbs 80% wettable powder), water (10 gals of spray per acre)
14. Madrone & Chinkapin	Applegate Area	Douglas-fir	1-1/2 2,4-D (6 lbs/gal) & .5 lb 2,4,5-T (6 lbs/gal) 1 gal No. 2 diesel oil (6-7 gal water)

Data sources: Classification of Brush Types are from "Timber Stand Improvement Handbook" (Feb. 1968, R-6 Amendment No. 9).

not fully understood. Many experiments with many different chemicals have been conducted and from these experiments knowledge has been gained as to what chemical should be used for certain plant species. However, even without brush control, forests can be established, but it may take a long time to establish them through the natural competitive process. This also lowers the unit forest land productivity in terms of resource utilization. Before the 1960's, herbicides were still in the experimental stage in forest brush control operations. Since 1960, as foresters derived more knowledge from experiments, forest managers have begun large-scale spraying on the National Forests, Bureau of Land Management forest, State Forests, and private forests. Now, thousands of acres are sprayed annually.

Objectives of the Study

Thousands of acres are sprayed each year and many experiments concerning chemical brush control are conducted, but the economic benefits are not often evaluated. So far, most of the experiments relate to the physiological and ecological aspects of chemical control. From these experiments, people began to learn that the function of spraying is to release the crop trees from brush competition, to aid in site preparation, and to obtain a better survival rate. But, evaluating the economic benefits is still a problem. This study will develop a method for evaluating the economic benefits.

The objectives of this study are:

1) To quantify the cost of chemical brush control on various

sites for different species, areas, chemicals and different capital and budget constraints.

2) To evaluate the profitability of chemical brush control investment under different combinations of site, stumpage prices and interest rates for Douglas-fir, ponderosa pine and western hemlock by utilizing internal rate of return and benefit-cost ratio.

Specification of the Objectives

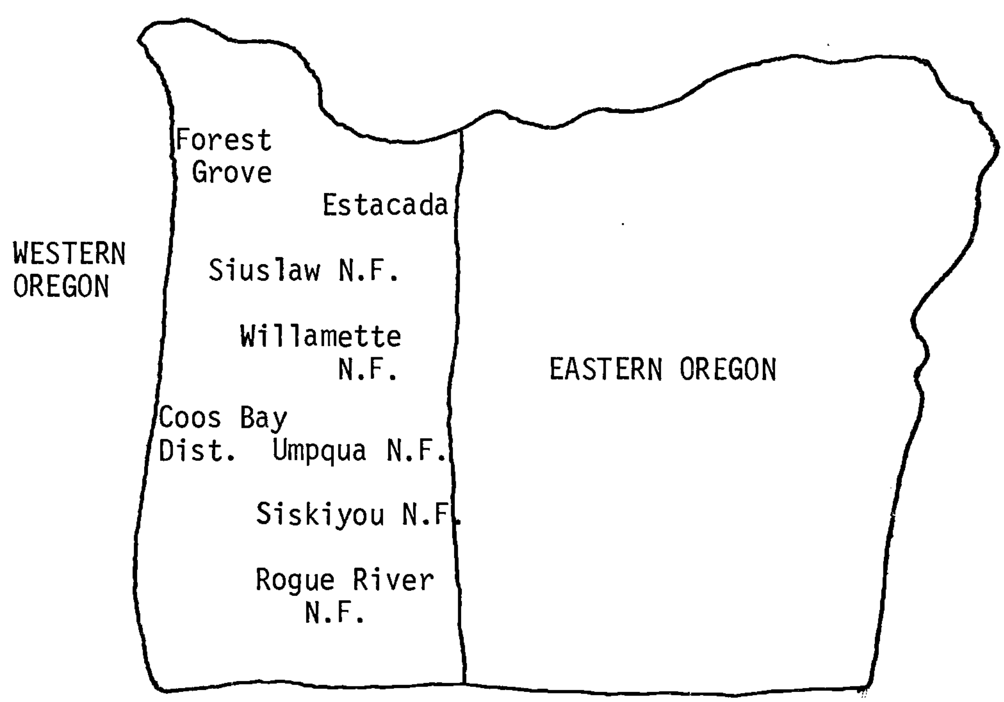
The productivities of forest lands vary by site and brush competition. In some areas, the productivity is so low that even the removal of brush with herbicides may not produce a net return. However, some areas produce a great economic benefit after removing the brush competition.

The first objective is to compare the cost of chemical brush control under different situations. The second objective is derived from the first one. Because money for forest management is limited, it should be spent wisely. Therefore the second objective is to develop criteria to help the forest manager choose those forest operations he should spend his budget on. There are an unlimited number of forest operations, such as pruning, thinning, and fertilizing, and chemical brush control is just one of them. In this study, internal rate of return and benefit-cost ratios are chosen as criteria for economic benefit evaluation. The results from the first objective are programmed into a computer and used to develop a guide for managers to justify their investments. This fulfilled the second objective.

II. AREA OF STUDY AND METHODOLOGY

Area of Study

The area of this study is confined to Western Oregon, defined as the area west of the summit of the Cascades. The crop tree species are Douglas-fir (Pseudotsuga menziesii), ponderosa pine (Pinus ponderosa), and western hemlock (Tsuga heterophylla) - the three most important economic species in Western Oregon. The data were collected from five National Forests, four Bureau of Land Management districts and one state forest. The National Forests included the Siuslaw, Willamette, Umpqua, Siskiyou and the Rogue River National Forests. The Bureau of Land Management districts included Eugene, Roseburg, Coos Bay, and Estacada. The State Forest in Forest Grove was also included. These areas cover the whole area of Western Oregon, as can be seen in the map below.



Two areas were chosen as representative of chemical brush control for Douglas-fir, the Siuslaw area and the Siskiyou area. The former one represents a high production area for Douglas-fir in Western Oregon, the latter one represents an arid, low production area. The distribution of western hemlock is mainly on the coast where a moist and foggy climate induces the western hemlock to grow rapidly. The coastal area in Lincoln County was chosen as a typical area for western hemlock in this study. Because of the availability of sufficient data, Josephine County was chosen as representative for ponderosa pine. This study focuses on these four areas, although data from other areas are included.

Methodology

In an economic analysis for an investment, the effects of general economic conditions are always involved. To evaluate the feasibility of an investment, one usually chooses certain economic criteria to evaluate the possible benefits under specified assumptions.

The assumptions made for this study are as follows:

1) Commercial production of timber is the only use for the forest land. Other benefits from forest land, such as recreation, watershed management, wildlife, etc., are not included in this research. This simplifies the problem and enables one to calculate the economic return from selling stumpage.
2) The brush competition is the only limiting factor for regeneration success. Some regeneration failures are caused

by lack of moisture, by animal damage, soil condition or other kinds of biological problems in addition to brush competition. These cases are not included in this study. In other words, this study deals only with brush problem areas.

3) If forest land is covered with brush, the probability of natural regeneration success to have fully stocked stands without chemical brush control is virtually zero. Present evidence indicates that artificial regeneration by any means when planting in brush problem areas without brush control is also doomed to fail. We further assume that planting under chemical brush control will attain full stocking. It may be necessary in some situations to repeat treatments but eventually full stocking will be realized. However, to be realistic crop trees have survived and overcome brush for thousands of years. Some crop trees eventually would grow through brush competition even without brush control, but it may take a long time to establish stands through this natural competitive process and the result would be an understocked forest. Under these circumstances, the production of wood fiber would be delayed and the amount produced per acre reduced increasing future supply costs. Therefore, most foresters will agree that the probability of success in natural regeneration and planting in brush problem areas without brush control is nearly zero. In any event, low stocking and lengthened

rotation are to be avoided if possible. Since herbicides have become a main tool to obtain satisfactory regeneration, this assumption enables us to calculate the entire return from regeneration as solely attributable to chemical brush control.

4) The ecological effects of herbicidal application are not considered. In other words, the change in the ecosystem, if any, due to the herbicidal spray is beyond the scope of this study.

5) The budget is a constraint in forest operation, and chemical control is included in the budget.

6) Economic conditions are assumed to be static from the planting to the final harvest. This enables us to apply the same stumpage prices and interest rates to the whole rotation length.

Under the above assumptions, the decision to use chemical brush control becomes a problem of decision-making under certainty because a) we face a static economic condition, b) we have a zero success probability of natural regeneration on brush competitive forest land and c) we assume that regeneration success will be certain, that is success with full stocking, if we have chemical brush control.

But assumption 3) may not hold all the time. Some foresters, especially those dealing with herbicidal spray, emphasize the importance of chemical brush control and say that the zero probability of natural regeneration without chemical brush control is essentially correct in brush problem areas. Others maintain that this assumption may be overstating the case for brush control. They argue that chemical control may result in partial stocking which needs interplanting to reach full stocking. It is also possible to have regeneration failure with chemical brush control. Therefore, the probability of success even with chemical brush control can be uncertain. But changes of the foregoing assumptions make analysis of chemical brush control a problem of decision-making under uncertainty. The techniques for making an economic analysis of brush control under uncertainty will be considered in a later section.

Methods of Analysis

Two types of decision-making problems exist in the application of chemical brush control; one is decision-making under certainty and the other is decision-making under uncertainty. Two economic criteria were chosen for analysis of the decision-making under certainty; that is, the internal rate of return and benefit-cost ratio. The details of calculation and the results of analysis are shown in chapters III and IV.

For the analysis of decision-making under uncertainty, the maximization of expected value is used as a criterion for evaluation. The degree of survival rate is considered as a state of nature. For this study three states of nature corresponding to three levels of stocking were chosen; that is, fully stocked (250 or more seedlings per acre), partially stocked (100 to 250 seedlings per acre) and needing interplanting to be fully stocked, and failure (under 100 seedlings per acre) and needing replanting. Chemical brush control or absence of chemical control is treated as two actions. The details and results are shown in chapter V.

III. DECISION-MAKING FOR CHEMICAL BRUSH CONTROL UNDER CERTAINTY

"Certainty" means that the probability of regeneration success with chemical brush control for a fully stocked stand is one. By assuming certainty we can calculate the return and cost, using economic criteria, and decide whether the investment in chemical brush control is worthwhile.

This chapter is devoted to the specification of internal rate of return and benefit-cost ratio which are derived from the gross return, fixed and variable costs under the assumptions mentioned earlier.

Returns from Forest Land Management

The return from forest land in this study is assumed to be solely from the sale of stumpage. The benefits derived from commercial thinning and other kinds of intensive management are not included. The hypothetical production curve under intensive management has a greater slope than the curve for extensive management. Many forest operations such as thinning, pruning, animal and brush control, etc., contribute to intensive management.

To avoid confusion, the yield for Douglas-fir in the Siuslaw area is assumed to approximate the volume shown in Bulletin 201, "The Yield of Douglas-fir in the Pacific Northwest". The production level for Douglas-fir in the Siskiyou area, according to forest managers contacted in the area is only 60 percent of the normal volumes in Bulletin 201, therefore this correction factor was applied in calculations for yield of Douglas-fir in the Siskiyou area. In the Siuslaw area, mainly in Benton County, site quality is generally classified from site I to site IV. For this study the site quality index chosen is 200 for site I, 170 for site II, 140 for site III and 110 for site IV.

The volume production for western hemlock was derived from Bulletin 1273, "Yield of Even-Aged Stands of Western Hemlock". The production for ponderosa pine used "Yield of Even-Aged Stands of Ponderosa Pine", Bulletin 630, as the standard.

The determination of site quality for species besides Douglas-fir is derived from comparable Douglas-fir stands. If there is no Douglas-fir present in the stands, then the market value of the standing volume is used as a criterion to determine the comparable site quality for Douglas-fir. Using these two rules to derive the comparable site, the site index for ponderosa pine is 90 for site III, 80 for site IV and 60 for site V. Site index for western hemlock is 200 for site I, 170 for site II, 140 for site III, and 110 for site IV (8).

If price projections for stumpage were available, then the stumpage return per acre would be easy to calculate. However, the time span used in forest management is longer than for most investments. In this study, for example, investment periods (rotations) varying from 40 to 120 years were used. Therefore, any stumpage price used in an analysis is subject to changes that may take place in the future, such as technological progress, inflation, and other economic relationships. According to the price index from 1910 to 1967, annual stumpage prices increased 6.6 percent for Douglas-fir and 5.6 percent for ponderosa pine (30). Western hemlock had little value prior to recognition of its high fiber quality, but in recent years, its value has increased greatly, because of its desirability for pulp and paper. Furthermore, demand from the Japanese market has pushed lumber and log prices upward. Based on these trends, the Department of Revenue, State of Oregon, has used projection prices of $70.00 to $80.00 per MBF for Douglas-fir in Benton County, $65.00 to $70.00 per MBF for western hemlock in Lincoln County, $40.00 to $50.00 per MBF for ponderosa pine in the Siskiyou area, and $55.00 to $60.00 per MBF for Douglas-fir in the Siskiyou area. In order to be a little conservative in estimation for the long-term projection and still consider the State Department of Revenue figures, the projection prices used in this study are:

Species	Area	$/MBF[1]
Douglas-fir	Siuslaw area (Benton County)	70 and 80
Douglas-fir	Siskiyou area (Josephine County)	55
Western hemlock	Coast area (Lincoln County)	65
Ponderosa pine	Siskiyou area (Josephine County)	40

1. Note: The stumpage prices used in this study were considered consistent with long run trends in 1972. Present prices are considerably higher but these are thought to be short run fluctuations. With recent inflationary trends, costs may also increase more rapidly than anticipated. The program in Appendices I and II, pages 90-92, enables one to recompute the benefit-cost ratio and internal rate of return for any cost and stumpage values.

The stumpage prices used also vary according to diameter class. Generally, the stumpage price increases as log diameter increases even if the end product is different, such as sawtimber or poles. In this way, the stumpage price per thousand board feet moves upward as the stand age increases because the diameter class distribution shifts upward. For species in some areas, stumpage prices are either not available by stand diameter classes or vary by a small amount, so researchers have often used the same stumpage price for different age classes. For my study, I used two standards for stumpage value. I used a floating stumpage price, which changes according to diameter class distribution, for Douglas-fir in the Siuslaw area, and a constant price for western hemlock, ponderosa pine and Douglas-fir in the Siskiyou area. According to a study of forest taxation in the State of Washington (25), stumpage prices increase at a rate of $2.28 per thousand board feet for each inch difference in average diameter. Stumpage prices for Douglas-fir in the Siuslaw area are calculated in the following way:

1) From the stand table in Bulletin 201, find the dominant diameter class for each rotation length from 40 to 120 years, and use this dominant diameter class as the representative diameter for that particular age class.
2) Assume $70 and $80 per M board feet for 31 inches breast height diameter class. Beyond 31 inches of DBH, the stumpage price remains the same.
3) Use stumpage price equals $70.00 - $2.28 (31 - DBH) or

stumpage price equals $80.00 - $2.28 (31 - DBH) as the formula to calculate the stumpage values for other diameter classes. The purpose of using two projection prices is to find the sensitivity of price change to the rate of return. The stumpage values for Douglas-fir, western hemlock and ponderosa pine are summarized in tables 3 to 6.

The Cost of Forest Regeneration

We assume that the only alternative for the utilization of forest land is producing timber. When one decides to reforest, many costs are incurred, and these become fixed costs because these costs must be incurred to restock an area. In a sense, even costs for fire protection, animal or insect control and taxes can be considered fixed once the decision is made to invest in growing trees. However, the cost of chemical brush control is one of the costs in forest regeneration, which can be varied. Therefore in this paper, since the goal is to find the return from chemical control of brush, this cost is separated from other kinds of costs. Thus fixed cost as used in this study is defined to include all regeneration costs except brush control. This classification of cost is arbitrary and only for the purpose of this analysis.

Fixed Costs

Fixed costs include expenditures for seedlings, planting labor, planting survey, administration, fire control and taxes. Cost data

Table 3. Gross return projection for Douglas-fir by age classes in the Siuslaw area in Benton County.

Harvest Age	Volume in MBF/Acre				Value in Dollars/Acre							
	Site I (200)	Site II (170)	Site III (140)	Site IV (110)	Site I		Site II		Site III		Site IV	
					$80/M	$70/M	$80/M	$70/M	$80/M	$70/M	$80/M	$70/M
40	24.4	11.9	4.5	.2	1061.9	817.9	490.8	371.8				
50	44.1	27.4	12.4	3.3	2120.3	1679.3	1192.5	918.5	511.4	387.4	128.6	95.6
60	62.0	42.8	23.8	8.1	3263.7	2643.7	1960.2	1532.2	1035.8	797.8	334.0	253.0
70	78.2	57.2	35.2	14.0	4473.0	3691.0	2880.6	2308.6	1612.2	1260.2	577.4	437.4
80	92.5	70.0	45.7	20.1	5923.7	4998.7	3684.8	2984.8	2093.1	1636.1	874.8	673.8
90	104.8	81.0	55.0	26.0	7189.3	6141.3	4448.5	3638.5	2644.4	2094.4	1131.5	871.5
100	115.1	90.4	62.8	31.4	8158.3	7007.3	5377.0	4473.0	3161.6	2534.6	1438.1	1124.1
110	123.7	98.3	69.4	36.3	9331.9	8094.9	6071.0	5088.0	3653.2	2959.2	1662.5	1299.5
120	131.1	105.1	75.0	40.7	10488.0	9177.0	6730.6	5379.6	4119.0	3369.0	1956.9	1549.9

Note: 1) Prices derived from stumpage price equals $70.00 - $2.28 (31 - DBH), or $80.00 - $2.28 (31- DBH).
2) Volume derived from Bulletin 201 (10).

Table 4. Gross return projection for western hemlock by age classes in Lincoln County.

Harvest Age	Volume in MBF/Acre				Value in Dollars/Acre			
	Site I (200)	Site II (170)	Site III (140)	Site IV (110)	Site I $65/M	Site II $65/M	Site III $65/M	Site IV $65/M
40	27	18	-	-	1755	1170	-	-
50	72	54	35	17	4680	3510	2275	1105
60	100	79	58	32	6500	5135	3770	2080
70	118	95	72	47	7670	6175	4680	3055
80	132	108	82	57	8580	7020	5330	3705
90	143	118	92	65	9295	7670	5980	4225
100	152	127	99	72	9880	8255	6435	4680
110	160	133	106	77	10400	8645	6890	5005
120	168	140	111	82	10920	9100	7215	5330

Note: 1) Volume is derived from "Yield of Even-Aged Stands of Western Hemlock", Technical Bulletin No. 1273, USDA, 1962 (1).
2) Stumpage price $65.00 per M for all DBH classes.

Table 5. Gross return projection by age classes for Douglas-fir in Siskiyou area.

Harvest Age	Volume in MBF/Acre Site III (140)	Site IV (110)	Site V (90)	Value in Dollars/Acre Site III $55/M	Site IV $55/M	Site V $55/M
60	14.3	4.9	2.1	785.4	267.3	85.8
70	21.1	8.4	4.4	1161.6	462.0	174.9
80	27.4	12.1	7.1	1508.1	663.3	283.8
90	33.0	15.6	9.9	1815.0	858.0	396.0
100	37.7	18.8	12.7	2072.4	1036.2	508.2
110	41.6	21.8	15.6	2290.2	1197.9	623.7
120	45.0	24.4	18.0	2475.0	1343.1	719.4

Note: 1) Volume calculated from 60 percent of Douglas-fir volume in Bulletin 201 (10).
2) Stumpage price of $55.00 per M board feet used for all DBH classes.

Table 6. Gross return for ponderosa pine in Siskiyou area.

Harvest Age	Volume in MBF/Acre Site III (90)	Site IV (80)	Site V (60)	Value in Dollars/Acre Site III $40/M	Site IV $40/M	Site V $40/M
60	9.1	5.1	.6	364	204	24
70	13.8	8.5	1.8	552	340	72
80	18.5	12.2	3.5	740	488	140
90	23.0	16.0	5.5	920	640	220
100	27.2	19.7	7.8	1088	788	312
110	31.1	23.1	10.2	1244	924	408
120	34.7	26.2	12.5	1388	1048	500

Note: 1) Volume derived from "Yield of Even-Aged Stands of Ponderosa Pine", Technical Bulletin No. 630, USDA (12).
2) Stumpage price is $40.00 per M for all DBH classes.

for seedlings, planting control, administration and planting survey were collected directly from the forest agencies. They are summarized in table 7. Costs for taxes are calculated from tax rates supplied by the State Department of Revenue.

Taxation of forest land can be a considerable cost in forest management. In western Oregon, there are several ways to calculate it. The most common tax laws used for commercial forests in western Oregon are the general property tax (ad valorem) and the yield tax. Because site quality is an important variable in this study, the general property tax is used. This tax law, called the Western Oregon Ad Valorem Timber Tax, assigns true cash values among the site classes of forest lands lying west of the summit of the Cascades.

Forest property taxes are calculated from the true cash value of forest land and its standing timber. These true cash values are determined by the State of Oregon's Department of Revenue.

There is no true cash value for timber until the trees reach a merchantable age class, which differs by species and by site qualities. The trees are not taxed during this period to encourage regeneration. After the trees reach merchantability, 30 percent of the immediate harvest value (the true cash value) of the standing timber becomes taxable if it is not harvested. For the year in which timber is harvested, the timber is taxed at 100 percent of the immediate harvest value. Table 8 shows the estimated age by site class when timber is first classed as merchantable by the Department of Revenue and assigned a true cash value, shown in Table 9.

Forest lands are taxed separately each year. Assessed values vary according to the area and site quality. Table 10 shows the true cash value of forest land in 1971 in the regions chosen for study. Annual forest property taxes are derived by multiplying the tax rate times the true cash value of forest land and standing timber plus any additional property taxes due for harvested timber.

In addition to forest property taxes, there is a tax for forest fire protection. It is 20 cents per acre per year. This is listed in the analysis (Table 7) as a fixed cost. Tax costs are calculated for each year and fed into the computer program directly for the calculation.

There is a cost for managing forest land. Forest managers estimate that the cost to manage an acre of forest land is about one dollar per year. This amount was added directly into the computer program and is not shown in the cost Table 7.

Variable Costs

As noted in the last section, variable costs include all of the costs directly attributable to chemical brush control; that is, costs incurred in chemical site preparation and release sprays. It includes the cost of the site priority survey, the preparation of the work project and the contract, and costs for flying, chemicals and field checking after spraying.

Table 7. Costs used in the economic feasibility analysis for some tree species in Western Oregon, 1971.

Cost Items	Douglas-fir & Ponderosa Pine in Siskiyou Area	Douglas-fir in the Siuslaw Area	Western Hemlock in Lincoln County
	(Dollars/Acre)	(Dollars/Acre)	(Dollars/Acre)
Fixed Costs			
Seedlings	$ 11.25	$ 10.80	
Planting Contracts	28.00	26.00	$ 30.00
Administration			
Regeneration	25.35	25.11	--
Other (Each Year)	1.00	1.00	1.00
Interplanting	41.66	40.08	20.00
Planting Survey			
1st Year	.85	1.47	.90
2nd Year	.90	1.47	.90
4th Year	.90	1.47	.90
Fire Protection (Each Year)	.20	.20	.20
Tax Rate	2.043%	2.07%	1.38%
Variable Costs			
Site Preparation			
Atrazine	$23.27	--	--
Other Chemicals	14.80	11.96	11.96
Release Spray	14.80	11.96	11.96

Date source: Collected from the U. S. Forest Service or from District Offices of the Bureau of Land Management.

Table 8. Age when stands are first considered merchantable for forest property taxation.

Area & Timber Class	Site Quality		
	Site II & Better	Site III	Site IV
Lincoln Coast Area & Siuslaw Area			
Douglas-fir			
Young Growth "D"	31 yrs	37 yrs	47 yrs
Young Growth "C"	45	50	60
Young Growth "B"	60	65	75
Young Growth "A"	75	80	95
Western Hemlock			
Young Growth "C"	30	37	45
Young Growth "B"	48	55	64
Young Growth "A"	65	70	80
Old Growth	90	95	100
Siskiyou Area	Site III	Site IV	Site V
Douglas-fir			
Young Growth "C"	40 yrs	50 yrs	60 yrs
Young Growth "B"	60	70	85
Young Growth "A"	80	90	110
Ponderosa Pine			
Bull Pine	42	47	52
Young Mature	90	90	90

Note: This table is derived from data used by the Tax Commission, Department of Revenue, Oregon, 1972.

Table 9. Immediate harvest value and true cash value for 1971.

Area & Species	True Cash Value* ($/M)	Immediate Harvest Value ($/M)
Siuslaw & Lincoln Coast Area		
Douglas-fir		
Young Growth "D"	12.0	40
Young Growth "C"	14.4	48
Young Growth "B"	17.4	58
Young Growth "A"	19.2	64
Western Hemlock		
Young Growth "C"	7.8	26
Young Growth "B"	10.5	35
Young Growth "A"	12.0	40
Siskiyou Area		
Douglas-fir		
Young Growth "C"	7.5	25
Young Growth "B"	10.5	35
Young Growth "A"	13.5	45
Ponderosa Pine		
Young Growth	2.7	9
Young Mature	5.4	18

*True Cash Value = 30% of Immediate Harvest Value

Note: This table is derived from data used by the Tax Commission, Department of Revenue, Oregon, 1972.

Table 10. True cash values of forest lands.

Area	Site Quality	True Cash Value Per Acre Dollars
Benton County*	Site I	67
	Site II	52
	Site III	40
	Site IV	22
Lincoln County*	Site I	58
	Site II	45
	Site III	38
	Site IV	31
Josephine County	Site III	28
	Site IV	21
	Site V	16

* For Benton and Lincoln County, these site qualities are equivalent to the land class from assessment office.

Data source: County Assessor's Office, Property Tax Division.

Site Priority Survey

The site priority survey takes place in the fall, in preparation for chemical spraying in the spring. This is used to find the degree of brush competition on cutover areas. The brush competition may be critical in one area and it may be less so in another area. Field surveys are used to find the size of the critical areas and to determine brush species to be eliminated. Both of these factors are used to identify the brush problem. The costs vary from $.20 to $1.00 per acre depending upon the size of the areas and the chemicals used.

Preparation of Work Project and Contract

After identifying the brush species, and location and size of critical brush areas, preparation of the work project and the contract begins. This work includes signing the contract and making preparation for the spraying. The cost for this preparation, ending finally in the call for bids and awarding a contract, varies with the size of the area and its location. The range is from $.25 to $1.00 per acre.

Contract Cost

Contract costs vary from owner to owner, and from contractor to contractor. The contract may include flying cost only, or it may also include chemicals if the contractors supply the chemical.

Several factors contribute to the variation of the per acre flying charge. The size of the spray area and its distribution and the intensity of the spray have the most significant effect on cost. Other factors, such as the distance from home base, location of the heliport, water supply, and methods of spraying also affect the cost. The estimate of cost by an aerial spray contractor is primarily based on flying time. The cost of flying is charged on an hourly basis. Factors which increase flying time likewise increase the per acre spray cost.

In this study, the charge per hour of flying time was approximately two hundred dollars. On the average, a spray plane could carry and spray 1000 gallons of herbicide in an hour, which would cover 100 acres at a spray rate of 10 gallons per acre. The spraying cost would thus average about two dollars per acre. However, this cost will vary depending upon the factors mentioned above. Since these figures are based primarily on data from federal agencies, they relate primarily to large spray areas.

Chemical Cost

There are many kinds of chemicals and chemical combinations used as herbicides in brush control. Some are still in the experimental stage, and some are used in special cases. The most reliable and common chemicals foresters use are Atrazine, 2,4-D and 2,4,5-T. Atrazine is mainly for grass control, and 2,4-D and 2,4,5-T are for the control of shrubs and undesirable tree species. Water, diesel oil and other kinds of surfactants are usually necessary. The dosage varies from region to region because of the different species of crop tree and brush.

Due to the price difference between Atrazine and other chemicals such as 2,4-D and 2,4,5-T, the chemical costs are separated by Atrazine, coded as A, and other chemicals, coded as B, and their combination, coded as A + B. If the problem is grass competition, then Atrazine is the only chemical applied. If the problem is caused by some undesirable brush species, then 2,4-D and/or 2,4,5-T are applied. If both grass and grass and undesirable brush species are the problem, then a combination of Atrazine and 2,4-D and 2,4,5-T are used. It may take only one spraying to establish the stand if the brush problem is slight, but if brush competition is severe, it may take two or more sprayings in order to obtain satisfactory control. For one spray the chemical cost ranges from about two dollars per acre for 2,4-D and 2,4,5-T, to twenty-three dollars for Atrazine, or fifteen dollars for a combination of both.

Cost of the Spray Evaluation

In the fall following spraying, a field survey is usually made to check the results. Sometimes, water samples are taken from nearby streams for analysis. The cost for these operations was estimated at ten cents per acre.

Variable costs, except chemicals, are the same for site preparation or release sprays. In other words, brush control costs per acre for site preparation are the same as the release costs in one area if the same chemicals are applied. All items of variable costs are listed in Table 7. In the Siskiyou area using Atrazine for grass control costs $23.27 per acre, and 2,4-D and 2,4,5-T costs $14.80 per acre. In the Siuslaw area, no Atrazine has been applied because grass is not a problem in this region (Table 12). Common herbicides applied in this area are 2,4-D and 2,4,5-T; one spraying of these chemicals costs $11.96 per acre, either for site preparation or for release spray.

Spray Patterns and Treatments

The timing for spraying each kind of chemical affects costs and is important for establishment and release of seedlings. The variable costs in the last section listed the spray cost, either for site preparation or for release control, but did not indicate the sequence or timing of the spray operation. It is necessary to know when spraying must be done because the benefit-cost ratio and internal rate of return are affected by the timing of the variable costs.

As noted previously, brush types and species of crop trees are the main factors affecting the selection of herbicides. They are also important factors determining the amount and frequency of spray used. For this study spray types are separated into three categories - one is the spray of Atrazine, used for grass control; a second is the spray of chemicals other than Atrazine, such as 2,4-D and 2,4,5-T for brush species and a third consists of the combinations used for the control of competing species other than grass. Sometimes, there are areas which have both grass and brush problems. A combination of

Atrazine and other chemicals is required for the control of these areas.

This classification is arbitrary, it is based on the species competing with the seedlings and the resulting cost differences. Grass problems occur during site preparation and during the first three years after planting when the seedlings are small and weak. After the third year, when seedlings are well established, grass is no longer a serious problem. So, grass control, that is spraying with Atrazine, is done only during site preparation and for the first release spray. But other brush species can be a problem from the beginning and may last up to five years, sometimes even longer.

Frequency of spray depends on the intensity of the brush problem. Seedlings and weather conditions contribute their effects, too. Healthy seedlings and favorable weather during and after planting result in a better survival rate. The survival rate is improved, because the seedlings grow faster and compete better with brush. Therefore, fewer applications of spray are needed in order to obtain full stocking. The density of brush growth is the main criteria in deciding the number of times it is necessary to spray. Light brush problem areas need only one chemical application for site preparation. If sufficient seedlings are established, some areas need only one release spray. Still other areas need two or three release sprays in addition to the spray for site preparation.

In the Siskiyou area, there may be three times when regeneration areas are sprayed. These are the:

1) Site preparation spray.

2) Site preparation spray plus one release spray.

3) Site preparation spray plus two release sprays.

Combining the timing of these three chemical applications and the types of chemicals applied, we can generalize the possible combinations into six treatments (Table 11).

Table 11. Combination and timing of chemical treatment and their corresponding costs in the Siskiyou area, 1971.

Timing & Costs	Douglas-fir and Ponderosa Pine			Costs (Dollars per Acre)		
Treatments	1st yr	3rd yr	5th yr	1st yr	3rd yr	5th yr
1	A			23.27		
2	B			14.80		
3	A	A		23.27	23.27	
4	B	B		14.80	14.80	
5	B	B	B	14.80	14.80	14.80
6	A+B	B		28.75	14.80	

Note: The letters indicate the chemical used:
"A" is Atrazine.
"B" represents either 2,4-D or 2,4,5-T or a combination of the two.
"A+B" means a combination of the two classes of chemicals.

Data source: Collected from the Siskiyou National Forest.

In the Siuslaw area there is no grass problem, so Atrazine has not been applied. The chemicals applied in this area are mainly 2,4-D and 2,4,5-T. There are three instances where spray is used. One is for site preparation, the other two are for one release spray or two release sprays. The spray pattern and its corresponding costs are presented in Table 12.

Table 12. Combination and timing of chemical treatment and their corresponding costs in the Siuslaw area.

Timing & Costs / Treatments	Douglas-fir 1st yr	Douglas-fir 3rd yr	Douglas-fir 5th yr	Costs (Dollars per Acre) 1st yr	Costs (Dollars per Acre) 3rd yr	Costs (Dollars per Acre) 5th yr
1	B			11.96		
2	B	B		11.96	11.96	
3	B	B	B	11.96	11.96	11.96

Note: "B" code is for either 2,4-D or 2,4,5-T or their combinations.
Date source: Collected from the Siuslaw National Forest.

Western hemlock in the coastal area in Lincoln County has little or no grass competition. The timing of brush control is like that for Douglas-fir in the Siuslaw area. The same three treatments and corresponding costs are also applied to western hemlock.

The treatments used here are not considered alternatives for each other; each treatment is determined by the physical and biological condition of the site. One treatment may be sufficient for one site but inadequate for another. Therefore the decision-maker cannot substitute treatment one for treatment two, because the competing vegetation is different. For example, treatment one in the Siskiyou area is for grass control, but treatment two is for other vegetation. Substitution of treatments on the basis of costs is not biologically feasible since the chemicals used are specifically designed to kill certain species of competing vegetation. Similarly, treatment four cannot substitute for treatment two because some areas need one release spray in addition to chemical site preparation before the land manager can obtain satisfactory regeneration.

Formulation of Analysis

Based on these assumptions and the evaluating criteria, we can choose the method of calculating the economic feasibility of chemical brush control. Because of the budget constraint assumptions, one should know the dollar-return-per-dollar-invested before one can make the decision to invest in forest operations. The purpose of this section is to present the methods used to find the dollar-return-per-dollar-invested in chemical brush control.

In order to systematize the data for computer calculation, I handled the data on a yearly basis. Fixed costs, variable costs and gross returns are calculated for each year. All the items included in each of these three groups are summed separately. In the first year, for example, the planting cost, land taxes, fire control cost and administration cost are combined together as fixed cost. If there are no costs in one group for a particular year, then this is recorded as zero. In this way we have the data input from planting time to harvesting the whole rotation period. The rotation lengths range from 40 to 120 years in ten-year intervals, and the results of analysis are presented for each rotation length. One can thus observe the variation in return from rotations of 40 to 120 years.

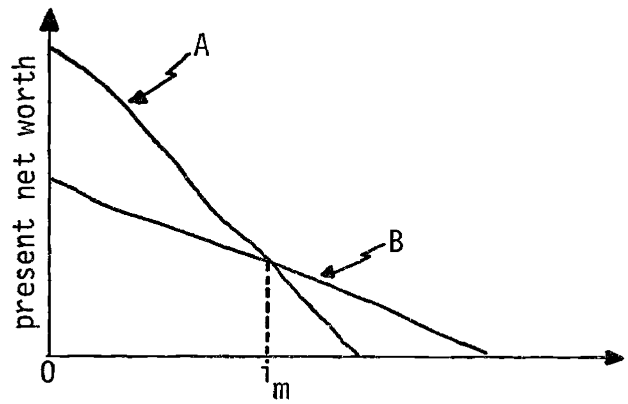
Choosing an evaluation method to determine the relationship between benefits and costs in an economic analysis of an investment is usually a debatable problem. A vast literature exists in the field of capital theory relating to investment criteria, such as Henry H. Webster in his "Profit Criteria and Timber Management" (pp. 260, Journal of Forestry, 1965), Dennis E. Teeguarden and Joseph Buongiorno in their "An Economic Model for Selecting Douglas-fir Reforestation Projects" (Hilgardia, July 1973), Teegarden in his "Economic Guides for Douglas-fir Reforestation in Southwestern Oregon" (18), and Robert Marty and John Fedkiw in their "A Guide for Evaluating Reforestation and Stand Improvement Projects" (Agriculture Handbook No. 304). However, no consensus has been reached establishing a theoretically perfect criterion, though most authors seem to agree that the proper goal in making investment decisions is present net worth maximization.

The benefit-cost ratio is an evaluating method using the criterion of present net worth maximization in ranking the priority of investments. We calculate the ratio of the present net worth of each project to the input of that resource and rank the project according to that ratio until the resource is exhausted. Using this method for evaluating a project, the initial cost is an important factor. The initial cost of the project and the interest rate related to this initial cost are vital factors for determining the ratio. This evaluating method favors the project with 1) a low initial cost, 2) a short return period and 3) a low interest rate. A project with an early return is preferable to one with a late return given the same interest rate and initial cost. A project with a high initial cost and a high discounted rate usually has a low ranking among investment alternatives.

The internal rate of return is another method commonly used in ranking investments. The higher the internal rate of return a project has, the higher its investment priority will be. An investor uses it not because it is intrinsically better than other measures but because it is a widely understood and accepted measure of an investment's economic desirability. It measures the rate at which an investment grows toward the return it eventually generates, and takes into account the amount and timing of both costs and returns. It does not emphasize its initial cost and the discount rate used as the benefit-cost ratio does.

Before using the internal rate of return in ranking a project, we should be aware of its limitations. The sensitivity of the internal rate of return, used as a measure of economic desirability, decreases as the investment period lengthens. It requires only 10 percent increase in returns, or decrease in costs, to cause a 1 percent increase in internal rate of return when the investment period is 10 years. But when the investment period is 50 years, it requires a 60-percent increase in the return-cost ratio to cause a 1-percent increase in internal rate of return. Since the rotation lengths used in this study are ranged from 40 to 120 years, the small difference in internal rate of returns for two treatments will have a great difference in their return. The internal rate of return also cannot handle the non-market costs and returns and has inability to treat the interaction among management activities.

Using these two methods may result in a different ranking of an investment's priority. The conflict may result from different periodic income flows, or from resource constraints other than the budget. For two mutually exclusive projects with different income flows (such as the following diagram: Project A with late income flow and Project B with early income flow), there is an interest rate (i_m in the diagram) which makes the benefit-cost ratios (or present net worths) of these two projects equal. The ranking of priority for projects is the same by either the internal rate of return of the benefit-cost ratio if the given interest rate for calculating benefit-cost ratio is greater than the rate i_m, that is the right side of i_m. In other words, under high interest rates, the two methods tend to give projects the same ranking of priority and under low interest rates, ranking may be inconsistent when the two methods are used, that is the left side of i_m in the diagram.



The rationale for presenting results for both methods is not for comparison of ranking projects but rather to give an analyst a choice, depending upon his preference. The internal rate of return is a widely understood and accepted measure of an investment's economic desirability but has its related deficiencies. Benefit-cost ratio is more consistent in ranking projects but may be hard to apply to the comparison of projects with different budget sizes because it considers the initial cost. Some projects have their economic sizes. A project with its particular budget and economic size cannot have the same benefit-cost ratio if we reduce its share of budget. In this way, there is a problem in the distribution of limited budget by using benefit-cost ratio for ranking priority when we deal with projects of different budget sizes. The choice between these two methods depends on the matove and objective of the individual forest manager. The application and calculation of these two evaluating methods are specified in the following sections:

Internal Rate of Return

Internal rate of return is a method for evaluating an investment. By this method, one finds a rate of interest that will make the present value of the cash proceeds, expected from an investment, equal to the present value of the cash outlays required by the investment (2). Internal rate of return is derived from the present-value concept but seeks to avoid the arbitrary choice of a rate of interest in evaluating an investment proposal. When we present a proposal for chemical brush control to a forest manager, we are often asked the question, "What return can I expect from the amount of money that I spend?" He is a decision-maker faced with budget constraints. He should know the return for each alternative before he can manage a tight budget and invest it wisely. Internal rate of return may be the best means for comparing alternative investments with an investment in brush control. The formula used for calculation is as follows:

$$\frac{P_n Q_n}{(1+I)^n} - \sum_{j=1}^{n} \frac{F_j}{(1+I)^j} = \sum_{k=1,3,5} \frac{V_k}{(1+I)^k}$$

$$\text{or} \quad P_n Q_n - \sum_{j=1}^{n} F_j (1+I)^{n-j} = \sum_{k=1,3,5} V_k (1+I)^{n-k}$$

Where,

P_n : Stumpage price per MBF at rotation year n.

Q_n : Harvest volume per acre in M board feet.

F_j : Total fixed costs at year j.

V_k : Total variable costs at year k.

n : Rotation lengths, 40 to 120 years in ten-year intervals.

j : The year when fixed costs are incurred, ranging from 1 to 120 years.

k : The year when variable costs are incurred, that is, 1st, 3rd and 5th years.

$\bar{I}$: Internal rate of return.

In this equation, n, j and k are given. The planting year is the starting point for the rotation. F_j is the sum of all fixed cost at jth year; and V_k is the total variable cost at kth year. I is the internal rate of return to be calculated for this investment.

Benefit-Cost Ratio

If the forest manager asks, "What is the dollar-return-per-dollar-investment at a given interest rate?", then a benefit-cost ratio analysis is the best method to use. The benefit-cost ratio estimates the dollar value of benefits (present value) that each collar value of cost (present value) is expected to earn. It is derived by dividing the discounted net benefits, which is the difference between gross return and the fixed costs (by definition for this research) by the discounted "variable" costs.

The formula for benefit-cost ratio calculation is as follows:

$$B/C_i = \frac{P_n Q_n/(1+i)^n - \sum_{j=1}^{n} F_j/(1+i)^j}{\sum_{k=1,3,5} V_k/(1+i)^k}$$

$$\text{or} \quad B/C_i = \frac{P_nQ_n - \sum_{1}^{n} F_j(1+i)^{n-j}}{\sum_{k=1,3,5} V_k(1+i)^{n-k}}$$

Where,

B/C : Benefit-cost ratio.

i : Given interest rates (0.5 to 7.0 percent).

P_n, Q_n, F_j and V_k are defined as in the calculation for the internal rate of return.

The market interest rate reflects the market condition for alternative investments or borrowing and the private forest manager bases his investment judgement on these alternatives. Sources of capital vary; at times he can obtain money for forest investment from low interest government loans, at other times he may have to borrow at higher rates of interest from private sources. In this analysis, interest rates range from 3 percent, which was the general rate for government long term borrowing, to 7 percent, which was the common market rate at the time of the analysis, with the interval of 1 percent. Some special low interest rates, such as 0.5 percent to 2 percent with the interval of 0.5 percent, are used for forest lands with low productivity in order to find the economic range of interest rates needed if, in the future, these kinds of forest lands need to be reforested.

This research is mainly for the private forest owner. Although the public forest managers or decision-makers do not pay taxes (as this study assumes), they do share their stumpage returns with the counties. If public agencies are going to apply the results from this study, they should include the share of stumpage receipts to the county as a cost item just as the private owner pays taxes to the government, and then compute their own internal rate of return or benefit-cost ratio for comparison with other kinds of projects. However, they can use my results directly for the comparison among different chemical treatments.

Two computer programs are used in calculation (see Appendices I and II). One is for calculating the benefit-cost ratio, and the other for the internal rate of return. The results for each case are analyzed and explained in the next chapter.

IV. RESULTS OF THE ANALYSIS

Based on the assumptions, which were specified in Chapter II, and the treatments, which were derived from Tables 11 and 12, four separate representative cases were developed for the study. In each case, internal rates of return and benefit-cost ratios were developed for each treatment for different rotation lengths and site quality. The results from these analyses are offered as a guide for investment in chemical brush control.

Table 13. The maximum number of treatments required for selected case studies of regeneration in Western Oregon.

Case	Species	Area	No. of Treatments
1	Douglas-fir	Siuslaw area	3
2	Western hemlock	Coastal area & Lincoln County	3
3	Douglas-fir	Siskiyou area	6
4	Ponderosa pine	Siskiyou area	6

Note: Each case represents a combination of sites and treatments for each species.

Case 1 represents the high production area for Douglas-fir in Western Oregon. It includes the Siuslaw, Willamette, and Mount Hood National Forests and other parts of northwestern Oregon. Rainfall is plentiful and there is a heavy layer of green ground cover. The forest soil is productive. Both crop trees and brush grow rapidly but not at the same time in the same area because of competition.

The coastal area along northwest Oregon is typical area for western hemlock (case 2) because of its high rainfall and foggy climate.

Douglas-fir in the Siskiyou area (case 3) represents this species under low production conditions which applies to southwestern Oregon. Ponderosa pine (case 4) grows in a dry climate. Therefore the Siskiyou area is another ideal representation of this forest type in western Oregon. These four cases will give a fairly complete investment guide for the forest manager or decision-maker in western Oregon. The results of the analysis of these four cases will be offered and discussed in the following sections.

Case 1: Chemical Brush Control on Douglas-fir Stands in the Siuslaw Area

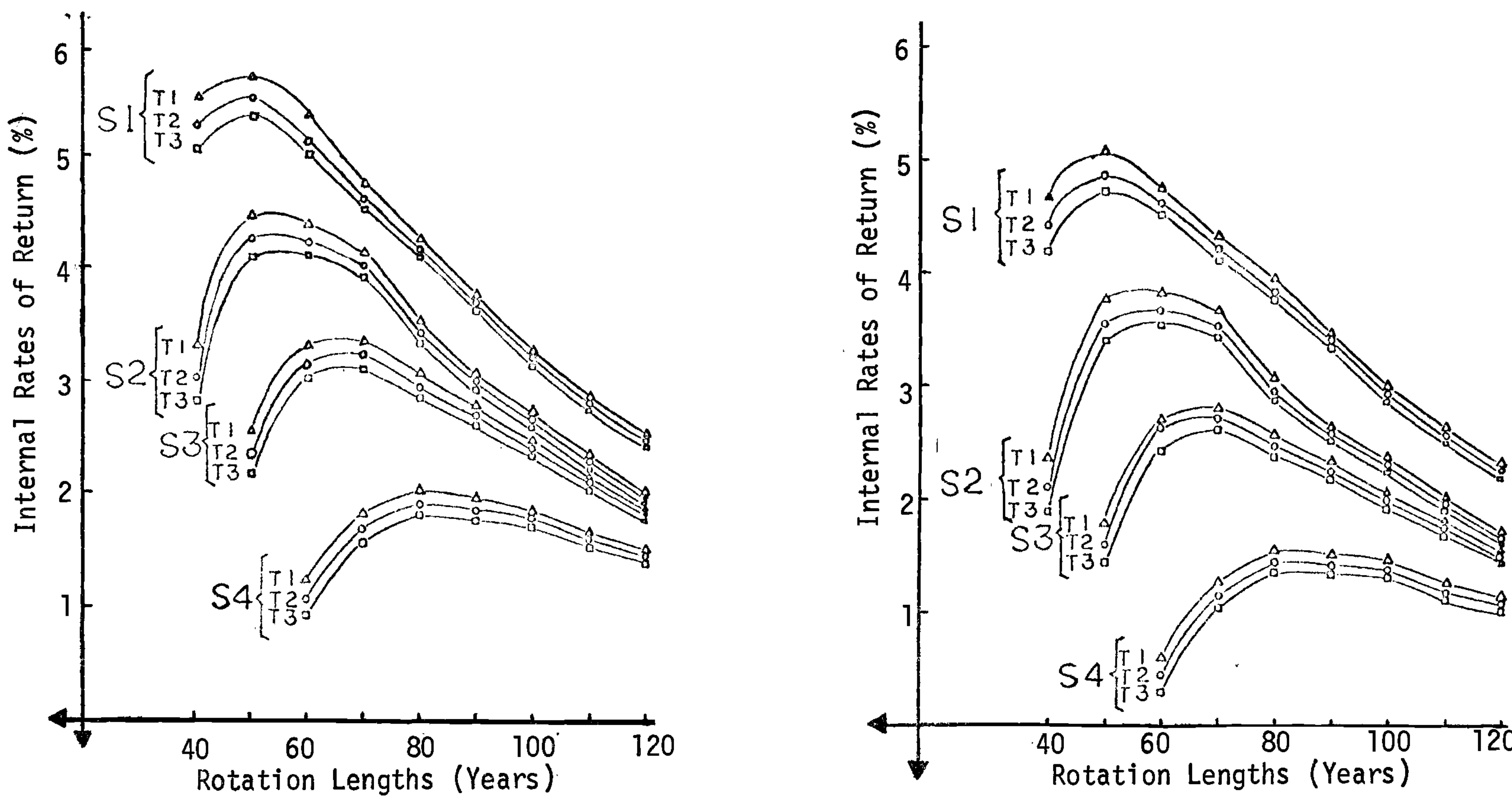
Douglas-fir in the Siuslaw, Willamette, Mount Hood National Forests and other parts of northwestern Oregon, represents the main portion of the forest production potential in Oregon and a significant portion nationally. Site quality varies from site 1 to site 4. The main brush species found in the area are alder, salmonberry, ceanothus and maple. Because of the large amount of rainfall and the highly productive soil, the brush grows rapidly and has caused large acreages of forest land to be unproductive, especially site 1 and site 2 lands.

Figures 1-a and 1-b show the internal rates of return for Douglas-fir in this area, derived from the assumptions and stumpage

Figure 1. Internal rates of return for different treatments and site qualities for Douglas-fir in the Siuslaw area, 1971.

a. Given P =$80.00 - $2.28 (31-DBH)

b. Given P = $70.00 - $2.28 (31-DBH)



prices and costs listed in Tables 3 and 7. Return varies with the treatment, stumpage price, rotation length and site quality.

The difference between internal rates of return among treatments in the same site class are very small. This means that the reduction of rate of return due to the cost of additional spray treatments is very small in the same site class.

Stumpage price has a great impact on the amount we can afford to invest for brush control. Figures 1-a and 1-b show the differences between two assumed stumpage prices. A higher stumpage price shows a higher rate of return at the same volume output. For treatment 1 in site 1, Figure 1-a, using a stumpage price of $80 per M board feet shows an internal rate of 5.7% for a rotation of 50 years, about .6% higher than the internal rate shown for a $70 stumpage in graph IV-1b. As stumpage price goes up, assuming costs rise at a slower pace, it is expected that more investments will be made in chemical brush control in order to bring forest land into full production. One question may be raised at this point, that is, "Who knows what the price will be after 50 years when the timber is harvested?" Generally the prospects of a higher stumpage price in the future is used to encourage more investment in timber production for the future.

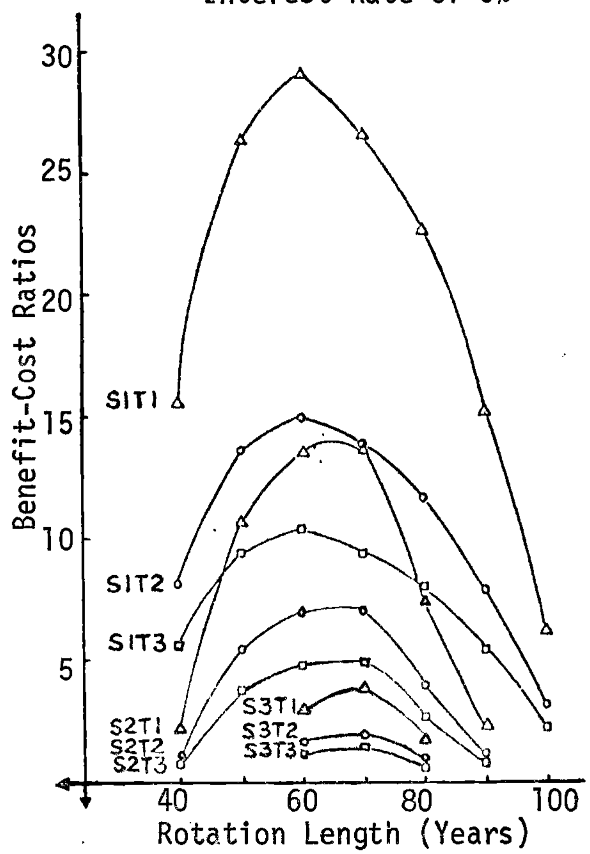
Site quality is the most influential factor to be considered before one invests in chemical brush control. Both graph IV-1a and -1b show the effect of site quality on the return from chemical brush control. The return for three spray treatments in site 1 is is higher than the return from one spray in site 2. Better site quality produces more volume and therefore indicates higher return on investment. Suppose the minimum return that can be accepted is 3%, site 4 will drop out of production because it is not economic to invest under our assumed stumpage prices. Site 3 in Figure 1-b will be eliminated, too. If the minimum return rate goes up, then site 2 in Figure 1-a will become uneconomic for production unless the stumpage price goes up.

The time factor plays an important role in terms of return on an investment, especially for long term investment. Thus, rotation length is an important factor for investment in forest production. The internal rates of return decrease after the culmination of mean annual increment, as the rotation length is extended. It is important to find out the maximum return for each site class for the rotation range of 40 to 120 years. The rotation length for maximum return is about 50 for site 1 and site 2, 70 years for site 3, and 80 years for site 4. The rotation as determined by internal rate of maximum return becomes longer as the site quality decreases. This is influenced by the natural productivity of forest land not by the difference in treatments.

Figures 2 and 3 show the results of the benefit-cost ratios. The most striking point in these results is the great effect of a given interest rate. Given a 3% interest rate, the ratio for treatment 1 is 29.1 for 60 years' rotation in Figure 2-a, but it is 12.0 when the interest rate is changed to 4% and other conditions remain

Figure 2. Benefit-cost ratios for different treatments and site qualities for Douglas-fir in the Siuslaw area.

a. Given P = $80.00 - $2.28 (31-DBH)
Interest Rate of 3%



b. Given P = $70.00 - $2.28 (31-DBH)
Interest Rate of 3%

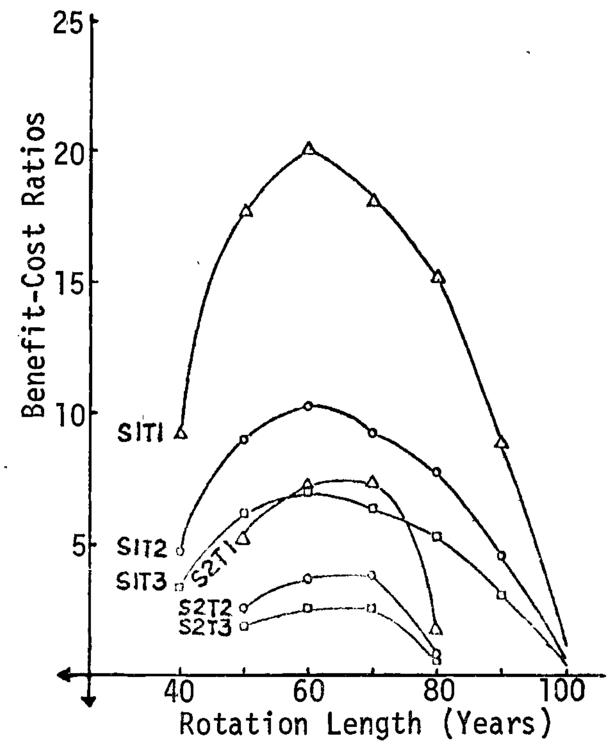
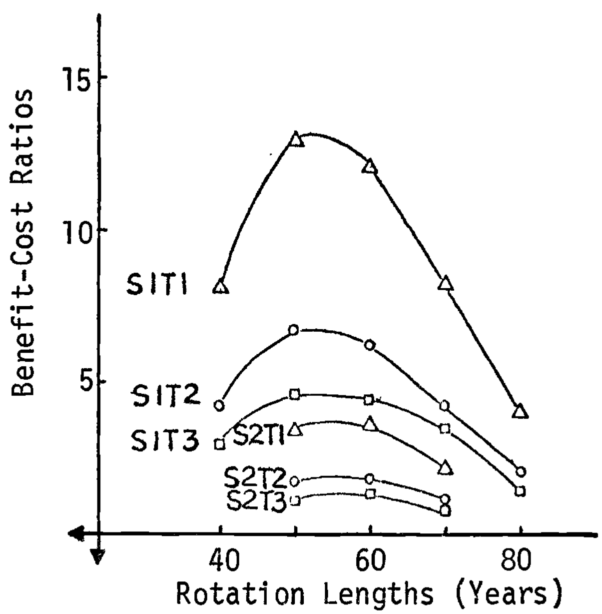
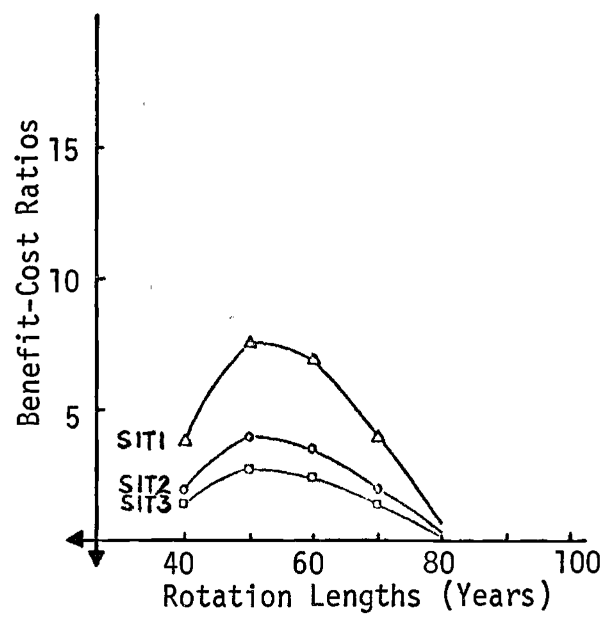


Figure 3. Benefit-cost ratios for different treatments and site qualities for Douglas-fir in the Siuslaw area.

a. Given P = \$80.00 - \$2.28 (31-DBH)
Interest Rate of 4%



b. Given P = \$70.00 - \$2.28 (31-DBH)
Interest Rate of 4%



the same. The benefit-cost ratio will reduce to 2.7 at 5% interest rate, and become uneconomic for investment if the interest rate is 6%. The result is similar to the internal rate of return. In order to put low site quality land into production, the interest rate must be low. If the interest rate is above 6%, it is not economical to produce any timber even on site class 1, unless stumpage prices and or volume production is higher than our assumption.

The effect of stumpage price on benefit-cost ratios is as great as its effect on internal rates of return. The comparison between graphs a and b in Figures 2 and 3 clearly illustrates this point. Site 3 is uneconomical to have in production under the low stumpage price assumption in Figure 2-b, however, Figure 2-a does show the production possibility under our high stumpage price assumption. If the stumpage price is given, one can tell how much to expect from brush control treatment.

The returns among three treatments have more distinction in benefit-cost ratios than in internal rates of return, especially in the high site classes. Based on the benefit-cost ratios, the return from one spray treatment on site 2 is better than the return from three sprays on site 1 considering the maximum return from one rotation.

The effect of time on the benefit-cost ratio is even more striking than on internal rate of return. The higher the given interest rate, the shorter the rotation length will be. When the given interest rate is low, the rotation length of maximum benefit-cost ratio is longer than when it is derived from the internal rate of return. But when the given interest rate is high, the rotation length of maximum return is shorter than those derived from internal rates of return. A comparison of maximum return rotation in Figures 1, 2 and 3 show these results: the rotation length of maximum return derived from internal rate of return remains the same because it has no relationship with the change in the given interest rate; the rotation length of maximum return derived from benefit-cost ratio becomes shorter as the given interest rate increases.

The maximum returns from each treatment, either from internal rate of return or benefit-cost ratios, are below the current market interest rate. The return for an investment should be higher than the market interest rate if it is to be profitable. The current market interest rate is above 7%. Using this as criteria for a profitable investment, then the investment of chemical brush control on Douglas-fir sites in the Siuslaw area cannot be justified at the stumpage prices and costs used. But these results are based on the assumptions we made. In Chapter VI,we will present a more detailed discussion of the results.

Case 2: Chemical Brush Control on Western Hemlock Stands on the Northwest Coast of Oregon and Lincoln County

Alder, salmonberry, ceanothus and maple are the main brush species in this area. Western hemlock is a shade tolerant species, flourishing in a foggy and moist climate. These characteristics make the establishment of regeneration quite different from Douglas-fir. The first year after planting, Douglas-fir has a better survival rate than western hemlock. But because western hemlock is shade tolerant, its survival rate after the first year remains almost unchanged, while the mortality rate for Douglas-fir increases. Therefore western hemlock requires less spray than Douglas-fir on the same area. The most common spray pattern for western hemlock on this area is T1 and T2, that is, one site preparation spray for regeneration, or with an additional release spray. Some areas need two release sprays (T3).

The internal rates of return of chemical brush control for western hemlock on the coastal area and Lincoln County are shown in Figure 4. The results are in terms of three treatments in four site classes with rotation lengths varying from 40 to 120 years.

The maximum returns for western hemlock are better than the returns for Douglas-fir in the Siuslaw area. On site 1, the rotation length of maximum return is 50 years with a return of 8.9% for one spray, 8.6% for two sprays and 8.4% for three sprays. On site 2, the rotation length of maximum return is 50 years, too, but the internal rates of return are lower, ranging from 7.7% for three sprays to 8.3% for one spray. The returns from site 3 and site 4 decrease but still remain above 5%. The maximum return rotation increases to 60 years for site 4.

The results of a benefit-cost ratio analysis, as shown in Figures 5 and 6, are very promising for chemical brush control

Figure 4. Internal rates of return for different treatments and site qualities for western hemlock on coastal area and Lincoln County, given stumpage price $65 per MBF.

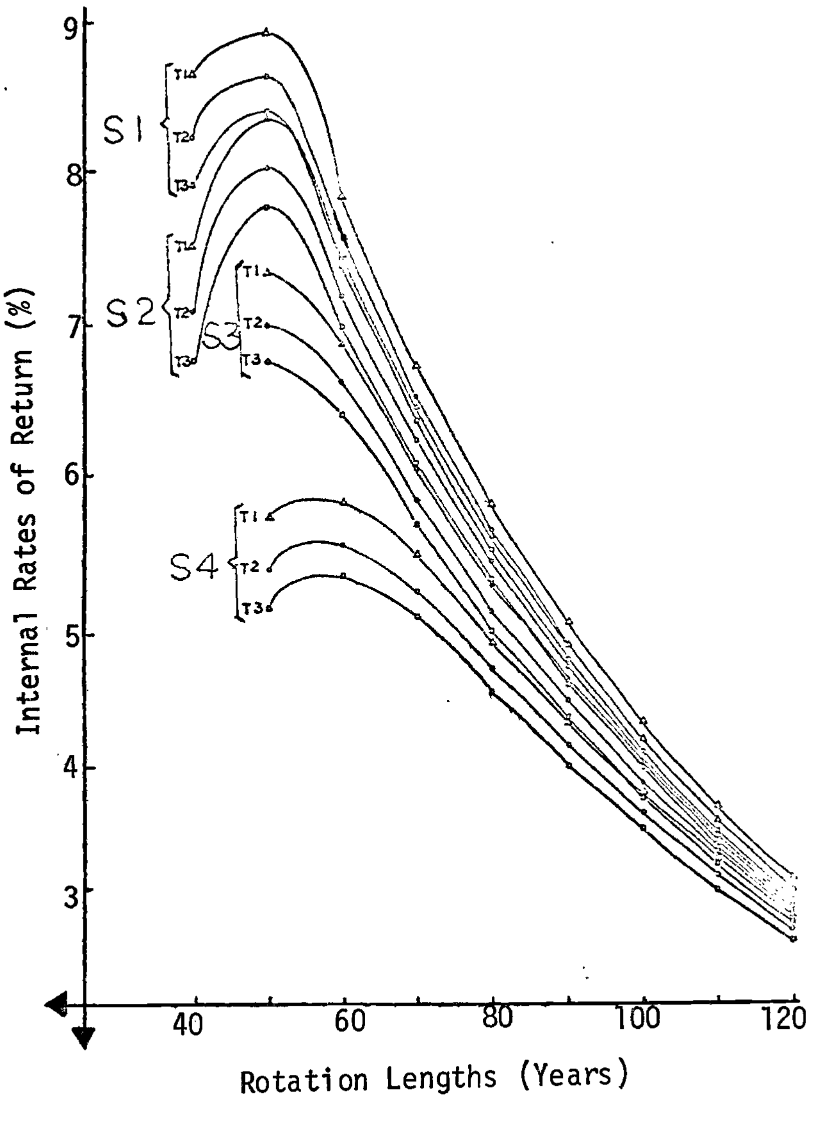


Figure 5. Benefit-cost ratios for different treatments and site qualities for western hemlock in coastal area and Lincoln County given stumpage price $65 per MBF.

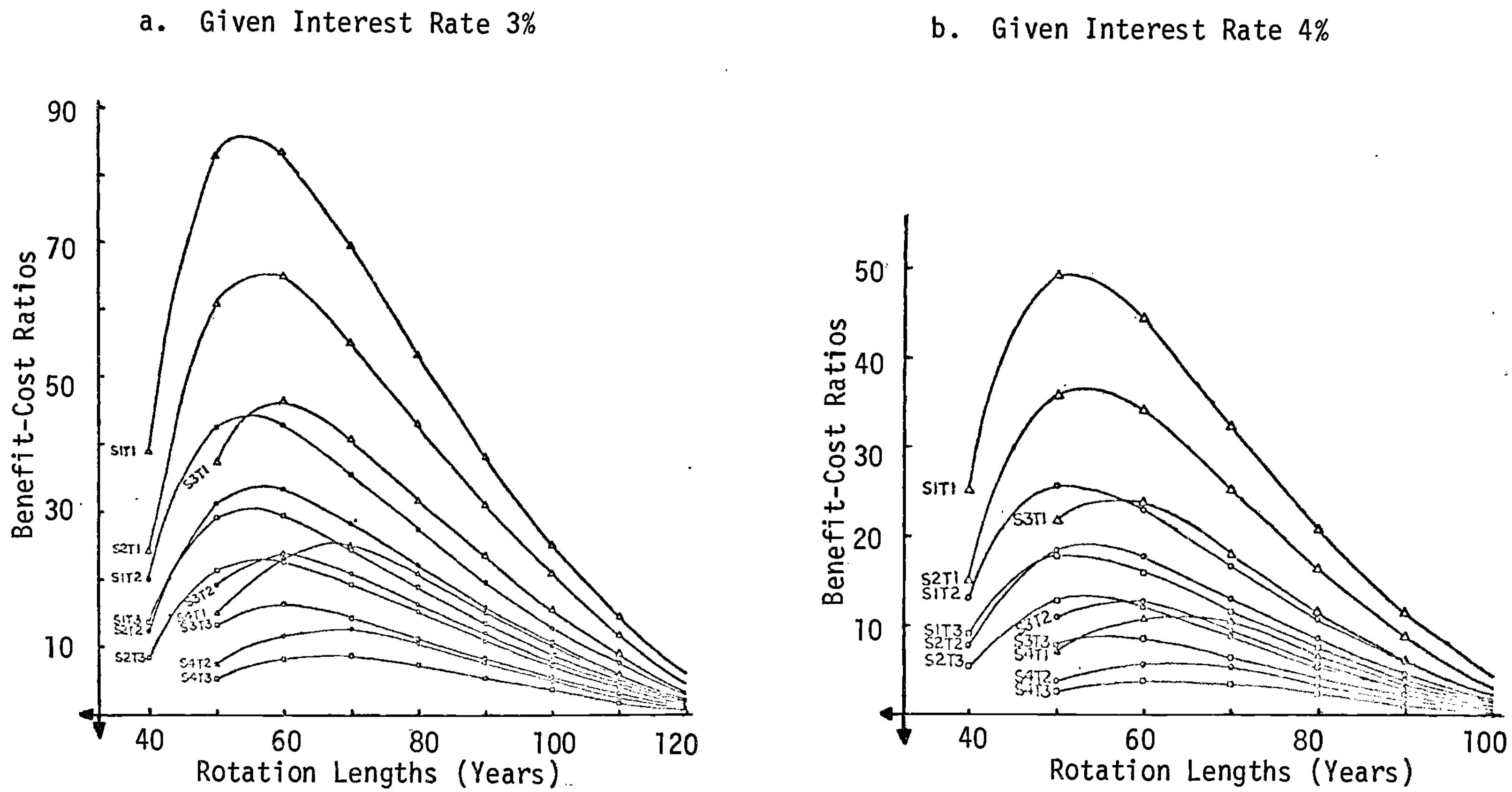
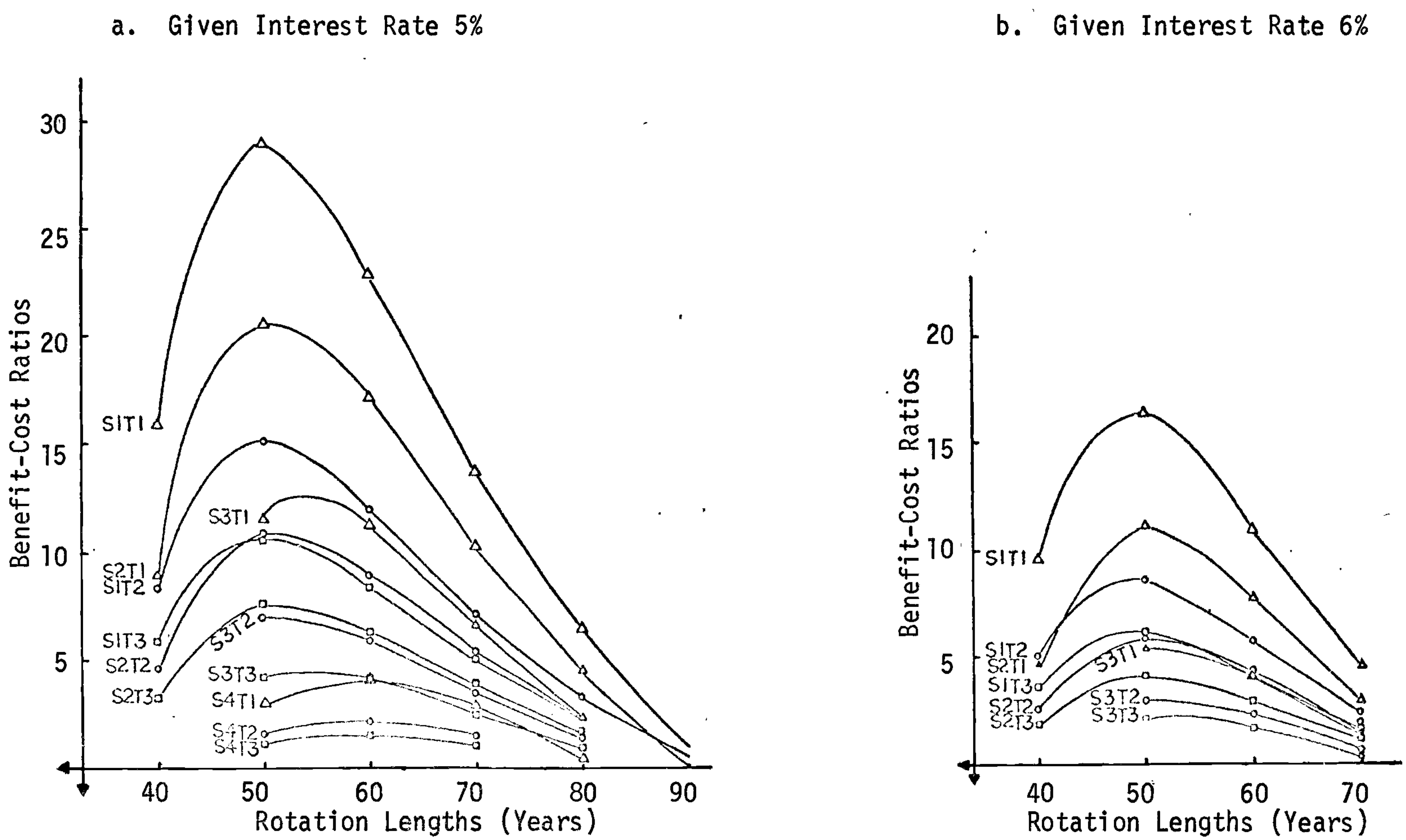


Figure 6. Benefit-cost ratios for different treatments and site qualities for western hemlock in coastal area and Lincoln County given stumpage price $65 per MBF.



investment in growing western hemlock. The Figures 5 and 6 show the results for interest rates varying from 3% to 6%. (The return for interest rate 7% is too low to show in the figure, though it was used in computer calculation.) For site 1, the rotation length of maximum return is somewhere between 50 and 60 years for given interest rates of 3 to 6%. The benefit-cost ratios range from 3.3 for treatment at 7% and 50 years rotation, to 83.1 for one treatment at 3% and 60 years rotation. The returns for the investment for site 1 are quite favorable. For site 2, the rotation length of maximum return remains between 50 and 60 years. The benefit-cost ratios for treatment 3 are 2.0 at 7% and 50 years rotation, and 64.7 for treatment 1 at 3% and 60 years rotation. The benefit-cost ratio show a very low return for site 3 and site 4 when the given interest rates are 6% and 7%. The rotation length of maximum return for the same interest rate becomes longer as the site quality decreases, but rotation length becomes shorter as the given interest rate increases.

The outlook for chemical brush control for hemlock, both from the standpoint of internal rate of return and benefit-cost ratio, look encouraging and is even better than the outlook for Douglas-fir in the Siuslaw area. There are several reasons for this.

1. The regeneration cost is lower. Thirty dollars per acre is required to regenerate hemlock whereas sixty-two dollars per acre is required for the regeneration of Douglas-fir in the Siuslaw area.

2. Western hemlock grows faster in terms of volume than Douglas-fir on the same site class. This is shown in Tables 3 and 4.

3. The assumed stumpage price is high and constant for all diameter classes. Before western hemlock was recognized for its excellent wood fiber, it was considered as an undesirable species. But stumpage price has increased steadily as forest products companies increased their demand for hemlock logs for pulp, for export and for manufacture into lumber. Many foresters and businessmen predict that the stumpage price for western hemlock will be equal to that of Douglas-fir in the long run as the demand for wood fiber increases. Using the assumption of constant stumpage price for all ages for western hemlock, rather than increasing stumpage price with age for Douglas-fir as in previous case, the price for western hemlock at 50 or 60 years rotation is higher than the price for Douglas-fir at the same age. This is another reason why the return for western hemlock is better than Douglas-fir.

Western hemlock is becoming more important. Judging from the higher return and the increased demand for wood fiber in the future, it is expected that more herbicides will be used in order to produce more western hemlock.

Case 3: Chemical Brush Control on Douglas-fir Stands in the Siskiyou Area

The areas covered in this case include central and southwestern Oregon, such as the Siskiyou, Umpqua, Roseburg and Rogue River areas. The Siskiyou area was used for the analysis. The main brush species in this area are tanoak, madrone, oak, ceanothus and grass. Some of these species grow well in the dry climate and can compete with the crop tree for the limited moisture. High mortality of planted seedlings is common in these areas. Characteristically, Douglas-fir in this area has a low production per acre resulting from the limited moisture and brush competition.

The regeneration cost per acre is very high in comparison with the Siuslaw area. It costs $63.60 per acre to regenerate Douglas-fir in the Siskiyou area (Table 7); a cost higher than for Douglas-fir in the Siuslaw area and western hemlock in the coastal area. Experience has shown that the production per acre for Douglas-fir in the Siskiyou area is only 60% of that listed in Bulletin 201 (10), which was used for the production of Douglas-fir in the Siuslaw area. This makes it even more difficult to justify the investment in chemical brush control in this area.

Figures 7 and 8 show the results of 6 treatments for sites 3 to 5. The internal rates of return are below 3.1%, even for site 3, the highest site in this area. A positive benefit-cost ratio can be shown with interest rates as low as 1% and 2%. Under our assumed stumpage price and collected cost data, no investment in chemical brush control (which implies no forest production) is justified unless there is a subsidy from government or a compensate benefit other than our assumed unique forest income - stumpage sale, or from the viewpoint of criteria besides market interest rate, such as allowable cut effect of regulated forests.

With such low return rates, the problem is not how much one wants

Figure 7. Internal rates of return for different treatments and site qualities for Douglas-fir in the Siskiyou area given stumpage price $55 per MBF.

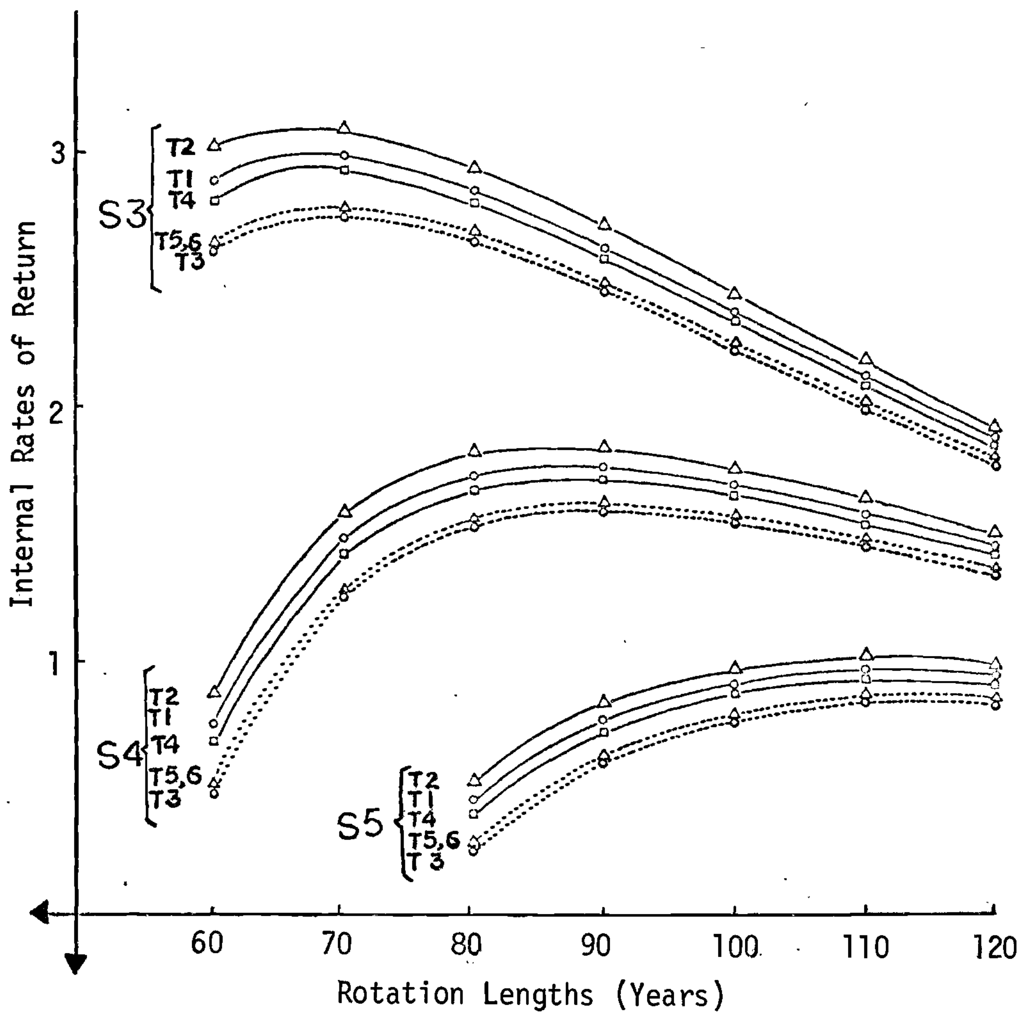
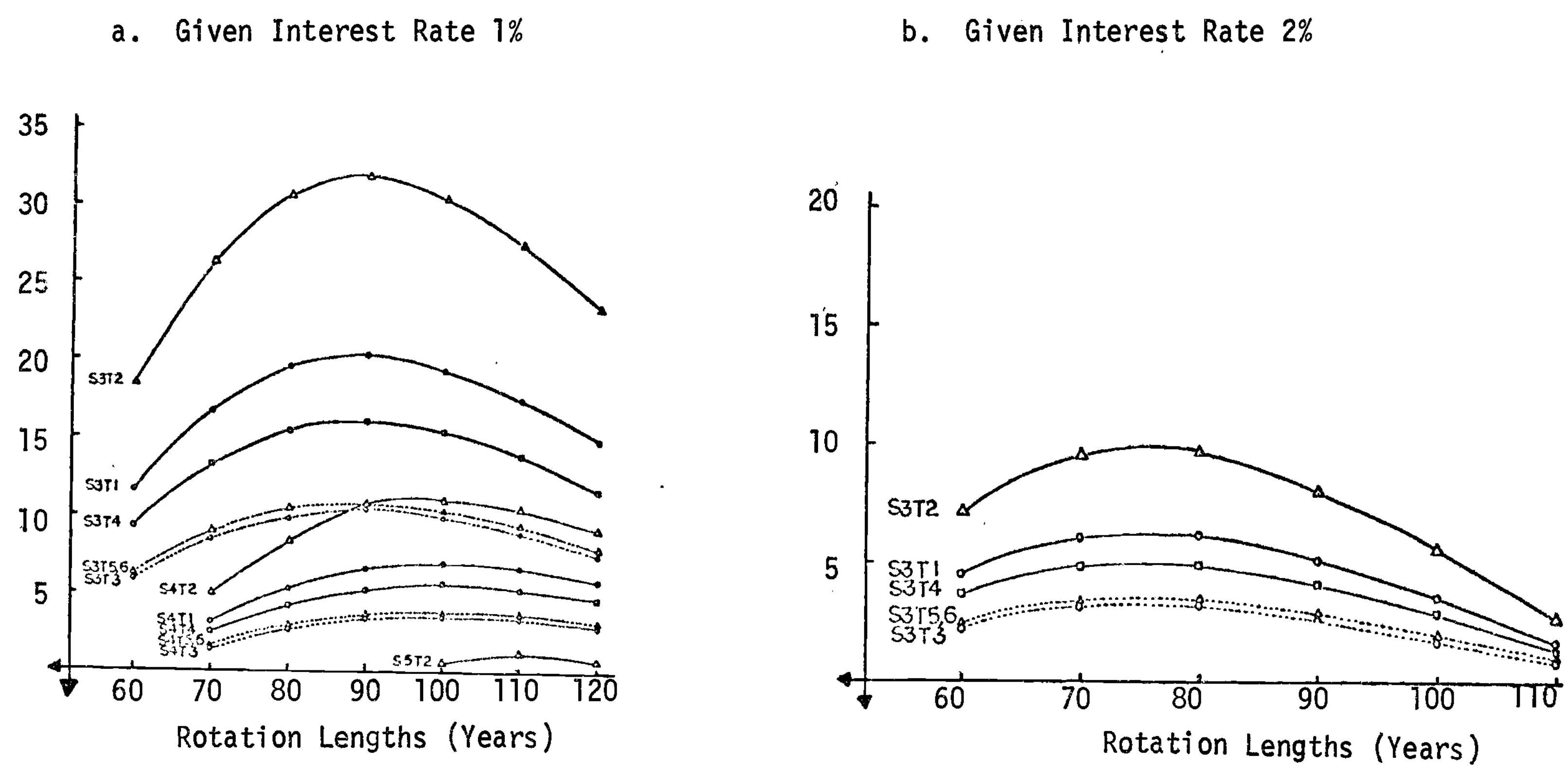


Figure 8. Benefit-cost ratios for different treatments and site qualities for Douglas-fir in Siskiyou area given stumpage price $55 per MBF.



to spend on chemical brush control, but whether one even wants to consider regeneration under this condition. Obviously, the return is much too low for a forest operation if the forest income is in terms of stumpage sales only. Therefore, to justify chemical brush control, the forest management must include water and recreation benefits produced by adequately stocked forest land.

Even though the focus of forest management is on multiple-use, there is a negative income from non-productive forest land. If the forest lands are not put into production because of the low return from stumpage sales, the land owner still needs to pay tax, and it may cost more to convert the land into production at a later time if the land is unused and covered by brush. This is one justification for forest management in low production areas.

Case 4: Chemical Brush Control on Ponderosa Pine Stands in the Siskiyou Area

Ponderosa pine grows in areas with a dry climate, such as eastern and southwestern Oregon. It grows in pure stands where the moisture is insufficient to support Douglas-fir. On marginal Douglas-fir land, ponderosa pine grows in mixed stands with Douglas-fir. In western Oregon, ponderosa pine in the Josephine and Jackson areas were used for the analysis.

Figures 9 and 10 show the results of the analysis. Internal rates of return are equal to or under 2.2%, the highest return rate for site 3 land. The rotation lengths for maximum return, based on

Figure 9. Internal rates of return for different treatments and site qualities for ponderosa pine in the Siskiyou area given stumpage price $40 per MBF.

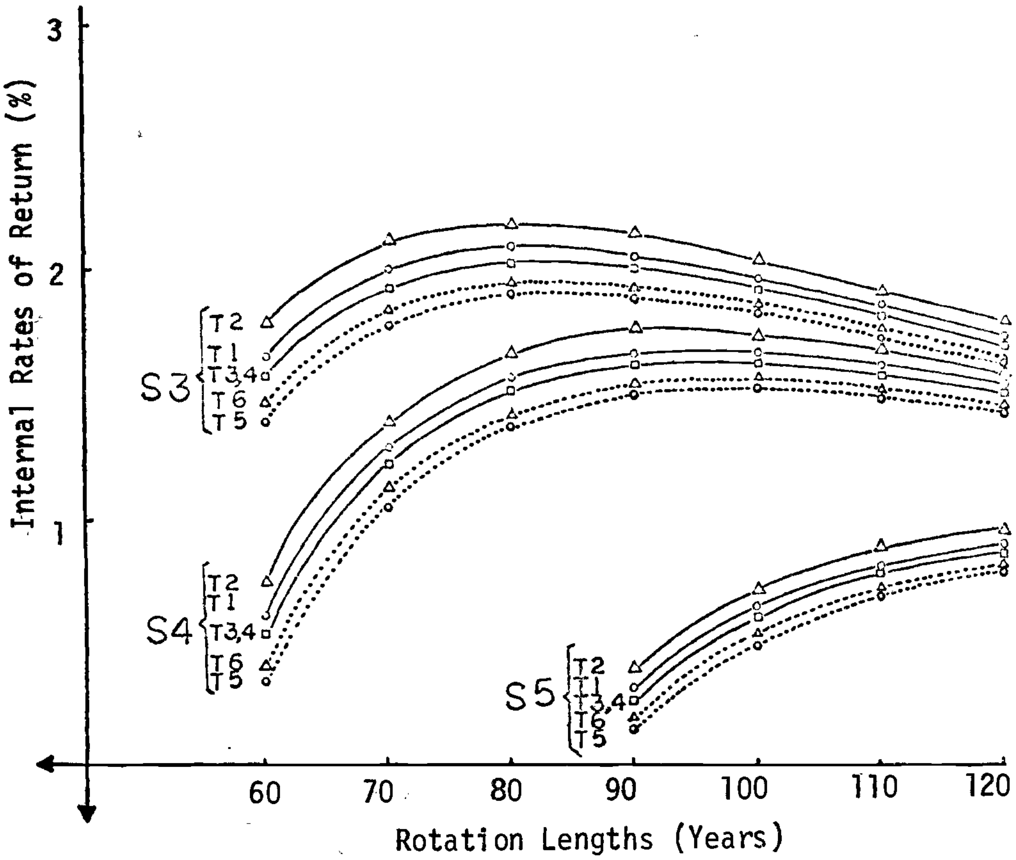
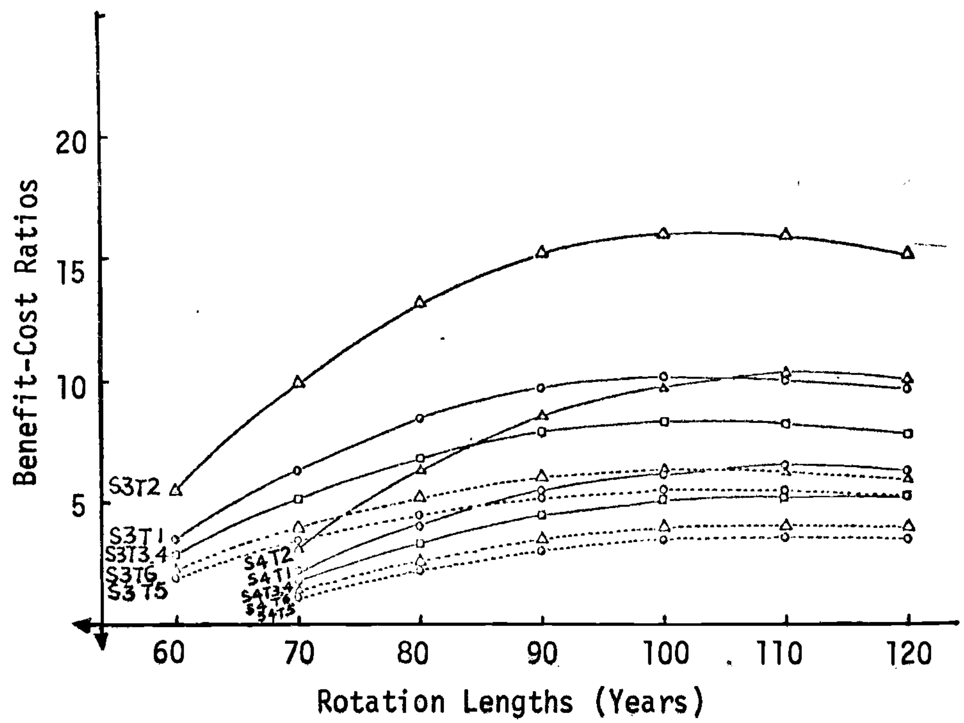
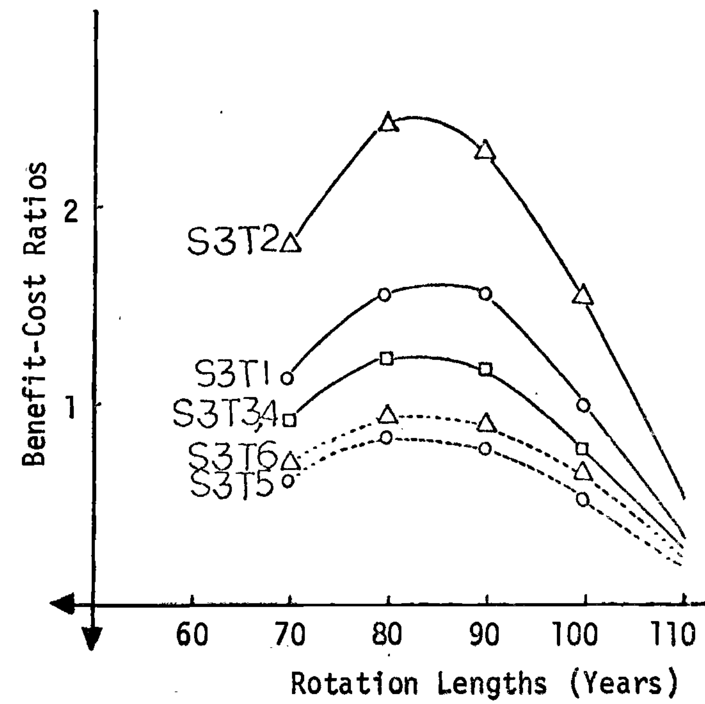


Figure 10. Benefit-cost ratios for different treatments and site qualities for ponderosa pine in the Siskiyou area given stumpage price $40 per MBF.

a. Given Interest Rate 1%



b. Given Interest Rate 2%



the internal rate of return, are 80 years for site 3, 90 years for site 4, and 120 years for site 5. The analysis of benefit-cost ratios shows similar results, a low return for all treatments, even on site 3. Again, rotation increases as site decreases if returns (benefit-cost ratios) are maximized. Low benefit-cost ratios result even at interest rates as low as 1% and 2%. If these forest lands are to be put into production and income is to be derived from the sale of stumpage only, then the justifiable interest rate must be below 1%. An interest rate above 2% is not economical for forest production even for site 3.

The problem in case 4 is similar to case 3. The productivity of forest land is too low to afford any regeneration expenditure if forest income depends only on the sale of stumpage. Therefore, no herbicides can be applied economically under this condition, and forest management should be based on multiple-purpose usage or on long term social benefits, or from the viewpoint of the allowable cut effect of regulated forest. One must also consider that there is a negative effect from the unmanaged forest land.

V. DECISION-MAKING OF CHEMICAL BRUSH CONTROL APPLICATION UNDER UNCERTAINTY

"Uncertainty" in this study means that the probability of regeneration success with chemical brush control to obtain fully stocked is not assumed to be one, on the assumption we have made for certainty in the last two chapters. Even if a chemical is effective in brush control, and the aerial spray is applied using our best professional knowledge in terms of wind speed, temperature, moisture content, and other biological and non-biological factors, the results could still be uncertain. This problem of uncertainty may not yet be clearly seen by the decision-makers or forest managers, but gradually, as spray operations spread more widely and intensively, experience will make managers more aware of the problem. In this study no field data have been developed for analysis under uncertainty but in this chapter the method for incorporating uncertainty in the decision process is explored.

There are numerous publications about the theory of decision-making under uncertainty. Many approaches and criteria have been developed to cope with the uncertainty problem (5, 20). In this study, the maximum expected value was chosen as a criterion for decision-making. The approach suggested to derive maximum expected value under uncertainty for application to brush control problem will be discussed in the following sections. Because of the lack of actual data, the value and probabilities are arbitrarily made for the purposes of discussion.

To establish the components of the decision-making framework in chemical brush control, we should define some terms we will use in our discussion. Specifically, we should define such terms as state of nature, decision alternatives or actions, consequences, probability of regeneration success, expected value and its maximization.

State of Nature

The term "state of nature" is defined as "the way things really are". This term will not refer to all of nature but to that portion which governs the immediate phenomenon (5, 9). They are the future conditions or occurrences which are beyond the control of the decision-maker but which influences the result of his decision (20). In this study, as we have specified in chapter II, we define states of nature as the three levels of stocking at the time of planting survey.

Regeneration with brush control or without brush control will result in certain stocking levels, and the survival rate for these stocking levels can range from zero to 100 percent. According to the criteria used by National Forests, at least by the Siskiyou and Siuslaw National Forests, three levels of survival are used as standards for judging the degree of regeneration success. Three stocking levels are as follows:

1) Fully Stocked (Z_1) - There are 250 or more seedlings (evenly spaced) alive at the time of the planting survey. This is considered a successful

regeneration. No replanting or interplanting is required before the next planting survey.

2) Partially Stocked (Z_2) - The survival rate at the time of planting survey is between 100 and 250 seedlings. Interplanting is required in order to fully stock the area. The cost of interplanting is about two-thirds of the original regeneration planting.

3) Failure (Z_3) - If less than 100 seedlings per acre have survived, the planting is classed as a failure. The entire area is replanted.

These three levels of stocking are considered as three states of nature in this study and the codes Z_1, Z_2 and Z_3 are used to represent them. The eventual success of the planting (state of nature) is unknown. If it were known in advance then the decision to spray would be easily made.

Decision Alternatives or Actions

Decision alternatives or actions are defined as the possible alternatives to obtain an objective. In this study, there are two alternatives to solve the brush problem: one alternative is to do without brush control, and the other is to have chemical brush control.

1) With Chemical Brush Control - coded as Action a_1.

2) Without Chemical Brush Control - coded as Action a_2.

We don't know which state of nature will result. If we did, we could make a choice between these two actions. Suppose for example, we know that even without chemical brush control, a planting will result in a fully stocked area, then chemical brush control would be unnecessary and we would choose Action a_2.

Consequences

A "consequence" is defined as the value which is used as a base to choose among alternatives given the state of nature (20). This value may be in terms of utility, monetary profits, losses, or some other measure.

In this study, we assumed a utility value as the value to be used in choosing between these two actions. A utility value is a subjective value used by decision-maker in his decision-making. The values are shown in Table 14.

Table 14. Utility value for chemical brush control (CBC).

States of Nature		Actions	
		W/ CBC	W/O CBC
250+ Seedlings Survive	Z_1	C_{11}	C_{12}
100-250 Seedlings Survive	Z_2	C_{21}	C_{22}
Less than 100 Seedlings Survive	Z_3	C_{31}	C_{32}

The internal rate of return is coded as C_{ij}, which is the value of (Z_i, a_j), where Z_i are the states of nature and a_j are the actions, and C_{ij} is the utility value given each state of nature Z_i and action a_j.

Probability of Regeneration Success

Probability of success is defined as the probability of achieving a certain state of nature given a certain action. For example, given chemical brush control, that is, action a_1, the probability of obtaining the state of nature Z_1 is P_{11}. We define P_{ij} as the probability of having Z_i if given a_j. According to the characteristics of probability, the elements of probabilities are independent and sum to one. These conditions are specified as follows:

1) $P_{ij} = 1$

2) P_{ij} are disjoint or independent.

where,

$i = 1,2,3$ given $j = 1$

or $i = 1,2,3$ given $j = 2$

The elements of probabilities for each action are in Table 15, as follows:

Table 15. Probabilities for decision-making for using chemical brush control.

		Actions	
		W/ CBC	W/O CBC
State of Nature		a_1	a_2
250+ Seedlings Survive	Z_1	P_{11}	P_{12}
100-250 Seedlings Survive	Z_2	P_{21}	P_{22}
Less than 100 Seedlings Survive	Z_3	P_{31}	P_{32}

For each stage, that is from planting to planting survey or from planting survey to planting survey, there is a probability of reaching one of the states of nature, either with chemical control or without chemical brush control.

Expected Value and Its Maximization

Expected value is the value derived from the multiplication of the value for the action and its corresponding probability. The strategy with the maximum expected value generally appears to be the one in which we base our choice of action. The way to calculate the expected value is as follows:

Expected value for Action $a_1 = C_{11} \times P_{11} + C_{21} \times P_{21} + C_{31} \times P_{31}$

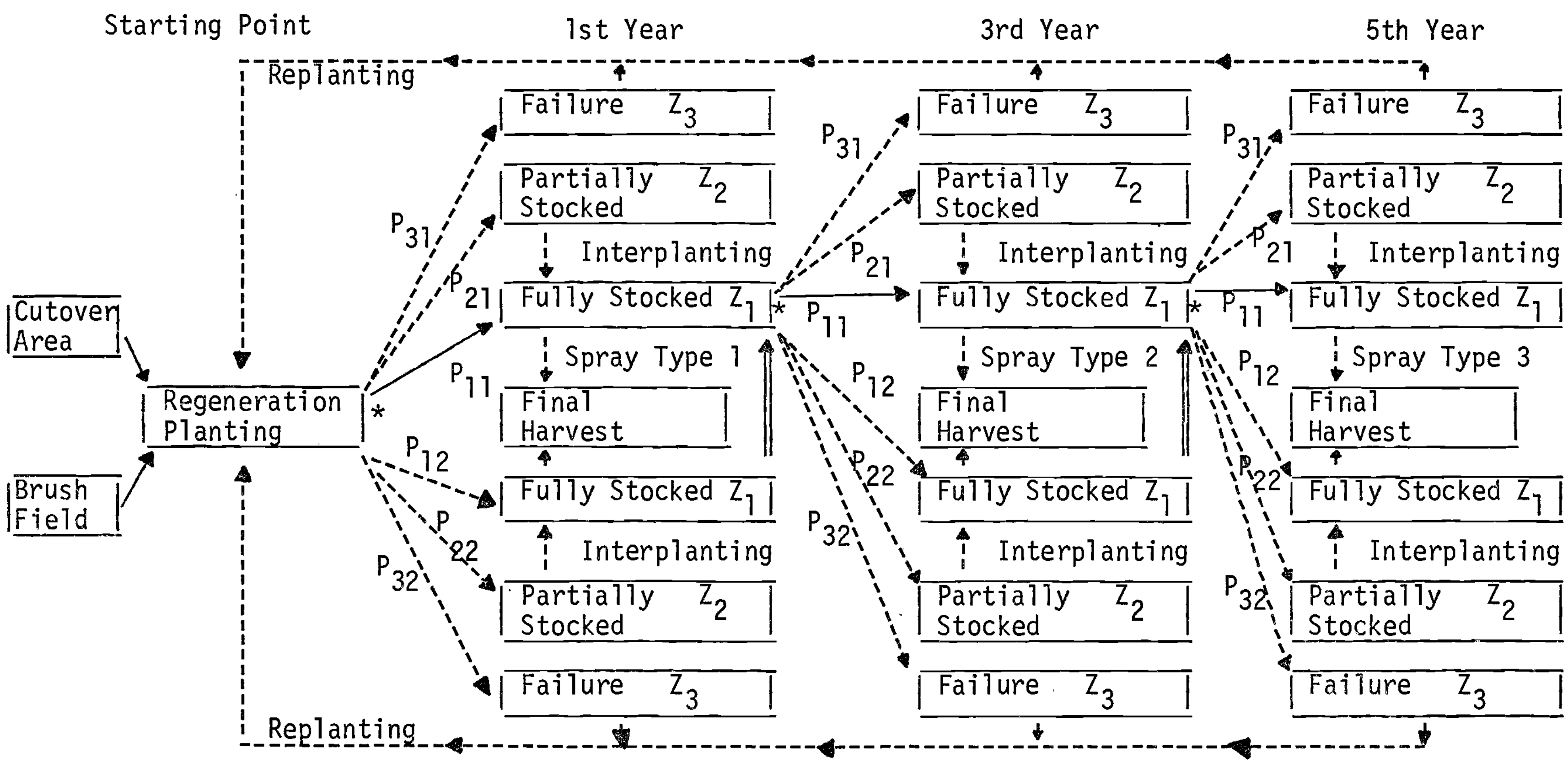
Expected value for Action $a_2 = C_{12} \times P_{12} + C_{22} \times P_{22} + C_{32} \times P_{32}$

In making a choice between actions a_1 and a_2, we choose the one with larger total expected value, determined by adding the expected values for the three (in this case) states of nature. Action a_1 is preferred to Action a_2 if the total expected value of a_1 is greater than the total expected value of a_2. This is the criteria we will use in this chapter.

Decision-Making Process

Using the maximum expected value criterion described in the last section, the decision process follows the pattern of the Decision Tree Diagram of Chemical Brush Control, which is specified in Figure 11, page 77. A decision tree represents a sequential relationship of

Figure 11. Decision Tree Diagram of Chemical Brush Control.



production decisions, chance events and value outcome. At each decision point (* sign in the diagram), the decision-maker makes his decision in choosing one of the two specified actions - with chemical brush control and without chemical brush control. The solid arrow lines represent the three spray types under our first assumption - the probability of natural regeneration success (i.e. fully stocked stands) without chemical brush control to be zero and with chemical brush control to be one. In other words, we assumed that for spray type 1, the probability P_{11} is one and other probabilities are zero. For spray type 2, we assumed that P_{11} in 1st year and in 3rd year are equal to one and the others are equal to zero. In spray type 3, probabilities P_{11} in 1st, 3rd and 5th years are equal to one and others are equal to zero. That means that with chemical brush control we can obtain fully stocked stands. The probabilities under this assumption are as follows:

States of Nature		Actions: W/ CBC a_1	Actions: W/O CBC a_2
250+ Seedlings Survive	Z_1	1	0
100-250 Seedlings Survive	Z_2	0	0
Less than 100 Seedlings Survive	Z_3	0	1

From the decision tree diagram, there are four rules we should follow in decision-making regarding chemical brush control.

1) Based on assumption 1, chapter II, page 14, forest land will

be used for timber production.

2) A fully stocked area is the only acceptable condition for management of stands. If land is classed as partially stocked (Z_2), trees will be interplanted.

3) If the regeneration fails (Z_3), forest land will be replanted.

4) Whether to invest in chemical brush control depends on the comparison between the expected utility values and the action with a maximum utility value is the one we choose.

If the expected utility value for action a_1 is greater than for a_2, we can say that a_1 is preferred to a_2, therefore we will choose a_1 as our management action. Using a minimum alternative return rate for our investment, we will not choose any action whose expected return rate is lower than the alternative minimum rate unless there is a subsidy or values for products other than timber sufficient to increase the internal rate of return to a point equal to the alternative minimum acceptable rate.

This decision-making process is repeated stage by stage. Furthermore, past decisions affect present ones. The decisions made in the 3rd year depend on the stocking level in the 1st year, and decisions in the 5th year depend on the stocking level in the 3rd year.

The following example will illustrate the decision-making process discussed in this chapter. The probabilities were supplied by Mr. John M. Hughes, a silviculturist in the Siuslaw National Forest. The internal rates of return were used as a utility value for the purpose of illustration.

Example: Decision-Making for Chemical Brush Control in the Coastal Range of the Siuslaw Area

Seventy percent of the area in the coastal range of the Siuslaw area is considered a brush problem area. The decision-making process illustrated here deals with this brush problem area. The probabilities and their corresponding values for the internal rate of return are as follows:

1) In the first year:

States of Nature		Probabilities		Values	
		W/ CBC a_1	W/O CBC a_2	W/ CBC a_1	W/O CBC a_2
250+ Seedlings Survive	Z_1	.7	.2	5.7	6.0
100-250 Seedlings Survive	Z_2	.2	.5	4.7	5.5
Less than 100 Seedlings Survive	Z_3	.1	.3	0	0

Expected value for a_1 is $5.7 \times .7 + 4.7 \times .2 + 0 \times .1 = 4.93$

and Expected value for a_2 is $6.0 \times .2 + 5.5 \times .5 + 0 \times .3 = 3.95$

Action a_1 is preferred to action a_2 because the expected value of a_1 is greater than the expected value of a_2. In other words, chemical site preparation is preferred to no chemical site preparation in this brush problem area.

2) In the third year:

States of Nature		Probabilities W/ CBC a_1	Probabilities W/O CBC a_2	Values W/ CBC a_1	Values W/O CBC a_2
250+ Seedlings Survive	Z_1	.95	.2	5.5	5.8
100-250 Seedlings Survive	Z_2	.05	.5	4.6	5.2
Less than 100 Seedlings Survive	Z_3	0	.3	0	0

Expected value for a_1 is 5.5 x .95 + 4.6 x .05 + 0 = 5.46

and Expected value for a_2 is 5.8 x .2 + 5.2 x .5 + 0 = 3.76

The expected value for a_1 is greater than the expected value for a_2 in this brush problem area, so that chemical brush release is preferred to no chemical brush release.

3) In the fifth year:

States of Nature		Probabilities W/ CBC a_1	Probabilities W/O CBC a_2	Values W/ CBC a_1	Values W/O CBC a_2
250+ Seedlings Survive	Z_1	.9	.7	5.4	5.7
100-250 Seedlings Survive	Z_2	.1	.3	4.5	5.0
Less than 100 Seedlings Survive	Z_3	0	0	0	0

Expected value for a_1 is 5.4 x .9 + 4.5 x .1 + 0 = 5.31

and Expected value for a_2 is 5.7 x .7 + 5.0 x .3 + 0 = 5.49

The expected value for a_2 is greater than a_1 under our assumed values and probabilities, a_2 is preferred to a_1. In other words, no chemical brush release is preferred to chemical brush release, according to the rule of maximum expected value.

The return shown in chapter IV is so low that it is difficult to achieve an acceptable return for timber production using chemical help. Thus far data are not available, especially for the probabilities of success to apply decision-making theory to chemical brush control. However, this is the technique that can be used if probabilities were available to apply the maximum expected value criterion.

In order to make this approach possible and applicable, we must accumulate more knowledge about the probabilities of regeneration success with and without chemical brush control. We may also revise the internal rate of return to be applied here or have a better evaluation (which includes benefits other than timber sale) method to have a more accurate value to base decisions on.

VI. CONCLUDING COMMENTS

This study has attempted to offer a model to evaluate the economic feasibility of chemical brush control. The assumptions made in chapter II may not apply to all situations, but the methods of evaluation remain the same even if some of the assumptions are dropped. This study demonstrates how to apply the internal rate of return and the benefit-cost ratio for the evaluation of the economic feasibility of chemical brush control.

Generally speaking, the rate of return from chemical brush control is low in comparison to the market rate, even for site class 1 land in the most productive Siuslaw area. This land shows a return of 4 to 6 precent.

Number of chemical applications has very little effect on rate of return. This can be observed from the different treatment return curves within a site class. The return curves for better sites are generally above the return curves for the lower site classes. The rate of returns from all applications on site 1 land has a better return than from one chemical application on site 2 land for Douglas-fir in the Siuslaw area and western hemlock in Lincoln County. These results are shown in terms of the internal rate of return.

The most influential factors governing the return rate in this study are productivity of forest land and stumpage price, not the cost of chemical or number of times an area is sprayed. The effects of stumpage price are very striking. The internal rate of return at

50 years rotation for Douglas-fir on site 1 land in the Siuslaw area is 0.6 percent higher at a stumpage price of $80 per M board feet than at a stumpage price of $70 per M board feet (Figures 1 and 2). The difference in benefit-cost ratios for the same case is 8.0 (Figures 2-a and 2-b). This effect is more than the results from the differences by treatments. We can expect that as demand increases for wood products, more can be invested in chemical brush control, especially on the more productive forest lands.

In general, the longer the rotation length is, the lower the return will be from chemical brush control. This relates primarily to the characteristics of tree growth rather than the cost of chemical application. Intensive management practices such as fertilization and thinning reduce rotations and will enhance the possibilities for using chemical brush control.

The rotation length with maximum return is around 60 years for site 1 and site 2 for Douglas-fir in the Siuslaw area and for western hemlock in Lincoln County. Higher sites tend to produce more wood volume but they also produce more brush. Therefore chemical brush control is especially important on the better sites.

The interest rate is a crucial factor in long-term investment in forest management. The longer the return is delayed, the more the interest rate influences present net worth. The benefit-cost ratios in the figures in chapter IV are reduced greatly as the given interest rate increases by one percent. Rotation lengths tend to shorten as the interest rate goes up. These results show that some investments may not be possible under the present market rate, but may become possible if low interest loans are made available or if some compensation is made for other products from forest land use such as wildlife, recreation, and water.

An investment in chemical brush control may be justified for regulated properties if the allowable cut can thereby be increased. (15, 16, 19). If we can increase the future forest inventory by restoring timber production on poorly stocked areas by means of chemical brush control, then we can harvest more at the present time. The increase in harvest at present attributable to chemical brush control, may make investment profitable even though the return from this kind of investment is lower than the market rate (32).

In order to have a complete understanding of chemical brush control problems, further study of two critical problems is necessary. They are: 1) the probability of regeneration success with and without chemical brush control in forest regeneration, and 2) the effect on investment of the extra volume harvested as a result of using intensive management practices including herbicides.

The first problem the decision-maker must face concerning chemical brush control is the uncertainty of regeneration success following chemical brush control. We have explored the possibility of using maximum expected value (internal rate of return used in the example) as a criterion for decision-making. But this criterion is inadequate unless we can accumulate more knowledge about the probability of regeneration success under these two actions, namely, with chemical brush control and without chemical brush control.

The second problem is to improve our knowledge of the additional revenue gained by more intensive management and from benefits other than stumpage produced by fully stocked forest stands. More intensive management, including thinning, fertilization, and chemical brush control will produce more wood fiber per acre. In other words, we should know how much the production curve shifts up with intensive forest practices including chemical brush control before we can really calculate the return derived from chemical brush control.

Lands covered with good forests will produce more water and provide a more attractive landscape as well as some other direct and indirect benefits. These are not as yet quantified. Since chemical brush control is the key toward forest establishment in brush problem areas, those benefits other than stumpage sale can be attributed to brush control. But additional quantitative data are required in order to calculate benefits in addition to stumpage sales, before we can measure the total benefits of chemical brush control. This requires further research in which forest physiologists, economists and foresters in other fields must cooperate.

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APPENDICES

Appendix I. Program for Benefit-Cost Ratios

```
      PROGRAM CBRATIO
C
C        MARCH  1972
C
C      THIS PROGRAM COMPUTES THE COST-BENEFIT RATIO
C
      DIMENSION TRT(3,6),RTN(9),FST(9),V(5),RAT(5),COST(120)
C
      READ (60,7)  ITRT  , IYER  ,  (RAT(I),I=1,5)
      KYER = 12 - IYER/10 + 1
      MYER = IYER - 10
C
C        INPUT DATA
C
  100 READ (1,1)  ((TRT(I,J),I=1,3),J=1,ITRT)
      IF  (EOF(1))  GO TO 70
      DO   10   I = 1 , KYER
   10 READ (1,2) RTN(I)  , FST(I)  , ID
      READ (1,4)  (COST(I),I=1,120)
C
C        PRINTS OUTPUT TITLE
C
      WRITE (2,5)
C
C        COMPUTES COST-BENEFIT RATIOS
C
      DO   60   NTRT = 1  , ITRT
      V(1) = TRT(1,NTRT)
      V(3) = TRT(2,NTRT)
      V(5) = TRT(3,NTRT)
      DO   50   NYER = 1  , KYER
      N = MYER + 10 * NYER
      TEMP = COST(N)
      COST(N)  = FST(NYER)
      DO   40   NRAT = 1  , 5
      RATE = RAT(NRAT)
      R = 1. + RATE
      FCOST = 0.
      DO   20   I = 1  , N
      FCOST  = FCOST  + COST(I)  * R**(N-I)
   20 CONTINUE
      VCOST  = 0.
      DO   30   J = 1  , 5  , 2
      VCOST  = VCOST  + V(J)  * R**(N-J)
   30 CONTINUE
      RATIO =  (RTN(NYER)-FCOST)  / VCOST
      WRITE  (2,6)  V(1),V(3),V(5),N,RATE,RATIO,ID
   40 CONTINUE
      COST(N)  = TEMP
   50 CONTINUE
   60 CONTINUE
      GO TO 100
   70 CONTINUE
C
C        FORMATS
C
```

Appendix I (continued)

```
      FORMAT (4(1X,3F6.0))
      FORMAT (3X,F9.2,3X,F6.2,5X,A4)
      FORMAT (10F7.2)
      FORMAT (1H1/3H0  ,54H  T R E A T M E N T   YEAR  RATE     C-B RAT
     1IO   IDIT/1H0)
      FORMAT (3X,F6.2,1H,,F6.2,1H,,F6.2,3X,I3,2X,F5.3,2X,F12.6,3X,A4)
      FORMAT (2I5,5F6.0)

      STOP
      END
```

Appendix II. Program to solve internal rate of return.

To find the internal rate of return, non-linear programming is used to solve the following problem:

solve $f(I) = b$ and find an $I > 0$, such that

$[f(I) - b]^2$ is minimum

In this study, I used *OPTIMAL in OS3 (see Manual ccm-73-02 by Billy Shu-chih Chou) to solve the equation and find the internal rate of return.