PUBLICATIONS
ROOM 118

FILE COPY

United States
Department of
Agriculture

Forest Service

Pacific Southwest
Forest and Range
Experiment Station

Research Paper
PSW-156

West Coast Tree Improvement Programs: a break-even, cost-benefit analysis

F. Thomas Ledig Richard L. Porterfield

The Authors:

F. THOMAS LEDIG is in charge of the Station's forest genetics research, with headquarters in Berkeley, California, and field facilities at the Institute of Forest Genetics, Placerville, California. He was formerly professor of forest genetics, Yale University, New Haven, Connecticut. He earned a forestry degree at Rutgers University (1962) and master's (1965) and doctoral (1967) degrees in genetics at North Carolina State University. **RICHARD L. PORTERFIELD** is director, Raw Materials Supply, Timberlands Division, Champion International Corporation, Stamford, Connecticut. He earned a bachelor's degree in forestry and business administration (1968) at Ohio State University, a master's degree (1970) in forestry and economics at North Carolina State University, and a doctorate in forestry and economics (1973) at Yale University.

Acknowledgments:

We thank the following persons for their contributions to this study: *Roy R. Silen*, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon, for cost figures on the progressive tree improvement program; *Jay H. Kitzmiller*, Pacific Southwest Region, Forest Service, San Francisco, California, for cost data on the Pacific Southwest tree improvement program; and *Jack Wanek*, St. Paul Seed Orchard, Salem, Oregon, and *Virgil Allen*, Dennie Ahl Seed Orchard, Shelton, Washington, for information on seed yields and on the costs of establishing and maintaining Douglas-fir seed orchards.

Cover: Pines at the Institute of Forest Genetics, Pacific Southwest Forest and Range Experiment Station, Placerville, California (photo by Dennis Galloway).

Publisher:

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

August 1981

West Coast Tree Improvement Programs: a break-even, cost-benefit analysis

F. Thomas Ledig Richard L. Porterfield

CONTENTS

IN BRIEF...

Ledig, F. Thomas, and Richard L. Porterfield.
1981. **West Coast tree improvement programs: a break-even, cost-benefit analysis.** Res. Paper PSW-156, 8 p. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Retrieval Terms: tree improvement, economic analysis, *Pinus ponderosa, Pseudotsuga menziesii,* sensitivity analysis, minimum genetic gain

Most previous economic analyses have focused on improvement programs for short rotation southern pines or for spruce in the Northeast and Canada. It may be more difficult to justify tree improvement for western conifers, not only because rotations are longer, but because local adaptation to a complex topography may prevent improved trees from being used over as wide an area as in eastern North America. The smaller the breeding zone, the greater the cost per acre planted.

We used a break-even, cost-benefit analysis to explore profitability for three representative programs: the Pacific Southwest's program for ponderosa pine in the Sierra Nevada and both a first-stage and a second-stage of the Pacific Northwest's progressive tree improvement program for Douglas-fir. The analysis used the best cost data available to determine the minimum volume improvement required to earn a fixed rate of return, 8 percent in our calculations. Sensitivity analysis, allowing assumptions to vary one at a time or in sets, was used to judge the risks associated with uncertain estimates.

The ponderosa pine program is in the traditional mode of southern pine improvement. Moderately rigorous selection is practiced in natural stands, and selected trees are grafted into seed orchards. Progeny tests provide information on which trees are, in fact, inferior, and these are removed from the orchard. Only a 6.3 percent volume improvement from the genetic approach will bring an 8 percent return on the investment, and based on experience in other species, 6.3 percent seems easily attainable.

Progressive tree improvement programs in the Pacific Northwest differ from the traditional approach. Selection is frequently weak, and seed for planting is collected from the selected trees where they stand, so that progeny have only one selected parent. Many selections are made and breeding zones are narrow. Progeny test information is used to determine which of the original selections should be eliminated. Although anticipated improvement is small, costs are low, so that only 1.8 percent volume improvement would return 8 percent on investment.

Progressive programs can enter a second, high-intensity stage at any time. Seedling seed orchards are established by thinning progeny test plantations to the best individuals in the best families. For a second-stage program for Douglas-fir, only an additional 1.0 percent improvement will pay for the investment, and this seems highly likely.

Sensitivity analysis of the underlying assumptions indicate that economic factors and silvicultural decisions affect profitability more than program design. The choice of interest rate and length of rotation are particularly crucial. With long rotations (120 years for ponderosa pine and 80 years for Douglas-fir) tree improvement will only be profitable if returns are possible from intermediate thinnings. Otherwise, rotations should be shortened to 50 years. Less improvement is necessary to justify expenditures on land of high site index than on sites of low productivity. The primary attributes over which the breeder has control are the number of selections, the size of the breeding zones, and the type of orchard. Small breeding zones, such as those in the progressive tree improvement scheme, reduce profitability. On the other hand, large zones such as those in the Pacific Southwest's program entail greater biological risks of planting nonadapted trees. The differences in establishment costs for grafted compared to seedling seed orchards seems less important. We conclude that with reasonable rates of interest, a realistic price increase for timber value, and good silviculture, both programs will be quite profitable.

Tree improvement can be a highly profitable investment (Porterfield and others 1975, Carlisle and Teich 1978, Davis 1967). In general, only small levels of improvement are needed to justify expenditures (Perry and Wang 1958). However, most previous analyses have dealt with southern pines that are grown on short rotations, and none have dealt with western conifers grown on long rotations.

Programs for the improvement of Pacific Coast conifers, such as Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), have unique features not common to programs for eastern species. Western forests are characterized by long rotations and complex topography that may result in local adaptation, thereby narrowing breeding zones—the operating unit for which improved trees are bred.

Our objective was to explore the economic justification of representative tree improvement programs for western conifers. Two contrasting programs were chosen as illustrations. The National Forest System's regional tree improvement program for the Pacific Southwest is in the traditional mode and depends on early establishment of seed orchards. Long rotations distinguish it from programs managed by industrial cooperatives, such as those in the Southeast and Pacific Northwest. The Pacific Northwest's progressive tree improvement program is characterized by small breeding zones, large numbers of selections, and seed collection from selected trees *in situ* rather than establishment of seed orchards. Major reliance is placed on progeny tests—tests of a parent's breeding value or its ability to produce superior progeny—rather than intensive selection in the forest (Silen and Wheat 1979, Silen 1966). The cost and benefit structure may be considerably altered in a progressive tree improvement program compared with the traditional approach.

Previously, we applied benefit-cost analysis to tree improvement programs in the Northeastern United States and Canada (Porterfield and Ledig 1977), and compared two proposals for improvement of black spruce (*Picea mariana* [Mill.] B.S.P.). Seedling seed orchards—orchards established with seedling progeny of wind-pollinated selections rogued to leave the best trees by using family test information—proved superior to a traditional grafted seed orchard program. However, sensitivity analysis revealed that initial estimates of seed yield and length of harvest rotation accounted for most of the difference between programs.

PROCEDURES

The programs analyzed are actual, on-going programs: the Pacific Southwest's program for conifers in the Sierra Nevada (Kitzmiller 1976), and the Pacific Northwest's program for Douglas-fir (Silen and Wheat 1979). In the initial analysis, we tried to adhere closely to the published descriptions of these programs. Later, we suggested the effects to be achieved by various changes.

The benefit-cost ratio is the present value of benefits divided by the present value of costs. A ratio of 1.0 or greater indicates a rate of return on investment equal to or greater than the interest rate used in the analysis. Because definitive information on economic benefits usually is not available in the early stages of tree improvement, program justification is difficult. We used a simple, break-even analysis that required a minimum of proven data. Essentially, we determined the minimum volume improvement required to earn the fixed rate of return used in the investment calculation. Such an analysis allows comparison of programs and enables an objective choice between competing proposals. Also, it permitted us to vary factors one at a time or jointly, to measure sensitivity of required volume gains to modifications in the program, or to judge the risks associated with uncertainty in market values.

We used an interest rate of 8 percent for our base rate, but examined the effect of different rates with sensitivity analysis. Higher or lower rates might apply, depending on the situation, but 8 percent seems a realistic compromise. Interest rates include a fraction due to inflation and a remainder that is a true interest component. Over the long term appropriate to investments in forestry, inflation has run about 5 percent. A rule of thumb is that the real rate is about one-half the nominal. For public investments a return of 5 to 6 percent is commonly used (6.2 percent was the rate for the Forest and Rangeland Renewable Resources Planning Act, but a case has been made for a rate of 4 percent). For National Forest programs, a 5- to

6-percent rate may be appropriate. For industrial members of tree improvement cooperatives a higher rate might be desirable, say 11 percent, reflecting present interest rates.

PONDEROSA PINE PROGRAM

The Pacific Southwest Region's tree improvement program for the National Forests includes several species and breeding zones of California conifers (Kitzmiller 1976), but our analysis was restricted to one species, ponderosa pine, and one breeding zone. Within a breeding zone, 200 selections are made. Wind-pollinated seed is collected to establish progeny tests early in the program. Simultaneously, cuttings are collected to establish a grafted seed orchard at 15 by 15 feet. With progeny test results as a guide, the orchard will be rogued to the best 50 selections by age 15.

Characteristics and economic base for the ponderosa pine tree improvement program are:

Characteristics	
Number of trees selected	200 trees
Number of acres of orchard	14 acres
Commercial seed production of orchard begins	14 years
Orchard phased out	44 years
Rotation age	120 years
Operating area	336,000 acres
Annual planting	2,800 acres
Economic Assumptions	
Interest rate	8 percent
Current stumpage price	$110 per Mbf
Normal yield of unimproved forest (site III)	
at 120 years	100 Mbf
at 60 years	35 Mbf

Present value of costs per acre of orchard is $32,646 (*table 1*) and each acre is expected to produce sufficient seed to regenerate 200 acres of plantation each year of its commercial life. Although the tree improvement plan calls for establishing a grafted clone archive to facilitate crosses among the selections, and a program of matings, we ignored those costs. They are aspects of a second generation improvement program, produce no benefits for the first generation, and should not be charged to the first generation.

The ponderosa pine program assumes a 120-year rotation, but improved yields will be harvested in intermediate thinnings at 40, 50, 60, 70, 80, 90, 100, and 110 years. Final harvested volume at 120 years will be the same for improved stands as for unimproved stands. The assumption is not unreasonable, implying that biomass per acre is limited but the rate at which the limit is reached can be improved. We distributed 20 percent of the total genetic gain in volume for the rotation to the thinning at age 40, 40 percent to age 50, and 6.5 percent to thinnings in each of the next six decades. The benefits occur at the harvest age plus 14 years (the time between the start of the program and establishment of the first commercial plantations) for each seed crop over the commercial life of the orchard.

To evaluate the program, present values of tree improvement costs per acre planted were equated to the present value of incremental benefits. In general form:

$$\$163.23 = B \times \frac{I}{C},$$

in which:

B = a discounting factor giving the present value of receiving one dollar each year for the 30-year production life of the orchard (age 14 to 44),

I = the value increase per acre of plantation (volume gain × value per unit) as the result of genetic improvement, necessary to return 8 percent on the investment,

C = a discounting factor required to bring benefits back in time (the years before commercial seed collection plus the years until the first improved plantations are thinned).

Because thinning takes place in several cycles, I/C is a weighted sum under the present assumptions:

$$\begin{aligned}\$163.23 = {} & [(1.08^{30} - 1)/(0.08)(1.08^{30})] \times [0.2I/1.08^{54} \\ & + 0.4I/1.08^{64} + 0.065I/1.08^{74} \\ & + 0.065I/1.08^{84} + 0.065I/1.08^{94} \\ & + 0.065I/1.08^{104} + 0.065I/1.08^{114} \\ & + 0.065I/1.08^{124}].\end{aligned}$$

The break-even value for I is $2,250.75; in words, each acre of improved plantation must be worth $2,250.75 more than unimproved plantation for the benefit-cost

Table 1—*Present value of costs per acre of seed orchard in the ponderosa pine tree improvement program, Pacific Southwest Region, Forest Service, U.S. Department of Agriculture*

Activity	Present value per acre orchard (@ 8 percent)	Year cost incurred
Selection and cone collection	$1,971	1
	1,825	2
Orchard establishment	4,942	3
	4,576	4
	4,237	5
Orchard maintenance (annual)	4,260	4 to 44
Progeny test establishment	5,007	3
	4,636	4
Progeny test maintenance	92	4
	171	5
	158	6
	73	7
Progeny test maintenance (annual)	217	8 to 20
Progeny test evaluation	68	5 to 8
	413	9 to 20
Total present value per acre orchard	$32,646	
Total present value per acre plantation	$163.23[1]	

[1]Obtained by dividing cost per acre of seed orchard by 200 acres plantation per acre seed orchard.

ratio to be 1.0 and the return on the tree improvement investment to be just 8 percent. To translate this into volume improvement we assume a current value of \$110 per Mbf, which is the California Board of Equalization's projected timber value harvest schedule for the Central Sierra projected for the first half of 1980. The California Board of Equalization collects data and publishes commodity prices. However, our best estimate is that timber value will continue to follow the historic trend of 1.5 percent per year real price increase (USDA Forest Service 1974). Allowing for a 1.5 percent price increase, we solve for the required volume improvement. Required gain in value to return 8 percent on investment is:

$$\$2,250.75 = \sum_{i=1}^{8} V_i \times W_i \times T,$$

in which:

V_i = value per Mbf at time of the i^{th} thinning

W_i = proportion of the total increase in cut removed at the i^{th} thinning

T = total increase in volume cut during rotation.

Therefore:

$$\$2,250.75 = [(\$245.79)(0.2) + (\$285.25)(0.4) + (\$331.04)(0.065) + (\$384.18)(0.065) + (\$445.86)(0.065) + (\$517.44)(0.065) + (\$600.51)(0.065) + (\$696.92)(0.065)] \times T$$

Solving, T = 6.3 Mbf required gain in volume per acre over normal unimproved plantation to return 8 percent on the investment. Kitzmiller (1976) uses 16,100 cf as unimproved yields, and it is implicit in his other assumptions that this is equivalent to 80.5 Mbf. But, unimproved yields of 80.5 Mbf per acre seem unreasonably small. Given a 120-year rotation, we anticipate more than 100 Mbf on a medium site at final harvest alone. Therefore, the required improvement to return the investment of 8 percent interest is probably close to 6.3 percent. Thinning is likely to salvage timber that would otherwise be lost so total yield for the entire rotation would exceed 100 Mbf per acre. The effect of a higher estimate for unimproved yields would be to reduce the percentage improvement necessary to attain the break-even point. Nevertheless, a gain of 6.3 percent in volume from tree improvement seems easily attainable. In southern pine improvement programs, 15-percent gain is expected in the first generation. A 15-percent gain in the ponderosa pine program would pay a high internal rate of return on investment.

We examined the effects of modifications to the ponderosa pine program by varying the assumptions and recalculating the improvement necessary to break even (*table 2*). An interest rate of 5 percent reduces required improvement to such ridiculously low levels that an economic return seems certain. However, a rate of 11 percent requires an improvement of 35.4 percent over normal unimproved yields, and it is doubtful that such a substantial increase could be achieved by one generation of selection with the selection intensity currently used.

Table 2—*Sensitivity analysis for the ponderosa pine tree improvement program, Pacific Southwest Region, Forest Service, U.S. Department of Agriculture*

Assumptions	Required volume improvement	
	Mbf per acre	Percent
Base case	6.3	6.3
Changes		
Interest rate is 5 percent	0.9	0.9
Interest rate is 11 percent	35.4	35.4
No real price increase	20.5	20.5
No thinnings	539.9	539.9
No thinnings, rotation is 60 years	13.0	37.1
No thinnings, rotation is 60 years interest rate is 11 percent	116.4	332.6
Site index increased, normal unimproved yields 150 Mbf per acre	6.3	4.2
Breeding zone halved	9.1	9.1
Seed yield doubled	4.6	4.6
Seed yield doubled, planting program doubled	3.2	3.2

Real price changes also have a major effect on prospective returns. In the unlikely event that real price did not increase for the next 120 years, required volume improvement would be 20.5 percent, a marginal possibility.

The success of tree improvement programs in western conifers depends on the application of intensive silviculture, including intermediate cuts or thinning. If no thinnings were made so that all improvement was realized at rotation age 120 years, an improvement program could not possibly pay for itself. Even if the rotation were reduced to 60 years, the required improvement in volume would be 30 percent.

Site index also affects profitability in inverse fashion. If site productivity is doubled, the improvement necessary to attain the break-even point is halved. The lesson is that tree improvement should be practiced on the most productive sites first.

In common with most improvement programs, the ponderosa pine program runs a biological risk of losing locally adapted populations. It uses a high selection intensity with the assumption that widely adapted parents can be found in adequate numbers to maintain a broad genetic base. The larger the scale (that is, the higher the selection intensity and the broader the breeding zone in which the selected parents will be used), the greater the economic returns, but the greater the biological risk. Would the ponderosa pine program be profitable if breeding zones were reduced in size so that they supported a planting program of only 1400 acres as against 2800 acres? A breeding zone supporting a planting program of 1400 acres is suggested because it is comparable in size to those in the Pacific Northwest's progressive tree improvement program. Because of lower seed requirements, the orchard is cut to 7 acres, a size that increases the present value of costs to \$47,276 per acre of orchard or \$236.38

per acre of plantation. Costs per acre are increased even though establishment and maintenance costs are reduced because selection and progeny test costs remain the same and there are fewer acres over which to spread these costs. In this situation the required improvement is 9.1 Mbf per acre, or 9.1 percent (*table 2*) compared with only 6.3 percent for the larger original program, despite higher total costs for the latter. The difference could be one of profitability or nonprofitability, and emphasizes the economic desirability of large breeding zones. However, smaller breeding zones involve less biological risk and a 9.1-percent gain to return 8 percent on the investment is not unattainable through the genetic approach. Therefore, smaller breeding zones may be justifiable, depending on goals and investment policy.

Doubling seed yield is more problematic. Most analyses have indicated that the profitability of improvement programs strongly depends on seed yields (Danbury 1971, Marquis 1973). But this conclusion is reached by assuming that higher seed yields can be used to expand the planting program. If doubling seed yield merely results in halving the size of the seed orchard and its associated costs, then the required increase in volume in improved plantations is 4.6 percent, only 1.7 percentage points lower than the base case. This results because the cost reduction for orchard establishment and maintenance is a relatively small amount compared with costs of selection and progeny evaluation. The only way to substantially reduce costs is by reducing the genetic base, a highly undesirable approach. In addition, small orchards present a problem in pollen management.

If doubling seed yields in the ponderosa pine program means doubling the planted acreage, then even without a reduction in orchard costs it would only be necessary for improved plantations to yield 3.2 Mbf per acre more at maturity than unimproved plantations to break even as against the 6.3 Mbf required with lower seed yields. Note that doubling the planting program means doubling the size of the breeding zone, and with the same number of selections is equivalent to a reduction in the genetic base per unit operating area. Increasing the scope of the planting program (or, what is the same thing, the size of the breeding unit) offers potential for improving profitability, but entails a biological risk.

In summary, economic factors such as interest rate and real price changes are the major determinants of profitability in a long-rotation, western conifer. The silvicultural system in which tree improvement is applied is also important. Length of rotation and utilization of thinnings have more effect on profitability than program design. However, program design and operation are under control of the breeder, whereas interest rate and price changes are not. Reducing the size of the breeding zone will increase costs per acre of improved plantation and increase the amount of improvement required to earn the desired return on investment. Increasing seed yields in the seed orchard will have a limited effect on profitability unless the increased yields can be used to increase the size of the planting program, which is equivalent to increasing the size of the breeding zone. The exception would be efforts to improve seed yields at early orchard ages, either by attempting to reach commercial production prior to age 14 and/or increasing early yields. We were forced to assume a uniform level of seed production in the analysis, whereas actual production is low in the beginning and increases throughout the early years of the orchard.

FIRST-STAGE PROGRESSIVE PROGRAM FOR DOUGLAS-FIR

In a progressive tree improvement program, better-than-average trees are selected along roadsides by subjectively grading them against some perceived standard for the breeding zone. Accessibility and evidence of cone production are the major criteria because the selected trees must provide seed for planting without further multiplication in seed orchards. A large number of trees are selected, perhaps 300 for each 100,000-acre operating unit, to ensure a broad genetic base. Because of the emphasis on accessibility and cone production and the desire to maintain the genetic base, selection intensity in many cooperatives is low for growth rate and form.

Characteristics and economic base for the progressive tree improvement program for Douglas-fir are:

Characteristics	
Commercial seed production of selected trees	1 to 18 years
Rotation age	80 years
Operating area	100,000 acres
Annual planting	1,250 acres
Seedlings planted per acre	500 seedlings
Economic assumptions	
Interest rate	8 percent
Stumpage (second growth)	$275 per Mbf
Normal yield of unimproved forest at 80 years, site III land, site index of 130 (McArdle and others 1961)	66.8 Mbf

The initial seed collections are used for progeny testing. When progeny tests reveal differences among parents, seed collection from the poorer parent trees is discontinued. Eventually, seed collection is concentrated on the 75 trees that produce the best progeny. At this point, several options are available for moving into a second-stage program; for example, either collecting the superior parents into a clonal seed orchard or initiating another generation by selecting among the best of the progeny. Because it is likely that a second-stage program will follow, we assumed for purposes of calculation that seed collection from the selected trees will continue only from year 1 to year 18. Costs for this initial program include only selection and progeny testing (*table 3*). Costs of seed collection are not included because these would be at least as high if there was no improvement program. Similarly, we ignore costs

Table 3—*Incremental costs per acre of improved plantation for a first-stage, progressive tree improvement program for Douglas-fir*[1]

Activity	Cost per acre planted (1979 dollars)	Year cost incurred
Tree selection and release	$ 10.93	1
Progeny testing	189.32	1 to 16
Total present value of cost @ 8 percent	$166.48	

[1]Data in 1974 dollars supplied by Roy R. Silen, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon. Costs brought to 1979 at 8 percent, a rate approximating the 1974-1979 change in the producer price index for all commodities.

of plantation establishment and culture, which would be the same with or without tree improvement.

Although Silen and Wheat (1979) assume an 80-year rotation without thinning, it seems likely that thinning will become more common in the Pacific Northwest. For land with a site index of 170 on the Siskiyou National Forest in Oregon, a volume of 63.9 Mbf per acre is expected without thinning on a rotation of 85 years. If the same stands are thinned at 10-year intervals beginning at age 25, then the accumulated cut from thinnings and harvest at 85 years would be 105.3 Mbf per acre. Therefore, for our analysis we assumed thinnings at 40, 50, 60, and 70 years. For arguments similar to those used for the ponderosa pine program, we distributed most benefits to the earliest thinnings, 30 percent of the total genetic gain in volume for the rotation to the thinning at 40 years, 40 percent at 50 years, and 10 percent to thinnings at 60 and 70 years and to the harvest at 80 years.

To evaluate the program, we set the present marginal value of costs per acre planted, $166.48 (*table 3*) equal to the present value of benefits:

$$\$166.48 = B \times \frac{I}{C}$$
$$= [(1.08^{18} - 1)/(0.08)(1.08)^{18}] \times [0.3I/1.08^{41} + 0.4I/1.08^{51} + 0.1I/1.08^{61} + 0.1I/1.08^{71} + 0.1I/1.08^{81}],$$

in which factors are as in the analysis of the ponderosa pine program. The break-even value for I is $799.56 over returns from normal unimproved plantations.

A conservative value for second-growth Douglas-fir stumpage in the Pacific Northwest is currently $275 per Mbf. We assume a real price increase of 1.5 percent per year and solve for T, the volume improvement equivalent to the break-even value of $799.56:

$$\$799.56 = [(\$506.34)(0.3) + (\$587.63)(0.4) + (\$681.96)(0.1) + (\$791.45)(0.1) + (\$918.51)(0.1)] \times T$$

Solving, T = 1.2 Mbf per acre increase over the base of 66.8 Mbf per acre of normal unimproved plantation, a 1.8 percent improvement. However, 66.8 Mbf per acre is volume at final harvest. Accumulated thinnings would bring production to more than 100 Mbf per acre, so the required improvement in volume to reach the break-even point would be less than 1.2 percent.

A sensitivity analysis (*table 4*) was used to explore several factors and how they affected the profitability of the progressive program. As for the ponderosa pine program, site quality and changes related to appreciation of timber values and utilization of smaller logs have a major effect on profitability. Failure to realize any real annual price increase will more than double the amount of improvement necessary to break even at 8 percent. Length of rotation also has a major effect. Most industrial landowners in the Pacific Northwest currently think in terms of short rotations. For a rotation of 50 years the required volume increase to break even on the investment in tree improvement even without thinnings is only 1.5 Mbf per acre or 4.9 percent more than the yield of normal unimproved stands (31.4 Mbf per acre at 50 years with a site index of 130; McArdle and others 1961). But a reduction in rotation age from 80 to 50 years is equivalent to increasing the size of the planting program to 2000 acres per year and can be accomplished only if the selected trees produce adequate seed to serve the additional planting requirement. Short rotations will substantially reduce the improvement required to break even on an 8-percent-interest rate. If tree improvement efforts are restricted to sites of higher quality, the required improvement is even more easily attainable. With a site index of 170, only a 1.2-percent improvement in yield will pay for a tree improvement program.

We assume that program costs can be reduced only by reducing the scope of the program. If half as many

Table 4—*Sensitivity analysis for a first-stage, progressive tree improvement program for Douglas-fir*

Assumptions	Required volume improvement	
	Mbf per acre	Percent
Base case	1.2	1.8
Changes		
Interest rate is 5 percent	0.3	0.4
Interest rate is 11 percent	4.8	7.3
No real price increase	2.9	4.4
No thinnings	9.9	14.8
No thinnings, rotation is reduced to 50 years	1.5	4.9
No thinnings, rotation is reduced to 50 years, no real price increase	3.3	10.4
No thinnings, rotation is reduced to 50 years, interest rate is 11 percent	7.1	22.6
Number of selections is halved to 150	0.6	0.9
Number of selections is halved, no thinnings	4.9	7.4
Selected trees are used for seed production twice as long (that is, 36 years)	1.0	1.4
Site index is 170	1.2	1.2
Site index is 170, no thinnings	9.9	9.6

selections will suffice at the risk of narrowing the genetic base, the required volume increase for improved plantations drops from 1.8 percent to only 0.9 percent. Assuming a longer period of seed production for the selected trees has less effect, doubling their productive life drops the required improvement only 0.4 percentage points to 1.4 percent, so there is little economic advantage in delaying the start of a second-stage program.

In summary, because of the low cost of the progressive program only small improvements are necessary to return the investment. This is well, because initial gains are not expected to be large either. As was the situation for the ponderosa pine program, interest rate, real price changes, length of rotation, and thinning have major effects on profitability. Program changes such as reducing the number of selections or increasing the size of the breeding zone will increase profitability but will also increase the biological risk.

SECOND-STAGE PROGRESSIVE PROGRAM FOR DOUGLAS-FIR

At some point, the present progressive tree improvement cooperatives must decide whether to enter the second stage; that is, to establish seed orchards. A likely second-stage scenario for Douglas-fir is to establish seed orchards with seedling progeny of selected parents. Seedling seed orchards avoid incompatibility, a common problem in grafted Douglas-fir seed orchards. The seedling orchard is established by pairing the 300 selected parents in any desired combination and crossing them to produce full-sib seedling progeny; that is, progeny with both parents known. The full-sib families are planted in a standard design to maximize separation between replicates of the same family, and when progeny test results are available, the poorer families and the poorer individuals in superior families are removed, leaving the best individuals in the best families. At the earliest, the orchard can be established 3 years after inception of the second stage program and commercial seed production will begin 15 years later. Usable life of the orchard is 18 years, or until the 36th year of the program, at which time another orchard should be in production if the program progresses to a third stage.

To make the scope of the program comparable to that of the first stage we assumed that an orchard of 1 acre could supply an annual planting program of 1250 acres. The assumption is predicated on the basis that 1 acre of orchard is sufficient to supply between 982,000 to 1,767,000 seed[1] (Silen 1978, Owston and Stein 1974). Therefore, with a 50-percent nursery cull and a planting density of 500 seedlings per acre, 1 acre of properly sited orchard should be capable of supplying an annual planting of 1000 to 1800 acres. The estimate is lower than that of some orchards. In the St. Paul Seed Orchard in Salem, Oregon, 1 acre of orchard, with one good seed year in every three, can supply sufficient seed to plant 6000 acres, but a safety factor of two is allowed.[2] Within reasonable limits, seed yields per acre will be independent of orchard density, although yields per tree decline with increasing density. Our assumption that an acre is sufficient to plant 1250 acres per year is likely conservative. However, we realize that such a small orchard would present management problems and be an inefficient operation.

We assumed that a first-stage progressive program was already underway so costs of selection and progeny testing were not included in the second-stage analysis.

Program characteristics and economic base for a second-stage, progressive tree improvement program are:

Characteristics

Number of trees selected	300 trees
Number of single pair matings	150 crosses
Commercial seed production of orchard begins	18 years
Orchard phased out	36 years
Production per acre of orchard per year	625,000 seedlings
Rotation age	80 years
Operating area	100,000 acres
Annual planting	1,250 acres
Seedlings planted per acre	500 seedlings
Seed yield per acre of orchard	1,250,000 seed
Nursery cull	50 percent

Economic Assumptions

Interest rate	8 percent
Stumpage (second growth)	$275 per Mbf
Normal yield of unimproved forest at 80 years, site III land, site index of 130 (McArdle and others 1961)	66.8 Mbf

[1] Personal correspondence from Virgil Allen, Dennie Ahl Seed Orchard, Shelton, Washington, May 31, 1979.

[2] Personal correspondence from Jack Wanek, St. Paul Seed Orchard, Salem, Oregon, June 1, 1979.

Table 5—*Costs per acre of seedling seed orchard in a second-stage, progressive tree improvement program for Douglas-fir*[1]

Activity	Cost per acre orchard (1979 dollars)	Year cost incurred
Single pair crossing	$37,500	2
Seedling production	80	3
Orchard establishment	1,000	5
Orchard maintenance[2]	100/yr	6 to 36
Total present value per acre orchard	$36,360	
Total present value per acre plantation	$29.09[3]	

[1] Based on personal correspondence with Roy R. Silen, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon, and Jack Wanek, St. Paul Seed Orchard, Salem, Oregon.

[2] Maintained as progeny test from years 6 through 18.

[3] Obtained by dividing cost per acre of seed orchard by 1250 acres plantation per acre seed orchard.

Table 6—*Sensitivity analysis for a second-stage, progressive tree improvement program for Douglas-fir*

Assumptions	Required volume improvement	
	Mbf per acre	Percent
Base case	0.6	1.0
Changes		
Interest rate is 5 percent	0.1	0.1
Interest rate is 11 percent	4.2	6.3
No real price increase	1.9	2.8
No thinnings	4.9	7.4
No thinnings, rotation is reduced to 50 years	0.8	2.5
No thinnings, no real price increase, rotation is reduced to 50 years	2.1	6.7
No thinnings, rotation is reduced to 50 years, interest rate is 11 percent	5.8	18.5
Selection and progeny testing charged to second stage	4.3	6.5
Selection and progeny testing charged to second stage but size of breeding zone increased tenfold	0.5	0.7

Using these data and *table 5*, we set costs per acre of plantation equal to benefits as before:

$$\$29.09 = [(1.08^{18} - 1)/(0.08)(1.08^{18})] \times [0.3I/1.08^{58} + 0.4I/1.08^{68} + 0.1I/1.08^{78} + 0.1I/1.08^{88} + 0.1I/1.08^{98}],$$

where factors are as in previous equations. Solving, the break-even point, I, is a present-valued return of $516.98. Allowing for a 1.5-percent real price increase in stumpage, this translates to 0.6 Mbf per acre increase over normal, unimproved plantation yields or only 1.0 percent of 66.8 Mbf per acre. Differences of this degree are not detectable in most field tests and seem easily attainable by tree improvement.

A sensitivity analysis was run to test the effect of several factors on profitability (*table 6*). What happens when selection and progeny testing are charged to the second stage of the progressive program? This is equivalent to the situation in which an incipient progressive program enters a seed orchard phase from the beginning without relying on selections for *in situ* seed collection. The progressive program then converges in approach with the Pacific Southwest program. In that situation, the required volume improvement to pay an 8-percent return on investment is 6.5 percent, an expectation well within reasonable limits of the genetic approach. However, if we speculatively increase the scope of the program (continuing to charge selection and progeny testing to the second stage) to serve 1,000,000 acres rather than 100,000, the required improvement is reduced nearly tenfold, to 0.5 Mbf per acre or 0.7 percent of unimproved yields. The difference between 6.5 percent and 0.7 percent improvement illustrates the influence of scale on profitability, but increase in scale increases the risk of losing locally adapted populations.

CONCLUSIONS

Economic assumptions and silvicultural decisions have more effect on the profitability of the three tree improvement programs analyzed than do program design or costs. Tree improvement combined with intensive silviculture and better utilization of smaller materials in thinnings results in a highly profitable picture. Tree improvement is only one component of intensive forest management practices to improve forest production. If returns from tree improvement are realized early in the rotation through commercial thinnings, only small improvements in growing stock can amply repay the investments in a breeding program. In fact, under reasonable expectations internal rates of return should be substantially higher than 8 percent. However, without intermediate cutting, realistic rates of interest cannot be carried over long rotations of 80 to 120 years without substantial benefits that seem beyond the possibilities of the genetic approach. With shorter rotations of 50 years, investment in tree improvement can be easily justified.

Benefits from improvement in stem and crown form were not considered in our analysis, but such gains are anticipated and would improve the financial outlook. Almost all tree improvement programs select for stem and crown form. Straighter stems and smaller branches reduce handling costs and improve grade recovery and merchantable yields.

In time the Pacific Southwest and the progressive programs will converge in practice, particularly as better information develops on the genetic resource. The second stage progressive program with costs of selection included differs from the Pacific Southwest program in the emphasis placed on selection of trees on the basis of their appearance, in the size of the breeding zone, and in slightly lower costs of establishment for seedling rather than clonal orchards. Genetic improvement is almost certain to be greater in the Pacific Southwest program where select trees interbreed in seed orchards than in the first stage progressive program. Although the required improvement to return the investment is small for a first stage progressive program, neither are large gains anticipated. Improvement is directly proportional to selection intensity, and in the first-stage progressive program, selection intensity is low. Furthermore, select-trees are wind-pollinated *in situ*, so that the pollen parents represent unselected trees, presumably the population average. Crossing of select parent trees back to the population should result in only half the improvement attainable by intercrossing of selected parents in seed orchards. Conversely, the larger breeding zone and higher selection intensity of the Pacific Southwest program constitute a biological risk that cannot be evaluated without detailed information on seed source and progeny variation. Nor is it conclusively demonstrated that selection in natural stands is effective for western conifers. In the second-stage progressive program, progeny from seed orchards are likely to equal or exceed the gains achieved in first generation orchards made up of selections from natural stands, as used in more traditional programs.

Direct economic comparison of the programs for the two species is not possible because of differences in biological assumptions. For example, seed production of Douglas-fir and ponderosa pine differ, so the ratio of seed orchard to planting acreage differs greatly. In addition, costs, although current, are not the same for the two analyses. Orchard maintenance for ponderosa pine in the Pacific Southwest is manyfold greater than similar figures we obtained for Douglas-fir in the Pacific Northwest. Despite their differences both approaches appear to be quite profitable given the available information.

LITERATURE CITED

Carlisle, A., and A. H. Teich.
1978. **Analysing benefits and costs of tree-breeding programmes.** Unasylva 30(119-120):34-37.

Danbury, D. J.
1971. **Seed production costs for radiata pine seed orchards.** Aust. For. 35:143-151.

Davis, L. S.
1967. **Investment in loblolly pine clonal seed orchards.** J. For. 65:882-887.

Kitzmiller, J. H.
1976. **Tree improvement master plan for the California Region.** Region 5. Forest Serv., U.S. Dep. Agric., San Francisco, Calif., 123 p.

McArdle, R. E., W. H. Meyer, and D. Bruce.
1961. **The yield of Douglas-fir in the Pacific Northwest.** U.S. Dep. Agric. Tech. Bull. 201, 74 p. U.S. Gov. Print. Off., Washington, D.C.

Marquis, D. A.
1973. **Factors affecting financial returns from hardwood tree improvement.** J. For. 71:79-83.

Owston, P. W., and W. I. Stein.
1974. ***Pseudotsuga* Carr. Douglas-fir.** *In* Seeds of woody plants in the United States. C. S. Schopmeyer (tech. coord.), U.S. Dep. Agric., Agric. Handb. 450, Washington, D.C., p. 674-683.

Perry, T. O., and C. W. Wang.
1958. **The value of genetically superior seed.** J. For. 56:843-845.

Porterfield, R. L., and F. T. Ledig.
1977. **The economics of tree improvement programs in the Northeast.** *In* Proc. Twenty-fifth Northeast. Forest Tree Improv. Conf. [July 27-29, 1977], Orono, Maine, p. 35-47.

Porterfield, R. L., B. J. Zobel, and F. T. Ledig.
1975. **Evaluating the efficiency of tree improvement programs.** Silvae Genetica 24:33-44.

Silen, R. R.
1966. **A simple, progressive tree improvement program for Douglas-fir.** U.S. Forest Serv. Res. Note PNW-45, 13 p. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

Silen, R. R.
1978. **Genetics of Douglas-fir.** USDA Forest Serv. Res. Paper WO-35, 34 p. Forest Serv., U.S. Dep. Agric., Washington, D.C.

Silen, R. R., and J. G. Wheat.
1979. **Progressive tree improvement program in coastal Douglas-fir.** J. For. 77:78-83.

USDA Forest Service.
1974. **The outlook for timber in the United States.** U.S. Dep. Agric. Forest Serv., Forest Resour. Rep. 20, Washington, D.C., 374 p.

Ledig, F. Thomas, and Richard L. Porterfield.
1981. **West Coast tree improvement programs: a break-even, cost-benefit analysis.** Res. Paper PSW-156, 8 p. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Three tree improvement programs were analyzed by break-even, cost-benefit technique: one for ponderosa pine in the Pacific Northwest, and two for Douglas-fir in the Pacific Northwest—one of low intensity and the other of high intensity. A return of 8 percent on investment appears feasible by using short rotations or by accompanying tree improvement with thinning. Interest rates, length of rotation, the inclusion of thinnings, and site index had greater effects on profitability than program design. Large breeding zones improved profitability, although they incur the biological risks of nonadaptation to local conditions and loss of local genetic resources. Increasing orchard seed yield affected the results only slightly unless the planting program could be expanded, which is equivalent to increasing the size of the breeding zone. If the increase in seed yield merely reduced the required acreage of seed orchard and associated costs, the financial results improved only slightly.

Retrieval Terms: tree improvement, economic analysis, *Pinus ponderosa, Pseudotsuga menziesii,* sensitivity analysis, minimum genetic gain