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FOREST SERVICE
PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION
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October 31, 1980

Dr. Jay Kitzmiller
Chico Tree Improvement Center
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Dear Jay:

In an attempt to be fair to Roy Silen I rewrote the manuscript on economics of West Coast tree improvement programs. Three other reviewers agreed that a comparison of the PSW and progressive programs was not possible because of the difference in treatment and assumptions. When thinnings were incorporated, the progressive program looked as good as the PSW program. Reviewers also indicated that I should not tout larger breeding zones without mentioning the greater biological risk associated with large breeding zones compared to small zones. Finally I reanalyzed the PSW program using your new cost figures. Thanks for your help.

Because this could be a very sensitive subject, I wanted you to see the new draft before publication. Let me know if you see anything in the manuscript that will cause you problems. Don't be afraid to point out questionable statements.

Sincerely,

Tom

F. THOMAS LEDIG
Project Leader
Institute of Forest Genetics

Economic Aspects of Tree Improvement for Western Conifers

by

F. Thomas Ledig and Richard L. Porterfield

The Authors

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Abstract

A break-even cost/benefit analysis is applied to the U. S. Forest Service, Pacific Southwest Region's improvement program for Sierra conifers and to first and second stages of a "progressive tree improvement program" for Douglas-fir in the Pacific Northwest. Both programs appear easily able to return at least 8% on the investment if short rotations are used or if tree improvement is accompanied by a silvicultural system using early thinnings. Sensitivity analysis was used to suggest ways in which profitability was affected by program design. Scale was important. Large breeding zones improve profitability, although they entail a biological risk of non-adaptation to local conditions and of loss of the local genetic resource. The effect of increasing orchard seed yield is small unless it enables expansion of the planting program. If it merely reduces the required acreage of seed orchard and associated costs, the financial picture is improved only slightly.

Introduction

Several analyses have demonstrated that tree improvement is a highly profitable investment (e.g. Porterfield et al. 1975, Carlisle and Teich 1977, Davis 1967). In general, only small levels of improvement are necessary to justify expenditures (Perry and Wang 1958). However, most analyses have dealt with southern pines that are grown on short rotations, and none have dealt with long-rotation western conifers. Our objective was to explore the economic justification of representative tree improvement programs for western species.

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

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 the early establishment of seed orchards. Nevertheless, 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" has novel features such as small breeding zones, low selection intensity, large numbers of selections, seed collection from selected trees *in situ* rather than establishment of seed orchards, and a major reliance 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 to the "traditional" approach.

Because definitive information on economic benetfits is usually not available in the early stages of tree improvement, program justification is difficult. We employed 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, enabling an objective choice between competing proposals. Furthermore, 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 previously 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 (i.e. orchards established with seedling progeny of wind-pollinated selections) rogued to leave the best trees 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.

Procedure

Although data on costs are limited, it is useful to apply the break-even technique to West Coast tree improvement programs to provide at least some estimate of their potential. The benefit-cost ratio is defined as the present value of benefits divided by the present value of costs, and a ratio of 1.0 or greater indicates a rate of return on investment equal to or higher than the interest rate used in the analysis. The importance of errors in initial assumptions or in cost estimates can be determined by using several sets of assumptions or allowing them to vary one at a time.

The three programs we analysed are actual programs: 1) the Pacific Southwest program for conifers on National Forests in the Sierra Nevada (Kitzmiller 1976), 2) a first stage or low intensity progressive tree improvement program for Douglas-fir followed by 3) a second stage or high intensity program (Silen and Wheat 1979). In the initial analysis we tried to adhere as closely as possible to the published descriptions of these programs. Later we suggested the effect to be achieved by various modifications.

We used an interest rate of 8% for our base rate. A return on investment of 8% seems realistic. Interest rates include a fraction due to inflation and a remainder which is a true interest component. Over the long term appropriate to investments in forestry, inflation runs about 5%. A rule of thumb is that the true rate is about half the nominal. For public investments a return of 5% to 6% is commonly employed (6.2% was used under the Forest and Rangeland Renewable Resources Planning Act, but there is an arguement for a rate of 4%). Because the Pacific Southwest program is a program for the National Forests and many of the cooperators in the Progressive program are also National Forests, a 5% to 6% rate might be appropriate. For industrial members of tree improvement cooperatives a higher rate, say 11%, reflecting present interest rates might be desireable. Therefore, we examined the effect of different interest rates with sensitivity analyses.

Program for the Pacific Southwest Region, Forest Service

The "high level" program of the U.S. Forest Service for the Pacific Southwest Region was described by Kitzmiller (1976). The program includes several species and breeding zones of California conifers, but our analysis was restricted to one species, ponderosa pine, and one breeding zone. Within a breeding zone, 200 selections will be made. Wind-pollinated seed will be collected to establish progeny tests early in the program. Simultaneously, cuttings will be collected to establish a grafted seed orchard at 15 x 15 feet. Using progeny test results as a guide, the orchard will be rogued to the best 50 selections by age 15. Costs are listed in Table 1, and program characteristics in Table 2. Present value of costs per acre of orchard is $30,663 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 establishment of a grafted clone archive to facilitate crosses among the selections, and a program of matings, we ignored those costs. They are correctly aspects of a second generation improvement program, produce no benefits for the first generation, and should not be charged to the first generation.

The Pacific Southwest program assumes a 120-year rotation, but improved yields will be harvested in intermediate thinnings at 40, 50, 60, 70, 80, 90, and 100 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% of the total genetic gain in volume for the rotation to the thinning at age 40, 40% to age 50, and 6.5% to thinnings in each of the next five decades. The benefits occur at the harvest age plus 14 years, the time between initiation of the program and establishment of the first commercial plantations.

To evaluate the program, present marginal values of costs per acre planted were equated to the present value of benefits:

In general form:

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

where:

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 required value increase [(volume gain) x (value/unit)] due to genetic improvement per acre of plantation necessary to return 8% on the investment,

C = a discounting factor required to bring benefits back in time (the year until 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:

$$\$163.22 = [1.08^{30} - 1)/(0.08)(1.08^{30})] \times [0.2I/1.08^{54} + 0.4I/1.08^{64} + 0.065I/1.08^{74} + 0.065I/1.08^{84} + 0.065I/1.08^{94} + 0.065I/1.08^{104} + 0.065I/1.08^{114} + 0.065I/1.08^{124}].$$

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 in order for the benefit-cost ratio to be 1.0 and the return on the tree improvement investment to be just 8%. To translate this into volume improvement we assume a present value of $110/Mbf, which is the California Board of Equalization projected timber value harvest schedule for the Central Sierra in the first half of 1980. However, our best estimate is that timber value will continue to follow the historic trend of 1.5% per year real price increase. Allowing for a 1.5% price increase, we solve for the required volume improvement.

Required gain in value to return 8% on investment is:

$$\$2,250.75 = \sum_{i=1}^{8} Vi \times Wi \times T,$$

where:

V_i = value/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.

So:

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

Solving, T = 6.3 Mbf required gain in volume per acre over normal unimproved plantation to return 8% 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. However, unimproved yields of 80.5 Mbf/acre seem unreasonably small. We would anticipate over 100 Mbf on a medium site at final harvest alone, given a 120-year rotation. Therefore, the required improvement to return the investment of 8% interest is 6.3%. Thinning is likely to salvage timber that would otherwise be lost so total yield over the entire rotation would exceed 100 Mbf/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% in volume from tree improvement seems easily attainable. In southern pine improvement programs, 15% gain is expected in the first generation. A 15% gain in the Pacific Southwest Program would pay a high internal rate of return on investment.

We examined the effects of modifications to the Pacific Southwest program by varying the assumptions and recalculating the improvement necessary to break even (Table 3). An interest rate of 5% has the effect of reducing required improvement to such ridiculously low levels that an economic return seems certain. On the other hand, a rate of 11% would require an improvement of 35.4% 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. Real price changes also have a major effect on prospective returns. In the unlikely event that real price remained stable for the next 12 years, required volume improvement would be 20.5%, 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 of 120 years, an improvement program could not possibly pay for itself. However, if the rotation was reduced to 60 years, the required improvement in volume would be only 5.1%, even without the application of intermediate thinnings.

Site index also affects profitability in inverse fashion. If site productivity is doubled, then 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 Pacific Southwest program runs a biologic risk of losing locally adapted populations. It uses a high selection intensity under the assumption that widely adapted parents can be found in adequate numbers to maintain a broad genetic base. The larger the scale (i.e. 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 Pacific Southwest program be profitable if breeding zones were reduced in size so they supported a planting program of only 1,400 acres (vs. 2,800 acres)? A breeding zone supporting a planting program of 1,400 acres is chosen because it is comparable in size to those in the Pacific Northwest's progressive tree improvement program. Because of lower seed requirements, the size of the orchard is cut to 7 acres, which increases the present value of costs to $47,276/acre of orchard or $236.38/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. Under this situation the required improvement is 9.1 Mbf/acre, or 9.1% (Table 3) compared to only 6.3% with the larger original program, despite higher total costs for the latter. The difference could be one of profitability or non-profitability, and emphasizes the economic desireability of large breeding zones. However, small breeding zones would involve less biological risk and 9.1% gain is not unattainable through the genetic approach and would return 8% on the investment. Therefore, smaller breeding zones might be justifiable, depending on goals and investment policy.

Doubling seed yield is more problematic. Most analyses have indicated that the profitability of improvement programs is strongly dependent 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%, only 1.6 percentage points lower than the base case. This results because the cost reduction for orchard establishment and maintenance is a relatively small amount compared to 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 Pacific Southwest program meant 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/acre(vs. the 4.3 Mbf above) more at maturity than unimproved plantations to break even. Note that doubling the planting program would mean 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 great 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 will be applied is also important. The length of rotation and the 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 return the 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.

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 important 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. Typical program characteristics are provided in Table 4. Because of the emphasis on accessibility and cone production and the desire to maintain the genetic base, selection intensity is necessarily low for growth rate and form.

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 which produce the best progeny. At this point, there are several options for moving into a second stage program; for example, either collecting the superior parents into a clonal seed orchard or initiating a second generation by selecting among the best of the progeny. Assuming the second stage program begins at once, with the establishment of a seed orchard by year three, and with orchard seed production by year 18, seed collection from the parent trees will continue only from year one to year 18. Costs for this initial program include only selection and progeny testing (Table 2). 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 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 Northwest. For site index 170 land on the Siskiyou National Forest a volume of 63.9 Mbf/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/acre. Therefore, for our analysis we assumed thinnings at 40, 50, 60, and 70 years. For arguments similar to those used for the Pacific Southwest program we distributed most benefits to the earliest thinnings, 30% of the total genetic gain in volume for the rotation to the thinning at 40 years, 40% at 50 years, and 10% to thinnings at 60 and 70 years and to the harvest at 80 years.

To evaluate the Progressive Program, we set the present marginal value of costs per acre planted, \$166.48 (Table 5) equal to the present value of benefits:

$$\$166.48 = B \times \frac{I}{C}$$

$$= [(1.08^{18} - 1)/(.08)(1.08)^{18}] \times [0.3I/1.08^{41} + 0.4I/1.08^{51} + 0.1I/1.08^{61} + 0.1I/1.08^{71} + 0.1I/1.08^{81}],$$

where factors are as in the analysis of the Pacific Southwest program. The break-even value for I is \$799.56 over returns from normal unimproved plantations.

A conservative value for Douglas-fir stumpage in the Pacific Northwest is \$275/Mbf. We assume a real price increase of 1.5% 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/acre increase over the base of 66.8 Mbf/acre of normal unimproved plantation, a 1.8% improvement. However, 66.8 Mbf/acre is volume at final harvest. Accumulated thinnings would bring production to over 100 Mbf/acre, so the required improvement in volume to reach the break-even point would be less than 1.2%.

A sensitivity analysis (Table 6) was used to explore several factors and how they affected the profitability of the progressive program. As for the Pacific Southwest 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%. Length of rotation also has a major effect. Most industrial landowners in the Pacific Northwest presently 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/acre or 4.9% over the yield of normal unimproved stands (31.4 Mfb/acre at 50 years on site index 130; McArdle <u>et</u> <u>al</u>. 1961). But it should be noted that 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 only be accomplished if the selected trees produce adequate seed to serve the additional planting requirement. Taken together, short rotations and a real price increase will substantially reduce the improvement required to break-even on an 8% 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% 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. For example, if half as many selections will suffice at the risk of narrowing the genetic base, the required volume increase for improved plantations drops from 1.8% to only 0.9%. Assuming a longer period of seed production for the selected trees has less effect; doubling the productive life drops the required improvement only 0.4 percentage points to 1.4%.

In summary, with the low cost of the progressive program very small improvements are necessary to return the investment. This is well, because initial gains are not expected to be large either. As was the case for the Pacific Southwest 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 also increase 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; i.e. 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 incompatability which is 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 (i.e. both parents known) seedling progeny. 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. Under ideal conditions, the orchard can be established three years after inception of the second stage program and commercial seed production will begin 15 years later. Useable life of the orchard is 18 years, or until the 36th year of the program, at which time a second generation orchard should be in production.

To make the scope of the program comparable to that of the first stage we assume that an orchard of one acre could supply an annual planting program of 1,250 acres. The assumption is predicated on the basis that one acre of orchard is sufficient to supply between 982,000 to 1,767,000 seed (Silen 1966; Owston and Stein 1974; Virgil Allen, personal communication). Therefore, with a 50% nursery cull and a planting density of 500 seedlings per acre, one acre of properly sited orchard should be capable of supplying an annual planting of 1,000 to 1,800 acres. The estimate is low compared to that of some orchards. In the St. Paul Seed Orchard in Salem, Oregon one acre of orchard, with one good seed year in every three, can supply sufficient seed to plant 6,000 acres, but a safety factor of two is allowed (Jack Wanek, personal communication). 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 1,250 acres per year is likely conservative. However, we realize that such a small orchard would present management problems and be an inefficient operation.

It was 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. Using the data in Tables 7 and 8, we set costs per acre of plantation equal to benefits as before:

$$\$29.09 = \frac{1.08^{18} - 1}{(0.08)(1.08^{18})} [0.3I/1.08^{56} + 0.4I/1.08^{66} + 0.1I/108^{76} + 0.1I/1.08^{86} + 0.1I/1.08^{96}],$$

where factors are as in previous equations. Solving, the break-even point, I, is a present-valued return of $443.17. Allowing for a 1.5% real price increase in stumpage, this translates to 0.6 Mbf/acre increase over normal, unimproved plantation yields or only 0.8% of 66.8 Mbf/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 9). It is interesting to consider 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 collections. The progressive program then converges with the Pacific Southwest program . In that case, the required volume improvement to pay an 8% return on investment is 5.7%, an expectation well within reasonable limits of the genetic approach. However, if the scope of the program (continuing to charge selection and progeny testing to the second stage) is increased to serve 1,000,000 acres rather than 100,000, then the required improvement is reduced nearly ten-fold, to 0.4 Mbf/acre or 0.6% of unimproved yields. The difference between 5.7% and 0.6% improvement illustrates the influence of scale on profitability, but an increase in scale increases the risk of losing locally adapted populations.

Conclusions

It is immediately apparent that economic assumptions and silvicultural decisions have more effect on the profitability of West Coast tree improvement programs than program design or costs. Tree improvement combined with intensive silviculture and better utilization of smaller materials 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, then only small improvements in growing stock can amply repay the investments in a breeding program. In fact, internal rates of return should be substantially higher than 8% under reasonable expectations. 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. Under shorter rotations of 50 to 60 years, investment in tree improvement can be easily justified.

Benefits from improvement in stand and crown form were not taken into account in our analysis, but gain in these areas is anticipated and would improve the financial outlook. Virtually 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.

The Pacific Southwest and the progressive programs will converge in time, 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 based on 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 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.

Direct economic comparison of the two programs is not possible because of these and other 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 the Pacific Southwest is manyfold greater than simliar figures we obtained for Douglas-fir in the Northwest.

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Table 1. Present value of costs per acre of seed orchard in the Pacific Southwest Region's tree improvement program for ponderosa pine.

Activity	Present value/ acre orchard	Year cost incurred
Selection and cone collection	$1,825	1
	1,690	2
Orchard establishment	4,576	3
	4,237	4
	3,923	5
Orchard maintenance (annual)	4,275	4-44
Progeny test establishment	4,636	3
	4,293	4
Progeny test maintenance	86	4
	158	5
	146	6
	68	7
Progeny test maintenance (annual)	227	8-20
Progeny test evaluation	87	5-8
	436	9-20
Total Present Value/Acre Orchard	$30,663	
Total Present Value/Acre Plantation	$ 153.32[1]	

[1] To obtain cost per acre of plantation established with seed orchard seed, divide by 200 acres plantation/acre seed orchard.

Table 2. Program characteristics and economic base for the Pacific Southwest Region's tree improvement program for ponderosa pine.

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%
Stumpage	$110/Mbf
Normal yield of unimproved forest at 120 years	100 Mbf

Table 3. Sensitivity analysis for the Pacific Southwest Region's tree improvement program for ponderosa pine.

Assumptions	Required volume increase (Mbf/acre)	Required improvement (%)
Base case	6.3	6.3
Changes		
Interest rate is 5%	0.9	0.9
Interest rate is 11%	35.4	35.4
Real price remains stable	20.5	20.5
No thinnings	211.6	211.6
No thinnings, rotation is 60 years	5.1	5.1
Site index increased, normal unimproved yields 150 Mbf/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

Table 4. Program characteristics and economic base for a first-stage, progressive tree improvement program for Douglas-fir.

Characteristics	
Commercial seed production of selected trees	1-18 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%
Stumpage (second growth)	$275/Mbf
Normal yield of unimproved forest at 80 years, site III land, site index 130 (McArdle *et al.* 1961)	66.8 Mbf

Table 5. Incremental costs per one acre of improved plantation for a first-stage, progressive tree improvement program for Douglas-fir.[1)]

Activity	(1979 dollars) Cost/acre planted	Year cost incurred
Tree selection and release	$ 10.93	1
Progeny testing	189.32	1-16
Total present value of cost @ 8%	$167.10	0

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

Table 6. Sensitivity analysis for a first-stage, progressive tree improvement program for Douglas-fir.

Assumptions	Required volume increase (Mbf/acre)	Required improvement (%)
Base Case	1.2	1.8
Changes		
1. Interest rate is 5%	0.3	0.4
2. Interest rate is 11%	5.1	7.6
3. Real price remains stable	2.9	4.4
4. No thinnings	9.9	14.8
5. No thinnings, rotation is reduced to 50 years	1.5	4.9
6. No thinnings, rotation is reduced to 50 years, no real price increase	3.3	10.5
7. Number of selections is halved to 150	0.6	0.9
8. Number of selections is halved, no thinnings	4.9	7.4
9. Selected trees are used for seed production twice as long (i.e. 36 years)	1.0	1.4
10. Site index is 170	1.2	1.2
11. Site index is 170, no thinnings	9.9	9.6

Table 7. Costs per acre of seedling seed orchard in a second-stage, progressive tree improvement program for Douglas-fir[1].

Activity	Cost/acre orchard (1979 dollars)	Year cost incurred
Single pair crossing	$37,500	2
Seedling production	80	3
Orchard establishment	1,000	5
Orchard maintenance [3]	100/yr	6-36
Total present value/acre orchard	$36,360	0
Total persent value/acre plantation	$29.09[2]	

[1] Costs based on personal communications with R. R. Silen and J. Wanek.

[2] To obtain cost per acre of plantation established with seed orchard seed, divide by 1,250 acres plantation/acre seed orchard.

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

Table 8. Program characteristics and economic base for a second-stage, progressive tree improvement program for Douglas-fir.

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%
Economic Assumptions	
Interest rate	8%
Stumpage (second growth)	$275/Mbf
Normal yield of unimproved forest at 80 years, site III land, site index 130 (McArdle et al. 1961)	66.8 Mbf

Table 9. Sensitivity analysis for a second-stage, progressive tree improvement program for Douglas-fir.

Assumptions	Required Volume Increase (Mbf)	Required Improvement (%)
Base Case	0.6	0.8
Changes		
Interest rate is 5%	0.04	0.06
Interest rate is 11%	0.7	1.1
Real price remains stable	1.6	2.4
No thinnings	2.0	3.0
No thinnings, rotation is reduced to 50 years	0.2	0.6
No thinnings, no real price increase, rotation is reduced to 50 years	0.6	1.8
Selection and progeny testing charged to second stage	3.8	5.7
Selection and progeny testing charged to second stage but size of breeding zone increased 10-fold	0.4	0.6