Economic Analysis of A Tree Improvement Program for Western Larch

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*ABSTRACT — An individual-tree simulation model called Prognosis and an economic subroutine called CHEAPO were used to determine financial rotation ages (in this analysis defined as the age at which net present value is maximized) for stands grown with genetically improved and unimproved western larch (*Larix occidentalis*) in north Idaho. Three hypothetical but reasonable growth functions were tested on two site classes. Sensitivity analyses showed that the tree improvement investment was likely to be profitable at 4 and 5 percent discount rates on excellent sites and at 4 percent on good sites. The analysis was most sensitive to changes in discount rate, site quality, and cone production rate. It was moderately sensitive to variation in time to seed production, number of productive orchard years, and differences among the assumed biological functions. As the hypothetical growth functions were designed to be conservative, economic gains are likely to be larger than those indicated in the analysis.*

Tree improvement programs may involve selection of individual trees from throughout an ownership, establishment of progeny tests and seed orchards, clonal propagation, matings between selected individuals in breeding orchards, and production of advanced generations of seed orchards or clonal stock. Such programs involve costs incurred over many years prior to the return on investment. Since the competition for investment dollars has intensified, rigorous economic analysis has become a necessity. Previously published analyses have indicated that even with relatively small genetic gains (well within attainable amounts for most species), intensive high-cost programs can be economically justified. In fact, most analyses have shown that the return on investment is influenced more by changes in discount rates and management regimes than by the expected genetic gains (Marquis 1973, Porterfield et al. 1975, Porterfield and Ledig 1977, Carlisle and Teich 1978, Ledig and Porterfield 1981, 1982).

The main purpose of this article is to evaluate the economic returns of a western larch tree improvement program in north Idaho and to demonstrate the use of an individual-tree simulation model to test the sensitivity of the analysis to alternative economic and biological assumptions. Unique to our study is an examination of three hypothetical growth functions that describe the performance of improved material under field conditions.

Assumptions

In any economic analysis of a tree improvement program, two kinds of biological information are particularly important: the shapes of the growth curves for improved and unimproved material, and the magnitude of the differences between them over time. As little is known about growth functions or volumes of improved material at rotation ages, some previous authors have relied on regional yield tables for unimproved stock, and either assumed fixed increases in volume from the improved stock (Porterfield and Ledig 1977) or estimated the amount of gain necessary at fixed harvest ages for programs just to pay for themselves (Ledig and Porterfield 1981, 1982). These approaches work well for agencies constrained by legal mandates specifying the time of harvest, but many industrial organizations are better served by analyses based on financial rotations. We therefore assumed neither fixed rotation ages nor fixed increases in volume from the improved material throughout the rotation. We based our analysis on the volumes and values at computer-estimated financial rotations, testing three hypothetical but biologically reasonable growth functions for the improved stock.

In the Inland Empire, a computer-based, individual-tree simulation model called the Prognosis Model for Stand Development (Stage 1973, Wykoff et al. 1982) has been designed and calibrated to predict growth and yield under alternative management regimes. With Prognosis, the shapes and magnitudes of the growth curves can be varied, and volume gains can be estimated for each separate set of assumptions. A subroutine called CHEAPO (Medema and Hatch 1979) can be used to determine financial rotation age (the age at which net present value is maximized) Prognosis thus offers a highly sophisticated tool for analysis using well-established growth information for alternative management regimes and alternative hypotheses about differences between improved and unimproved trees.

In 1974, a cooperative tree improvement program was started for western larch as part of the Inland Empire Tree Improvement Cooperative. Rather than use one specific member of the cooperative in our example, we here assume an organization whose aim is to produce larch sawtimber on a large land base in north Idaho. Our hypothetical organization has selected 100 trees in the area of interest and collected cones from them. Other cooperators have selected an additional 200 trees and collected cones from them for progeny tests. The initial seed orchard will include grafted clones of the phenotypically best 100 selections from natural stands (Staubach and Fins 1983). Our organization is responsible for establishing and maintaining one of three 10-acre progeny tests. Seedling needs are 1.3 million annually, enough to plant 2,400 acres per year at a spacing of 9 by 9 feet (538 stems per acre).

The organization will establish a 12-acre seed orchard which when at full capacity will supply the seeds needed annually. Modest genetic gains (specified below) are assumed in the three hypothetical growth functions, including small gains from phenotypic selection under field conditions and early roguing of the orchard. Additional gains from later roguing are not included in the analysis. These modest gains are consistent with those predicted for southern Idaho lodgepole and ponderosa pines, and Douglas-fir in the Rocky Mountains (Rehfeldt et al. 1980, Rehfeldt 1980, 1983) and conservative compared with those used in some other economic analyses in which estimates range between 10 and 25 percent (Porterfield et al. 1975, Zobel 1974).

Steps in the Analysis

Biological yields.—The Prognosis model was used to project the biological yields for both the genetically improved and unimproved stock. Three growth patterns were assumed for the improved stock, and genetic gains were expressed relative to the diameter and height growth of unimproved stock over time. The resulting three functions for the improved material were: (a) a constant volume advantage (equivalent to approximately 8 percent at 10 years); (b) a constant proportional advantage (approximately 8 percent) through the rotation; and (c) a maximum volume advantage of about 18 percent by age 20 years and a decrease in both the absolute and proportional advantage over the rotation until volumes were approximately equal at maturity. The simulated volume yields (*fig. 1*) for each of these assumptions were generated by using appropriate multipliers for height and diameter growth functions in the model. The growth assumptions for improved material were chosen to be conservative.

Analyzing the costs and benefits.—The economic analysis subroutine of the Prognosis Model, CHEAPO, was used to analyze the costs and benefits associated with the projected yields. The revenue produced by a regime is determined by multiplying the volume removed times the regionwide stumpage price for western larch. The costs of planting and other management were identical for improved and unimproved stock, and therefore had no effect on the analysis.

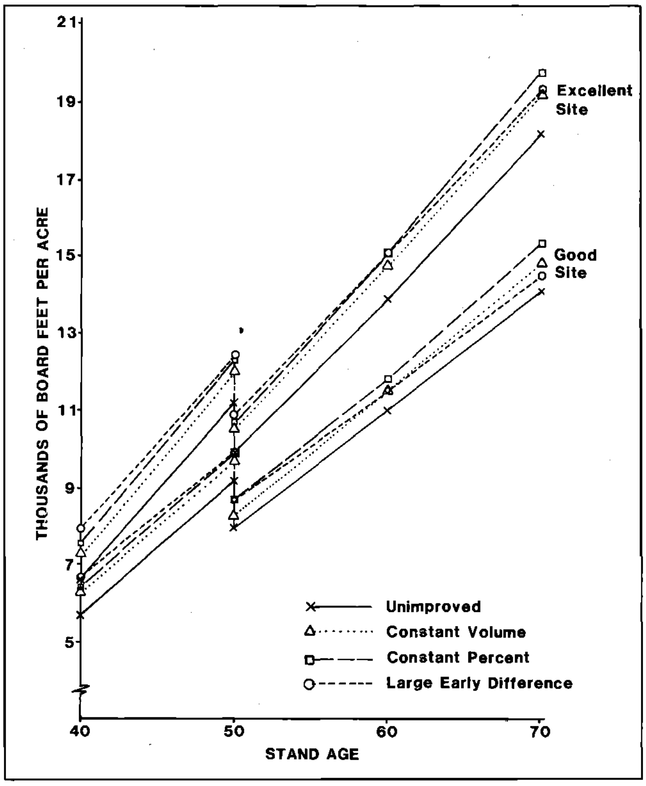

Figure 1. Yields of three hypothetical growth functions for genetically improved and unimproved western larch on good and excellent sites in northern Idaho. Includes commercial thinnings at stand age 50 years. Volume units are given in board feet (Scribner rule to a 6-inch top).

Costs associated with the tree improvement program were charged only to the improved material.

CHEAPO allows for cost and price appreciation or depreciation over time at a specified rate. Most studies agree that real prices of stumpage have increased at a rate of 3.0 to 3.5 percent over time (USDA Forest Service 1973, Mills et al. 1976, Christophersen et al. 1978). We assumed a 2.0 percent stumpage price appreciation. We used real discount rates of 4, 5, and 6 percent to determine the sensitivity of the results to changes in the discount rate.

Our main criterion for preference of improved over unimproved material was financial optimization. That is, the preferred option was the regime and rotation age that produced the largest net financial gains as defined by net present value (NPV). Some previous authors have used similar approaches (Lundgren and King 1965, Schreuder 1971).

Management regime.—One commercial low thinning was scheduled at stand age 50. Financial rotations, based on maximum NPV, were used for all growth assumptions.

Four managed-stand yield tables were produced for each of two site classes: a good site and an excellent site for western larch growth and development. The good site approximated a *Thuja/Pachistima* habitat type and the excellent site was a *Tsuga/Pachistima* (Daubenmire and Daubenmire 1968).

Tree improvement assumptions.—In our base case we assumed that seed production begins at year 7 after orchard establishment, and that the productive life of the orchard is 25 years. The orchard, planted initially at 28 by 7 feet (222 trees per acre) with 100 clones, occupies 12 acres. Final average spacing will be 28 by 28 feet, with 25 clones remaining. Seed yields are estimated at 0.5 lb per bushel of cones—enough to provide 7M plantable seedlings (USDA 1982). The progeny test occupies 10 acres and will be maintained for 25 years. The costs listed for tree improvement (*table 1*) were based on recent experience of local managers.

Given our critical assumption of early seed production in the base case, it was important also to examine the effects of both delayed seed production and a compensating pro-

Table 1. Activity costs for the tree improvement program —base case.

Activity	Cost per orchard acre	Program age	Net present value at discount rates of —		
			4 pct.	5 pct.	6 pct.
	Dollars	*Years*	*Dollars*		
Tree selection[a]	1,250	1	1,250	1,250	1,250
Grafting[b]	1,778	2	1,644	1,613	1,582
Orchard establishment	750	2	693	680	667
Orchard management[c]	1,150	3–31[d]	17,363[d]	15,041[d]	13,123[d]
Progeny test establishment[e]	1,833	2	1,695	1,665	1,631
Test maintenance and evaluation	167	3–27	2,319	2,033	1,792
TOTAL COSTS			24,964	22,282	20,045

[a] *$150 per tree for selection and cone collection.*
[b] *$1.25 per graft plus technical time.*
[c] *Includes one-fourth time technician at $18,000 annually; $675 per acre annually for travel and supplies; $100 per acre annually for equipment maintenance.*
[d] *Program age and NPVs will vary with assumptions on length of productive life of the orchard and time to seed production.*
[e] *10 acres of test at $1,000 per acre, plus $12,000 total for nursery stock.*

longed productive life of the orchard. Our sensitivity analysis included three additional sets of assumptions about orchard production: beginning at 9 and 12 years and continuing for 25 years, and beginning at 9 years and continuing for 30 years. *Table 2* gives total costs for the seed orchard cases. Finally, we looked at the possibilities for breaking even or reaping additional economic gains by planting the maximum acreage possible with three alternative average levels of seed production from the orchard.

Calculations of net present value.—Net present values were calculated in a standard fashion by these formulas:

For a single sum paid in the *n*th year:

$$V_o = \frac{V_n}{(1+i)^n} \qquad (1)$$

where V is the sum paid in the *n*th year, *i* is the discount rate, and *n* is the year in which the sum is paid. For a series of terminable annual payments:

$$V_o = a \frac{(1+i)^n - 1}{i(1+i)^n} \qquad (2)$$

where *a* is the amount paid yearly, *i* is the discount rate, and *n* is the number of years the payment is made. When a series of payments begins in a year after the start of the program, formula 2 is applied first, and then formula 1 is applied to the total to discount it to the beginning of the program.

Importance of Discount Rate, Site, And Orchard Productivity

Results of the economic analysis for the three biological functions, 2 sites, 3 discount rates, and 4 orchard scenarios are presented in *table 3*. Two features of the analysis are easily seen. With the assumed 200 acres planted per year per acre of seed orchard, site productivity and discount rates were the most important factors influencing the return on investment. Small delays in seed production and/or the five-year extension in orchard life had lesser effects. At the 4-percent discount rate on both sites, benefits exceeded costs for all but the third case (i.e., seed production delayed until year 12) on the good site. Profitability on the excellent site proved variable at 5 percent, with only function B consistently showing returns greater than costs for all orchard cases. On the good site, only biological function B combined with earliest seed production proved profitable at 5 percent. In no case was it profitable to plant improved material at 6 percent.

We were particularly interested in comparing results from the 3 hypothetical growth functions. At discount rates of 4 and 5 percent, the assumption of a constant percentage

Table 2. Tree improvement costs per acre of western larch seed orchard for 4 cases.[a]

Discount rate	Case 1 (base), 7/25 yrs.	Case 2, 9/25 yrs.	Case 3, 12/25 yrs.	Case 4, 9/30 yrs
Percent	*Dollars*			
4	24,964	25,583	26,424	26,932
5	22,282	22,731	23,327	23,679
6	20,045	20,371	20,795	21,039

	Orchard cases			
	1	*2*	*3*	*4*
[a] *Seed production begins (yr)*	*7*	*9*	*12*	*9*
Productive orchard life (yrs)	*25*	*25*	*25*	*30*

Table 3. Economic gain per acre of seed orchard derived from planting genetically improved rather than unimproved stock.[a]

Discount rate	Biological function[b]	Age at financial rotation	Increased yield per acre of plantation	Difference in net present value: Case 1[c] (base), 7/25 yrs.	Case 2,[c] 9/25 yrs.	Case 3,[c] 12/25 yrs.	Case 4,[c] 9/30 yrs.
Percent		*Years*	*Bd. ft.*	*Dollars*			
Good site							
4	A	60	627	6,186	3,217	−836	4,954
	B	60	967	23,714	19,409	13,568	22,870
	C	60	720	11,372	8,035	3,446	10,280
5	A	60	627	−7,316	−9,745	−11,601	−8,859
	B	60	967	1,284	−1,365	−4,863	−375
	C	60	720	−4,636	−6,721	−9,487	−6,215
6	A	50	525	−11,481	−12,753	−14,405	−12,835
	B	50	754	−7,749	−9,429	−11,617	−9,257
	C	50	747	−7,863	−9,531	−11,695	−9,367
Excellent site							
4	A	60	948	22,000	17,847	12,162	21,140
	B	60	1,304	39,742	34,249	26,784	39,296
	C	60	1,185	33,164	28,157	21,348	32,552
5	A	60	948	286	−2,267	−5,653	−1,359
	B	60	1,304	8,838	5,513	1,055	7,127
	C	60	1,185	5,484	2,469	−1,565	3,807
6	A	50	777	−7,389	−9,097	−11,335	−8,899
	B	50	993	−3,861	−5,951	−8,701	−5,513
	C	50	1,135	−1,535	−3,907	−6,963	−3,309

[a]*Assuming 200 acres planted per year per acre of seed orchard.*

[b]*The functions are—*

A: Volume difference between improved and unimproved trees is constant.

B: Percentage difference between improved and unimproved trees is constant.

C: Large early difference between improved and unimproved trees, decreasing with time.

[c]*See footnote a, table 2.*

difference between improved and unimproved material (function B) produced the largest benefits *(table 3)*, whereas a constant volume difference between improved and unimproved material (function A) produced the smallest benefits at all discount rates. Function C was intermediate. Information is not available to determine which of the three growth functions most closely resembles real growth throughout a rotation. Scanty data for loblolly pine suggest that any of the three functions may be reasonable approximations for the first half of a rotation (Talbert 1981).

Neither site quality nor the differences among the three growth functions influenced the financial rotation age, which varied only with discount rate *(table 3)*. We believe that the financial rotations would have varied with growth functions had we exaggerated the volume differences among them.

To test the effect of orchard productivity, we compared our base case of 0.28 bushel of cones per orchard tree (0.14 lb seed) to rates of 1.0, 0.4, and 0.2 bushel, yielding 0.5, 0.2, and 0.1 lb of seed, respectively. If all seeds were used, these yields would have allowed planting 725, 307, 200, and 153 acres annually for every acre of seed orchard. To compare those figures with the area that would need to be planted each year per acre of seed orchard for the program just to pay for itself, we used the formula:

$$Ac = \frac{X}{Y \cdot Z}$$

where X is the cost per acre of seed orchard, Y is the dollar gains per acre planted, and Z is the number of productive orchard years. *Table 4* lists the break-even number of acres to be planted each year for each case used in the previous analyses.

In *table 5*, we have schematically represented the possibilities for economic gains if the maximum number of acres were planted for all four cone production rates. It is important to note that with orchard production at 2.5 times the base case (i.e., at 1.0 bu of cones per tree), an acceptable return on investment was realized for all of the hypothesized growth curves, discount rates, and orchard scenarios. At 0.4 bu of cones per tree a return on investment was realized for both sites at 4 percent, on the more productive site at 5 percent, and for two-thirds of the cases on the less productive site at 5 percent. At low orchard productivity (0.2 bu of cones per orchard tree), neither site produced a return at 5 or 6 percent. At 4 percent, the excellent site produced returns, but on the less productive site results were variable.

On the excellent site, at 0.28 and 0.2 bu of cones per tree at the 5-percent discount rate, the break-even and maximum acres that could be planted were almost equal, indicating that even small differences in biological functions and orchard productivity could determine the profitability. Therefore, accurate quantification of biological functions and orchard scenarios is important for these conditions. On good sites the analysis was similarly sensitive at 4-percent discount rate at the lowest cone production rate.

Clearly, discount rate, site quality, and cone production rate are the most important factors influencing profitability. But if seed production from the orchard is kept high and planting programs are large enough to use all of the seed, profitability of the western larch tree improvement program is virtually assured. ■

Table 4. Break-even number of acres to be planted per year per acre of western larch seed orchard.[a]

Discount rate	Biological function[b]	Case 1,[c] (base) 7/25 yrs.	Case 2,[c] 9/25 yrs.	Case 3,[c] 12/25 yrs.	Case 4,[c] 9/30 yrs.
Percent		Acres			
Good site					
4	A	160	178	207	169
	B	103	114	132	108
	C	137	152	177	145
5	A	298	350	398	320
	B	189	213	253	203
	C	253	284	337	271
6	A	468	535	651	513
	B	326	372	453	357
	C	329	376	457	361
Excellent site					
4	A	106	118	137	112
	B	77	86	99	81
	C	86	95	111	91
5	A	197	222	264	212
	B	143	161	191	154
	C	160	180	214	172
6	A	317	361	440	347
	B	248	283	344	271
	C	217	247	301	237

[a]Costs per acre of seed orchard divided by [(benefits/acre planted) × (years of planting)].
[b]The functions are—
A: Volume difference between improved and unimproved trees is constant.
B: Percentage difference between improved and unimproved trees is constant.
C: Large early difference between improved and unimproved trees, decreasing with time.
[c]See footnote a, table 2.

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Table 5. Comparison of maximum number of acres plantable to break-even number of acres for four cone production rates and four assumptions regarding year of initiation of seed production and number of productive orchard years.[a]

		Annual cone production per tree[b]															
		1.0 bushel				0.4 bushel				0.28 bushel				0.2 bushel			
Site and discount rate	Biological function[c]	Cases[d]: Case 1, 7/25 yrs.	Case 2, 9/25 yrs.	Case 3, 12/25 yrs.	Case 4, 9/30 yrs.	Case 1, 7/25 yrs.	Case 2, 9/25 yrs.	Case 3, 12/25 yrs.	Case 4, 9/30 yrs.	Case 1, 7/25 yrs.	Case 2, 9/25 yrs.	Case 3, 12/25 yrs.	Case 4, 9/30 yrs.	Case 1, 7/25 yrs.	Case 2, 9/25 yrs.	Case 3, 12/25 yrs.	Case 4, 9/30 yrs
Percent																	
Good site																	
4	A	+	+	+	+	+	+	+	+	+	+	≃	+	–	–	–	–
	B	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	C	+	+	+	+	+	+	+	+	+	+	+	+	+	≃	–	≃
5	A	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–
	B	+	+	+	+	+	+	+	+	+	–	–	≃	–	–	–	–
	C	+	+	+	+	+	+	–	+	–	–	–	–	–	–	–	–
6	A	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–
	B	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–
	C	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–
Excellent site																	
4	A	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	B	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	C	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5	A	+	+	+	+	+	+	+	+	≃	–	–	–	–	–	–	–
	B	+	+	+	+	+	+	+	+	+	+	≃	+	≃	≃	–	≃
	C	+	+	+	+	+	+	+	+	+	+	–	+	≃	–	–	–
6	A	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–
	B	+	+	+	+	+	+	–	+	–	–	–	–	–	–	–	–
	C	+	+	+	+	+	+	≃	+	–	–	–	–	–	–	–	–

[a]*Key:* + *Potential acres plantable > break-even*
≃ *Potential acres plantable within ± 10 acres of break-even*
– *Potential acres plantable < break-even.*

[b]*Average yield per bushel of cones is assumed to be 0.5 pound seed.*

Bu of cones	*1.0*	*0.4*	*0.28*	*0.02*
Plantable acres	*725*	*307*	*200*	*153*

[c]*The functions are—*
A: Volume difference between improved and unimproved trees is constant.
B: Percentage difference between improved and unimproved trees is constant.
C: Large early difference between improved and unimproved trees, decreasing with time.

	Orchard cases			
	1	*2*	*3*	*4*
[d]*Seed production begins (yr)*	*7*	*9*	*12*	*9*
Productive orchard life (yrs)	*25*	*25*	*25*	*30*

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