Research Contribution 37

Timber Harvest Projections for Private Land in Western Oregon

by

Darius M Adams

Randall R Schillinger

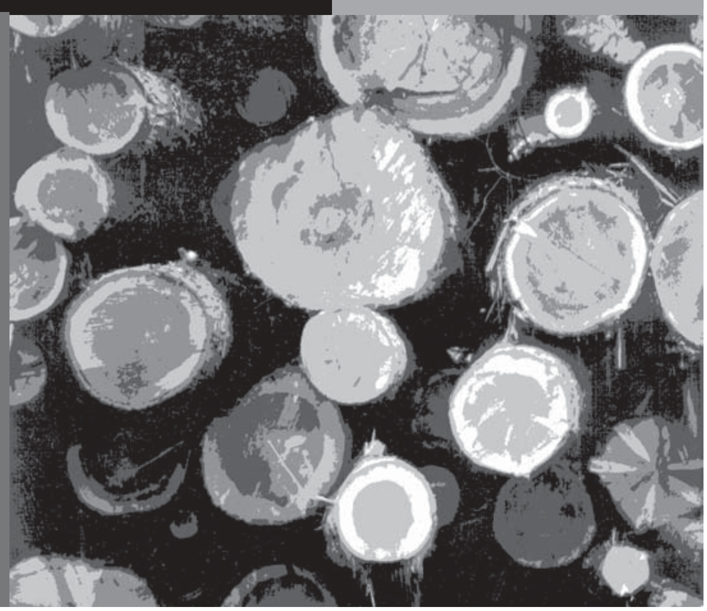
Greg Latta

Adrienne Van Nalts

May 2002

Oregon State University
College of Forestry

Forest Research Laboratory



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The Authors

Darius M Adams is a professor, Randall R Schillinger is a former graduate research assistant, Greg Latta is a faculty research assistant, and Adrienne Van Nalts is a research associate in the Department of Forest Resources, Oregon State University, Corvallis.

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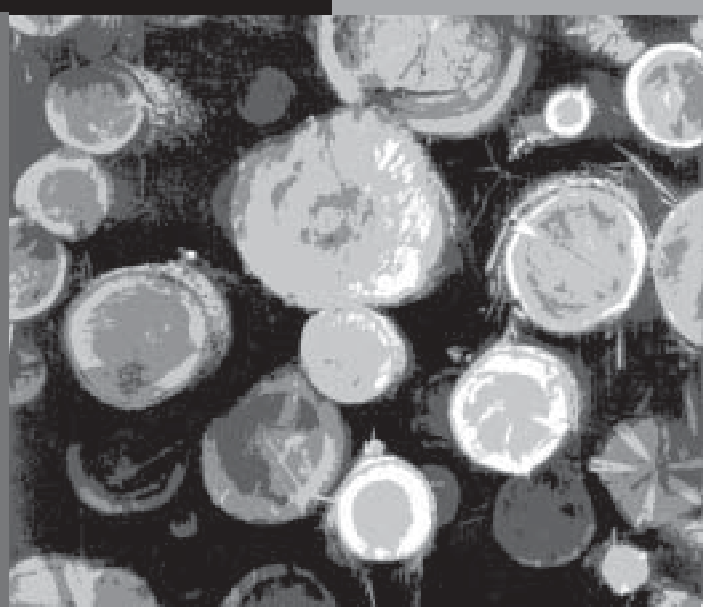

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ABSTRACT

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In this analysis, volume-flow and market-based models of the western Oregon timber sector are developed. The volume-flow model finds the maximum, long-term, even-flow level of cut for each ownership (industry and non-industrial private forest). The market model simulates the interaction of log demand and timber owner supply to find the market balancing harvest quantity and log price. In both models, owner decisions on the intensity of timber management (silviculture) are made within the models consistent with owner objectives (volume or wealth maximization). Model projections suggest that western Oregon forest industry owners could sustain cut at recent (1995–1999) levels, stemming the 40-yr declining trend in their harvest. Nonindustrial private forest owners could raise harvests to near historical peak levels. These harvests could be maintained over the next five decades with no reduction in the growing stock inventory. Management would continue to shift toward the more intensive forms on both ownerships. The average age of the inventory would decline over the projection. Simulated riparian protection policies lower harvest roughly in proportion to the land base reduction and raise log prices. A policy to increase the minimum age of clearcut harvests would lead to large near-term reductions in industrial harvest but less marked reductions on NIPF lands. Prices would rise sharply in the near term. Over the longer term, the policy would act to expand inventory, raising harvest, and to depress prices.

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English Units	Metric Units
1 cubic foot (ft^3)	0.0283 cubic meter (m^3)
1 acre (ac)	0.4047 hectare (ha)
1 cubic foot/acre (ft^3/ac)	0.0699 cubic meter/hectare (m^3/ha)
1 board foot (bd ft)	2360 cubic centimeters (cm^3)

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INTRODUCTION[1]

Private lands have always been an important timber source in western Oregon, providing roughly half of the aggregate harvest over the past half century. With the sharp drop in harvest on federal lands beginning in the early 1990s, however, private lands have become the primary timber supplier. Their share of total harvest has risen to more than 80%, and questions regarding their future harvest potential have taken on critical importance for the timber-related portion of Oregon's economy. Future management and harvesting of private lands have also become of interest to Oregon's citizens in general, as their awareness of and concern for the condition of the State's forest environment have increased.

In considering the future prospects for private timber harvest in western Oregon, this study, like its many predecessors in Oregon and in other western states, has four broad objectives:

1. **Providing a view of the future harvest potential for private lands.** We project timber harvest and management into the future under a variety of conditions and assumptions about the behavior of private owners, the markets for their timber, and the public policies that influence their actions. Of course, many sets of assumptions for our projections were possible and we do not know which will eventuate. Comparison of results obtained under an array of assumptions, however, suggests a range of possible outcomes. Since harvest is always free to vary downward, we normally focus on the upper bounds on harvest under a given set of assumptions and on how long these levels can be maintained.

2. **Identifying critical determinants of future harvest behavior.** We are interested in specific harvest projections, to be sure, but we also must understand why the projections behave as they do. This is a process of sensitivity analysis. Over the course of multiple simulations, it is possible to learn what conditions limit or constrain harvest and hence which assumptions or conditions might be most critical in the projections. This analysis also provides a basis for understanding the impacts of change in public policy on harvest.

3. **Assessing future conditions of the resource base.** We are also concerned with identifying and projecting conditions of the resource base itself, such as its age structure,

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[1] A preliminary version of this analysis was originally prepared for the *Symposium on Oregon's Forests at the Millennium*, September 9, 1999, Oregon State University, Corvallis, Oregon. The first version of the projection model was developed as part of Schillinger's MS thesis in the Department of Forest Resources, Oregon State University (Schillinger 1999).

species composition, and forms of management input. These attributes, in turn, can be used to assess impacts of future harvest and management trends on wildlife habitat conditions, patterns of biodiversity, and other broad metrics of environmental quality.

4. **Developing a policy analysis tool for future application.** This study can consider only a few of the current and potential issues that face forest policy makers in western Oregon. Thus, the harvest projection models developed in this study should be flexible enough to examine a broad array of alternative policies that could affect timber harvest both today and in the future.

Relation to Past Studies

The present analysis extends projections of western Oregon harvest proposed by Beuter et al. (1976) and Sessions (1991). Gedney et al. (1975) provide still earlier projections of western Oregon timber harvest with inventory data from the early 1960s and a growth model based on diameter classes and increments, but without shifts in management investment over time. It differs from these earlier reports in several respects:

- We derived inventory data exclusively from the system of 942 periodically remeasured plots on private lands maintained by the Forest Inventory and Analysis program unit of the USDA Forest Service Pacific Northwest Research Station. Unlike past studies, it was not possible to access surveys or summaries of inventory conditions developed by private owner groups. As a result, many of the smaller land strata in this study (defined by owner, region, age, forest type, site class, stream proximity, development zone/slope, and management intensity class) were sampled with a limited number of plots.

- We used variants of the ORGANON model (Hann et al. 1997; see also http://www.cof.orst.edu/cof/fr/research/organon/) to develop yields for all stands in all regions.

- We focus exclusively on private ownerships. During the 1990s, public timber harvests in western Oregon fell to only a fraction of their previous levels. Timber harvest policies on these lands are clearly in transition, with wide divergence in some cases between official management plans and actual harvest activity. Since the relation between future harvests and inventory characteristics or timber growth on these lands is unclear, we made no attempt to analyze public harvests or harvest potential. In the market-based projections where estimates of public supply are needed, we assumed that public cut would be constant in the future at the average of the past 5 yr.

- The harvest scheduling methods used in earlier studies of private lands generally involved a sequential look-ahead, even-flow approach computed with a binary search algorithm. Harvest in each period was set at the highest level that could be sustained over the look-ahead interval, starting in the current period and moving sequentially from the first to the last period in the projection. In this study, in contrast, the market simulation emulates the interaction of demand and supply in the sawlog market, establishing both private harvest levels and log/stumpage prices over time. We also computed the traditional even-flow projection to explore the variability and sensitivity of harvest trajectories. These models are all solved through direct optimization by means of a linear programming algorithm.

- In addition, there are many smaller differences, such as the proportions of the nonindustrial land base assumed to be reserved from timber harvest and yield reductions due to losses in harvesting.

These differences are highly diverse in form and action. Depending on which are considered, harvest projections for the current study could be either higher or lower than those in the past. The net effect is not evident *a priori*.

Nature of Inventory Database

The timber inventory data used in this report were derived from various preliminary releases of the Occasion 4 (OC4) survey conducted in 1995-1997 by the Forest Service in western Oregon. Because the agency had not completed all of the usual consistency checks and adjustments of the field data nor formally released the results of this survey at the time of this analysis, we had to revise and complete some aspects of the database. The most recent OC4 inventory at this writing, released by the Forest Service on 15 December 2000, thus differs from information reported here. Tables 1 and 2 compare timberland area and growing stock inventory in the present study, in previous studies, and in the December 2000 OC4 release. Reasons for the differences are discussed in later sections.

Table 1. Comparison of private timberland area estimates (in thousand acres) from past and current studies.

	Study								
	FI	NIPF	Total	FI	NIPF	Total	Difference		
Region	Beuter et al. (1976) for 1975			Western Oregon Study for 1997			FI	NIPF	Total
North Coast	1301	574	1875	1286	566	1852	-15	-8	-23
N. Willamette	177	188	365	215	184	399	38	-4	34
Mid-Willamette	395	179	574	425	169	594	30	-10	20
Eugene	593	220	813	588	202	790	-5	-18	-23
Roseburg	763	362	1125	792	334	1126	29	-28	1
South Coast	578	284	862	628	220	848	50	-64	-14
Medford	272	403	675	408	255	664	136	-148	-11
Western Oregon	4079	2210	6289	4342	1931	6273	263	-279	-16
	Sessions (1991) for 1986			Western Oregon Study for 1997					
North Coast	1266	500	1766	1286	566	1852	20	66	86
Willamette	571	365	936	640	353	993	69	-12	57
Eugene	568	220	788	588	202	790	20	-18	2
Roseburg	750	287	1037	792	334	1126	42	47	89
South Coast	551	218	769	628	220	848	77	2	79
Medford	343	268	611	408	255	664	65	-13	53
Western Oregon	4049	1858	5907	4342	1931	6273	293	73	366
	McKay et al. (1998) for 1995			Western Oregon Study for 1997					
Northwest	1198	621	1819	1142	688	1829	-56	67	10
Westcentral	1295	395	1690	1373	433	1806	78	38	116
Southwest	1608	783	2391	1828	810	2638	220	27	247
Western Oregon	4101	1799	5900	4342	1931	6273	241	132	373
	FIA OC4 (Dec. 2000) for 1997			Western Oregon Study for 1997					
Northwest	1119	710	1829	1142	688	1829	23	-22	0
Westcentral	1375	431	1805	1373	433	1806	-2	2	1
Southwest	1812	802	2614	1828	810	2638	16	8	24
Western Oregon	4306	1943	6248	4342	1931	6273	37	-12	25

Note: FI = forest industry; NIPF = nonindustrial private forests.

Table 2. Comparison of private growing stock inventory estimates (million cubic feet) from past and current studies.

	Study						Difference		
	FI	NIPF	TOTAL	FI	NIPF	TOTAL			
Region	Beuter et al. (1976) for 1975			Western Oregon Study for 1997			FI	NIPF	TOTAL
North Coast	3952	2104	6056	4480	1300	5781	528	-804	-275
N.Willamette	382	674	1056	492	526	1018	110	-148	-38
Mid-Willamette	1317	538	1855	1509	462	1970	192	-76	115
Eugene	1496	470	1966	1431	539	1970	-65	69	4
Roseburg	2925	608	3533	1850	833	2684	-1075	225	-849
South Coast	1425	721	2146	1598	441	2038	173	-280	-108
Medford	515	732	1247	818	554	1371	303	-178	124
Western Oregon	12012	5847	17859	12178	4655	16833	166	-1192	-1026
	Sessions (1991) for 1986			Western Oregon Study for 1997					
North Coast	4054	1842	5896	4480	1300	5781	426	-542	-115
Willamette	1340	1212	2552	2001	988	2989	661	-224	437
Eugene	1600	580	2180	1431	539	1970	-169	-41	-210
Roseburg	1586	663	2249	1850	833	2684	264	170	435
South Coast	1177	492	1669	1598	441	2038	421	-51	369
Medford	466	545	1011	818	554	1371	352	9	361
Western Oregon	10223	5334	15557	12178	4655	16833	1955	-679	1276
	McKay et al. (1998) for 1995			Western Oregon Study for 1997					
Northwest	4106	1915	6021	3911	1747	5658	-195	-168	-363
Westcentral	3483	1043	4526	4001	1080	5081	518	37	555
Southwest	3587	1951	5538	4266	1827	6093	679	-124	555
Western Oregon	11176	4909	16085	12178	4655	16833	1002	-254	748
	FIA OC4 (Dec. 2000) for 1997			Western Oregon Study for 1997					
Northwest	3893	1753	5645	3911	1747	5658	18	-6	13
Westcentral	3947	1058	5005	4001	1080	5081	54	22	76
Southwest	4312	1680	5992	4266	1827	6093	-46	147	101
Western Oregon	12152	4491	16642	12178	4655	16833	26	163	190

Note: FI = forest industry; NIPF = nonindustrial private forests.

Harvest Trends and Resource Conditions

Before discussing the projection methods and the projections themselves, we briefly review recent trends in resource conditions and timber harvest in the western Oregon region. This review provides a context for considering future harvests and offers some insight into what can be expected in the projections.

Over the past four decades, annual harvest from private industrial timberlands in western Oregon has decreased steadily, declining by some 200 million ft^3 (about 1 billion bd ft), roughly 27%, between the early 1960s and the late 1990s (Figure 1). Cut from nonindustrial private forests (NIPFs), in contrast, has shown wide swings but little trend. With the sharp decline in federal harvests in the early 1990s, stumpage prices rose dramatically, but a harvest response was clearly discernible only on nonindustrial ownerships. We can expect additional market impacts from this shift in timber supply structure. For example, beyond simply providing timber volume, public ownerships helped to modulate regional stumpage price swings through the large uncut volume under contract inventories carried by purchasers. With this inventory gone, both short-term and long-term fluctuations in timber price could increase (Adams et al. 1991). A practical test of this hypothesis was forestalled by the relatively buoyant lumber market of the late 1990s and early 2000.

These trends, of course, differ somewhat across the four ecoregions employed in the present study (Western Coast Range, Other Coast Range, Western Cascades Range, and Klamath; Figure 2). Ecoregions are defined on the basis of distinct vegetative characteristics (Ohmann and Spies 1998).[2] We have departed from Ohmann and Spies in that the Coast Range is divided into "Western" and "Other" Coast Range regions. Each ecoregion also represents a different set of forest resource and timber demand characteristics. Approximate harvests are shown by owner group in each ecoregion in Figure 3. Industrial harvests have declined in all regions except Other Coast Range. In the Western Coast Range and Western Cascades, harvests have fallen by about a third since the mid-1960s, while the decline in the Klamath region has been nearly 55%. Nonindustrial harvests,

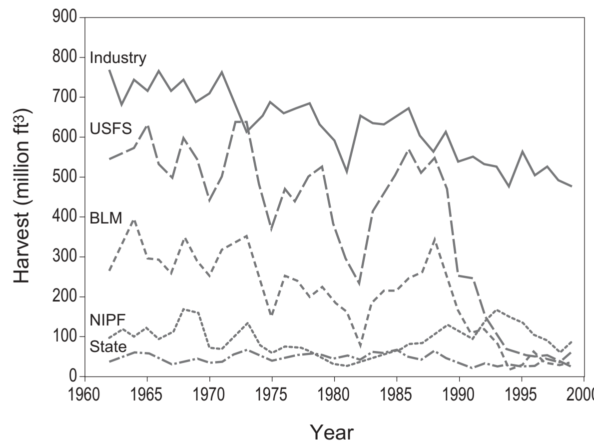

Figure 1. Western Oregon timber harvest by owner, 1962-1999.

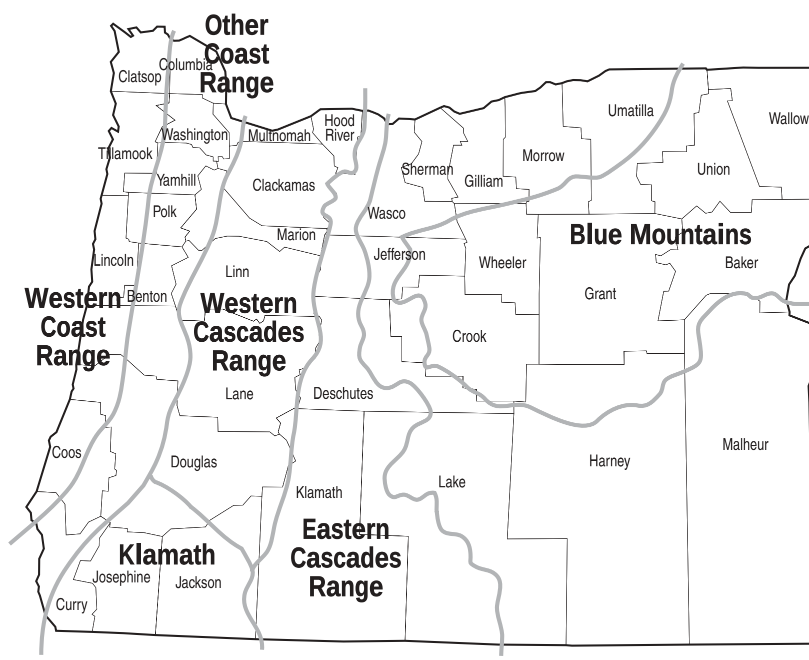

Figure 2. Ecoregions in Oregon (adapted from Ohmann and Spies 1998).

[2] The present study uses ecoregions for geographic subdivisions rather than "timbersheds" composed of counties, as in earlier Oregon timber supply studies. This shift reflects, in part, the move to develop forest policies on a geographic basis that recognizes commonalities in the affected ecosystems. Ecoregions are coming to serve this function in western Oregon. In addition, with the decline in public harvest and growth in stumpage and log prices over the past decade, logs are being shipped longer distances and timbershed boundaries have changed from those in earlier studies.

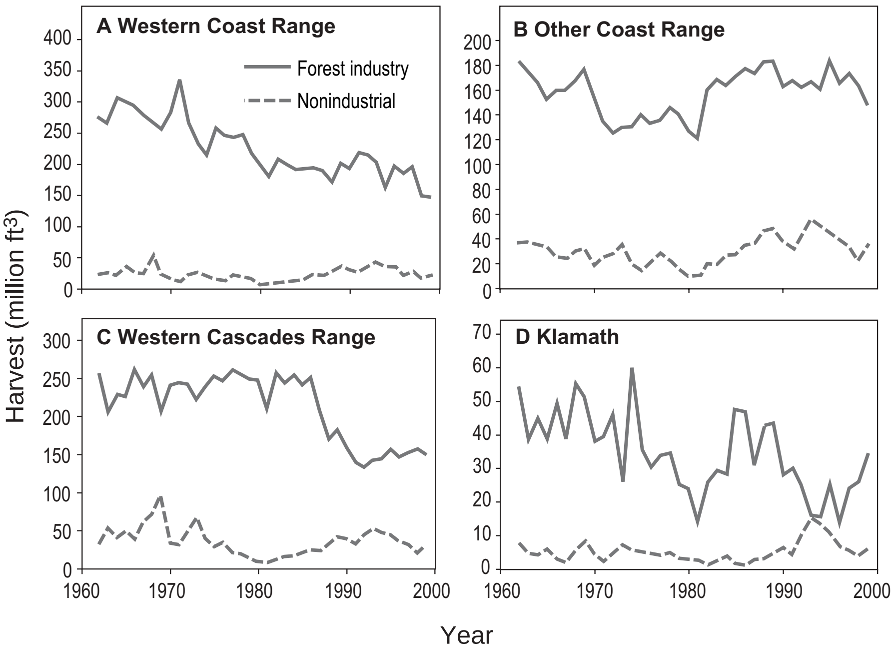

Figure 3. Harvest trends by ecoregion.

in contrast, exhibit little clear trend, but the response to higher prices in the late 1980s and early 1990s is evident in all regions.

The harvest pattern on industrial lands in part reflects trends in merchantable timber inventory volume. Early in the period shown in Figure 1, industrial harvests were drawn from inventories still comprising large areas of old-growth and mature second-growth timber, mostly over 100 yr old. Growth was low, harvest exceeded growth, and the inventory volume fell steadily, though at a declining rate, until the late 1970s (Figure 4). As the area of more rapidly growing second-growth stands has expanded, harvest has come in line with growth, and inventory volume has stabilized.[3] A similar process occurred on nonindustrial ownerships, although the harvest/growth imbalance was less extreme and the decline in inventory less dramatic (Figure 4).

Trends in private timber inventories have also been influenced by changes in the size of the private land base. In western Oregon, as in the rest of the United States, land base trends have diverged for industrial and nonindustrial owners (Figure 5). Between 1961 and 1995, the net gain in the industrial land base, about 470,000 ac, was related mostly to transfers from nonindustrial owners (McKay et al. 1998). This shift to the industrial base was correspondingly the largest form of loss from the nonindustrial base, followed by shifts to agriculture, infrastructural uses, and urbanization, for a net reduction of some 695,000 ac from 1961 through 1995. In many cases, these lands were transferred after harvest, so their impact on inventory has occurred over several years, with the growth of replanted stands.

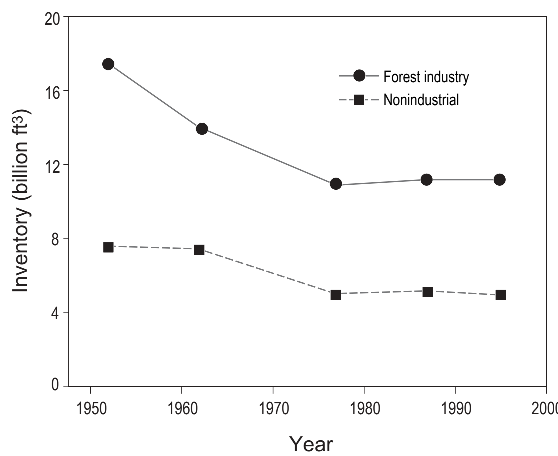

Figure 4. Private growing stock inventory in western Oregon.

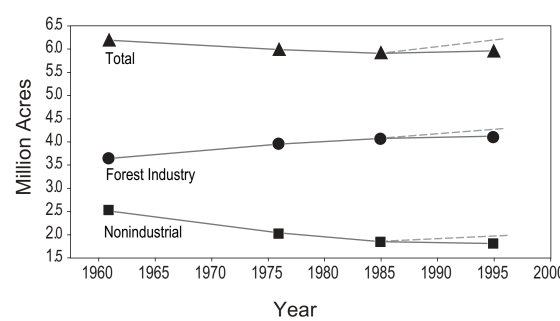

Figure 5. Western Oregon private timberland area. Dashed lines show area trends from OC4 data for 1997.

[3] Data in McKay et al. (1998) indicate that both the total softwood inventory and the sawtimber portion in trees over 9 in. dbh were roughly constant between 1984-86 and 1995. Although reported harvests have been declining (Figure 1), it does not follow that growth has been declining. The volumes shown in the figure are volumes of all types of logs removed from the forest, not removals of growing stock alone. Measured on a growing stock basis, growth has been rising and has come into rough equality with total growing stock removals (for both products and other losses).

Beyond inventory, harvest, and land base trends, one of the most useful characteristics for understanding potential private harvest on these lands is the age class structure of forests—the proportions of the land base in various age groups. Since age is correlated with size, the age class distribution provides a rough indicator of the fraction of the land base supporting merchantable stands. Given the types of management practiced in western Oregon, age 40 is a rough lower bound or minimum merchantability threshold. Thus, the distribution also tells how much area will become merchantable at future points. Virtually all of the trees that will be harvested over roughly the next 40 yr already exist. We can simply advance the age distribution to estimate the abundance or paucity of harvestable volume at points during this interval.

Forest industry land is more heavily concentrated in the younger age classes than is the case for nonindustrial ownerships (Figure 6). On industry land, 90% of the inventory is 60 yr old or younger, with about 35% of the inventory in each of the first two 20-yr age classes.[4] Assuming no changes in practices or restrictions on harvestable volumes, nothing in this inventory suggests a need for harvest reduction in the future. Current cut is coming from the older ages and timber just passing the minimum merchantability threshold (roughly 40 yr). About 35% of the inventory will move into the 40–59-yr-old class in the next two 20-yr periods, exceeding the proportions presently available in the four oldest classes (40–59 yr old and older).

On nonindustrial land, 90% of the inventory is 80 yr old or younger.[5] Relative to industry lands, older age classes make up a larger fraction of the inventory, with about one-quarter of the inventory in each of the first three 20-yr classes. The inventory is spread over more age classes, but, as in the industrial lands, nothing in the age structure of forest stands on nonindustrial lands suggests a need to decrease harvests in the future.

These aggregate data indicate that harvest and growth are roughly in balance for both types of private ownership. Given their respective age class structures, it is likely that they can sustain their current harvest levels for some time into the future. Whether there is any potential for harvest expansion, however, and how sensitive the inventory might be to special restrictions or constraints on the nature and form of harvest, will require additional, more detailed analysis.

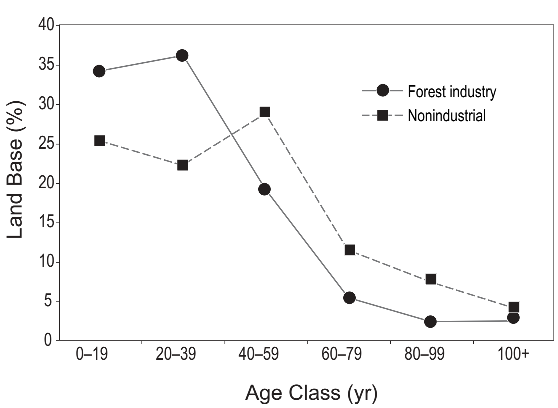

Figure 6. Age class structures of western Oregon private ownerships.

Harvest Projection Methods

The process of projecting future harvests, in this or any timber harvest study, has five major elements:

- basic data on the extent and structure of the **inventory**—volumes, areas, species, locations, site quality, past management, and other conditions that determine current and possible future volume yields.
- details on the nature of current and possible future **management regimes**—silvicultural practices now being used and those that might be applied to future stands.
- models of **growth and yield** in current and future stands—what volumes will grow in the various strata of the inventory in the future, both in existing stands and in stands cre-

[4] Note that stands classified as managed on a selection basis in the projections are included in the 100+ year category.

[5] On nonindustrial lands, a sizable portion of stands are of mixed age and hence are less uniform in age structure than the use of specific age classes in this report would suggest. About 13% of nonindustrial forest area (based on area in McKay et al. 1998) had to be allocated to age classes by aging standards less rigid than those normally employed by the Forest Service in its inventory reports. Another 18% was "unclassified" as to age class in the survey data, but this was due to low stocking, recent cut-over, burn, etc., so that age class assignment was not in doubt (it was classed as not stocked).

ated after harvesting under the various management regimes.

- what will happen to the **forest land base**—areas gained from and lost to other uses and the nature of the stands that are shifted in and out of the base.

- some form of **harvest simulator** to generate estimates of harvest, adjust the inventory, apply management regimes, and regenerate future stands. This element applies some logic to determine harvest in each period and grows the forest under this harvest logic and associated management assumptions over time.

Inventory

In this analysis, we used the OC4 timber inventory compiled by the USDA Forest Service Forest Inventory and Analysis unit at the Pacific Northwest Experiment Station. This survey provided many improvements over earlier samples, including measurement of proximity of each subplot to streams and other water bodies and the subdivision of plots into condition classes that are homogeneous in terms of land class and vegetation characteristics. Our basic inventory unit was the condition class, rather than the plot. Thus, a stratum in our aggregate inventory representation (defined on stand age, site class, forest type, and so forth) comprises many condition classes or homogeneous portions of plots, rather than whole plots, as has been necessary with past inventories. In addition, we derived the yield of each stratum in the existing inventory by aggregating the growth projections for all the individual condition classes comprising the stratum.

Although these new data offer many advantages, they were available only in preliminary form at the time of this study. Thus it was necessary to revise or adjust the data to reflect problems in

- **site index computations.** Wherever possible, we have recomputed site index values for plots and conditions classes from original site trees with the SICALC utility from ORGANON (Hann et al. 1997).

- **land classification.** In several counties, plots were incorrectly classified as to land class (timberland or nontimberland) because of errors in the computation of site index in the original compilations. Where possible, we have revised erroneous land classifications at the condition class, rather than plot level.

- **"access denied" plots and plot expansion factors.** During the field measurement portion of the OC4 inventory, crews were denied access to remeasure a limited number of plots. The data set used in this analysis includes these plots, with tree values projected from OC3 to OC4. Inclusion of the plots also led to differences between plot expansion factors as given in the preliminary databases and those that would be appropriate with the full complement of plots. We used the most recent expansion factor values available from the Forest Service, which assumed that all plots were included in the sample.

Timberland and Inventory Base Comparisons

Each of the two earlier studies of Oregon's timber supply potential used a different initial inventory database; in both cases, Forest Service survey plot data were supplemented with information obtained directly from owners for forest industry lands. Table 1 compares initial area values for the present study, the two earlier timber supply studies, the most recent published inventory using Forest Service plot data based on a plot update (McKay et al. 1998), and the most recent OC4 data release. The current study includes 373,000 ac more than that of McKay et al. (1998), roughly a 6% increment, mostly within the forest industry ownership and predominantly in McKay's Southwest Oregon survey unit (our Klamath and Other Coast Range ecoregions). This increase could be related to the land classification problems mentioned earlier, but a full explanation remains to be established. Area differences between the current study and the most recent release of OC4 data are relatively small (our total area is about 0.4% higher than that reported by the Forest Service), varying in sign across ownerships, and with some concentration in the Northwest unit.

Table 2 shows total growing stock inventory volumes by geographic region and owner for the same studies. Corresponding to its higher timberland area, this study has a larger estimate of inventory [about 5% above McKay et al. (1998) for the total], with the largest differences in forest industry and McKay's Southwest survey unit. Differences from the OC4 release are again small (our total estimate is about 1.1% larger than the Forest Service total) and largest on nonindustrial ownerships. They are spread across all survey units, with some concentration in the Southwest.

Stratification of Inventory

We stratified the timber inventory (areas of forest land and associated volumes of timber) on nine dimensions to model harvest behavior and to project yield. The harvest projection tracks the disposition of the forest inventory by these nine elements at each point in the projection period:

- **age by 5-yr class.** In past studies in the Northwest, timber customarily has been classified into 10-yr age groups. As management has become more intensive on both industrial and nonindustrial ownerships and typical rotations have declined, knowledge of inventory structure on a finer time scale has become important (see Adams et al. 1992 for a similar approach in western Washington).

- **site productivity.** Three classes (LO, MED, HI) correspond to potential wood volume growth of ≤119 ft^3/ac/yr, 120–164 ft^3/ac/yr, and ≥165 ft^3/ac/yr.

- **ecoregion.** Ecoregions are Western Coast Range, Other Coast Range, Western Cascades Range, and Klamath (Figure 2).

- **forest type.** The four classes are Douglas-fir, other conifer, hardwoods, and nonstocked.

- **proximity to stream course.** One of 12 proximity values was assigned, 6 for each of 2 classes of streams: Class 1, a permanent stream, or Class 2, an intermittent stream. Proximity values are within 20, 50, 70, 100, or 200 ft, and >200 ft. Streams or lakes of any size are included.

- **development zone.** This element describes the form of land use and the extent of human development (structures, roads, and infrastructural developments and their density) in three classes: forest only, mixed forest and agriculture, and mixed forest and urban. Azuma et al. (1999) discuss the construction of these zones.

- **slope class.** This element is the average slope of the plot in percent in three groups (LO, MED, HI): 0–49%, 50–69%, and ≥70%. Slope class is included as a possible means of examining policies focused on slope stability and timber harvest. As a consequence, we have broken the continuous slope measure into classes that appear to be related to slope stability questions and have not included the more common 35–40% break point for slope as the upper bound for ground-based yarding systems.

- **ownership.** There are two groups. The industrial group includes owners integrated with processing facilities, along with other owners not integrated with processing but holding at least 5,000 ac. The other group, NIPFs, includes owners not integrated with processing who hold <5,000 ac.

- **management intensity.** Nine management intensity classes (MICs) describe the methods of regeneration (natural or planted), stand density control (precommercial or commercial thinning), fertilization, and method of harvest (partial cutting or clearcutting). A tenth class is area reserved from harvest (Table 3).

Management Regimes

In cooperation with the Oregon Forest Industry Council (OFIC) during early 1998, the Oregon Department of Forestry (ODF) surveyed industrial forest land owners regarding their current management practices and future management intentions for lands in Oregon. A similar survey of ODF forest practice and service foresters was also completed to provide information on current and potential management actions of nonindustrial owners. Data from these surveys provided the details of activities in the management regimes. Ten regimes, or classes, were defined, with final clearcut harvest in all cases except PARCUT (Table 3). The silvicultural details of each regime vary by site class, forest type, and ecoregion. Table 4 provides an example for mid-site, Douglas-fir type, Western Cascades Range. Development of yields is described in Appendix A.

Allocation of the initial inventory to each class by site class, forest type, ecoregion, and owner group was based on information derived from forest owner surveys.

Table 3. Acronyms and general descriptions of management intensity classes (MIC).		
1	RESERVE	Reserved from harvest, no cutting at any time during the projection
2	PARCUT	Partial cutting[a]
3	NAT	Natural regeneration
4	NATCT	Natural regeneration and one commercial thinning (CT)
5	NATPCTF	Natural regeneration, precommercial thinning (PCT), and fertilization (F)
6	NATPCTFCT	Natural regeneration, precommercial thinning, fertilization, and one commercial thinning
7	PL	Plant
8	PLCT	Plant and one commercial thinning
9	PLPCTF	Plant, precommercial thinning, and fertilization
10	PLPCTFCT	Plant, precommercial thinning, fertilization, and one commercial thinning

[a]A partial cutting regime has not been included in previous studies of western Oregon timber supply. Problems in developing yields and details of this regime are presented in Appendix A.

Allocation to stream proximity, slope, and development zone classes was in proportion to the area in these three classes.

In the projections, assignment of future stands to an MIC class was determined within the harvest projector consistent with the management objective. This method differs from those used in all previous studies of timber supply, both in Oregon and Washington, where future management regimes were preassigned, usually based on surveys of owner intentions.

Growth and Yield

We developed yield projections for existing stands with the Stand Management Cooperative (SMC) version of ORGANON (Hann et al. 1997), except for the Klamath region, for which we used the Southwest Oregon version (see Appendix A). For existing stands, we compiled tree lists from inventory records, in some cases adjusting actual tree species to species accepted by the appropriate version of ORGANON. Young condition classes were grown to 15 yr breast height age in SYSTUM1 (Ritchie 1993) and then transferred to ORGANON for the remainder of the projection period. For future stands (created during the course of the projection), we developed initial (regeneration) tree lists from the silvicultural characteristics of each management intensity class (see Table 4 for example) and data on existing young stands in the OC4 inventory. Young stands were

Table 4. Example of details of management actions within management intensity classes for medium site, Douglas-fir forest type, Western Cascades ecoregion.

	Management Intensity Classes[a]									
Management Action	MIC 1 RES	MIC 2 PARCUT	MIC 3 NAT	MIC 4 NATCT	MIC 5 NATPCTF	MIC 6 NATPCTFCT	MIC 7 PL	MIC 8 PLCT	MIC 9 PLPCTF	MIC 10 PLPCTFCT
Regen Trees per Acre	521	521	521	521	521	521	436	436	436	436
PCT Age					14	14			14	14
Trees per Acre after PCT					261	261			261	261
CT Age		20[b]		38		20		35		20
CT % removed		25		31		23		29		23
Fertilization 1					30	30			30	30
Fertilization 2					35	35			35	35
Minimum Harvest Age	-	-	47	48	46	48	46	40	38	45
Distribution of Area of Existing Stands %[c]										
FI Young Stand	1	0	6	1	2	1	18	14	25	32
FI Old Stand	1	0	29	5	20	15	6	3	9	11
NIPF	0	50	33	0	8	0	8	0	1	0

[a]See definitions of management intensity classes in Table 3. FI is forest industry, NIPF is nonindustrial private forest owners.
[b]For PARCUT the "CT Age" refers to the reentry period and the "CT% removed" is the fraction of growing stock removed in partial cut.
[c]For existing stands, "young stands" are less than 25 yr and "old stands" are 25 yr or older. Existing stands enter the modeling process with tree lists and age as derived directly from the inventory and receive management inputs appropriate only for subsequent ages.

grown to age 15 using SYSTUM1; yields in older stands were derived from ORGANON. To account for breakage during harvesting and the effects of natural forces, such as endemic disease and insect loss, we reduced yield model projections by 15%. We made no special adjustments for yield impacts of Swiss needle cast in the Western Coast Range ecoregion.

Land Base and Forest Types

The rate of decline in the private land base has slowed over the past several decades (Figure 5). This reflects changing patterns in the economic and social values of forest lands, with growing land owner interest in the retention of forest cover and slower conversion to non-forest uses. The trend could reflect as well state and local land use and zoning ordinances that have been erected to limit development of forests and other wildlands. Despite these trends, much uncertainty surrounds potential shifts in the private forest land base. Using OC3 and OC3.5 inventories, McKay et al. (1998) found that the nonindustrial forest land base in western Oregon fell by 69,000 ac between 1985 and 1994 (about 0.38% per yr), whereas forest industry area rose by 57,000 ac over the same period (about 0.14% per yr), largely because of purchases from nonindustrial forest owners. According to the latest (OC4) Forest Service inventory for western Oregon, however, estimated land areas for both owner groups are greater than the McKay et al. (1998) values and the OC3 estimates. These new areas are shown in Figure 5 as dashed lines.

Until revisions in plot classifications in the OC4 inventory and differences relative to OC3 and earlier surveys are reconciled, historical land area trends remain unclear. We therefore assumed for this analysis that rates of change in land use will be small and that the land base in both private ownerships will remain essentially constant over the projection period.

In the harvest projections developed for this study, forest type conversion (e.g., from hardwoods to softwoods or from other conifers to Douglas-fir) was not a decision option in the model, although such changes have resulted from both management actions and natural processes in the past. Thus, given the stable land base assumption, the areas by forest type also remain stable over the analysis period.

Harvest Simulator

Almost without exception, past studies of private harvest potential in the western United States have been based on some physical volume model that projects future cut.[6] Though specific numerical methods differ, these studies have all employed some variant of even-flow harvest scheduling (even-flow with bounds on period-to-period variation, sequential constant look-ahead even-flow, or nondeclining even-flow). Producers are assumed to set harvest so as to maximize the even-flow level attainable over some period in the future, possibly subject to additional constraints on rates of harvest change. In general, these models focus exclusively on volume flow decisions. Investment behavior (planting and all other silvicultural activities) is treated as exogenous and follows a predetermined pattern as the projection proceeds.

Though simple in concept and abstracted from the full complexity of private owner decision making, volume flow methods are extremely valuable in exploring future harvest potential. In this study, we examine only the even-flow approach, which finds the highest harvest level that can be maintained over the projection without variation up or down. *The projection approach we used finds the even-flow only for volumes of softwood sawtimber. Hardwood and non-sawtimber volumes on a given harvest area are assumed to be cut at the same time as the softwood sawtimber. In computing the total harvest, we added these volumes to the softwood sawtimber. The total harvest therefore might not have a constant or even-flow trajectory (for example, see Figures 7A and 7B).* Unlike many past studies, here the volume flow schedule is determined with direct optimization in a linear programming formulation, rather than through a binary search algorithm. Although this approach increases computational costs, it allows us to consider a wide range of potential policy scenarios. It is also possible to develop mixed projections, combining attributes of the market and volume flow simulations.

[6] See, for example, Beuter et al. (1976) and Sessions (1991) for Oregon, Adams et al. (1992) for western Washington, Krumland and McKillop (1990) for California, Flowers et al. (1993) for Montana, and Bare et al. (1995) for eastern Washington. Adams et al. (1992) are an exception in their use of an econometric supply equation in addition to an even-flow model.

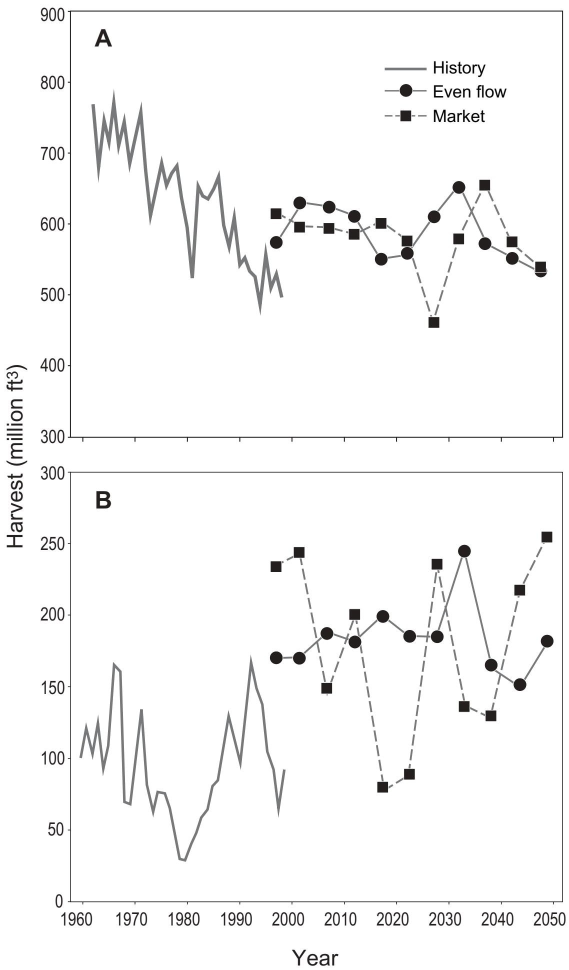

Figure 7. Harvest projections under current policies for (A) western Oregon forest industry and (B) nonindustrial private owners in western Oregon.

To supplement the volume flow approach, we developed a model of private harvest behavior based on market simulation. Based on earlier work at the national and regional level, we constructed a model of the market for softwood sawlogs in western Oregon.[7] Market equilibrium occurs at the point where demand equals supply in all periods of the projection. The model maximizes the present value of the sum of producer profits and consumer surplus, less costs of log production and transportation, over the projection period. We used econometric methods to derive functions representing the demand for delivered sawlogs from historical data on sawlog use in domestic milling (lumber, plywood, and miscellaneous products) and offshore export (see Appendix C for details). We augmented these data with relations explaining softwood log trade with adjacent states and eastern Oregon. Private log producer supply is an implicit function of the costs of growing timber over time, its harvest, and delivery to the point of utilization. Private suppliers are seen in this context as wealth or present-value maximizers in a market where their supply actions (harvest or absence of harvest) can influence the current and future prices of logs. Just as the volume-based scheduling methods err by failing to consider any market or financial motivation in the determination of private harvest, so the market model errs in treating these as if they were the only objectives of private owners. Both approaches are too extreme, yet in juxtaposition they provide more insight into the potential range of harvests than either would in isolation.

As a further extension, we structured both the volume and market models to allow internal determination of management investment decisions. The management intensity classes of stands created after the start of the projection are determined within the harvest projection analysis and need not be preset as in past studies. In the market model, this means that investments (choice of MIC for regenerated stands) are consistent with the wealth-maximizing objective. In the volume flow model, investments further achievement of the volume-maximizing objective.

We emphasize that decisions regarding the characteristics and timing of areas harvested are endogenous in both volume flow and market projections. Thus, the composition of harvest in each period by age of stand, species, site class, MIC class, forest type, zone/slope class, and ownership (in a combined owner projection) is determined within the model and not by preset harvest ordering rules. Projections are made for 100 yr, but in this report we address only the first 50 yr as the policy-relevant period.

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[7] See Adams et al. (1996) and Lyon and Sedjo (1983) for examples, though both of these approaches are anticipated in earlier work by Johnson and Scheurman (1977). Appendix B provides a detailed mathematical representation of the present market model.

Projections under Current Policies

Harvest Projections

Industrial Ownerships

Harvest through 2047, derived from the market and even-flow models, for western Oregon industrial owners is projected in Figure 7A. As noted earlier, the even-flow schedules vary because they were computed only on softwood sawtimber volume. Volumes of other products and species were simply added to the softwood sawtimber. Since these vary over stands and time, they cause the fluctuations shown in the figures. The schedules begin at or above the average harvest levels of the past 20 yr. In the market projection, demand is essentially stable over time, following projections from the Timber Assessment model of the U.S. Forest Service (Haynes et al. 1995; Adams and Haynes 1996). Thus, variation in the harvest volumes derives from the supply side and the expansion and contraction of the merchantable inventory. In this case, the market simulation does not call for large harvests at the beginning of the projection, as might be expected in a model of owner wealth maximization. As we have seen, the inventory is heavily concentrated in the younger age classes (≤59), so options for large near-term cuts are limited. The average level of the even-flow schedule over the projection is similar to that of the market schedule.

Nonindustrial Private Owners

Harvest projections for nonindustrial ownerships are shown in Figure 7B. Initial harvests in both schedules begin at or above peak historical volumes for this ownership. Because a large fraction of nonindustrial inventory lies at or above minimum merchantable ages, the market projection involves large near-term harvest levels and the even-flow schedule only infrequently falls below historical peaks. The market forecast is also far more volatile than the industrial case, though its average level over the projection (173 million ft^3/yr) is close to the average even-flow level (185 million ft^3/yr). High harvests at the outset quickly reduce volumes in the older age classes and lead to a long-term cycle in inventory and harvest.

Comparison of Figures 7A (for industry) and 7B (for nonindustrial owners) shows a series of opposing movements in harvest in the market projection that are particularly marked after 2020. These movements derive initially from the pattern of harvest on nonindustrial lands and associated impacts on inventory, as just described. They are perpetuated in the projection by the market mechanism that reduces industry harvest in periods when larger volumes of harvestable material are available on nonindustrial lands and increases industrial cut when the opposite is true. The result is a set of cycles in the market harvest projections with a trough every 20 yr in nonindustrial cut and a peak in industrial cut.

Inventory Projections

Given the similarities in the market and even-flow schedules for industrial ownerships, it is not surprising that the total growing stock inventories are similar as well (Figure 8A)[8]. The dip in market cut in 2027 allows inventory to accumulate, and the market inventory rises above the even-flow level for the remainder of the projection.

For nonindustrial private owners, we see the effects of the large initial harvests in the market forecast in the initial dip in total growing stock volume (Figure 8B). Like the industrial case, the large mid-projection harvest reduction allows inventory to accumulate and rise above the even-flow case.

Market vs. Even-Flow Projections: Industrial Ownerships

Over the first 30 yr of the projections, there is little difference in the concentration of harvesting by age class between the market and even-flow projections for industrial owners. As a result, the age

[8] In Figures 8A and 8B, the 1997 starting inventory volumes are somewhat higher than those derived from the inventory plots shown in Table 2. These data reflect in part the use of a different merchantability standard in the harvest simulation model (cubic volume in trees of all diameters to a 2-in. top) compared to the inventory (trees 5 in. dbh and larger to a 4-in. top) and the deduction of field-estimated volumes for cull material in the inventory data. Higher volumes also occur because the tree volume equations in ORGANON (and the harvest simulation model) do not give the same cubic volume for trees of a given diameter, height, and species as the volume equations used in the inventory compilation.

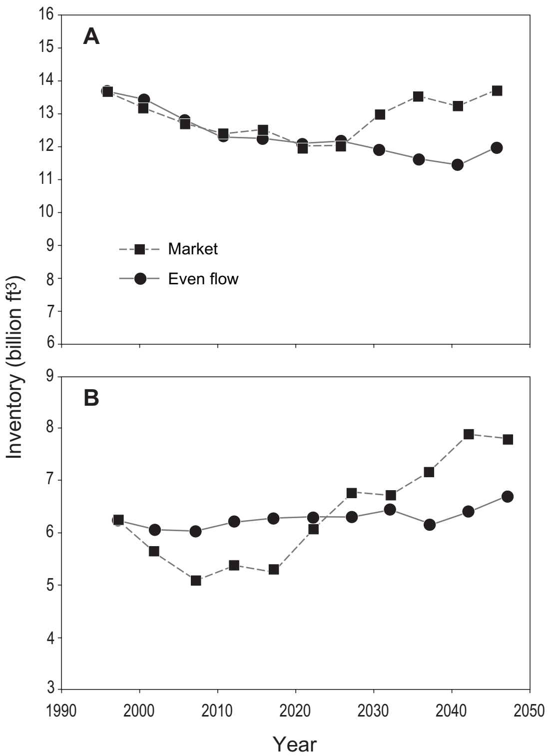

Figure 8. Total growing stock inventory for (A) forest industry and (B) nonindustrial private owners in western Oregon under market and even-flow projections.

class distributions by 2027 are similar as well (Figures 9A and 9B). After 2027, however, the market projection produces a nearly uniform distribution of area in the first three 20-yr age classes, whereas the even-flow schedule continues the heavy concentration of area in the 20–39-yr class. In both cases, acres remain concentrated (≥90%) in the three youngest classes, as was the case in the 1997 inventory.

Market and even-flow projections are also similar in their implications for the shift in the management concentration of industry lands away from regimes using natural regeneration toward ones based on plantations (Table 5). Estimates developed for the present study indicate that more than half of current stands originated naturally. The projections indicate that after 50 yr this fraction will have dropped to less than 20%. The two projections show greater differences at the detailed MIC level. In the market projection, nearly 55% of the land base is enrolled in the plant-PCT-fertilize regime, 12% in the plant-only regime, and less than 10% in other plantation classes. In the even-flow schedule, where costs and returns are ignored, there is a wider distribution of areas by MICs within the planting-based regimes. More than 30% of the land base is managed under the plant-CT regime, 15% in plant-PCT-fertilize, and more than 12% in the most intensive plant-PCT-fertilize-thin regime.

Market vs. Even-Flow Projections: Nonindustrial Private Owners

In the nonindustrial age class structures (Figures 10A and 10B), we see a marked difference between the market and even-flow cases. The initial cycles in the market projection compress acres into one large class by 2027. As this class ages, it provides the basis for future cyclical peaks. Despite this extensive cutting, the 2047 inventory has more absolute area in older classes than the initial distribution. In the even-flow schedule, in contrast, the age distribution is somewhat smoother by 2047, with substantially more area in the younger classes.

As in the industrial case, achieving the harvest schedules in Figure 8B would require a shift in the relative use of management regimes (Table 5). In the 1997 inventory, less than 5% of the nonindustrial land base was enrolled in a management regime that involved actions beyond natural regeneration. By 2047 in the market projection, natural regenera-

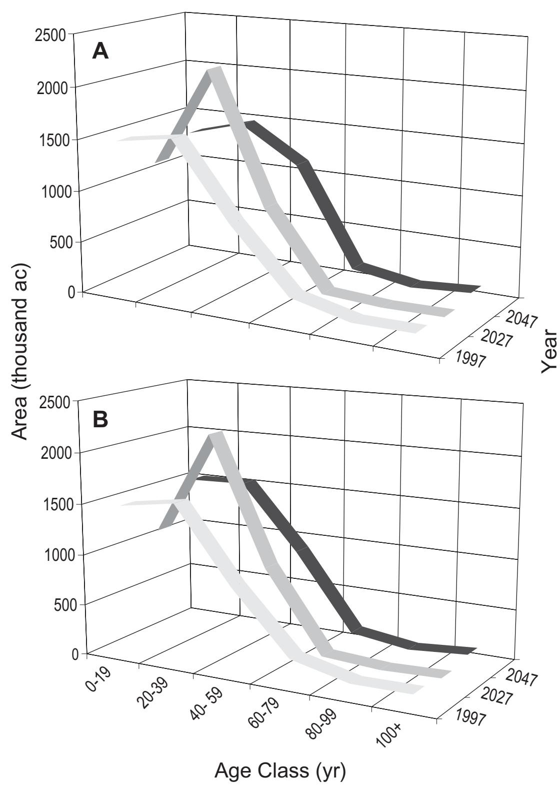

Figure 9. Current and projected area by age class for forest industry lands in western Oregon from (A) market simulation and (B) even-flow simulation.

Table 5. Private timberland area (thousands of acres) by management intensity class (definitions given in Table 3) under market and even-flow projections for 1997 and 2047.

	Management intensity class										
Forest type	NAT	NATCT	NAT PCTF	NAT PCTFC	PARCUT	PL	PLCT	PLPCTF	PL PCTFCT	RESERVE	Total
Forest industry											
1997	1526.2	193.8	252.3	233.0	272.6	694.3	259.8	375.3	409.2	125.6	4342.2
2047 market	110.4	422.6	0	99.2	438.0	521.3	287.7	2313.0	24.7	125.6	4342.2
2047 even-flow	280.3	464.8	41.1	40.5	379.6	351.8	1516.6	628.1	513.7	125.6	4342.2
Nonindustrial private											
1997	1090.8	12.3	46.8	0	632.8	84.0	0	4.8	0.3	59.0	1930.7
2047 market	27.8	770.5	5.1	79.2	712.3	33.6	186.3	56.9	0	59.0	1930.7
2047 even-flow	71.8	134	3.2	28	730.2	209.5	475.5	124.2	95.2	59.0	1930.7

Notes:

Total land areas are constant, consistent with the base assumption of a stable land base.

Detail may not sum to total because of rounding.

tion remains the primary approach, but is augmented with a commercial thinning at mid-rotation. In the even-flow projection (again recalling that costs and revenues are ignored), management shifts heavily to plantations with a large proportion in the plant-CT class. In both projections, the partial cutting regime remains important, increasing its share of the land base from 34% in 1997 to more than 38% by 2047.

Regional Harvest Conditions

To illustrate harvest prospects by region within western Oregon, we disaggregated the base market projection into the four western Oregon ecoregions. The market projections varied greatly over time at the ecoregion level (Figure 11). For industrial ownerships, average projected harvests were at or above recent historical levels in the Western Coast Range, Western Cascades Range, and Klamath ecoregions. In the Other Coast Range ecoregion, industrial harvest cycled widely between peaks and troughs, and the projection period average at 123 million ft^3/yr was about 22% below the 1962–1998 average. On nonindustrial lands, average projected harvests were at least as large as recent levels in all regions and higher than historical peak levels in the Other Coast Range, Western Cascades Range, and Klamath ecoregions.

Log Prices

The market model also allows projection of prices resulting from the interaction of supply and demand in the western Oregon log market. With the sharp drop in fed-

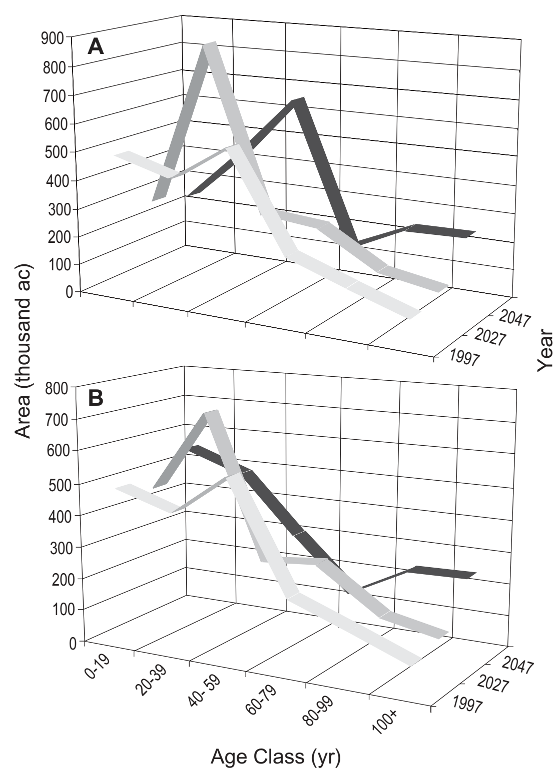

Figure 10. Current and projected area by age class for nonindustrial private lands in western Oregon from (A) market simulation and (B) even-flow simulation.

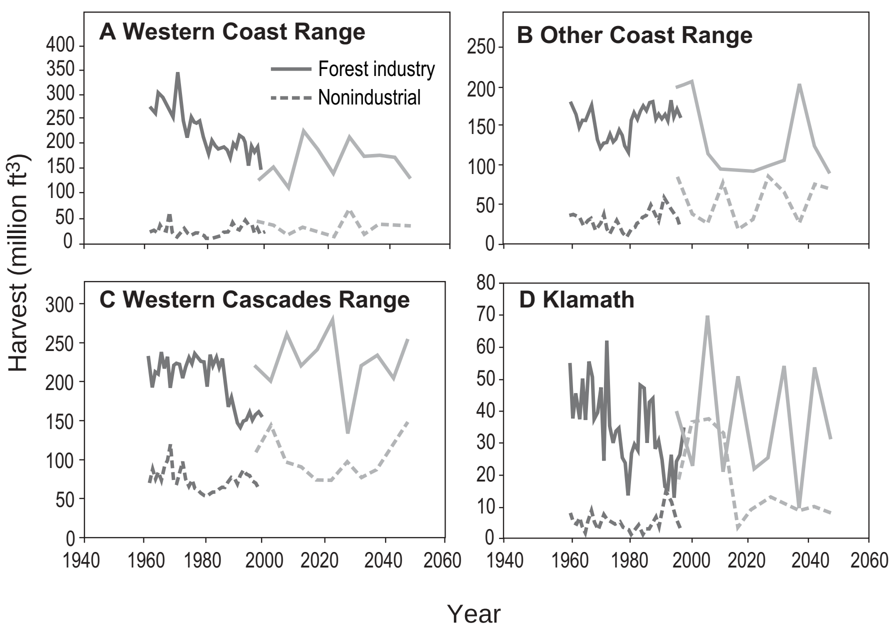

Figure 11. Harvest by ecoregion and owner in western Oregon from market base run. Historical data are on the left in each figure.

eral timber harvest and recovery in the housing market in the early 1990s, real log prices in western Oregon rose dramatically to a peak in 1993. Prices fell in subsequent years, reflecting reductions in product prices and the decline in regional lumber and plywood processing capacity, though they have remained 30–50% higher than the average levels of the 1970s and 1980s. The base case projection is shown in Figure 12. Prices hold steady near recent historical levels with no major trends.

Interest Rate Sensitivity

In the market model, harvests are determined so as to maximize an objective function that is the present value of a series of future consumer surplus and producer profit measures. Thus, the interest rate used in the discounting computation could have an important impact on results. To examine this possibility, we developed two additional projections using 2% and 6% real interest rates. Base case results reported to this point use a 4% rate.

Relative to the base case, higher interest rates entail higher opportunity costs of postponing harvest and could lead to larger near-term harvests and lower prices. Over a longer period, lower prices and higher interest rates reduce the incentive to invest in more intensive forest management and could reduce harvest.

On industrial lands, despite limited initial inventories, first period harvest shifts markedly with the interest rate, whereas changes are damped in later years (Figure 13A). In the longer term, the lower interest rate appears to generate less dramatic cyclical swings in cut than the 4% or 6% runs. On nonindustrial lands, in contrast, changes in the first period are small but expand in later periods (Figure 13B). The 6% rate leads to an increase in cut in the second and third periods but somewhat lower harvests thereafter. The lower rate produces a lower cut in the second and third periods, but harvests are near or above base levels in the remaining periods. Viewed in the aggregate, the two alternative interest rates do not markedly alter the time patterns of harvest. Averaged over 2002–2047, total regional harvest in both cases differs by less than 1% from the base case. In individual periods, however, differences can range up to 20%. Differences for a given period within an owner group can range as high as 100%.

Alternative interest rates also influence land values that depend on the discounted sum of future net returns. High

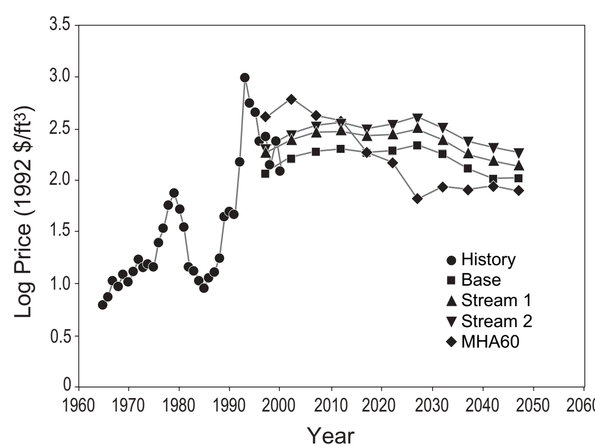

Figure 12. Deflated prices of logs delivered to the mill in western Oregon, with history and projections under base case and three alternatives.

rates reduce land prices; low rates raise them. In the model, land values can be estimated by examining the contribution to the objective function (shadow price) of an additional acre of some specific land type (species, site class, newly regenerated or existing, at various points in time). As examples, the following tabulation gives per-acre bare land values for mid-site timberland in the Western Coast Range and Western Cascade Range (averaging present values over forest type for the period to 2047) under the three alternative interest rates:

Value of Mid-site Bare Timberland in 1992 Dollars per Acre

	INTEREST RATE		
	2%	4%	6%
Western Coast Range	$5,427	$1,954	$698
Western Cascades Range	$5,672	$1,834	$698

Harvests under Alternative Policies

Forest practice regulations can influence rates of private timber harvest in many ways. In the near term, regulations might act to:

- directly delimit the harvestable area (e.g., by excluding riparian zones, habitat areas, or other sensitive areas).
- restrict the types of trees that can be harvested (e.g., by excluding trees based on diameter, age, or species).

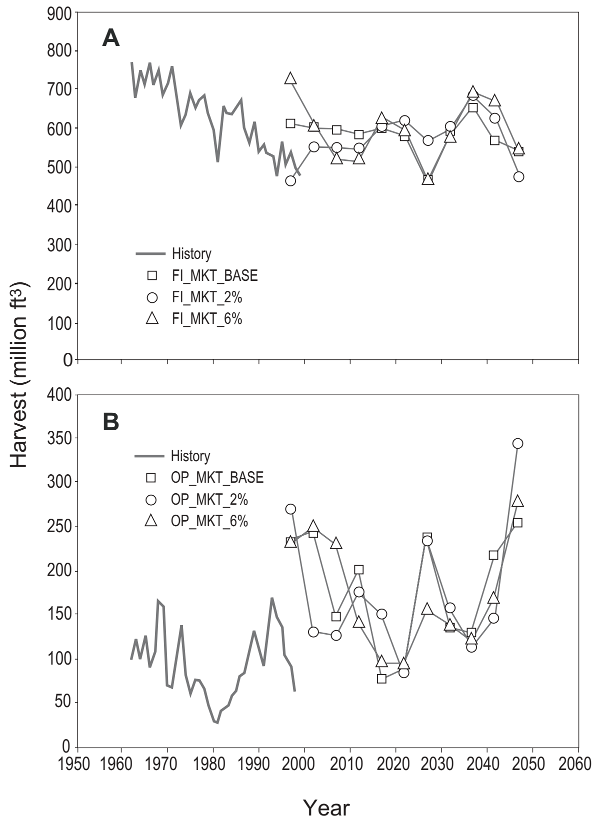

Figure 13. (A) Forest industry harvest (FI) and (B) nonindustrial private harvest (OP) under base case assumption of 4% discount rate and alternative projections with 2% and 6%.

- limit harvest methods or practices (e.g., clearcutting or partial harvest) or the forms of equipment that may be employed.
- require or preclude certain post-harvest conditions (e.g., soil disturbance, impacts on stream channels, non-tree vegetation, or wildlife).

These actions also will affect harvest and harvest potential in the long term as they alter the levels and structure of residual timber inventories and their growth. Forest policies could act with specific focus on long-term outcomes. For example, requirements for certain forms of management investment (such as planting or ensuring minimum seedling establishment after harvest) were originally adopted with a primary concern for maintaining long-term stocks of harvestable timber on private lands. Proposals have also been entertained in some jurisdictions to directly regulate the *rate* of harvest, largely to preclude concentration of cutting in restricted geographic regions (such as single drainages or watersheds).

In recent years there has been much discussion of policy changes in western Oregon that would 1) further restrict harvesting in riparian zones, either through direct exclusion, modification of the form of practice, or both, and/or 2) restrict the minimum size or age of tree that could be harvested. Here we employed the harvest projection model to explore the potential harvest impacts of these types of restrictions. The choice of management investments in these projections is still endogenous. The market projection still attempts to find the market solution that maximizes the "net market welfare" and the present value of returns to the forest landowner, given prices. The even-flow projection still tries to find the highest possible even-flow level. Thus the results include the effects, if any, of modifications in the choice of management regimes over time to mitigate the impacts of the restrictions. As a result, the changes shown here are generally lower than would be the case if the time patterns of management regimes were fixed. In most past studies, the selection of management regimes over time was preset or exogenous and there was no response from private owners to changes in policy other than through harvest levels.

Riparian Protection

Buffer strips or corridors along streams and lake shores have long been used in forest practice regulations to 1) protect these water bodies from direct disturbance, pollution, and increased sediment through runoff from harvested areas, 2) ensure shade for temperature control, and 3) provide sources of large woody debris. In the present analysis, we stratified the inventory on the basis of distance from streamcourse or lake (for any water, perennial or intermittent). As illustrated in Figure 14, the proximity zones are corridors that parallel water bodies. The figure shows only three zones: <50 ft, 50–100 ft, and >100 ft.

We considered two hypothetical scenarios. In the first, softwood harvest was prohibited in the <50-ft zone and only partial cutting of softwoods was permitted in the 50–100-ft zone. Hardwood harvest was prohibited in both zones. This scenario emulates a staged approach of somewhat less severe restrictions as distance from the stream increases. In the second scenario, harvesting of all species was prohibited within 100 ft of a water body.

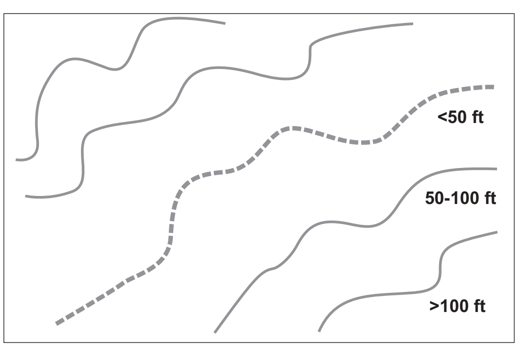

Figure 14. Stream proximity zones for alternative riparian protection policies.

Results of these scenarios appear in Figures 15A and 15B for forest industry ownerships and in Figures 15C and 15D for nonindustrial ownerships. The general impacts are similar for both owner groups and for both the even-flow and market harvest schedules. Eliminating softwood harvest in the first 50 ft and requiring partial cutting in the 50–100-ft corridor in the first scenario accounts for the largest part of harvest reduction: 14.3% on average for industry and 17.9% for nonindustrial owners over the 2000–2050 period. Eliminating all cutting in the 50–100-ft corridor in the second scenario has a smaller incremental effect (even though there is more area in the 50–100-ft corridor), because the movement to partial cutting has already reduced yields sharply, relative to clearcutting. In the second scenario, industry harvest falls by 23.6% relative to the original case, whereas nonindustrial cut falls 25.2% below the original case. Harvest and land area fall in a nearly parallel fashion on both ownerships, suggesting that the land removed from harvest in these scenarios does not involve a disproportionate share of area in any specific age classes relative to the inventory as a whole.[9]

As the riparian protection scenarios limit harvest, log prices rise. Because supply restrictions commence immediately, price increases begin at the start of the projection as well (Figure 12). Prices rise on average 6.9% over the projection period in riparian scenario 1 and about 11.7% under scenario 2. Shifts in price trajectories are nearly parallel over time. In the aggregate, total western Oregon harvest under scenario 2 falls by less than 24% per period on average over the projection, with an average price increase of 11.7%. Since demand is stable in the analysis, the supply shifts effectively trace out the demand function. These results imply a demand elasticity (percentage change in quantity relative to the percentage change in price) of roughly -2.0.[10]

Thus, riparian protection leads to changes in timber harvest and prices. These in turn should induce private owners to modify their management investment patterns. In this study, land allocation by MIC (after the initial period) is determined within the projection consonant with the objective of the simulation. Figures 16A and 16B illustrate the impacts

[9] In the second scenario, roughly 25.3% of industry land *area* and 24.1% of nonindustrial land are removed from harvest, yielding 23.6% and 25.2% reductions in harvest, respectively. Approximately 26.6% of the initial *volume* of forest industry inventory lies within the 100-ft zone (27.4% for nonindustrial lands).

[10] Using the demand and supply relationships described in Appendix C, the elasticity of log demand from *private ownerships alone* at the mean values of harvest and prices in the 1970–1998 period is approximately -1.17, whereas the elasticity at 1994–1998 averages is -1.98. These elasticities are higher than might be expected because they deal solely with the demand for private timber. Demand for private timber can be viewed as total demand less supplies from non-private sources. As a result, the demand for private timber alone is more elastic than total demand. Because projected harvest volumes are close to the 1994–98 average, apparent elasticities in the projections are close to the 1994–1998 levels as well.

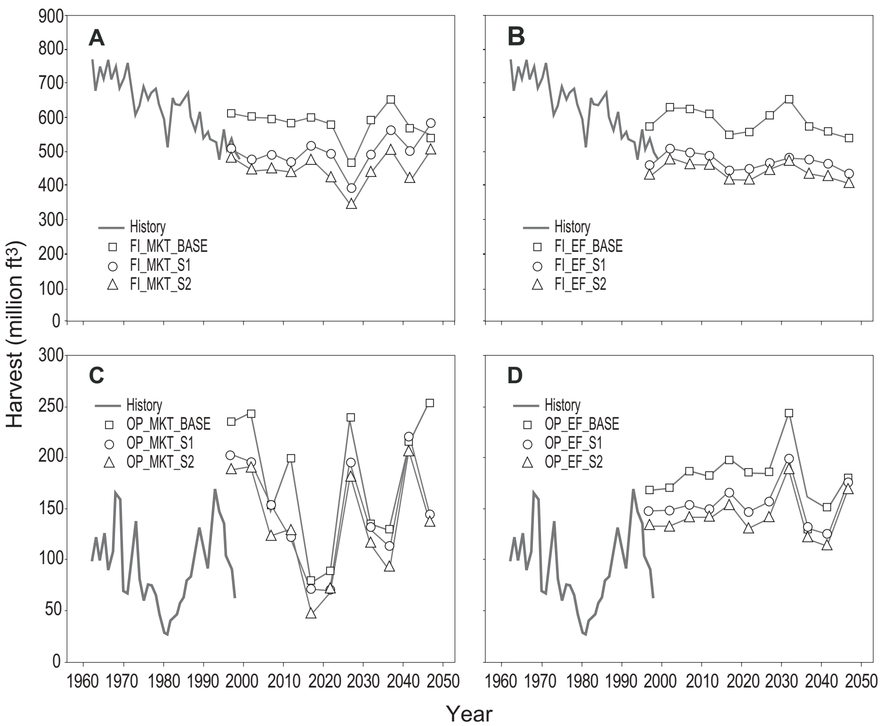

Figure 15. Harvest comparison for (A) forest industry from the market projection under current policy (_MKT_BASE), streamside protection scenario 1 (_S1: no cutting within 50 ft), and scenario 2 (_S2: no cutting within 100 ft), (B) forest industry from the even-flow projection under current policy (_EF_BASE), streamside protection scenario 1 (_S1), and scenario 2 (_S2), (C) nonindustrial private owners from the market projection under current policy (_MKT_BASE), streamside protection scenario 1 (_S1), and scenario 2 (_S2), and (D) nonindustrial private owners from the even-flow projection under current policy (_EF_BASE), streamside protection scenario 1 (_S1), and scenario 2 (_S2).

of riparian scenario 2 on MIC allocation for industrial and nonindustrial owners for the year 2047 of the market projections. In both cases, there are modest shifts away from the dominant MICs in the base case, but no major movement toward more intensive management to compensate for the harvest restrictions. Nonindustrial owners do shift small additional areas into the PLCT and PLPCTF classes, but industrial owners react by expanding three of the natural regeneration options, which have somewhat lower yields. In the even-flow projections (not shown in Figures 16A and 16B), industry owners generally shift land into lower MICs (from PL to NAT options); there is almost no change in the MIC distribution on nonindustrial ownerships.

Raising Minimum Harvest Age

Several states have considered forest policies that limit the minimum age at which trees can be harvested. Part of the objective of these restrictions is to reduce the frequency of site disturbance and associated impacts on soils, roads, and drainage structures; water runoff to streams; deleterious visual impacts; and related phenomena. Other proponents favor longer rotations because harvest volumes on the same land base would rise in the long term, as harvest age approaches culmination of mean annual increment. Older stands also have larger trees and

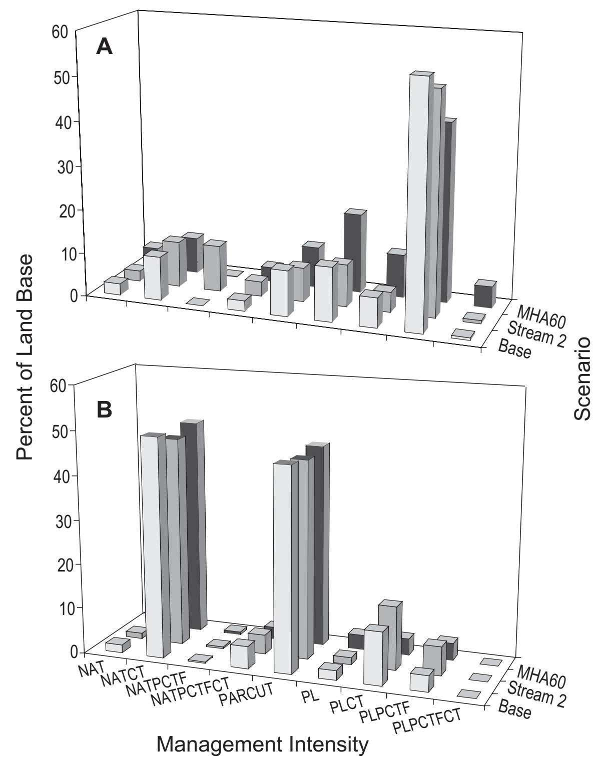

Figure 16. Percent of land base by management intensity class (Table 3) for (A) industrial ownerships and (B) nonindustrial private owners from market base, stream protection scenario 2, and 60-yr minimum harvest age projections (MHA60) for 2047.

provide habitat for an array of wildlife species not favored by the general drift toward short rotation silviculture. In the present analysis, we consider a single example of extending all even-age rotations uniformly to a minimum of 60 yr for softwoods. Some MICs already have minimum harvest ages longer than 60 yr in the base case, but most stands can be cut in the range of 45–55 yr.

In both market and even-flow harvest schedules, the impacts on industrial ownerships are dramatic (Figure 17A). From 2000 to 2050, the even-flow schedule falls by more than 50%. The initial reductions in the market projection also exceed 50%, but the schedule then rises, exceeding the market base after 2020. Early in the projection period, the age restriction causes industry owners to accumulate inventory. Once these areas reach 60 yr, their volumes are substantially larger than those under lower minimum harvest ages. The age class structure of the ownership is adjusted to concentrate most lands at or below 60 yr. Once this transition is achieved, cut can be sustained indefinitely at levels higher than the market base case. In effect, the lower cut during the first 20 yr of the projection is the cost of "reregulating" the inventory on a longer rotation age.

Impacts in percentage terms are smaller for nonindustrial owners (Figure 17B) than for industry, but changes in the time patterns of harvest are still substantial. The market simulation indicates large initial drops in 2002 and 2007. After 2010, the cycles in harvest are damped and reversed relative to the base. There is no rising trend as in the industry case, given the large portion of the inventory already exceeding 60 yr. Shifts in nonindustrial harvest also result from interactions with the markedly altered industrial harvest schedule in the market context. Cut falls in the even-flow case, but by only 6% on average relative to the even-flow base.

These differences in harvest impacts between industrial and nonindustrial lands are closely related to the initial age class structures on the two ownerships. On industrial lands, as discussed previously, only a small fraction (about 10%) of the 1997 inventory is in ages 60 yr and older. If the source of harvest is restricted solely to these acres, cut must fall sharply. On nonindustrial lands, in contrast, a larger percentage (about 23%) is in classes 60 yr and older, which provides a larger harvestable pool under the harvest age restriction, meaning that cut does not have to fall as much.

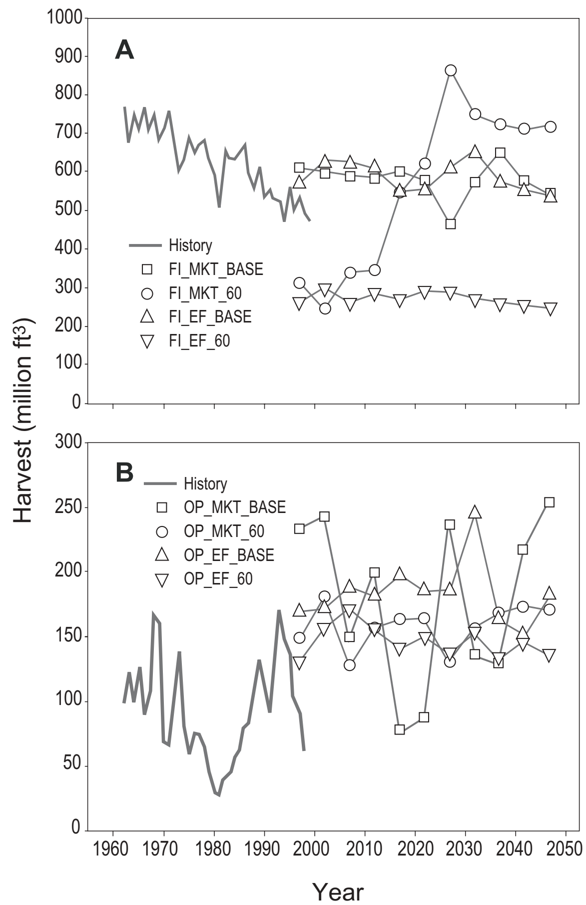

Figure 17. Harvest comparison for (A) forest industry and (B) nonindustrial private owners for market (_MKT) and even-flow (_EF) projections under base (_BASE) and 60-yr minimum harvest age (MHA60).

Management intensity adjustments are illustrated in Figures 16A and 16B. The industrial response to higher minimum harvest ages is more substantial than in the streamside protection cases. There is some movement into both more intensive and less intensive classes. The nonindustrial allocation, in contrast, is very close to the base case. MIC shifts can do little in the short run to compensate for the harvest impacts of higher harvest ages. And in the long term, lower prices resulting from higher yields per acre (relative to the base) and higher harvests act against uniform shifts into more intensive management. In the even-flow projections (not shown) both industrial and nonindustrial owners shift significant areas into the less intensive MICs (relative to the base). In this case, the harvest level is largely controlled by the availability of inventory over 60 yr old in the first few periods of the projection.

SUMMARY OF FINDINGS

In terms of projected future harvest, the qualitative results of this analysis do not differ greatly from those of its predecessors (Beuter et al. 1976; Sessions 1991). The 1976 (projections B-1) and 1989 industry projections are lower than both recent history and the projections from the present study (Figure 18A). Nonetheless, all of the projections suggest that forest industry lands could maintain harvests in the neighborhood of recent historical levels for at least the next 50 yr. The declining trend of the past 40 yr need not continue. The average of even-flow and market projections for industry lands from the current study is 580 million ft^3/yr over the next 50 yr. The average projection from the 1976 and 1989 studies was 440 million ft^3/yr. The average harvest for the years 1990–1999 was 520 million ft^3/yr.

The harvest projections from this study approximately equal growth, yielding an inventory that is roughly stable over the projection (Figure 8A). Maintained over long periods, harvest equal to growth would gradually lead to a regularization of the age class structure of a forest; the area would be distributed in a roughly uniform fashion over a range of ages. For industry lands in western Oregon, the result would be a continued compression of the land base into ages below 60 yr. The harvest projections also entail a continued shift toward more intensive forms of silviculture that involve treatments beyond insuring establishment of regeneration.

Comparison of projections from the current study and from past studies for nonindustrial owners (Figure 18B) illustrates the considerable harvest potential of these lands, as well as the uncertainty regarding future harvest and management investment behavior. All projections suggest that nonindustrial lands in western Oregon could maintain harvests near recent historic peaks for at least the next 50 yr, roughly doubling the historical average level of harvest. Under the conditions of both market and even-flow projections, a stable to rising inventory would result, with harvest at or below growth.

Higher initial harvests in the market projection lead to an irregular age class structure with a large block of acres moving toward the older classes over the next 50 yr–the result of large harvests in the first few periods of the projection. The even-flow projection, in contrast, entails a more uniform distribution. Both cases indicate a shift toward more intensive management, though this is much less pronounced in the market simulation.

Simulations of the two alternative forest policies revealed marked differences in response, both to the form of the policy and between private owner groups. The riparian zone harvest restrictions had similar impacts across the two owner groups, reducing total cut by 24–25% in the 100-ft no-harvest scenario. In this case, the land removed from harvest cut across the range of age classes in both ownerships and did not exacerbate the problem of limited area in older ages on industry lands. Harvest fell by roughly the same percentage as the operable land base.

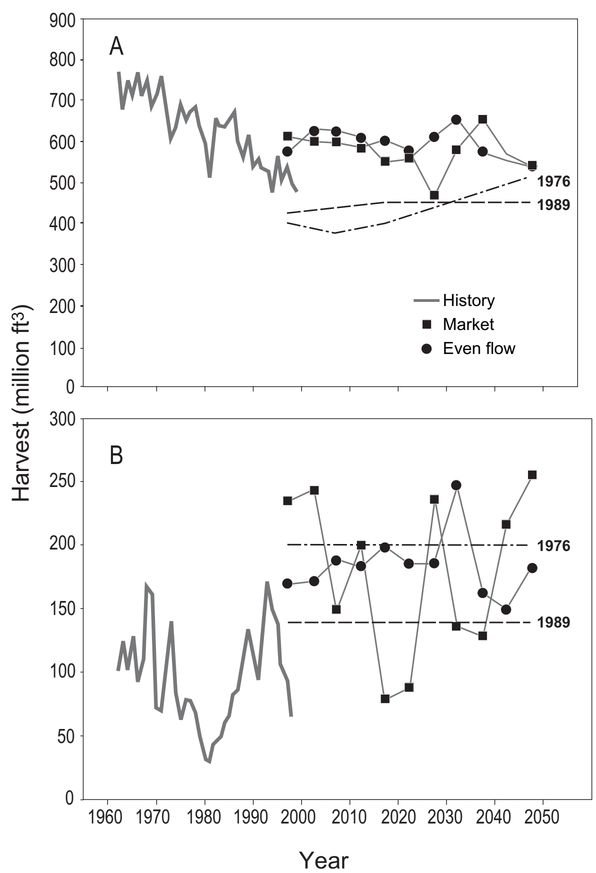

Figure 18. (A) Forest industry and (B) nonindustrial private harvest projections from current and earlier studies of western Oregon.

To offset the impacts of these policies on harvest, further intensification of management on unaffected lands has been suggested by some observers. The projections, however, allowed both ownerships to shift their lands into alternative management intensity classes in an optimal fashion, given the objective of the simulation. Examination of changes in MIC distributions did not reveal major shifts toward more intensive management in response to either policy. More intensive management clearly would not raise the even-flow levels, because the even-flow level is limited by near-term inventory restrictions. More intensive management could raise the projected market-based harvest levels. It would do so, however, at the cost of reducing projected net market benefits to log producers and consumers, who presumably are the targets of the mitigation effort.

The minimum harvest age simulations reflect the sensitivity of harvest from industrial ownerships to policies that directly limit access to older age classes. With a relatively small fraction of the industrial land base in stands over 60 yr of age, raising minimum harvest age to 60 sharply reduces the area and volume available for harvest. For the harvest schedules employed in this study, the result was near-term harvest reductions in excess of 50%. These reductions were essentially permanent in the even-flow projection (given the nature of this harvest schedule), but were followed by rising harvests in the market simulation as acres accumulated in older ages with higher volumes per acre. For nonindustrial owners, with twice the inventory proportion in ages 60 and older, the percentage of harvest reduction was substantially reduced.

We emphasize that the policies examined here were chosen for illustrative purposes. Policy changes that would include these types of restrictions have been much discussed. State and federal policy-making bodies are considering many other policy options, however, and many of the details of the two policy types examined here would probably be different from the assumptions employed in our projections. We believe, nonetheless, that these simulations help illustrate some important attributes of western Oregon private timber inventories and their potential response to policy changes. As additional policy options emerge, the projection tools developed for this analysis can be used to simulate their impacts.

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Appendix A: Inventory and Growth and Yield Estimates

As do all timber supply projections, the western Oregon timber supply study needs estimates of the future yields of timber stands in the current timber inventory, as well as of stands that will be regenerated over the course of the timber supply projection. These yields must vary across the site qualities and other physical conditions of the forest resource, and also by the management intensity class or management regime applied by owners. For the harvest projection model, existing and future stands are aggregated into strata defined by the dimensions: age, site productivity class, forest type, management intensity class (or management regime), development zone (extent of human development), slope class, proximity to stream course, owner, and ecoregion.[1] Age, site class, forest type, management intensity class, and ecoregion are the dimensions that matter in projections of stand yields.[2]

In projecting future volumes of existing stands, we have attempted to avoid potential bias in yield estimates at the strata level by first projecting yields of smaller, more homogeneous inventory components, then aggregating these to obtain strata volumes. Within the 1995–1997 (OC4) Forest Service inventory of western Oregon, plots are subdivided into condition classes, which are intended to be areas of homogeneous site productivity and current vegetation conditions.[3] For the plots classified as timberland in the OC4 inventory, there are 1,108 plot/condition class units. We first projected the volumes of each of these plot/condition class units, then aggregated these volumes to obtain the strata-level yields.

Yields for stands that originate after the start of the projection were developed from tree lists for regenerated stands created to match the specific assumptions of each management intensity class. Regeneration tree lists were grown to breast height age of 15 yr using SYSTUM1 (Ritchie 1993). Subsequent yields for all stands were developed with ORGANON (Hann et al. 1997).

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[1] Ecoregion acronyms are: Western Coast Range, WCST; Other Coast Range, OCST, Western Cascade Range, WCASC; and Klamath, KLAM. See Figure 2 for ecoregion boundaries.

[2] Ownership influences the yield of *existing* stands because of past actions that impact current stand conditions. In future stands, however, a given management intensity class produces the same yields for a given site class and forest type on any ownership.

[3] Specifically, land class (timberland, nonforest, etc.), stand size, forest type, tree stocking, and harvest since OC3 are supposed to be uniform within a condition class.

Table A-1. Forest Service site productivity classes.

Site productivity class	Mean annual increment at culmination (ft^3/ac/yr)	Current study site class
I	225+	HI
II	165–224	HI
III	120–164	MED
IV	85–119	LO
V	50–84	LO
VI	20–49	LO

Table A-2. Percent of timberland area by site productivity class.

Citation	Year of Study	HI	MED	LO
Forest industry				
Current study	1997	45	33	22
FIA OC4 (2000)	1997	44	33	23
McKay et al. (1998)	1995	34	40	26
Sessions (1991)	1986	34	40	27
Beuter et al. (1976)	1975	47	41	13
Nonindustrial private				
Current study	1997	28	39	33
FIA OC4 (2000)	1997	27	38	35
McKay et al. (1998)	1995	23	35	42
Sessions (1991)[1]	1986	–	–	–
Beuter et al.	1975	39	35	26

[1]Proportions not available from 1991 study.

Site Index Background

Each plot/condition class unit in the OC4 inventory was assigned to a site productivity class based on estimates of site index and Forest Service algorithms that link site indices to mean annual increment at culmination in normal yield tables for site index species. The Forest Service uses six site productivity classes (Table A-1). In our first attempts to use the OC4 data, we detected errors in Forest Service estimates of site index in several counties. In these cases, we used the ORGANON supplementary program, SICALC, to recompute site index from original site tree age and height. This process led to the recalculation of MAI (mean annual increment) at culmination by means of the Forest Service algorithms.

We aggregated these productivity classes into three site classes (low, medium, and high), as indicated in the far right column of Table A-1. Using the Forest Service's productivity class algorithms at the condition class level, we assigned all plot/condition class units to one of these three classes. Table A-2 shows the resulting distribution of forest industry and nonindustrial private timberland area by site class, compared with findings from the OC4 final data release and earlier studies.

The distribution of timberland area by productivity class in the current study is closer to the results of Beuter et al. (1976), with more area in the medium and high classes, than to the more recent findings of Sessions (1991) and McKay et al. (1998), possibly because of the previously noted errors in site index computation in an earlier version of the OC4 inventory. Correction of these errors led to productivity class reassignments for several conditions classes and shifted more than 359,000 ac to timberland from nontimberland (growth <20 ft^3/ac/yr). These errors also might have been present in the earlier OC3 inventory, thus affecting the Sessions analysis and the McKay et al. inventory update. The latter did not remeasure site trees or recompute site indices or productivity classes from OC3 values.

To determine the average site index within each site class for use in growth and yield models, we began by examining the actual site tree data associated with each plot/condition class unit. Data for 4,067 Douglas-fir, western hemlock, and ponderosa pine trees on 808 condition classes in 759 plots were recorded in the inventory. These data represent 73% of all the plot/condition class units used in the model. The remaining plot/condition classes did not have site trees, though the plots did have productivity class assignments, suggesting that the Forest Service assigned productivity class from earlier plot measurements or by means of soil or plant indicators.

Table A-3. Average Douglas-fir site indices for productivity classes by forest type and ecoregion.

Forest	Site index				Plot condition classes				Acres represented (thousands)			
type/site	WCST	OCST	WCASC	KLAM	WCST	OCST	WCASC	KLAM	WCST	OCST	WCASC	KLAM
Douglas-fir												
HI	141	140	137	139	28	43	69	2	185	272	451	16
MED	118	117	117	109	15	30	92	13	73	140	571	71
LO	96	92	91	80	4	9	29	39	23	51	163	229
Other softwoods												
HI	133	127	139		14	2	4		100	13	27	
MED	122	127	118	100	5	3	9	2	30	14	61	24
LO	89	94	93	87	5	2	4	12	31	9	21	96
Hardwoods												
HI	142	133	146		16	13	9		96	63	51	
MED	127	120	117		7	31	16		38	138	78	
LO	105	94	96	73	2	19	19	26	10	88	102	190

Breast height age and total height for each site tree were entered into the ORGANON supplementary program, SICALC, to obtain site indices. We used Bruce (1981) to calculate Douglas-fir site indices in all regions except the KLAM, where we employed the Hann and Scrivani (1987) index. We used Flewelling (1994) for western hemlock and Hann and Scrivani (1987) for ponderosa pine. We first calculated average site indices for each condition class, then averaged them across condition classes. Table A-3 shows average site indices for Douglas-fir only for the three productivity classes by forest type, the number of plot/condition class units, and associated acreage used to compute the average site index. This acreage is for plot/conditions classes with site tree data only. It does not represent distribution of the total inventory shown in Table A-2.

Outline of Yield Projection Approach

Existing Stands

We used the Stand Management Coop (SMC) version of ORGANON to model all regions except the KLAM region, for which we used the Southwest Oregon version. Tree lists for existing stands were compiled at the condition class level. In some cases, actual tree species were adjusted to species accepted by the appropriate ORGANON version. Young condition classes were grown to 15 yr breast height age in SYSTUM1 and then transferred to ORGANON for the remainder of the projection period. Details of ORGANON projections and adjustments are given in the next section on new stands. For existing stands, the site indices used for each condition class in the growth and yield estimation were the actual site indices, or the average site indices from Table A-3, if no site trees were available for that particular condition class. For younger stands to be grown in SYSTUM1, the Powers and Oliver (1978) site index, based on a total age rather than breast height age, was calculated. Where there was no site tree information for the younger stands, the site indices were decreased by 14 index units to approximate the Powers and Oliver index.

New Stands

Table A-4. Initial trees per acre by forest type and ecoregion for natural origin stands.

Ecoregion	Douglas-fir	Other softwoods	Other hardwoods
WCST	468	467	883
OCST	397	248	758
WCASC	521	663	684
KLAM	486	486	596

Table A-5. Initial trees per acre by site class for planted stands in all ecoregions.

	Site class		
Forest type	LO	MED	HI
Softwoods	403	436	443
Hardwoods	437	470	477

Projecting new stand yields comprised three steps: initial (regeneration) tree list development, young stand modeling, and older stand modeling. The first step in compiling tree lists was to develop estimates of the average number of stems per acre and the distribution of stems by species in regeneration stands. We began by computing averages of stems per acre and species composition for all stands under age 15 in each ecoregion from the OC4 inventory data. For natural stands, we assumed that total stems per acre would be equal to the density values computed from the plots. We assumed in addition that 90% of the total trees per acre would be the species of the primary forest type and adjusted expansion factors accordingly. For planted stands, we further adjusted these same species proportions to planting densities specified in owner management intentions surveys.[4] Although trees per acre in naturally regenerated stands (Table A-4) varied with the empirical averages across ecoregions, densities in planted stands (Table A-5) did not. Diameters and heights of stems were set at the averages for the species at 2-yr breast height age, as derived from the OC4 data. If no 2-yr breast height trees of a particular species were available, a softwood or hardwood average was applied.

The rationale for generating tree lists in which 90% of the trees had to be of the primary forest type was to create stands approximating what owner surveys had indicated as target plans for the stands, as well as what the mature stand composition might be. The young stand tree lists gleaned from the OC4 data had much variability in species. In modeling these young stands, it might have been appropriate to start a stand with the full set of young trees with all its variability, then precommercially thin, targeting the unwanted species. It

[4] In cooperation with the Oregon Forest Industry Council during early 1998, the Oregon Department of Forestry undertook a survey of industrial forest land owners' current management practices and future management intentions for lands in Oregon, using nine management intensity classes. Similarly, ODF and Extension field foresters surveyed in order to provide information on potential management actions of nonindustrial owners. Data from these surveys provide the details of each management regime. Based on the results of these surveys, we expanded the number of management intensity classes to 10 to include more thinning options. Information on regeneration stocking density of naturally regenerated stands was not collected in these surveys, hence our assumptions.

Table A-6. Years to reach breast height by ecoregion and site class.[1]

	Site class		
Ecoregion	LO	MED	HI
WCST, OCST, and WCASC	7	5	3
KLAM	9	7	5

[1]Based on communication with the Nursery Technology Cooperative, Oregon State University.

was not clear how to operationalize this procedure, however, given the scale of the present analysis.[5] Further, since our tree lists begin with one average tree per species to be represented, thinning from below would remove all trees from the smallest species, leaving the larger species untouched. To circumvent this potential problem, we opted to adjust the species composition before projecting growth.

Using SYSTUM1, we modeled young stand growth and yield in all ecoregions.[6] We calculated Powers and Oliver (1978) site indices based on total, rather than breast height, age for each stand, decreasing the values in Table A-3 by 14 as previously described. Competing vegetation was ignored. For the MICs that included precommercial thinning, we assumed a proportional thinning by simply reducing all expansion factors proportionally to the prescribed post-PCT density. New stands entered SYSTUM1 at total age 10 for planted stands and total age 12 for natural stands, which gave a planted stand a 2-yr head start over a naturally regenerated stand. We calculated total ages with the estimates of years to reach breast height (Table A-6).

In the original management intention surveys, thinning regimes were characterized in terms of the percentage of stand volume to be removed and whether the thinning was to be from above, from below, or proportional. Most of the responses indicated that thinning would be from below. To accommodate this approach within the structure of ORGANON, we attempted to begin the new stand yield estimation with user codes for different trees and sizes in the tree list. Thirty years into the rotation, however, when the thinning was to take place, we could not be certain that thinning a proportion of the originally targeted trees would remove the appropriate percentage of volume from the entire stand. As an alternative, we considered projecting the stands to the thinning year and ending the run, reading the output for stand basal area, then rerunning the stand projection using ORGANON's "basal area thin from below" option. This projection would have given the desired "thin from below," but would have markedly expanded the computational burden. We opted, therefore, to simulate thinnings as proportional. Tests with ORGANON suggested that post-thinning yields of stands thinned from below and proportionally did not differ markedly (though there were average diameter differences).

We used ORGANON to model older stand growth and yield in all regions. All new stand tree lists were entered at 15 yr breast height age. Timing of management activities originally specified in the owner intention surveys (see footnote 4) was adjusted to the nearest 5-yr period. Given the limitations of ORGANON in simulating management actions, fertilization occurs only if 80% of the stand is Douglas-fir. As described previ-

[5] New yield projections required 234 SYSTUM1 runs, followed by 468 ORGANON runs.

[6] Early reviews of our growth and yield projection approach suggested that SYSTUM1 might underestimate growth in intensively managed stands or produce trees with large diameter-to-height ratios. To resolve this problem in the northern and coastal regions, we had planned originally to use the Regional Vegetation Management Model (RVMM). The Windows-based platform for RVMM unfortunately was not readily adaptable to the multiple batch-style runs needed.

ously, we modeled all thinnings with the proportional removal option. Total stand volume (ft^3) was estimated for each stand in a run with volume measured from a 1-ft stump to a 2-in. top. An estimate of "sawlog" volume was obtained in a run measuring volume (ft^3) from a 1-ft stump to a 6-in. top (CV6).

In initial analyses of yield projections, yield volumes in simple plant-only or natural-regeneration-only management regimes appeared to be large. For example, projected yield volumes were at or near 20,000 ft^3/acre at age 100 for mid-site, planted Douglas-fir stands in the western Cascades. In contrast, McArdle et al. (1949) showed values less than 14,000 ft^3/acre for mid-site stands, with volumes approaching 20,000 ft^3 only for the highest site productivities. Volumes close to those of McArdle et al. (1949) were also found in tests with the FVS (Donnelly and Johnson 1997), DFSIM (Curtis et al. 1981), and SPS (Arney 1985) models.

To control projected yield volumes, we lowered the maximum stand density indices (max SDI) to expand the impacts of competition and hasten the onset of mortality. We employed the following max SDIs in all regions: Douglas-fir, 430; grand fir/white fir, 608; pine/hemlock, 596. These revised max SDIs are similar to those estimated from projections with the SPS and DFSIM models. FVS projections indicated max SDIs closer to our original, higher values. This might result, however, from the use of a version of FVS calibrated for substantially higher elevations than are characteristic of private lands in the study area.

Commercial Thinning Response

Projected yield responses for MICs involving commercial thinning were also large. Initial growth and yield estimates showed dramatic volume increases, with net volume (defined as standing or residual volume after thinning, plus the volume removed in the thinning) 15–20 yr after thinning rising far above volumes in comparable unthinned stands. We supposed that adjusting max SDI might resolve this problem as well, because mortality increases in unthinned stands as they near max SDI, whereas volumes in thinned stands, with fewer trees per acre and larger quadratic mean diameters, quickly catch up to volumes in unthinned stands. The SDI adjustments described previously, however, did not appear to affect the relative size of the post-thinning growth response, although they reduced total volumes.

Comparisons with other growth models also suggested that our thinning response might be high. DFSIM, for example, required more than 30 yr before net volume in the thinned stand surpassed that in its unthinned counterpart. For FVS, net volume in the thinned stand never caught up with that of the unthinned stand. Empirical studies have yielded similar results. In the Hoskins studies (Marshall 1994), only the lightest thinning regime produced net CVTS higher, by about 10%, than that of the unthinned control by age 50. In the Black Rock studies (Marshall 1991), light thinning also produced higher net CVTS volumes by age 80, averaging 13% above the control.

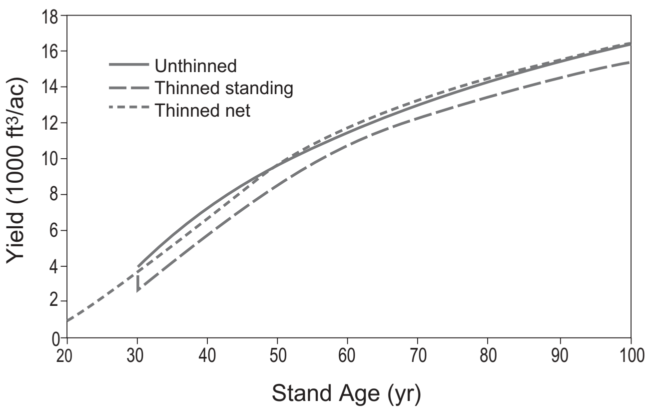

Figure A-1. Example yields for western Cascades Douglas-fir stands (2-in. top) on medium site for unthinned stand, standing volume for the thinned stand, and net volume (standing plus removed) for the thinned stand.

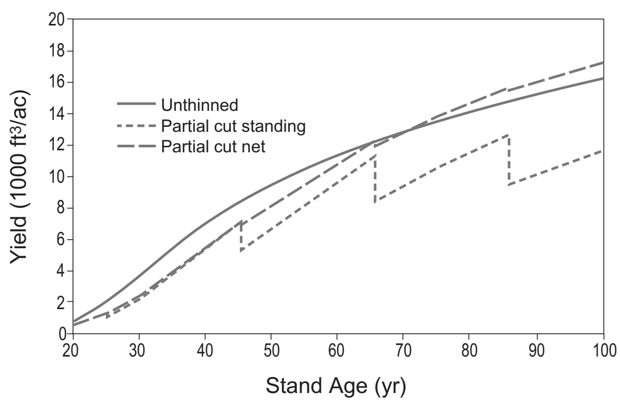

Figure A-2. Example yields for western Cascades Douglas-fir stands (2-in. top) on medium site for unthinned stand, standing volume for the partial cut stand, and net volume (standing plus removed) for the partial cut stand.

Rapid projected volume growth following thinning might result from not accounting for 1) mechanical damage and thinning shock in the thinned stand, 2) failure of the thinned stand to fully reoccupy the site (thinning can produce clumpiness or unevenly distributed stems, in which case the max SDI of the stand prethinning would no longer apply), and 3) breakage in the thinned material. To compensate for these sources of growth reduction, we employed a 5% downward adjustment in post-thinning growth of the residual stand following commercial thinning. Loss of volume because of breakage is reflected in a 5% reduction in the yield of thinned material. Net volume in thinned stands does eventually exceed that in the unthinned stand, but by a fairly modest amount (Figure A-1).

Partial Cutting Yields

The problems associated with yield projections in commercially thinned stands are magnified in the partial cutting MIC. In this case, none of the widely available growth-and-yield models is well adapted to simulating regimes of multiple entry thinning over long time periods. In our original projections, cumulative net yields (thinnings plus residual volume) rose dramatically and surpassed unthinned or single-thinning net yields by as much as 27% by age 100. This result seems large when compared with the results of the Hoskins and Black Rock studies previously cited (which were multiple entry experiments). As a consequence, the reductions applied to the single commercial thinning regimes are also applied to the partial cutting regimes at each entry. Adjusted partial cutting yields exceed unthinned yields by about 5% by age 100 (Figure A-2).

Appendix B: Mathematical Representation of the Market Model

The market model employs the basic approach suggested by Johnson and Scheurman (1977), and subsequently employed by Lyon and Sedjo (1983) and Adams et al. (1996), to find market equilibrium, maximizing the present value of the sum of consumers' and producers' surpluses in the log market summed over all periods in the projection. Consumers' surplus is computed as the area under the demand curve for logs in the region, less the cost of those logs. Consumers in this case are mills that use softwood logs. Producers' surplus is identical to the profit of log producers (log price minus production costs). Log producers in this case are forest owners. This combined surplus, termed "net social surplus" by Samuelson (1952), is maximized subject to (1) constraints on the areas harvested and regenerated and (2) the requirement that demand volumes equal volumes supplied. The problem must also include some accounting for the values represented by the inventory in the forest at the end of the projection period. In the present model, we include a reckoning of the net surpluses that accrue after the end of the projection period, assuming perpetual even-flow management. The model employs 5-yr periods. A projection encompasses 20 periods.

Abstracting from details of ownership, ecoregion, forest type, and the remaining dimensions used to stratify the forest, the optimization problem to be solved can be written as follows:

$$\text{MAX} \sum_t \int_0^{Q_t} P_t(q)dq(1+i)^{-t} - \sum_t C_t^N(N_{t,j})(1+i)^{-t} - \sum_t C_t^X(X_{i,t})(1+i)^{-t} - \sum_t (S_t + E_t - M_t)c_t(1+i)^{-t} + \frac{D_T(I_T) - C_T(I_T)}{i}(1+i)^{-T}$$

subject to

(1) Conservation of area in initial age classes

$$\sum_t X_{i,t} = A_i \quad \forall\ i$$

(2) Conservation of area in newly created age classes

$$\sum_j N_{t,j} = \sum_i X_{i,t} + \sum_{k<t} N_{k,t} - L_t \quad \forall\ t$$

(3) Total supply

$$S_t = \sum_i V_X(i,t)X_{i,t} + \sum_{k<t} V_N(k,t)N_{k,t} - E_t + M_t \quad \forall\ t$$

(4) Demand equals supply

$$Q_t = S_t \quad \forall\ t$$

(5) Terminal inventory

$$I_T = \sum_{k>T}\sum_i V_X(i,k)X_{i,k} + \sum_{j>T}\sum_{k\le T} V_N(k,j)N_{k,j}$$

where

$X_{i,t}$ is the area of age class i existing at the start of the projection that is cut in period t (*existing* stands),

$N_{i,j}$ is the area of forest regenerated in period i ($i < j$) that is cut in period j (*new* stands),

Q_t is total western Oregon softwood sawlog consumption at mills in period t,

$P_t(q)$ is the demand for softwood sawlogs in period t, a function of quantity q,

i is the discount rate,

$C^N{}_t$, $C^X{}_t$ are the planting and tending costs of new (N) stands and the tending costs of existing (X) stands, respectively, in period t,

c_t is the unit cost of harvest and transportation of logs from woods to mill,

$D_T(I_T)$, $C_T(I_T)$ are the area under the log demand curve at the even-flow harvest deriving from the terminal inventory (I_T) and the management costs associated with that annual level of harvest, respectively,

A_i is the area in existing stands that were in age class i at the start of the projection period,

L_t is the net gain (or loss) of land from the timberland base to non-timber uses in period t,

$V_X(i,t)$, $V_N(k,t)$ are the volumes per unit area in existing stands that were in age class i at the start of the projection and harvested in period t and the volumes per unit area in new stands that were planted in period k and harvested in period t, respectively, and

E_t, M_t are the volumes of logs imported to and exported from western Oregon, respectively, in period t.

In the actual model, E_t and M_t are also functions of price, which we ignore here to simplify the presentation. The treatment of terminal inventory is similar to the method employed by Adams et al. (1996). The inventory at the end of the final period in the projection is assumed to be perfectly regulated on a rotation equal to the minimum harvest age. The *annual* even-flow volume that would result from this inventory is approximated from von Mantel's formula (see Davis and Johnson 1987). The functions $D_T(I_T)$ and $C_T(I_T)$ represent the computation of the area under the demand curve $P_T(q)$ at the even-flow volume, q, and the planting and tending costs associated with this harvest level.

The demand equation, $P_t(q)$, was estimated as described in Appendix C.

Additional inputs and assumptions in the analysis include:

- 15% defect deduction on all harvests, representing the percentage of the stand volume that remains in the woods because of breakage or rot.
- 10% forest industry cost reduction in timber management practices relative to nonindustrial ownerships because of economies of scale and use of integrated services.
- 4% real discount rate for all owners.
- planting costs per tree independent of the species or number of species planted on any given acre.
- precommercial thinning costs the same across all regions and planting densities.
- harvest costs the same across all regions, species, size classes, and slopes.
- transportation costs the same for each region, regardless of species size class.

Appendix C: Western Oregon Log Market

Log supply and demand in western Oregon are composed of several flows originating both within and outside of the region. The log market model recognizes four components of log supply and five major elements of log demand (Table C-1). The table also shows estimates of the relative weights of each element in total supply or demand based on harvest, trade and production data from 1994 to 1998 and the two most recent Oregon and Washington mill studies (Ward et al. 2000; Larsen 1998). The third column briefly describes how each component is modeled in this study. The following sections describe these components and the parameters or fixed levels used to represent them in the model.

Table C-1. Components of log supply and demand in the western Oregon log market for 1994-1998 and their treatment in the projection model.

Component	Percent	Treatment in model
Supply		
Western Oregon harvest	80	Determined within model
Domestic imports	13	Price sensitive assuming an elasticity of 1
Eastern Oregon imports	6	Fixed at 25% of recent eastern Oregon harvest levels
Foreign imports	1	Fixed at recent levels
Demand		
Lumber production	65	Econometrically estimated via restricted normalized profit function
Plywood production	25	Econometrically estimated via restricted normalized profit function
Other consumption	4	Assumed to be portion of harvest which is not classified sawlog
Foreign exports	4	Price sensitive based on an elasticity of -0.4
Domestic exports	2	Fixed at recent levels

Log Supply

Domestic Imports

Western Oregon imports roughly 13% of its sawlog consumption, primarily from western Washington and, to a lesser extent, from northern California. We modeled the quantities supplied by each region with a simple, linear, price sensitive import supply function (Table C-2). To develop the intercepts and slopes for these functions, we used the

Table C-2. Parameters of linear domestic import log-supply equations.

Ecoregion	Intercept	Slope
WCASC	0	18.6
KLAM	0	12.67

1995 delivered mill price for softwood sawtimber in the Pacific Northwest Westside region from the RPA database (Adams and Haynes 1996) and import quantity data as reported by Ward et al. (2000). As no estimates exist for the price elasticity of logs exported from Washington or California, we assumed a unitary elasticity.

Eastern Oregon Imports

Initial analysis of harvest levels, log imports and exports, and log consumption for 1970 1998 showed western Oregon net log supply well below estimated log consumption. On the eastside, in contrast, the harvest level adjusted for *reported* trade was substantially higher than estimated log consumption associated with lumber and plywood production. The available mill studies do show some movement of logs from east to west, but the most recent report (Ward et al. 2000) also shows that the county of origin is unknown for approximately 750 million bd ft of logs consumed in the west. We believe that a portion of this volume involves flows from eastern into western Oregon—shipments that probably originated within the past decade in response to elevated log prices on the westside. We assumed that 25% of the eastern Oregon harvest is actually exported to western Oregon. The flow is represented as a fixed volume of some 48.8 million ft^3.

Foreign Imports

Foreign imports are assumed to enter western Oregon at a fixed level of 5.18 million ft^3/yr, based on values reported for 1998 in Ward et al. (2000).

Log Demand

Lumber and Plywood Production

Because the lumber and plywood industries both consume sizable volumes of softwood logs, we modeled each industry's consumption separately, using a normalized, restricted, quadratic profit function. Each industry was assumed to have one output (lumber or plywood). Inputs include logs, labor, and other variable inputs. Capital stock is treated as quasi-fixed and technology is represented by a time trend. The industries are assumed to be competitive, attempting to maximize profits subject to endogenous prices of output and logs and exogenous prices of labor and other variable inputs. Applying Hotelling's Lemma (Varian 1992) to each industry's indirect profit function ($\tilde{\pi}_o$), differentiation with respect to the relative price of logs yields the negative of the log demand curve:

$$\frac{\partial \tilde{p}_o}{\partial \frac{p_w}{p_n}} = x_w = a + \sum_{j=o,w,l} b_j \frac{p_j}{p_n} + b_k k + b_t t \qquad [1]$$

where o is the output (lumber or plywood), w is softwood roundwood, l is labor, n is other variable inputs, k is capital stock, t is level of technology, p_j is prices, and x_w is quantity of log demand.

The empirical model consists of Eq [1], along with the output supply, labor demand, and profit function equations, with symmetry imposed and normally distributed stochastic disturbances of mean zero and constant variance appended to each equation. Dummy variables were included in the lumber supply equations to represent the effects of labor strikes in British Columbia in 1975 and recession in 1980–1982. Output and roundwood prices were treated as jointly dependent with input and output volumes. Product prices were treated as exogenous.

We used time series data with annual observations from 1970 to 1998 in the estimation of the model. We obtained data for lumber production and prices from the Western Wood Products Association (http://www.wwpa.org/). Plywood production came from the APA–The Engineered Wood Association (http://www.apawood.org/) and prices came from Warren (1999). We obtained log consumption by multiplying lumber and plywood production by product recovery factors for the Pacific Northwest Westside region from the U.S. Forest Service's RPA Timber Assessment database (Adams and Haynes 1996). Log prices are an average of 2S and 3S log grades reported by the Oregon Department of Forestry for their western Oregon regions.[7] We obtained labor quantity and price for Standard Industrial Classification Codes 2521 and 2536 in western Oregon from the Oregon Department of Employment. Capacity, representing maximum service output of the stock as described in Adams and Haynes (1996), served as a proxy for capital stock in the lumber industry. Capacity in the early years for the plywood industry is from the APA–The Engineered Wood Association. For the more recent years, it comes from Spelter et al. (1997). The price index for other variable inputs is the United States all-commodity producer price index from the Bureau of Labor Statistics.

To estimate relations for the two industries, we used iterative, nonlinear, three-stage least squares, with the instrument set including exogenous variables together with the lagged values of all endogenous variables for all regions.[8] Curvature (convexity) was imposed on the system as described by Wiley et al. (1973). Table C-3 gives parameter estimates, asymptotic t-ratios, and goodness-of-fit statistics for the log demand equations. These parameters yield an unconditional (Marshallian) own-price elasticity of wood demand for lumber production of -0.47 and -0.72 for plywood production (at sample means). The conditional (Hicksian) factor demand elasticities with no supply adjustment are -0.05 for lumber and -0.001 for plywood.

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[7] Data were obtained from ODF's log price website at http://www.odf.state.or.us/tmbrmgt/logppage.htm (November 2001).

[8] We used the SHAZAM econometrics package to obtain coefficient estimates.

Table C-3. Parameters of log demand (factor input) relations for western Oregon lumber and plywood production. Numbers in parentheses are t-statistics.

	Constant	P_o	P_w	P_l	Capacity	Technology	R^2	DW
Lumber	-0.257	-0.507	0.397	0.853	-0.474	-0.029		
	(-0.046)	(-4.15)	(4.72)	(1.27)	(-6.24)	(-2.34)	0.90	2.19
Plywood	-0.837	-0.972	0.374	1.256	-0.150	0.004		
	(-1.37)	(-6.94)	(8.14)	(3.37)	(-2.71)	(0.28)	0.93	1.48

Other Consumption

Other consumption comprises logs used in chipping, pulp and board, shake and shingle, and post, pole, and piling production. We assumed that these industries will consume the portion of the projected harvest that is not classified as sawtimber. In the base market run, this portion amounts to 6.66% of the total softwood harvest over the first five 5-yr periods.

Foreign Exports

Table C-4. Parameters of linear foreign export log demand equations.

Region	Intercept	Slope
OCST	26.43	-4.24
KLAM	26.43	-4.24

The quantities of softwood sawtimber exports to foreign (off-shore) regions are determined by linear, price sensitive exports demand functions. To develop the intercept and slope for these functions, we used the 1995 delivered mill price for softwood sawtimber in the Pacific Northwest Westside region from the RPA database, along with import quantity data from Warren (1999). A price elasticity of -0.4 is assumed, based on a study of export log demand by Gallagher (1980). Table C-4 presents the parameters for foreign exports used in the model.

Domestic Exports

We set domestic exports from western Oregon to western Washington at a fixed level of 5.88 million ft^3/yr, roughly 2% of the annual harvest in the WCST and OCST regions (where the bulk of these exports originate). We set domestic exports to California (which come primarily from the KLAM region) at a fixed level of 1.11 million ft^3/yr, based on values reported for 1994 in Ward (1997).

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