Research Contribution 42

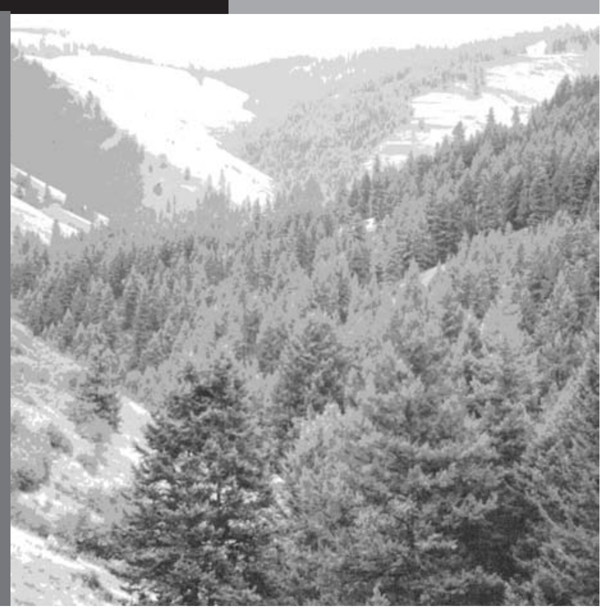
Private Timber Harvest Potential in Eastern Oregon

by

Darius M Adams

Gregory S Latta

October 2003



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ABSTRACT

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Growing stock inventory on industrial and nonindustrial private forest (NIPF) lands in eastern Oregon has declined over the past 20 yr, as harvesting and mortality losses to insects and disease have outpaced growth. Over the same time period, harvest rates on private lands have varied, with no distinct trend to the variation. In the most recent survey (1999), industrial and NIPF inventories differed by less than 8% (1.786 billion ft^3 versus 1.655 billion ft^3), while the NIPF timberland base was only two-thirds of the industrial base (1.105 million ac versus 1.603 million ac).

This study employs recent inventories and even-flow and market-based harvest simulators to develop projections of future harvest potentials. For industrial lands, even-flow and market-based projections of future harvest potential over the next 50 yr are approximately half of average harvests over the past 40 yr. For NIPF lands the even-flow projection is 20% higher than the historical harvest average, while the market-based projection indicates potential for a substantial but short-lived increase in near-term harvest. Inventories on industrial lands rise under both projections, while NIPF inventories remain fairly stable. Continued loss of land from NIPF ownerships to other owners and uses has limited influence on the market-based NIPF harvest projection until after 2050. A simulated policy of expanded riparian protection zones reduces harvest on both ownerships roughly in proportion to the area removed from the harvestable land base. A simulated requirement to retain 30% more residual volume in partially cut stands reduces harvest by 5% on combined private ownerships and increases total inventory by 13% after 50 yr.

Keywords: timber, supply, demand, markets, models, resource trends, NIPF, forest policy

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Introduction

Eastern Oregon's timber sector has faced an array of resource and policy changes over the past 2 decades that has put increasing pressure on private owners as timber suppliers. During much of this period, all ownerships have been beset by a major outbreak of bark beetles and defoliators, increasing mortality and slowing growth on the surviving stems. Increased fuel accumulations, particularly on public lands, have raised the risk of major inventory losses through fire as well. And, beginning in 1990, management policy shifts reduced timber harvest on public lands in eastern Oregon to approximately 10% of historical levels.[1]

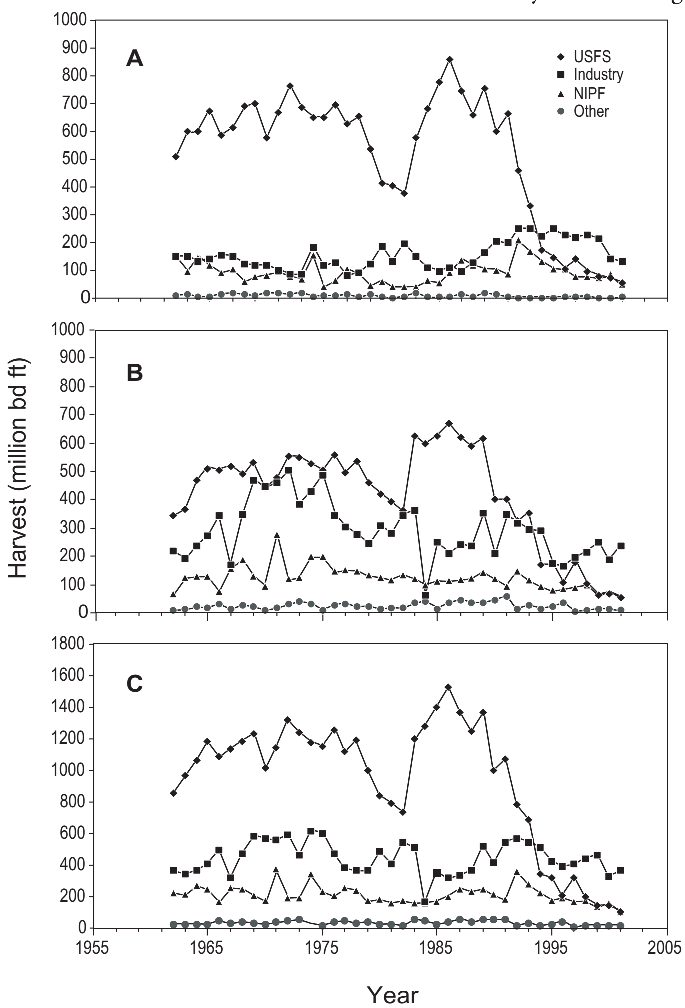

Figure 1. Timber harvest by owner and ecoregion in the Blue Mountains (A), Eastern Cascades (B), and all of eastern Oregon (C). Other *includes all non-USFS public lands. Harvest data from Oregon Department of Forestry, Resource Policy.*

These changes, and owners' responses to them, have had important impacts on the region's private forest resource. This study examines eastern Oregon's private forests and offers an assessment of their long-term timber harvest potential. We develop two projections of harvest and management using two markedly different models of harvest behavior—a market-based model in which timber demand and supply interact, and a volume-flow model that maximizes long-term even flow. Rather than focus on a single "most likely" forecast, we hope to develop a clearer understanding of the possible range of future harvest outcomes and the resource characteristics and aspects of owner behavior that most strongly shape future harvest potential.

This analysis and the models that support it also help to characterize the possible future conditions of the forest resource itself, such as its size structure, species composition, growth, and inventory levels. These results may be of value in assessing future wildlife habitat and biodiversity conditions. Finally, this analysis considers the harvest impacts of a limited set of changes in public policies that regulate private forest management practices. Results from this analysis may be applied to current policy discussions and may serve to further illustrate the influence of resource conditions on private owner response to policies.

[1]Based on a comparison of 1962–1990 and 2000–2001 harvest averages (see Figure 1).

Relationship to Past Studies

The present analysis differs in several respects from the two previous studies of eastern Oregon timber supply by Beuter et al. (1976) and Sessions (1991).[2]

(1) As in these past studies, inventory data for all private owners were drawn from permanent inventory plots on private lands maintained by the Forest Inventory and Analysis (FIA) unit of the USDA Forest Service Pacific Northwest Research Station. In this study, we used a preliminary version of the database for the 1999 remeasurement in which data were collected for the first time on a "condition class" basis on each of the plots. A condition class is a portion of a plot that is considered homogeneous in terms of species group, land class (forest, nonforest), stand size, tree stocking, and past harvest. We did not aggregate the condition classes in our analysis. Sessions (1991) used plot-level data from an earlier remeasurement with some aggregation of plots. Beuter et al. (1976) used aggregations of diameter class data at the equivalent of the subregional level in our study.

(2) Yields (for each management regime applied to each condition class in the initial inventory, and for each even-aged regime established during the course of the projections) were developed from the Forest Vegetation Simulator (FVS) model. Maintained by the Forest Management Service Center of the USDA Forest Service, several calibrated variants of FVS were available for eastern Oregon regions.[3] Previous studies used stand table projection (Beuter et al. 1976) and PROGNOSIS (Sessions 1991); the latter is a precursor of FVS with fewer eastern Oregon variants.

(3) This study examines private lands only. Note that nonindustrial private (NIPF) forestlands include Native American lands as well. Harvest from public lands was an input to our market-based harvest projection approach, but it was treated as "exogenous." Exogenous inputs are not determined by the model. Earlier studies devoted considerable attention to National Forests and other public lands, since at the time they contributed more than 60% of eastern Oregon harvest.

(4) Previous studies employed forms of "sequential even-flow" analysis to project harvest, whereby harvest in each period is set at the highest level that can be sustained over the look-ahead interval (a typical rotation) starting in the current period and moving sequentially from the first to the last period of the projection (Davis et al. 2001). In this study, we projected harvest using both market-based and volume-flow approaches. The market-based model simulates the interaction of timber demand and supply over time, including the key forest management investment decisions of private owners. The volume-flow model projects the maximum even-flow volume that can be sustained over the full projection period (100 yr).

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[2]Authors of the eastern Oregon portion of the 1991 study were K. Norman Johnson, John Beuter, Gary Lettman, and John Sessions.

[3]See USDA Forest Service, Forest Management Service Center, for descriptions of the model and variants.

Recent Harvest Trends and Resource Conditions

In the early 1990s, shifts in management of National Forests resulted in a significant decline in timber harvest in eastern Oregon. National Forest harvest dropped from an average of 1.2 billion bd ft/yr between 1980 and 1989 to slightly more than 0.1 billion bd ft/yr by 1999 (Figure 1). Since there was little basis in merchantable inventory for any long-term, compensating harvest response from private lands, total eastern Oregon harvest fell as well, from approximately 2.0 billion bd ft/yr to 0.8 billion bd ft/yr for the same time periods (Oregon Department of Forestry, Resource Policy). Loss of timber supply forced a corresponding reduction in wood products processing capacity. Lumber production dropped from 1.8 billion bd ft/yr in the late 1980s to 0.9 billion bd ft/yr by 1999, and the number of mills of all sizes declined from 42 in 1988 to 14 in 1998. Plywood production volumes for eastern Oregon are not publicly available; however, it is estimated that log consumption in veneer and plywood mills fell from 235 million bd ft in six facilities in 1988 to 119 million bd ft in three facilities by 1998.[4]

At the same time, eastern Oregon forests were subjected to major outbreaks of bark beetles and defoliation by the spruce budworm and Douglas-fir tussock moth. These depredations raised mortality and reduced growth of surviving trees. Few reports have attempted to characterize the extent of these impacts on timber inventory. Some insight can be gained from the comparison of surveys of eastern Oregon forests completed in 1986–1987 and 1992 (McKay et al. 1994) with earlier surveys and those conducted in adjacent western regions. From 1986 to 1992, softwood mortality was nearly 35% of gross growth on all private lands, somewhat higher on NIPF lands, and lower on industry lands. In comparison, softwood mortality on private lands in the entire Pacific Coast region (Oregon, Washington, California, and Alaska) was only 7% in 1996,[5] and prior to the current outbreaks, mortality as a percent of growth for all private lands in eastern Oregon and Washington averaged 15% between 1952 and 1976 (USDA Forest Service 1982). Thus, from the late 1980s to the early 1990s the ratio of mortality to gross growth in eastern Oregon was 3 to 5 times larger than in adjacent western regions or than observed in eastern Oregon during the preceding 20–30 yr.

Estimates of the extent of infestations can be generated from the 1992 eastern Oregon inventory database as well (McKay et al. 1994). In this survey, each live stem was examined for the presence and severity of an array of insect and disease attacks. Individual stem records (adjusted to represent the total inventory) indicate that 29% of the live trees on industry lands and more than 40% of the live trees on NIPF lands had some manifestation

[4]Lumber production data are from Western Wood Products Association, *Statistical Yearbook of the Western Lumber Industry*, various years. Data on log consumption and numbers of mills are from Howard and Ward (1991) and Ward et al. (2000). At this writing (early 2003) there is only one remaining plywood mill.

[5]See USDA Forest Service, Forest Inventory and Analysis, for current national resource statistics.

of an insect attack (bark beetle or defoliator). More than 80% of the affected trees were lodgepole pine, Douglas-fir, white fir, or grand fir. Ponderosa pine accounted for less than 1% of the stems. The proportion of inventory trees with signs of insect attack increased as diameter increased. Since volume per tree rises roughly as the square of diameter, the fraction of total inventory volume subject to some form of insect attack was higher than the fraction of total stems infected, at 39% for industry lands and more than 50% for NIPF lands.

Historical timber harvest by owner is shown for the ecoregions in eastern Oregon (the Blue Mountains and Eastern Cascades; Figure 1A, B) and for all of eastern Oregon (Figure 1C). Ecoregion boundaries and the counties used to approximate ecoregions in the harvest statistics are shown in Figure 2. For eastern Oregon, industrial and NIPF harvests show considerable year-to-year variation but no clear trend (Figure 1C). Neither private group shows a discernable shift in response to the major decline in National Forest harvest, despite the large increase in prices after 1990. Harvest detail at the ecoregion level (Figure 1A, B), however, suggests that stability for all of eastern Oregon has resulted from compensating shifts between the two ecoregions; harvest on both private ownerships in the Blue Mountains has increased since the early 1980s, while there is a declining trend in private harvests in the Eastern Cascades.

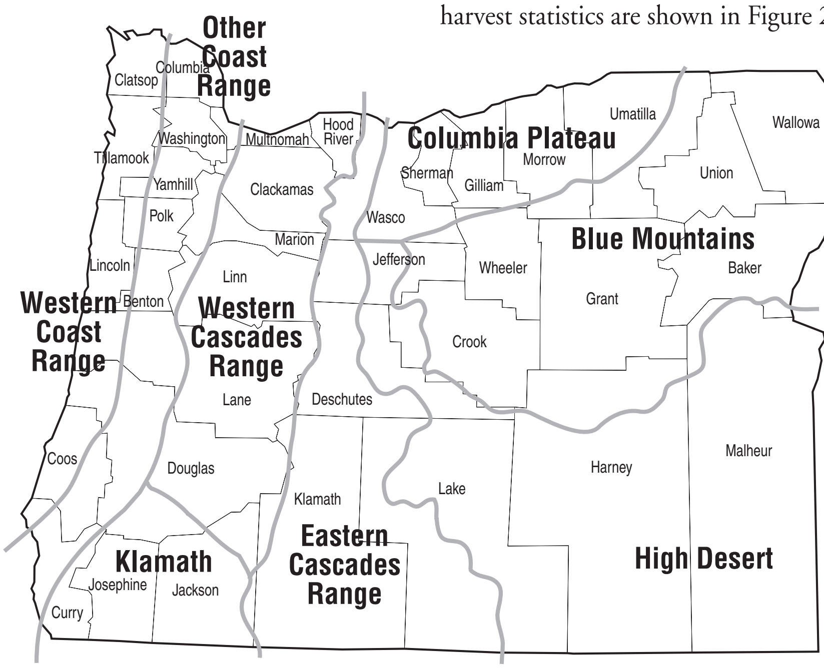

Figure 2. Ecoregions in Oregon (adapted from Ohmann and Spies 1998).

The decline in National Forest harvest has been accompanied by more extensive commerce in logs between the eastern Oregon ecoregions. (No causality is suggested here.) In 1988, Eastern Cascades mills obtained 7% of their log receipts from the Blue Mountains, while only 2% of receipts at Blue Mountain mills came from the Eastern Cascades (Howard and Ward 1991). By 1998, Blue Mountain mills obtained 9% of their log supplies from the Eastern Cascades, and Eastern Cascades mills obtained more than 20% of their supplies from the Blue Mountains.[6] The absolute volumes of both types of flows were also larger in 1998 than in 1988.

Land area under industrial ownership in eastern Oregon has declined since the early 1970s (Figure 3), though there has been a continual change in the identities of these owners.

[6]The 1998 version of the Oregon mill survey by Ward et al. (2000) contains, for the first time, a category for logs of unknown county of origin. However, analysis of the Eastern Cascades data indicates that, even if all the logs of unknown origin came from the Eastern Cascades, that region would still have imported at least 21% of its total receipts from the Blue Mountains. There were no receipts of unknown origin for Blue Mountain mills in the 1998 report.

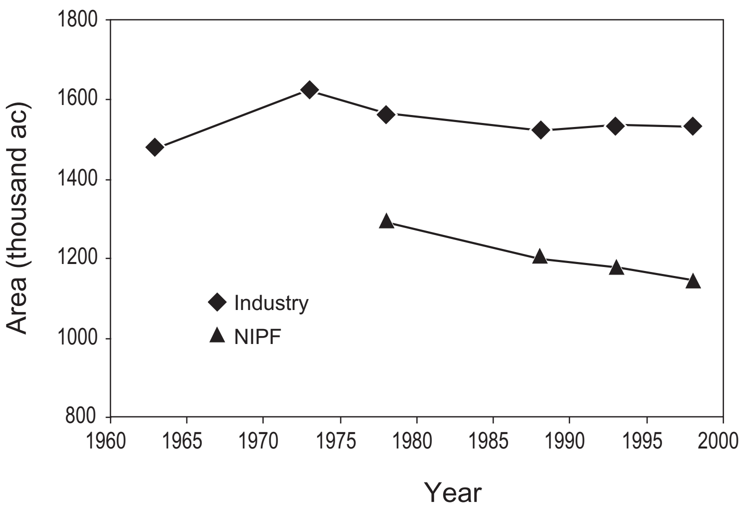

Figure 3. Timberland area by owner in eastern Oregon (1978 is the earliest year for which data can be adjusted to include Native American lands in NIPF group).

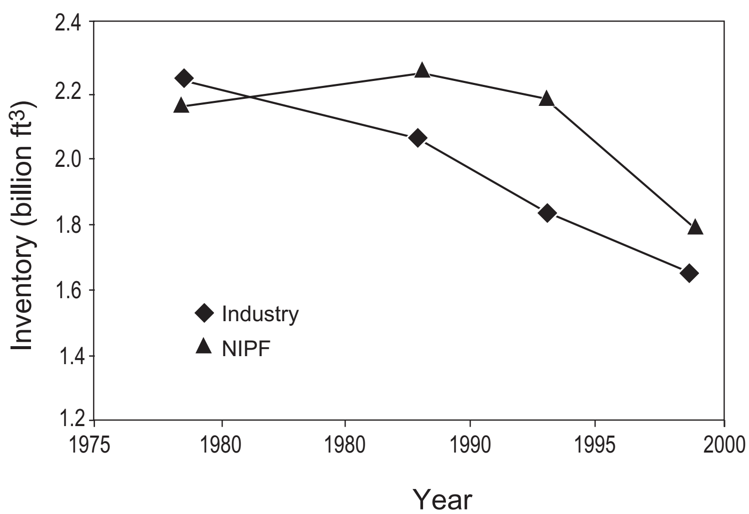

Figure 4. Growing-stock inventory by owner in eastern Oregon. Values for 1999 were computed by authors from draft Forest Service database.

There has also been a gradual shift in the composition of industrial ownership toward a larger fraction of owners that are not integrated with processing facilities but hold land for commercial timber production. The land area under NIPF ownership has declined steadily since 1978, by approximately 155,000 ac, or an annual rate of nearly 7,800 ac (Figure 3). This land was lost to other land uses, such as agriculture, urbanization, infrastructure, and sales to other forest owners. For example, Azuma et al. (2002) estimate that, between 1988 and 1999, NIPF owners in eastern Oregon lost 40,000 ac, while industrial ownerships expanded by 59,000 ac. The gain for industry was the result of a 1,000-ac net gain from other owners and uses, plus 58,000 ac acquired from NIPF lands. The NIPF net loss was the result of transfers to industry and other owners (a loss of 66,000 ac that includes the 58,000 ac noted), gains from conversion of nonforest to forest areas (a gain of 45,000 ac), and shifts to urban uses (a loss of 19,000 ac).

Unlike their counterparts in western Oregon, both private owner groups in eastern Oregon have experienced declining growing-stock inventories over the past 20 yr. Based on volume estimates we developed using data from the Forest Service FIA preliminary database, industry inventory in eastern Oregon has declined more than 25% since 1978, while NIPF stock has dropped by nearly 18% (Figure 4). For NIPF owners, part of this decline is due to loss of timberland area and associated volume to other owners and uses and increased mortality due to insect and disease attacks. However, the largest factor in the decline of inventory is the high rate of removals. On industry lands, Azuma et al. (2002) estimate that removals were 36% *greater* than gross growth from 1988 to 1999. NIPF removals were more than 80% of gross growth for the same time period.

Figure 5 provides a more detailed view of private inventories, showing the current (1999) distributions of total trees and volume by diameter class. Industrial ownerships had a greater proportion of total stems in the smallest diameter classes than did NIPF land; 65% of stems on industry lands were <4.9 in., compared with 54% of stems on NIPF lands (Figure 5A). Similarly, 59% of industry volume was in trees <15 in. in diameter, versus 44% for NIPF lands (Figure 5B).

In a dynamic context, harvest and mortality have had a dramatic impact on the size composition of private forest inventories over the past decade, as is evident from the large reduction in trees in the smaller classes on NIPF lands from 1987 to 1999 (Figure 6) and the decline in growing stock volume (Figure 7). For diameter classes below 25 inches, the absolute reductions on NIPF lands are greater than those on industry lands in nearly all cases (Figure 7).

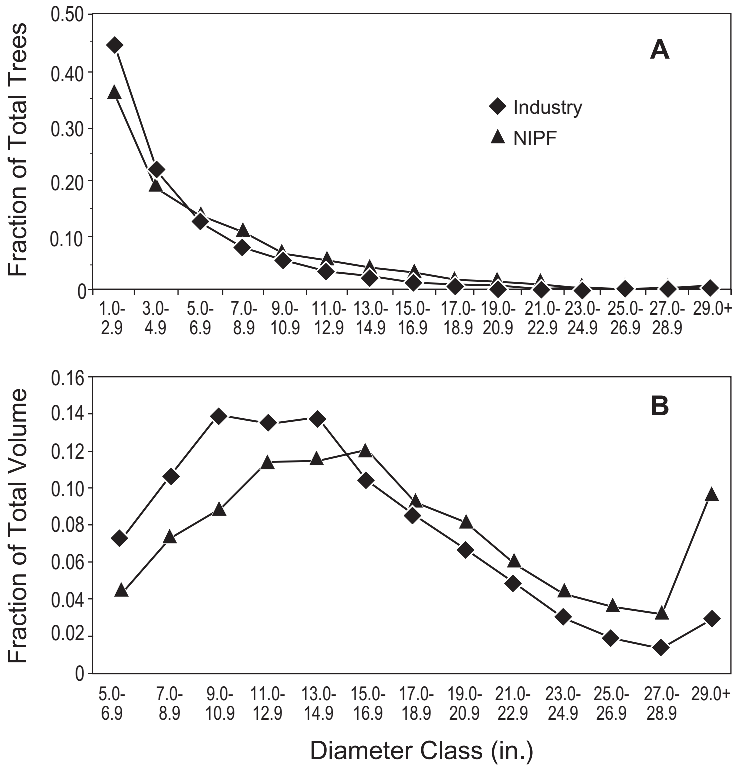

Figure 5. Fraction of trees (A) and growing stock volume (B) by 2-in. diameter class on industrial and NIPF lands in eastern Oregon.

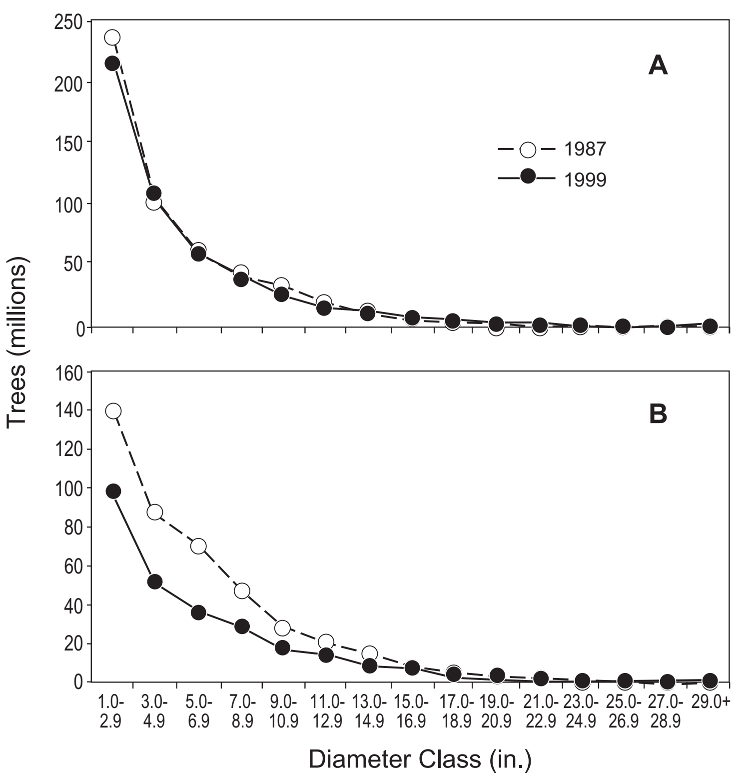

Figure 6. Number of trees by 2-in. diameter class on industrial (A) and NIPF (B) lands in eastern Oregon.

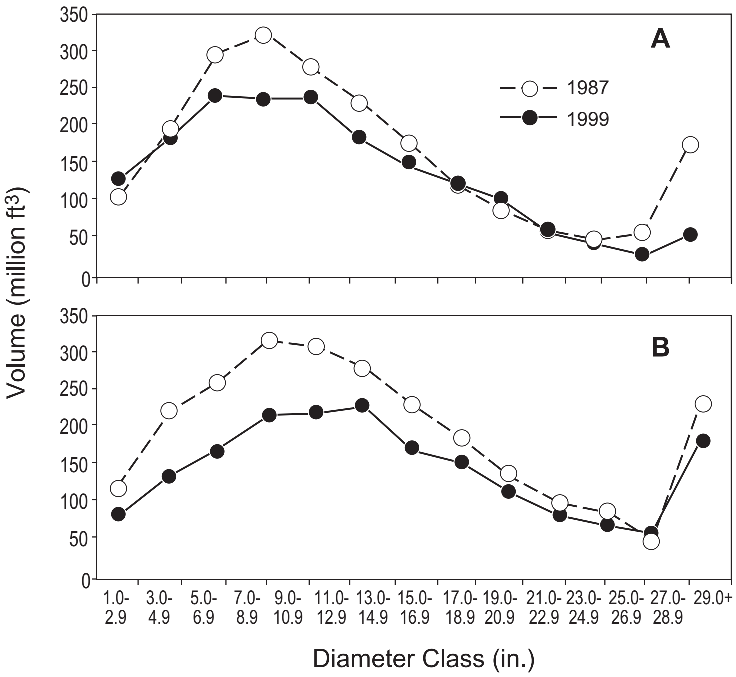

Figure 7. Growing-stock volume by 2-in. diameter class on industrial (A) and NIPF (B) lands in eastern Oregon.

Harvest Projection

The basic building blocks of any harvest projection are (1) inventory data, (2) assumptions about, or projections of, future silvicultural investment (or management intensity), (3) estimates of stand growth (yield projection) under each management option, (4) projections of future changes in the harvestable land base, and (5) a harvest decision simulator that computes the volumes to be removed.

Inventory

In the present analysis, inventory data derive from the Forest Service's 1999 remeasurement of permanent plots on private forestland in eastern Oregon (Azuma et al. 2002). Our work employed a preliminary version of this inventory, which differs somewhat from the final release. The primary differences between the preliminary version and final release are in the recomputation of site-index values, assignment of vegetation type for some plots, and expansion factors. Table 1 contrasts alternate estimates of land area by site-productivity class from our analysis and the inventory released by the Forest Service.

Management Intensity Classes

Management practices were divided into reserve (no harvest), even-aged, and uneven-aged groups. The even-aged and uneven-aged groups were further divided into three increasing levels of management intensity, termed management intensity classes *(MIC)* (Table 2). These regimes were adapted from an analysis of harvest potential in comparable forest types in eastern Washington (Bare et al. 1995).

Estimates of the current (1999) allocation of private lands to these classes were developed from responses to surveys of industrial owners and Oregon Department of Forestry field foresters regarding current and prospective future management actions on private lands

Table 1. Area of forested land by site-quality class from current study and USFS eastern Oregon inventory report (Azuma et al. 2002).

	Growth classes (ft^3/ac/yr)						Total
	165-224	120-164	85-119	50-84	20-49	<20	(excl <20)
Owner/Estimate	Thousand ac						
Industry							
Current	0	22	91	450	948	174	1511
USFS	0	17	104	591	892	0	1603
NIPF							
Current	8	8	85	365	633	257	1099
USFS	0	29	73	366	636	0	1105

Table 2. Management intensity class (MIC) definitions for even-aged and uneven-aged regimes.

Even-aged (E)	Uneven-aged (U)	Intensity
Clearcut if stand volume at least 12,000 bd ft/ac; natural regeneration	Cut if stand volume at least 7,000 bd ft/ac, leaving 3,000 bd ft/ac residual in trees ≥7 in.	Low
Clearcut if stand volume at least 13,000 bd ft/ac; plant to 250 trees per ac	Cut if stand volume at least 9,000 bd ft/ac, leaving 3,000 bd ft/ac residual in trees ≥7 in.	Medium
Clearcut if stand volume at least 16,000 bd ft/ac; plant to 250 trees per ac and thin to 175 trees/ac when stand height at least 15 ft	Cut if stand volume at least 9,000 bd ft/ac, leaving 1,000 bd ft/ac residual in trees ≥7 in.; underplant 100–150 trees/ac	High

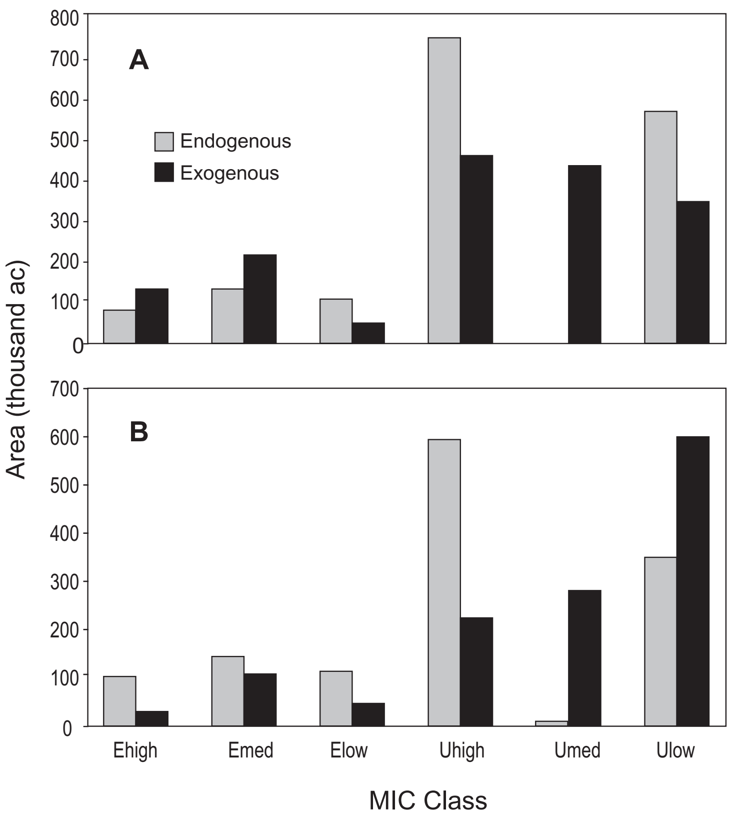

Figure 8. Comparison of initial endogenous and exogenous timberland allocations by MIC class for industrial (A) and NIPF (B) owners in eastern Oregon.

in Oregon.[7] A summary of this estimated initial distribution is represented as the "exogenous" (based on prior knowledge of current management practices) timberland allocations in Figure 8. This initial allocation can be forced on the model solution and is termed an "exogenous" allocation to initial MIC classes. As discussed below, our projection model also allows "endogenous" (by procedures within the model) determination of the initial MIC allocation based on the specific objective of the projection. Endogenous initial MIC allocations are employed throughout this study. Differences in harvest projections arising from the exogenous and endogenous initial allocations are examined in a later section.

Yield Projection

Estimates of current and future inventory volumes and stand conditions for all MICs were derived from the Forest Service FVS stand projection system (USDA Forest Service, Forest Management Service Center). Three variants corresponding to vegetation zones in eastern Oregon were employed.

[7]In cooperation with the Oregon Forest Industries Council, the Oregon Department of Forestry during early 1998 undertook a survey of industrial forestland owners' 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.

Since our initial (1999) stand volumes did not come directly from the inventory data, but were computed by FVS from the tree records, there are some differences between total inventory volumes derived from the draft Forest Service inventory database and our values. It is important to note that the FVS volumes include all trees with positive net cubic volume. It is customary, however, to compute the inventory only for growing-stock trees that are ≥5 in. in DBH. Table 3 compares these inventory values for different land types. We have adjusted the estimate derived from the Forest Service draft database to include all trees with net cubic volume. Our values are consistently lower, but are within 6% of the Forest Service estimates in all cases.

Appendix A gives further details of yield computation, site index adjustments, and treatment of regenerated stands.

Table 3. Estimates of total inventory volume on private ownerships in eastern Oregon by land type from the current study and the draft USFS inventory database, as of 1 January 1999.

	Timberland		Timberland + Other forest land	
Ownership/Land type	Current study†	USFS‡	Current study†	USFS‡
	Million ft^3			
Industry	1566	1655	1699	1782
NIPF	1709	1786	1912	1949

†Computed with FVS tree-volume equations for all stems.

‡Computed from the draft Forest Service database by the authors. These values include all trees with net cubic volume, not just with trees ≥5 in. DBH, as is customary in Forest Service growing stock computations, because the inventory in the present study includes all trees.

Land Base

As illustrated in Figure 3, the area of timberland in NIPF ownership in eastern Oregon has declined over the past 2 decades. In recent years, shifts to nonforest uses have been an important part of NIPF losses (Azuma et al. 2002). Past trends do not necessarily characterize future land-base changes, but there is strong popular belief that the NIPF area base will continue to decline.

To examine the impacts of further NIPF timberland losses, we developed projections under both a constant and a declining NIPF land base. The declining area simulation assumes periodic losses over the next 3 decades (through 2028) equivalent to the trend shift over the past 2 decades, with a stable base thereafter. This amounts to a loss of 199,300 ac from 1998 to 2028, a decline of approximately 15% relative to the NIPF 1998 land base.[8] Unlike past land shifts, we assume that all of this area is lost to nonforest uses with no transfers to industrial owners.

Harvest Simulation

The harvest simulator combines the initial inventory, land base, and estimates of future growth by MIC class to project timber harvests by owner group. Harvest simulations are based on two models: (1) volume-flow model—generates maximum long-term even flow and finds the highest harvest level that can be maintained over the projection period within some prespecified bounds of variation, and (2) market-based model—creates harvests based on the simulation of demand and supply interactions in the market for softwood timber. Appendix B gives a mathematical description of both approaches.

The volume-flow model is similar to approaches used in many other studies (Beuter et al. 1976; Sessions 1991), except that we employed linear programming to find the optimal solution directly, instead of using a form of successive approximation such as a binary search. Linear programming allows the imposition of an array of important restrictions or constraints on the volume flow or resource characteristics over time that are often difficult to examine in a binary search approach.

The market-based model finds the harvest quantities and prices that balance demand and supply for softwood sawlogs in eastern Oregon in all periods of the projection. Demand originates from sawmills and plywood producers for logs delivered to their mills. Supply represents the harvest decisions of industrial and NIPF owners plus a fixed volume assumed to flow from public lands. Functions representing the demand for delivered sawlogs were derived by econometric methods from historical data on sawlog use in eastern Oregon mills (Appendix C). Private log producer supply is an implicit function of the costs of growing timber over time, harvest, and delivery to the point of utilization. Private suppliers are seen in this context as wealth or present net worth maximizers in a market where their supply actions (harvest or absence of harvest) influence current and future log prices. We used a real discount rate of 6% in all market projections.

The harvest projections we developed represent outcomes under specific sets of behavioral assumptions that emphasize the production of timber in management decisions on private lands. They are not intended as "most likely" forecasts of the specific time patterns of future harvest. Because they emphasize timber production alone, ignore other objectives and conditions, and assume a 10-decade time horizon, they may be viewed as *long-term timber supply potentials*. Short-term market fluctuations and other considerations can raise

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[8]The 15% figure includes lands with less than 20 ft^3/ac/yr productivity in the base, as shown in Table 1. Excluding those lands, the 3-decade loss would be closer to 18%. The land-loss projections were based on a simple log-linear trend projection made using estimates of the NIPF land base from four inventory points between 1978 and 1998. Land was removed from the inventory in proportion to the current distribution of area by site class.

harvest above potential levels. Actual harvest for some owners may fall below potential for long periods. NIPF owners may consider future economic returns or volume flows in their harvesting decisions, but these concerns are likely constrained in various ways by other interests or may be augmented by other returns from the forest, such as amenities. In these cases, actual cut would fall below the levels projected by our models. Our representation of returns also ignores considerations related to any other aspect of the operation of timber producing firms, such as links to processing facilities. Finally, neither model (volume-flow or market-based) is calibrated or fitted in any way to historical harvest data. Since the projections are intended to represent *long-term harvest potential*, this would be inappropriate. In addition, as we note in later sections, deviations of the market model projections from historical levels in the initial periods of the simulation reveal useful characteristics of the inventory and actual harvest behavior.

Model Specification

The linear programming structure developed for our models is similar to the "model II" form described by Johnson and Scheurman (1977); however, it differs from past approaches in the way it defines activities (harvest timing and management combinations). Past applications of model II have generally defined activities at the stratum level, where a stratum describes a homogeneous grouping of the inventory (commonly species, age class, site, owner, etc.). The basic inventory data are aggregated from plots into strata with growth projections developed at the stratum level.

In this study, activities are defined on the basis of the condition class (as defined above).[9] This allows greater flexibility in making projections that depend on, or are constrained by, various characteristics of the resource base, since virtually every descriptor collected in the field survey can be employed in identifying the condition class. It also markedly reduces the size of the linear programming problem by reducing the potential number of activities. When activities are based on strata, increasing the number of dimensions on which strata are defined or described exponentially increases the number of potential strata and activities. For example, if a stratum is defined by its period of origin and period of harvest, each of which may have, say, 10 values, the number of possible activities is 10^2. If further descriptors are added, each with 10 possible values, the number of possible activities increases as 10^n.

When activities are defined at the condition-class level, information at the stratum level (where strata can be defined with any number of dimensions) can be obtained by simply

[9]There are two broad classes of activities in our model. For stands managed on an even-aged basis, there are "new" stands created after the start of the simulation and "existing" stands characterizing the forest at the start of the projection. Uneven-aged stands have only "existing" stand activities. Existing stand activities have only three dimensions in our formulation: condition-class identification, current management intensity class, and period of final harvest (this would be "never" in the case of uneven-aged stands). New-stand activities (only for even-aged stands) have four dimensions: condition-class identification, current management intensity class, period of origin, and period of final harvest.

sorting and summing condition-class information. For example, if activities are defined by the condition-class identifier (with i values) and the periods of origin and harvest, there would be $i10^2$ possible activities. Since each additional descriptor of the condition class is linked to the condition class identifier, no further descriptors or activities need to be added to the model. Condition classes that have a particular characteristic can be identified by matching the condition-class identifier and a list giving the characteristics of each condition class. This can be used for post-solution reporting purposes, such as obtaining area by age, site, and owner class, or defining constraints in the optimization.

In the simulations reported below, the models were used to project ahead 200 yr. Only results for the first 50 yr are displayed in the figures and tables.

Initial and Future Management Regimes

Our models allow some flexibiIity in handling the MIC class disposition of stands in the first period of the projection (the initial MIC allocation of stands that exist at the start of the projection) and for stands that are created after harvesting in subsequent periods (MIC allocation of future stands). The degree of flexibility depends on whether management is for even-aged or uneven-aged stands.

The MIC allocation of existing stands in the first period of the projection can either be exogenous (based on prior knowledge of current management practices) or endogenous (determined in an optimal fashion by the models). Allocation to even-aged or uneven-aged management types (whether exogenous or endogenous), however, is irrevocable. That is, a stand stays in the even- or uneven-aged management type for all periods once it is allocated in the first period. For a given stand, movement between even-aged and uneven-aged management is a potentially complex process, since both the timing of the shift and the cutting cycle or rotation of the subsequent stand are variable. These changes are not considered in this study.

Within the even-aged management type, a stand can be allocated to any of three MICs. Once the initial stand is harvested, the models determine the optimal even-aged MIC allocation for each subsequent rotation. In the market-based model, this means that investments (choices of MIC) are consistent with intertemporal wealth maximization. In the volume-flow model, investments are chosen to optimally enhance the volume maximization objective. For stands initially allocated to the uneven-aged management type, the MIC allocation is also fixed for all subsequent periods. In the projections, unless otherwise noted, we employ the endogenous initial MIC allocation option.

Base-Case Projections (Under Current Policies)

Industrial Owners

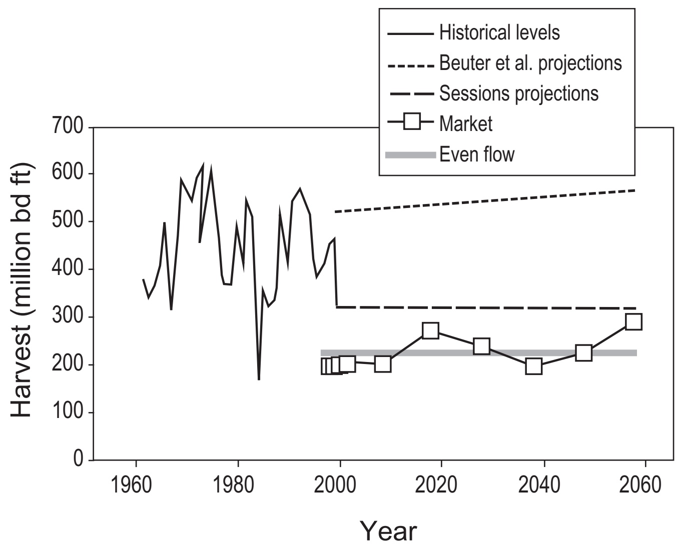

Figure 9. Projected base-case timber harvest levels on industrial lands in eastern Oregon, derived using market-based and even-flow simulators. Historical levels and projections from Beuter et al. (1976) and Sessions (1991) shown for comparison. Initial MIC distributions endogenous.

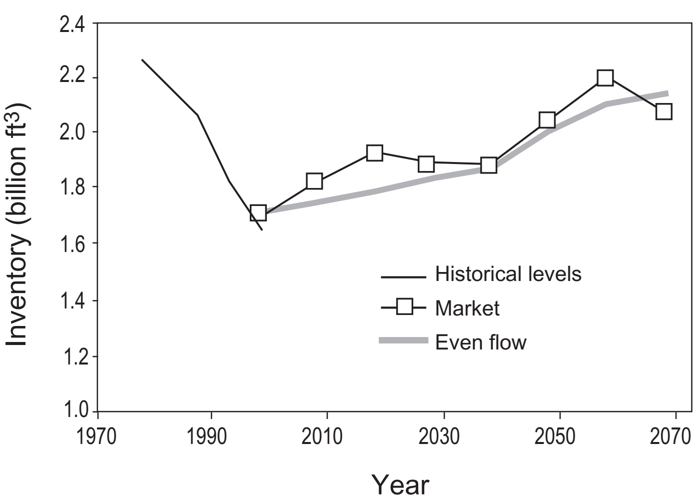

Figure 10. Projected base-case timber inventory for industrial lands in eastern Oregon, derived using market-based and even-flow simulators with endogenous initial MIC allocations.

Industrial inventory has been declining in eastern Oregon for at least the past 20 yr, while harvest has been relatively stable. In the most recent inventory cycle (1988–1999, taken as 11 yr), gross growth averaged 54 million ft^3/yr, mortality 11 million ft^3/yr, and removals 74 million ft^3/yr, for a net annual inventory reduction of 31 million ft^3/yr (Azuma et al. 2002). Reflecting this long-term inventory reduction, projected harvest in eastern Oregon drops dramatically in the initial period and all subsequent periods relative to historical levels (Figure 9). The volume-flow projection is approximately half of the 40-yr historical average. The market-based projection shows no large near-term increase in harvest relative to historical levels, suggesting that most inventory is growing more rapidly than the interest rate.[10] Sessions' 1991 projection of timber harvest dropped well below the projection made by Beuter et al. in 1976, in part because of the inventory decline; timber harvest in our projection falls an additional 30% (Figure 9).

With the projected slowing in future harvest, inventories build quickly (Figure 10), though in the market-based projection this increase cannot return harvest to historical levels. In the volume-flow projection, the inventory hiatus that controls the long-term, even-flow level lies in the present period. Because harvest can neither rise nor fall in an even-flow projection, inventory builds steadily. We also examined a more flexible volume-flow schedule in which cut could move up over time by 5% per decade. In this case, long-term harvest on industrial lands does rise with rising inventory, though, given the low site quality and slow growth on timberlands in eastern Oregon, a return to average historical levels requires more than 100 yr.

[10] The market-based projection attempts to maximize land value given a set of future timber prices. As a result, stands growing more slowly than the interest rate are generally harvested early in the projection. If there is a large volume in these stands, harvests in the initial periods of a projection can rise above cut in subsequent periods as these stands are liquidated. This is not seen in the current case.

Using an endogenous initial MIC allocation, Figure 11 illustrates the initial distribution between even-aged and uneven-aged MICs and the projected shifts within even-aged stands for the market-based projection. Uneven-aged stands cannot change management type after the start of the projection. In the even-aged stands, a larger fraction of future stands are managed under the low-intensity class than under the initial distribution. Table 4 gives a numerical summary of all projections for both owners.

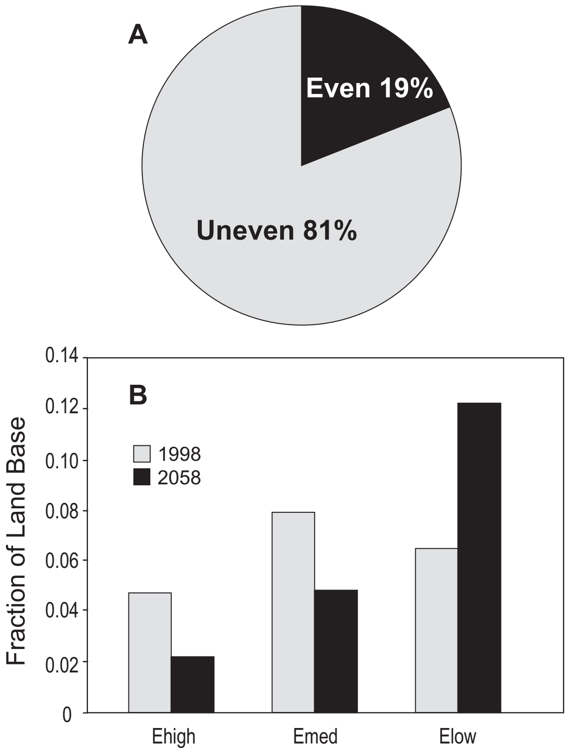

Figure 11. Initial endogenous allocation of forest industry land to even-aged and uneven-aged MICs (A) and changes to allocation for even-aged MICs over time (B) in market-based projection. See Table 2 for definitions of MICs.

Table 4. Projected harvest by owner, projection method, scenario, and treatment of initial MIC allocation for private lands in eastern Oregon. Average annual harvests for decades beginning in year shown in column headings.

Owner	Initial MIC	Projection Method	Scenario	1998	2008	2018	2028	2038	2048	2058
				Million bd ft/yr						
Industry	Endogenous	Market	Base	200.7	205.5	268.4	241.9	204.6	223.4	286.5
	Endogenous	Even-Flow	Base	223.0	223.0	223.0	223.0	223.0	223.0	223.0
	Endogenous	Market	Less NIPF Land	193.6	234.6	235.1	247.6	202.0	227.0	288.8
	Endogenous	Market	Expanded Stream Zones	194.3	175.2	217.9	195.4	190.6	237.1	239.5
	Endogenous	Even-Flow	Expanded Stream Zones	196.3	196.3	196.3	196.3	196.3	196.3	196.3
	Endogenous	Market	High Residual Stocking	177.5	228.7	210.8	205.7	197.9	238.6	324.2
	Exogenous	Market	Base	139.2	186.7	268.1	258.3	197.1	205.1	269.5
	Exogenous	Market	Expanded Stream Zones	136.0	144.1	238.6	213.2	187.0	193.9	250.2
NIPF	Endogenous	Market	Base	405.4	310.2	199.1	143.2	153.6	216.8	214.4
	Endogenous	Even-Flow	Base	257.4	257.4	257.4	257.4	257.4	257.4	257.4
	Endogenous	Market	Less NIPF Land	410.8	277.7	238.5	140.6	148.1	201.0	172.6
	Endogenous	Market	Expanded Stream Zones	331.3	238.4	150.7	132.7	116.8	166.5	192.3
	Endogenous	Even-Flow	Expanded Stream Zones	209.9	209.9	209.9	209.9	209.9	209.9	209.9
	Endogenous	Market	High Residual Stocking	413.2	244.1	196.8	141.3	129.4	194.7	220.4
	Exogenous	Market	Base	400.7	256.1	162.2	140.1	152.5	182.8	212.4
	Exogenous	Market	Expanded Stream Zones	312.3	199.7	130.0	129.7	125.2	153.8	175.9

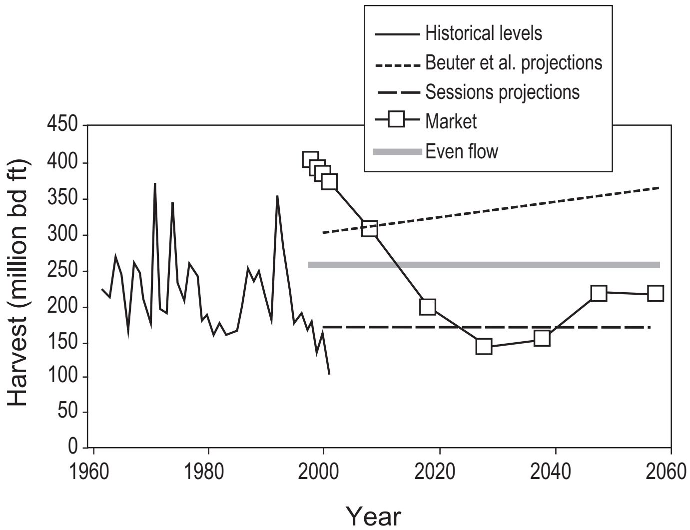

Figure 12. Projected base-case timber harvest levels for NIPF lands in eastern Oregon, derived using market-based and even-flow simulators. Historical levels and projections from Beuter et al. (1976) and Sessions (1991) shown for comparison.

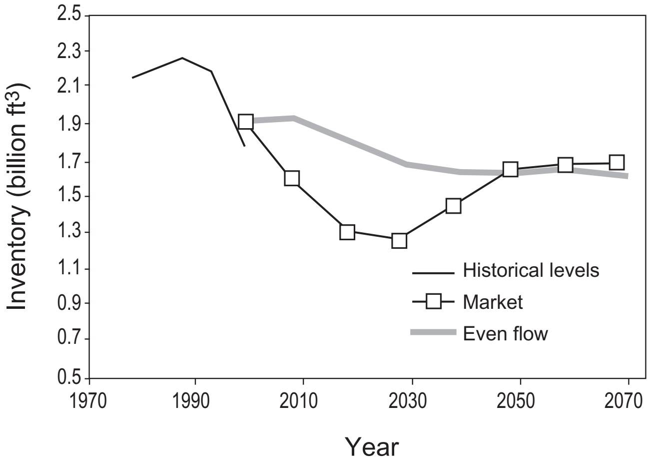

Figure 13. Projected base-case timber inventory for NIPF lands in eastern Oregon, derived using market-based and even-flow simulators.

NIPF Owners

Harvest potentials for NIPF owners are markedly different from harvest potentials for industrial owners (Figure 12), even though NIPF inventories, like their industry counterparts, have been falling in recent years. The high initial harvest potential of the market-based projection suggests the availability of sizable levels of merchantable volume in current inventory (growing at less than the discount rate). The even-flow projection of harvest potential for NIPF owners is approximately 20% higher than the 40-yr historical average. The long-term market-based projection (from 2008 on) is nearly equal to the 40-yr historical average (96%), despite high initial harvests.

Both the market-based and even-flow projections lead to initial inventory reductions (Figure 13). Inventories under both projections ultimately converge, however, to nearly the same level, about 10% below current volumes. Thus, NIPF owners would be able to maintain current harvest levels with little change in their inventories in the long term. Using an endogenously determined initial MIC distribution, only a small fraction of NIPF land would be managed on an even-aged basis, and projected optimal management of these even-aged stands would involve shifting a portion of these lands into less-intensive regimes (Figure 14).

Projections with Land Loss

An alternative base projection was developed simulating a further loss of 199,300 ac of NIPF land over the next 3 decades. It was assumed that all this land was shifted to nonforest uses and removed from the harvestable forest base. Harvest levels under constant and reduced land-base projections for both industrial and NIPF lands differ little over the first 50 yr (Figures 15 and 16). Average annual industrial cut falls by 0.1%, while NIPF cut declines by 2.7%. Because of the limited volume of growing stock on industrial lands, there is little basis for a response to the NIPF decline, and industrial cut is nearly unchanged over the projection. The largest departures of NIPF harvest from the constant land-base levels occur 50 yr into the projection (Figure 16). This lag may reflect the long cutting cycles in uneven-aged management regimes (given the slow growth rate on much of the NIPF land base) and changes in harvest timing of condition classes by the market harvest simulator to minimize the effects of the land base reduction.

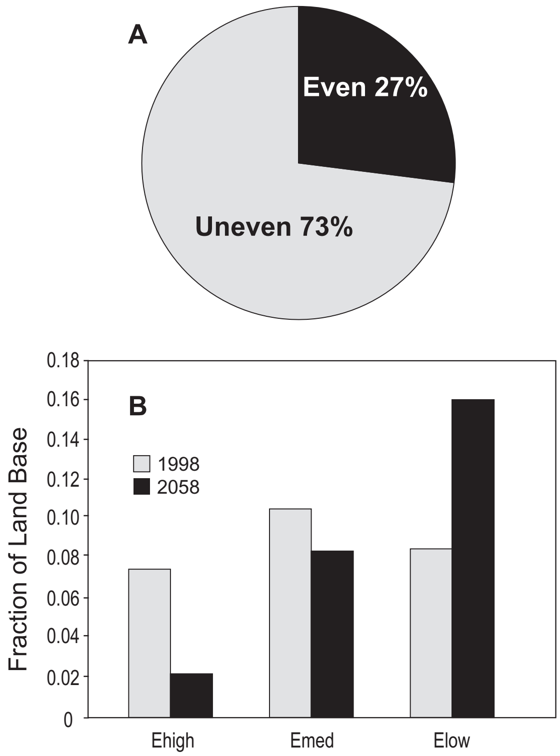

Figure 14. Initial endogenous allocation of NIPF land to even-aged and uneven-aged management MICs (A) and change to allocation for even-aged MICs over time (B) from the market-based projection. See Table 2 for definition of MICs.

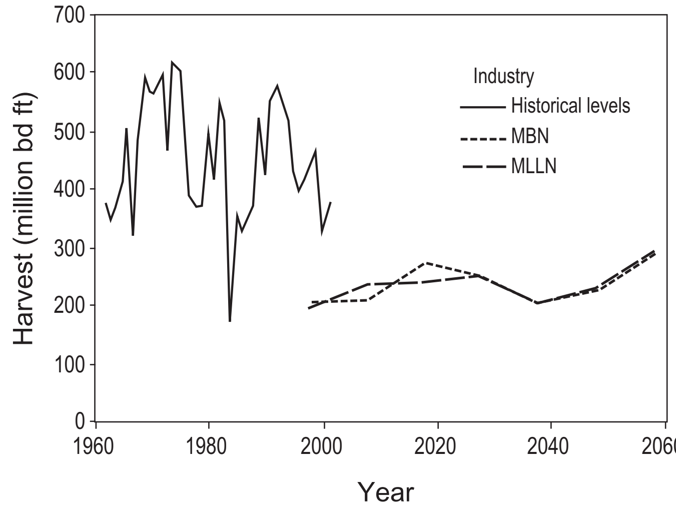

Figure 15. Market base-case projection for eastern Oregon industrial ownerships under constant NIPF land base (MBN) and declining NIPF land base (MLLN). Initial MIC distributions were endogenous.

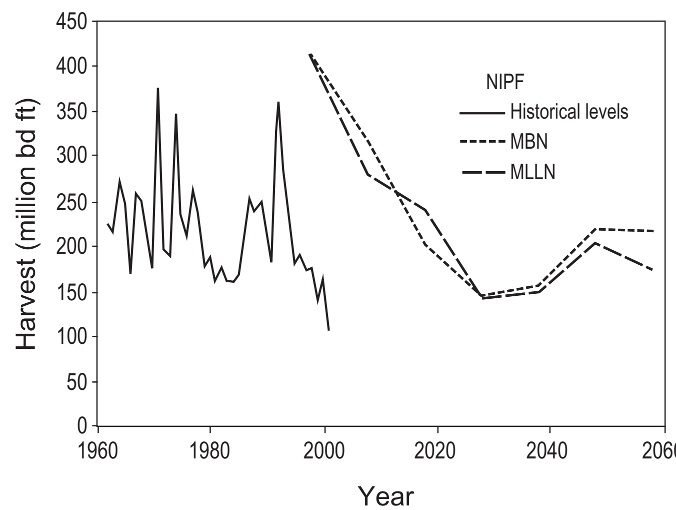

Figure 16. Market base-case projection for eastern Oregon NIPF ownerships under constant NIPF land base (MBN) and declining NIPF land base (MLLN). Initial MIC distributions were endogenous.

ALTERNATIVE PROJECTIONS (BASED ON POLICY CHANGES)

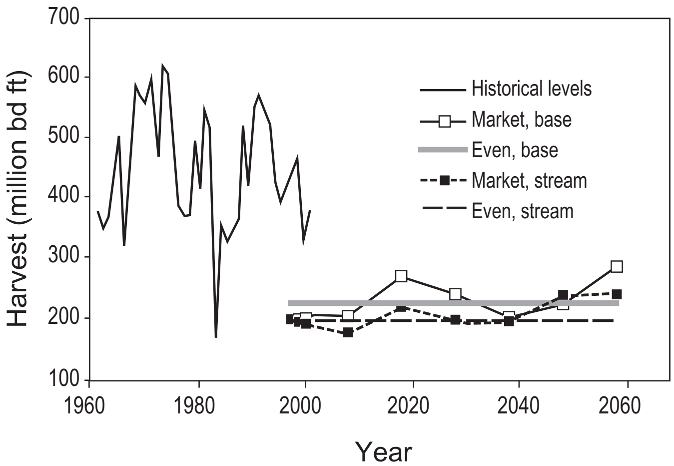

Figure 17. Harvest on industrial lands in eastern Oregon under the base-case and expanded-streamside-protection scenarios, for both market-based and even-flow projections. Initial MIC distributions are endogenous.

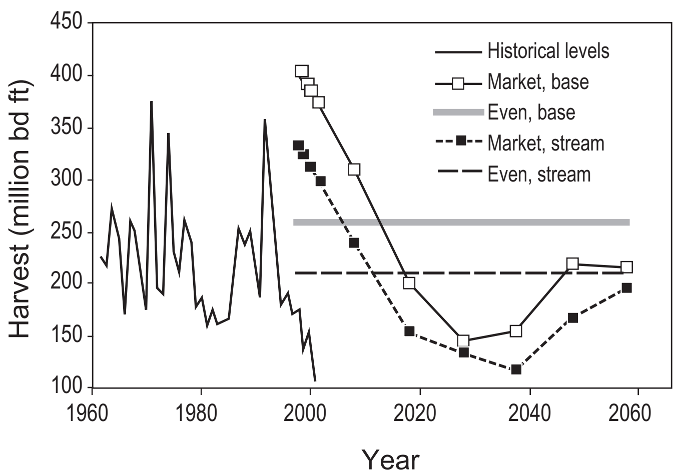

Figure 18. Timber harvest on NIPF lands in eastern Oregon under the base-case and expanded-streamside-protection policies, for both market-based and even-flow projections. Initial MIC distributions were endogenous.

To examine the sensitivity of the base-case projections to changes in management and resource conditions, we developed alternative harvest projections based on two types of hypothetical policy changes.

EXPANDED STREAMSIDE BUFFERS

We expanded the requirements for streamside buffers to protect riparian habitat so that no harvest of any kind is permitted within 100 ft of any perennial or intermittent stream. Current riparian protection requirements vary depending on the size of the stream and whether it is fish-bearing. Since our database allows identification only of the permanence of stream flow and not of stream size or fish-bearing status, we assumed a 20-ft no-cut buffer on all streams as the average in the base case.[11] This scenario represents a quintupling of the average width of the current no-cut corridor on each side of streams.

Under this alternative scenario of expanded riparian buffers, both industry market-based and even-flow harvest projections fall relative to the base case (Figure 17). The market-based projection declines irregularly over time, averaging approximately 11% below the base-case projection. The even-flow projection falls by approximately 12%. The area lost to harvesting in the expanded buffer is approximately 10% of the industrial base. NIPF harvest declines by 19% in the market-based projection and by 18% in the even-flow projection (Figure 18). The NIPF area loss in the expanded buffer is 18% of the NIPF base. As we found in similar scenarios conducted in western Oregon (Adams et al. 2002), the proportional reduction in eastern Oregon harvest is similar to the area reduction. This proportionality suggests that the areas removed from harvest in the expanded riparian zones represent a rough average of all stands in the two private ownerships in terms of both current

[11]In the 1999 FIA database, the distance of each subplot from the nearest stream course or water body is recorded for distances up to 65 m. The nature of the water body is also noted as either perennial or intermittent. These distances were linked to each condition class by using an average for the subplots in a condition class. The area within a given distance of a water body can be computed by using the condition-class expansion factors.

inventory and future harvest potential and are not concentrated in either particularly productive or unproductive types of stands.

Higher Residual Stocking

A second policy scenario was suggested by forest practice developments in California and by recent discussion in Oregon about lengthening the period between harvest disturbances and moderating the extent of disturbances. In this scenario, we raise the minimum post-harvest residual stocking volume in partial cutting by 30% relative to the base case. For example, in the least intensively managed, uneven-aged MIC the base case allows a minimum of 3,000 bd ft/ac after harvest, while the higher stocking scenario requires a minimum of 4,000 bd ft/ac. The effect of raising the minimum post-harvest residual stocking volume is to reduce the available volume of harvestable timber.

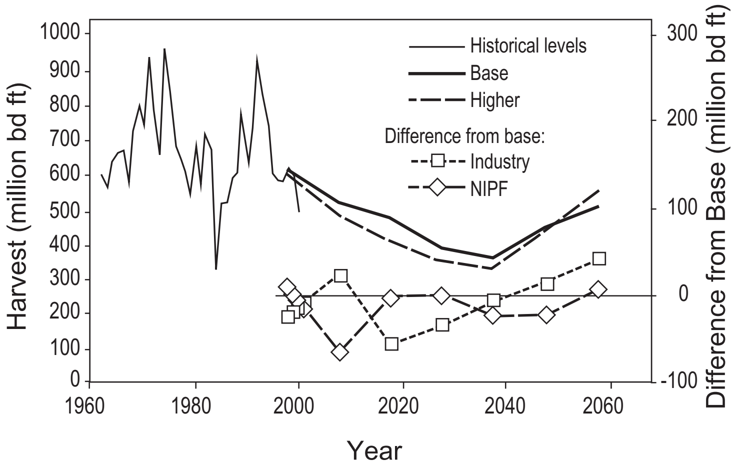

Figure 19. Harvest on all private lands in eastern Oregon under the base-case market-based projection and the simulated-higher-residual-stocking scenario with differences from base projection for industry and NIPF owners. Initial MIC distributions were endogenous.

In order to filter some of the short-term variability, we looked at the combined harvest for both owners (Figure 19). The average combined harvest reduction over the 50-yr projection is 5%. In the initial portion of the projection, harvest departs gradually from the base case. After 2040, projected harvest begins to rise as timber inventory builds, and by the final period it exceeds the base level. Combined inventory is approximately 13% higher by the end of the projection period (in 2058). Changes from the base case for each owner are also shown in Figure 19. There is a noticeable difference between groups. Industry harvest falls by an average of 2% per period, while NIPF cut falls 7%. The average absolute NIPF decline is larger as well, at 12 million bd ft, compared to 9 million bd ft for industrial lands. In this case, NIPF lands have higher average stocking levels than do industrial ownerships; more NIPF stands meet the minimum required stocking level for harvest in the first period, and harvest is well above the long-term average. Raising the minimum volume required for harvest affects more stands in NIPF ownership and has a larger proportional and absolute impact on NIPF cut.

Endogenous Versus Exogenous Initial MIC Allocation

In the preceding comparisons, the initial (first-period) allocations of lands to MIC classes on both ownerships were determined endogenously within the projection model. Under a policy change, the potential impacts are perfectly foreseen by the model and the initial MIC allocation is adjusted to minimize the effects of the policy on the market (or even-flow) objective. This endogenous approach is consistent with the view that many aspects of a given MIC allocation at the start of the projection could in fact be readily modified if policy conditions were to vary and expected future market conditions were to change. For example, any stand managed on an uneven-aged basis could be reallocated to any other uneven-aged MIC by reducing the residual volume at time of harvest or by lengthening the waiting period until first harvest. Except for origin (natural versus plantation), even-aged stands could also be shifted among MICs by varying the minimum harvest threshold. In analyses of alternative policies that use the endogenous allocation, one might anticipate smaller estimates of policy impacts than one would in a more typical analysis, where the initial allocation of MICs is fixed and based on exogenous information. With constraints on adaptive actions (in this case, not being able to adjust the current or initial MIC), adjustment costs could increase.

To examine the effects of endogenous initial MIC allocation, we compared the base-case market and expanded-streamside-protection simulations with and without endogenous allocation. For the exogenous initial allocations, we used the ODF-OFIC management survey discussed earlier. While the differences between the overall allocations to even-aged and uneven-aged groups are modest, there are some large differences in the allocation of land across the low to high MIC range in uneven-aged systems (Figure 8). For both industrial and NIPF landowners, little or no land is placed in the medium-intensity uneven-aged class in the endogenous allocation.

There are many possible reasons for these differences. Our specific yield representations of the low, medium, and high classes could differ from those envisioned by respondents to the ODF-OFIC survey, since no yield or specific stocking data were collected in the survey. Also, our results reflect initial inventory conditions, assumed yields, and other projection inputs. There is no reason *a priori* for the endogenous initial MIC distributions from the model to show area in all MICs.

For industrial lands, the impacts of a 100-ft no-cut zone are similar under both endogenous and exogenous initial MIC allocations (Figure 20A). In contrast, on NIPF lands the impacts under the endogenous allocation are larger (more negative) in most periods than under the exogenous allocation, although average harvest reductions over the first 50 yr are similar [19.3% and 18.5% for endogenous and exogenous allocations, respectively (Figure 20B)]. Our earlier expectation, in contrast, was that the exogenous allocations would produce larger changes than the endogenous case.

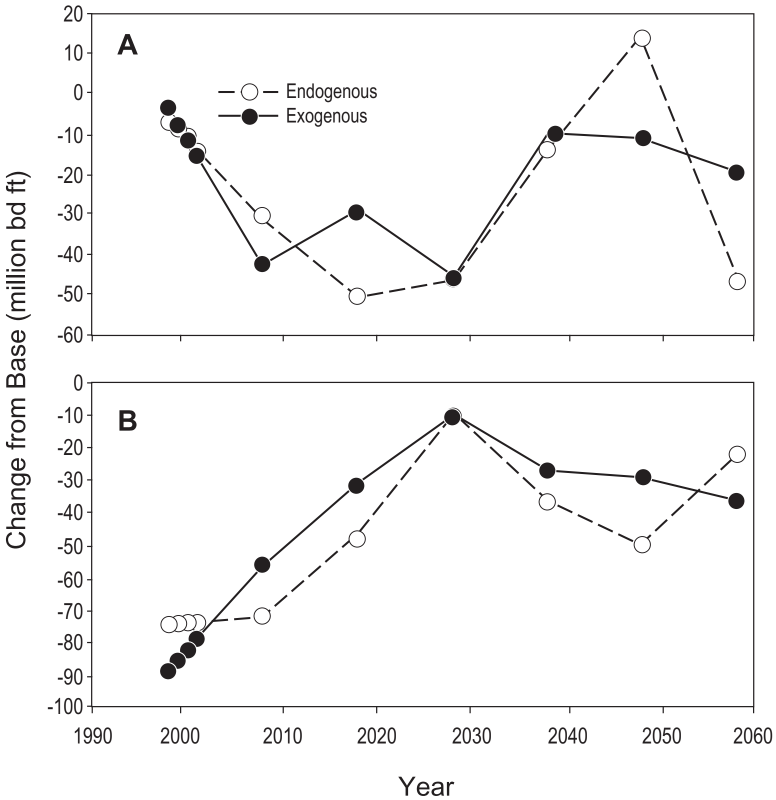

Figure 20. Differences in total harvest between base-case and expanded-streamside-buffer simulations, derived using endogenous and exogenous allocation of land to initial MICs for industry (A) and NIPF (B) owners in eastern Oregon.

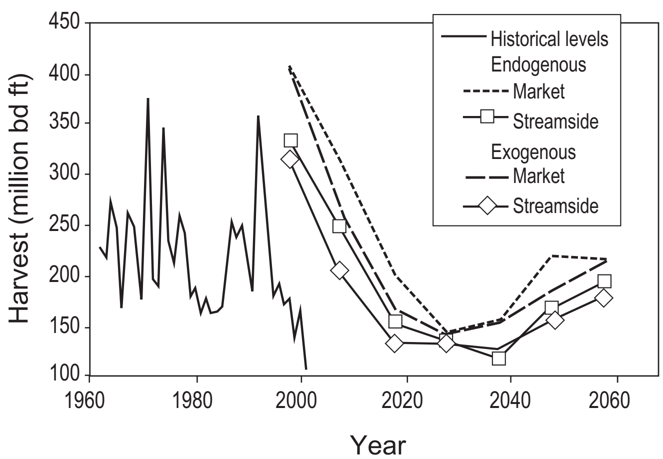

Figure 21. Comparison of eastern Oregon NIPF harvest projections, derived using endogenous and exogenous initial allocation from the market-based (market) and expanded-streamside-zone (stream) simulations.

The reasons for these counterintuitive results relate to the nature of the two types of simulations. From the perspective of the harvest scheduling model, simulations under the exogenous initial MIC allocation are suboptimal. The endogenous initial MIC allocation should allow higher NIPF harvests in both the base case and the 100-ft no-cut simulations. As illustrated in Figure 21, this is clearly the case. The endogenous simulations give higher harvest levels in nearly all years (compare the pair of solid lines and the pair of dashed lines in Figure 21). Since the exogenous runs begin with what are essentially arbitrary MIC allocations, from the model's perspective there is no reason to expect that the differences between the exogenous base case and 100-ft no-cut runs should be larger than the differences between the endogenous base case and 100-ft no-cut simulations. Both exogenous simulations are suboptimal, so the differences between them might be of any size. We conclude that, in general, it is not possible to judge *a priori* how the use of a fixed versus variable initial MIC allocation will impact the evaluation of policy impacts. Results depend on how far the initial exogenous allocations are from optimal.

Discussion

The most dramatic result of this analysis is that industrial harvest potential in eastern Oregon over the next 50 yr is 50% lower than recent historical levels. Past harvests have steadily reduced the industrial inventory base, shifting the concentrations of both numbers of trees and volume into the smaller diameter classes. The result has been lower aggregate growth and reduced long-term harvest potential. At the same time, despite this reduced inventory, industrial harvest potential does not appear to be more sensitive than its NIPF counterpart to the two forms of policy shifts examined here. Expansion in industrial harvest would be possible in the long term with "inventory savings" (harvest less than growth), but a return to historical average harvests would require many decades.

Harvest potential on NIPF lands in eastern Oregon appears to be similar to our findings for harvest potential on NIPF lands in western Oregon (Adams et al. 2002). Despite declining inventories over the past decade, a substantial volume of merchantable timber remains on these lands. Our even-flow base projection for harvest was above the long-term historical average, and the market-based projection showed very large near-term harvests concentrated in the currently merchantable surplus. Our simulation of continued trends in land area loss from NIPF ownership had only modest impacts on harvest, with the biggest changes coming 50 yr into the future.

Results of the market-based and volume-flow projections vary markedly by owner and suggest some important differences in resource characteristics of owner groups. Discounting in the market-based model produces a bias toward near-term harvest. In this case, high initial harvests suggest the existence of a pool of "super-merchantable" timber that provides the basis for some flexibility in future harvest levels.[12] This scenario is seen for NIPF ownerships but not for industrial ownerships.

The hypothetical 100-ft no-cut buffer simulation suggests that both ownerships could respond in similar fashion to this type of restriction. Projected harvests fell roughly in proportion to the area removed from operation. Increasing the minimum post-harvest stocking, in contrast, had a larger proportional and absolute impact on NIPF harvest. This latter result reflects differences in growth rates and in the distribution of volume across stands between the two owner groups.

Comparison of endogenous and exogenous initial (first-period) MIC allocations did not yield the anticipated results. For industrial lands, the impacts of the 100-ft no-cut zone were similar with both approaches, while on NIPF lands the endogenous allocation produced slightly larger average impacts. We conclude that no general results may be drawn

[12]There will be strong pressure to cut any merchantable volumes growing at less than the interest rate as close to the first period of the projection as possible. This pressure is offset only by the downward-sloping demand curve that yields lower prices as harvest rises.

in this comparison. Since the exogenous initial allocation is essentially arbitrary from the perspective of the projection model, it might yield higher or lower impacts relative to the endogenous allocation approach depending on its relation to the optimal endogenous allocation. If the exogenous allocation were identical to the endogenous allocation in the base case, then the impacts from the endogenous allocation would be smaller. Otherwise, the relative size of impacts cannot be predicted.

Finally, it is important to bear in mind that the projections presented here are potentials—what might be observed if all the assumed conditions were valid and all owners followed the specific objective of the projection. These projections are designed to expose some of the possible variation in cut and how changes in policies or resource conditions might influence harvest. As our results indicate, projections may depart markedly from past trends and should not be interpreted as "most likely" forecasts.

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Appendix A. Yield Computations and Adjustments

All yields in this study were computed by using the Forest Service FVS (Forest Vegetation Simulator) model (USDA Forest Service, Forest Management Service Center). Tree lists for initial stands were developed at the condition-class level from the 1998–1999 eastern Oregon Forest Service FIA plot data. FVS was used to project these tree lists into the future for the existing stands under each of the possible MICs. For the uneven-aged MICs, this included an array of possible times after the start of the projection at which to begin cutting (assuming the minimum residual volume conditions are met for the MIC being examined). For even-aged cases, FVS was also used to project volumes for stands replanted after clearcutting during the projection. In all yield computations, a 15% deduction was made from reported volumes for defect. This appendix describes adjustments made to the basic FIA inventory data to develop these projections and assumptions made about species and stocking in regenerated even-aged stands.

Site Indexes

Site productivity estimation is important both for determining which forested acreage to include in a model and for controlling stand growth and stocking levels in estimating future stand yields. The two basic components of site productivity in the FIA procedures are site index and plant association. Site index is used to determine the mean annual increment (MAI) at culmination, based on equations linking site index and MAI derived from normal yield curves for key species. Plant associations are used to adjust the MAI downward in plant associations that may be unable to reach the culmination MAI. Seven site-productivity classes are employed based on adjusted MAI at culmination (Table A-1).

Table A-1. Site-productivity classes used in eastern Oregon inventory and definitions in mean annual increment (MAI) at culmination.

Site-productivity class	MAI (ft^3/ac/yr)
I	225+
II	165-224
III	120-164
IV	85-119
V	50-84
VI	20-49
VII	<20

In the 1998–1999 eastern Oregon inventory, a generalized land class (GLC) code of 20 is given to forestland capable of producing at least 20 cu ft/ac/yr, while forestland incapable of producing 20 ft^3 is given a GLC code of 49. Figure A-1 shows the area of private forestland in each of the seven productivity classes for both eastern and western Oregon. While the GLC 49 lands are relatively insignificant in western Oregon, in eastern Oregon they account for more acreage than do lands in site-productivity classes I through IV combined. Further, GLC 49 lands also support a modest volume of merchantable timber that is potentially subject to harvest regardless of the growth potential of the land. Therefore, we included them as part of the timber supply base.

Due to the preliminary nature of the FIA database at the time this study was conducted, we had to develop procedures to estimate site productivity at the condition-class level for the 530 privately owned GLC 20 and GLC 49 condition classes in eastern Oregon. The site-tree measurements did not include complete information at the condition-class level.

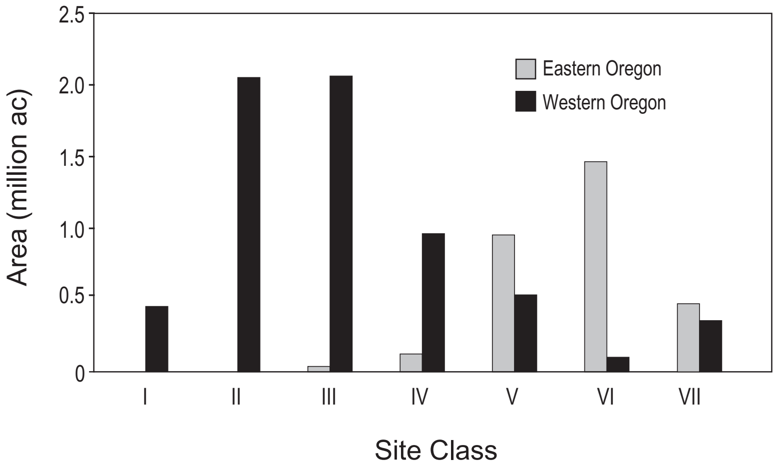

Figure A-1. Land area by site-productivity class for private landowners in eastern and western Oregon, based on the most recent Forest Service inventories (1996–1997 west, 1999 east).

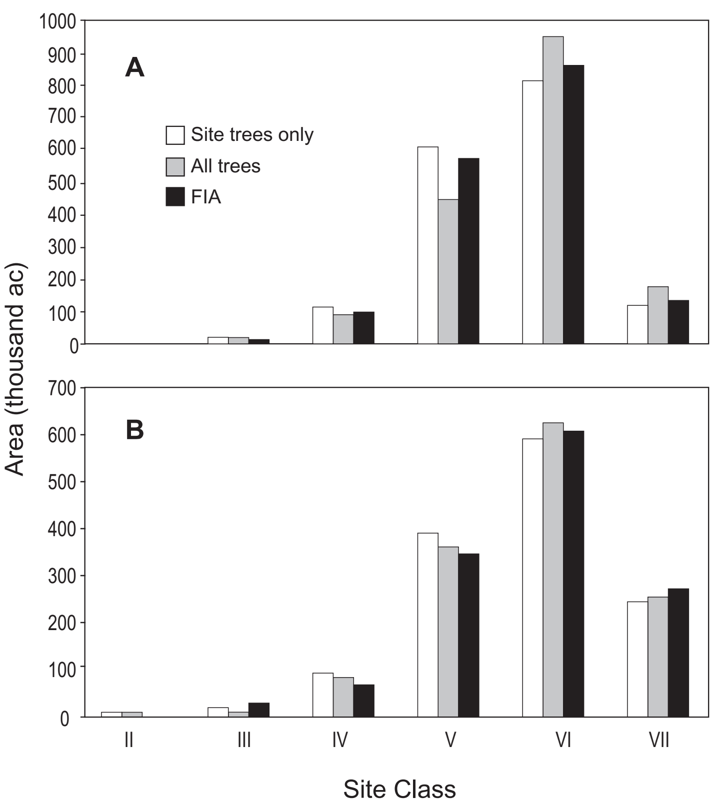

Figure A-2. Area by site class in eastern Oregon for forestry industry (A) and NIPF (B) ownerships. Three approaches were used to estimate site index.

As a consequence, site indexes were first computed at the plot level and assigned uniformly to all condition classes on the plot. The calculated culmination MAI was then adjusted at the condition-class level by applying the appropriate MAI discount factor for the plant association of the condition classes.

Site indexes were also required for use in growth and yield estimation with FVS. The original site-tree table in the 1998–1999 eastern Oregon database contained some trees with breast height ages >300 yr. Due to the increased possibility of error in counting such a large number of rings, along with the limited age ranges of the original site index equations, we eliminated any tree with an age >150 yr at breast height. This left 1,433 site trees on 427 of the plots. In an effort to develop calculated site indexes for as many of the 493 plots as possible, we used dominant and codominant (crown classes 2 and 3) trees from the plot tree lists if they were younger than 150 yr and had no damage code or sign of dwarf mistletoe. This added 1090 crown class 2 trees and 1080 crown class 3 trees and allowed us to calculate site indexes for 473 of the 493 plots. Figure A-2 shows a comparison of the estimated area by site class and owner taken from the eastern Oregon database and calculated using site trees <150 yr (site trees only) and site trees and dominant and codominant defect-free trees <150 yr (all trees). For the remaining 20 plots without site trees, the site class given in the database (determined presumably from previous stands or other indicators) was assigned to the plot.

Stand Density Indexes

Yield estimation with FVS also requires a plant-association code to determine the maximum stand density achievable by the stand. Unfortunately, the variants of FVS we employed do not recognize a number of the plant-association codes in the eastern Oregon database. While information regarding maximum stand density index (SDI) values is not readily available, the Forest Service has used field data from inventory plots on the National Forests to estimate growth basal area (GBA) for each plant association found on the forest. These data are published in a series of plant-association guides (Hall 1998). Cochran et al. (1994) developed a series of equations that uses these GBA values to estimate the maximum SDI for each plant association; the SDI values are species-specific and thus could be used directly in FVS. For species with no equations in Cochran et al. (1994), we adjusted their default FVS SDIs by the ratio of the computed to the default SDIs for the species for which equations were available.

Regenerated-Stand Tree Lists

Only limited information was available from the ODF-OFIC management intentions survey on the density and species mix desired following a regeneration harvest. We assumed that the density of young trees would be 250 tpa and that the species composition would be the same as in other stands existing in the database. The species and planting densities by site class are given in Table A-2.

Table A-2. Species and trees per ac after regeneration harvest on private lands in eastern Oregon.

Tree species		Site class			
Common name	Scientific name	III	IV	V	VI
		Trees per ac			
White fir	*Abies concolor*	0	27	37	19
Grand fir	*Abies grandis*	94	80	45	19
Subalpine fir	*Abies lasiocarpa*	0	0	0	3
Shasta red fir	*Abies magnifica* var. *shastensis*	0	0	1	0
Western juniper	*Juniperus occidentalis*	0	0	1	0
Western larch	*Larix occidentalis*	0	12	5	2
Incense cedar	*Calocedrus decurrens*	0	0	3	3
Engelmann spruce	*Picea engelmannii*	0	12	4	0
Lodgepole pine	*Pinus contorta*	0	36	68	92
Sugar pine	*Pinus lambertiana*	0	3	2	0
Ponderosa Pine	*Pinus ponderosa*	94	54	36	84
Douglas-fir	*Pseudotsuga menziesii*	63	27	47	25
Quaking aspen	*Populus tremuloides*	0	0	1	0
Oregon white oak	*Quercus garryana*	0	0	1	3

Appendix B. Mathematical Structure of the Harvest Projection Model

This appendix outlines the general structure of the harvest projection model in its market-based model form and describes modifications to obtain the even-flow, volume-based approach.

The market-based model uses a fairly standard form for intertemporal market analysis, maximizing the discounted sum of producer and consumer surpluses less transport and other costs (for example, see Berck 1979, Sedjo and Lyon 1990, and Adams et al. 1996). Consumer surplus is computed under the derived log input demand curves at each "processing center" in eastern Oregon (locations with one or more mills). Log supply is implicit in the costs of managing and harvesting timber in each condition class over time. The total area under the demand curves, less costs of management, harvesting, and transport costs, yields "net social surplus" (Samuelson 1952) and is maximized subject to constraints on the disposition of the total inventory area among management-harvesting activities and demand-supply balance. At the end of the projection period some account must be taken of the residual, unharvested inventory. We assume that this inventory will continue to provide even-flow harvests (in both the market-based and volume-flow models) on a perpetual basis in all future periods. The volume of this perpetual even flow is computed using von Mantel's formula and assumes that the terminal inventory is fully regulated. (We do not, in fact, force regulation of the terminal inventory.)

The objective function is:

$$MAX_{X,N} \quad \sum_{t=1}^{T-1}\left[\sum_{w} D(w,R(w,t)) - \sum_{c}\sum_{w} H(c,w)S(c,w,t) - \sum_{c} C(c,t)\sum_{a>t} N(c,t,a,m')\right](1+i)^{-t} +$$

$$\left[\sum_{w} D^{T}(w,R(w,T)) - \sum_{c}\sum_{w} H(c,w)S(c,w,T-1) - \sum_{c} C(c,T)\sum_{a>T-1}\tilde{N}(c,T-1,a,m')\right]\frac{(1+i)^{10}}{(1+i)^{10}-1}(1+i)^{-T}$$

subject to the constraints

$$\sum_{t}\sum_{m} X(c,t,m) = A(c) \quad \forall c$$ allocation of all existing area [1]

$$\sum_{l>t} N(c,t,l,m') \le \sum_{m'} X(c,t,m') + \sum_{a} N(c,a,t,m') \quad \forall c,t$$ future area of even-aged stands [2]

$$h(c,t) = \sum_{m'} X(c,t,m')V(c,t,m') + \sum_{m'}\sum_{a<t} N(c,a,t,m')V(c,t-a,m') + \sum_{m^0} X(c,t,m^0)V^{H}(c,t,m^0) \quad \forall c,t$$ harvest [3]

$$E(c,t)+\sum_{w} S(c,w,t) \le h(c,t) \quad \forall c,t$$ shipments from plots to processing centers [4]

$$M(w,t)+G(w,t)+\sum_{c} S(c,w,t) \ge R(w,t) \quad \forall w,t$$ receipts at processing centers [5]

$$I(t)=\sum_{c}\left[\sum_{m^0} X(c,t,m^0)V^I(c,t,m^0)+\sum_{m'}\sum_{a<t}\sum_{t<k} N(c,a,k,m')V(c,t-a,m')\right]$$ inventory [6]

where (in alphabetical order)

A(*c*) = initial area in condition class *c* at the start of the problem (this is the expansion factor for the condition class from the original inventory data)

c = condition-class identifier

C(*c*,*t*) = cost per ac of planting in condition class *c* at time *t*

D(*w*,*R*(*w*,*t*)) = area under the log demand curve (willingness to pay in dollars) in processing center *w* for log receipt volume *R*(*w*,*t*) in period *t*

$D^T(\cdot)$ = area under the log demand curve in all future periods beyond the end of the projection

E(*c*,*t*) = volume of logs exported (leaving eastern Oregon for any destination) from condition class *c* in period *t*

G(*w*,*t*) = volume of publicly owned logs received at processing center *c* in period *t*

h(*c*,*t*) = harvest volume from condition class *c* in period *t* summed across all MICs; periodic harvest in all future periods beyond the end of the projection is computed under the assumption that the final inventory [*I*(*T*)] is fully regulated by applying von Mantel's formula [periodic harvest = 2*I*(*T*)/rotation age] and assuming a fixed average future rotation age

H(*c*,*w*) = harvest and transport cost per unit volume from condition class *c* to processing center *w*

i = discount rate

I(*t*) = volume of timber inventory on all private lands in eastern Oregon at the end of period *t*

m = (m^0, m') and is the set of all MICs, m^0 includes only the uneven-aged MICs, and m' includes only the even-aged MICs

$M(w,t)$ = volume of logs imported (from any non-eastern Oregon source) to processing center w in period t

$N(c,t,a,m')$ = area of condition class c that was regenerated in period t, to be cut again in period a, in even-aged MICs m'

$R(w,t)$ = volume of logs received in processing center w at time t

$R(w,T)$ = volume of logs received in processing center w in all periods after the end of the projection

$S(c,w,t)$ = volume shipped from condition class c to processing center w in period t

t = period for $t = 1,\ldots,T\text{-}1,T$ with T-1 representing the final period of the projection and T the subsequent period in which harvests, returns, and costs for all future periods beyond the end of the projection are computed

$V(c,t,m')$ = volume per ac in the portion of condition class c allocated to even-aged MIC m' when first harvested at time t; these are volumes for stands that existed at the start of the projection when they were first clearcut harvested

$V(c,t - a,m')$ = volume per ac in the portion of condition class c planted in period a under even-aged MIC m' and cut again in period t ($t > a$ by at least the length of the minimum harvest age), so $t - a$ is the age of the stand when harvested; these are volumes for stands managed on an even-aged basis in their second and subsequent rotations

$V^H(c,t,m^0)$ = volume harvested in the portion of condition class c allocated to uneven-aged management regime m^0 in period t; this volume is non-zero only if a partial cut is scheduled for period t under this MIC's harvest regime

$V^I(c,t,m^0)$ = volume of inventory remaining in the portion of condition class c allocated to uneven-aged management regime m^0 at the end of period t

$X(c,t,m)$ = area of condition class c existing at the start of the problem allocated to MIC m that will be cut in period t

Under the volume flow objective, the objective function appears as:

$$MAX_{X,N} \sum_{t=1}^{T} \sum_{c} h(c,t) \qquad \text{volume flow objective function [7]}$$

subject to constraints [1], [2], [3] and [6] above and

$$\sum_{c} h(c,t) = \sum_{c} h(c,t-1) \quad \forall t > 1 \qquad \text{even-flow constraint [8]}$$

where harvest in period T is computed as described at $h(c,t)$ above.

Appendix C: The Eastern Oregon Log Market

Both log supply and demand in Oregon are composed of several flows originating within and outside the region. Table C-1 shows the components of log supply and demand in the eastern and (for comparison) western Oregon markets (see Adams et al. 2002). Virtually all foreign or out-of-state trade originates in western Oregon. The only outside influence on the eastern Oregon log market is modeled as a 25% net flow of logs to the west. 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 two recent Oregon and Washington mill studies (Larsen 1998, Ward et al. 2000) and a brief description of how each component is modeled in the present study. The following sections provide a description of these components and their representation in the model.

Eastern Oregon Log Supply

All of the logs used by market (processing) centers in the eastern Oregon model derive from lands in eastern Oregon. Private log supply is an implicit function of the costs of planting, growing, and harvesting timber over time. Total supply is augmented by an assumed fixed quantity from public lands.

Eastern Oregon Log Demand

Log consumption in lumber and plywood production

Since the lumber and plywood industries both consume sizable volumes of softwood logs, each industry's consumption is modeled separately by a normalized, restricted quadratic profit function. Each industry is assumed to have one output (lumber or plywood). Inputs

Table C-1. Average percent of supply and demand for components of the eastern and western Oregon log markets from 1994 to 1998, and description of how each component was modeled in the eastern Oregon analysis.

	%	How modeled
Eastern Oregon log supply		
Private harvest	80	Harvest schedule based on FIA condition class data
Public harvest	20	Assumed fixed at 1994-1998 average level
Eastern Oregon log demand		
Lumber production	59	Econometrically estimated via restricted normalized profit function
Plywood production	12	Econometrically estimated linear demand
Western Oregon exports	25	Fixed at 25% of recent eastern Oregon harvest levels
Other consumption	4	Assumed to be portion of harvest that is not classified as sawlog
Western Oregon log supply		
Western Oregon harvest	80	
Foreign imports	1	
Domestic imports	13	
Eastern Oregon imports	6	
Western Oregon log demand		
Lumber production	65	
Plywood production	25	
Foreign exports	4	
Domestic exports	2	
Other consumption	4	

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 to each industry's indirect profit function, differentiation with respect to the relative price of logs yields the negative of the log demand curve, as shown below:

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

where:

o = output (lumber or plywood)

w = softwood roundwood

l = labor

n = other variable inputs

k = capital stock

t = level of technology

p_j = prices

x_w = quantity of log demand

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

Time-series data with annual observations from 1970 to 1998 were used in the estimation. Data for lumber production and prices were obtained from the Western Wood Products Association (2001). Plywood production came from APA—The Engineered Wood Association (2001) and prices from Warren (1999). Log consumption was obtained by multiplying lumber and plywood production by product recovery factors for the Pacific Northwest Eastside region from the Forest Service's RPA Timber Assessment database (Adams and Haynes 1996). Log prices were an average of the diameter-class prices for ponderosa pine, Douglas-fir, and other softwoods reported by the Oregon Department of Forestry for the Klamath region (Oregon Department of Forestry 1996). To obtain a regional average, log prices by species were weighted by the proportions of species lumber production reported by the Western Wood Products Association (2001) for the region. Labor quantity and price were obtained for Standard Industrial Classification Codes 2521 and 2536 in eastern Oregon from the Oregon Department of Employment. Capacity, representing maximum service output of the stock as described in Adams and Haynes (1996), was used as a proxy for capital stock in the lumber industry. Capacity for the plywood industry in the early portion of the data sample is from APA—The Engineered Wood Association (2001) and in more recent years from Spelter et al. (1997). The price index for variable inputs is the United States all-commodity producer price index from the Bureau of Labor Statistics.

Relations for the lumber industry were estimated with the SHAZAM (1997) econometrics package, using iterative, nonlinear three-stage least squares. The instrument set included exogenous variables together with the lagged values of all endogenous variables for all regions. Convexity was imposed on the system as described by Wiley et al. (1973). Pa-

Table C-2. Estimated parameters for the negative of log demand equations for lumber and plywood production. DW is the Durbin-Watson statistic. Values in parentheses are asymptotic t-ratios.

	Constant	P_o	P_w	P_l	Capacity	Technology	R^2	DW
Lumber	-0.206	-0.075	0.079	0.688	-0.714	0.006	0.95	1.16
	(-1.41)	(-2.00)	(2.38)	(2.44)	(-13.27)	(2.41)		
Plywood	0.028	-0.048	0.170	0.041	-0.256	-0.001	0.78	2.11
	(0.75)	(-3.58)	(4.14)	(1.03)	(-5.33)	(-1.00)		

rameter estimates, asymptotic t-ratios, and goodness-of-fit statistics for the log demand equation are given in Table C-2. These parameters yield an unconditional (Marshallian) own-price elasticity of wood demand for lumber production of -0.201 (at sample means).

Relations for the plywood industry were estimated using iterative, nonlinear three-stage least squares, with the instrument set including exogenous variables together with the lagged values of all endogenous variables. Convexity was not imposed on the system, and only the output supply and input demand equations were estimated. Parameter estimates, asymptotic t-ratios, and goodness-of-fit statistics for the log demand equation are given in Table C-2. These parameters yielded an unconditional (Marshallian) own-price elasticity of wood demand for plywood production of -0.5 (at sample means).

Other consumption

Other consumption consists of log use in chipping, pulp, board (all reconstituted panel mills in eastern Oregon), shake and shingle, and post, pole, and piling production. It is assumed in the projections that these industries consume the portion of the projected harvest that is not classified as sawtimber. In the base-case market-based simulation, this amounts to 5.3% of the total softwood harvest over the first 100-yr period.

Exports to western Oregon

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

Logging and hauling costs

Due to the dispersed nature of the eastern Oregon log market and resource base, we undertook a detailed approach to estimating harvest and haul costs. A GIS database was developed with the locations of all wood processing centers and logging companies (logging services suppliers) in the region. The formulation of the harvest cost equation is based on the work of Fight et al. (1999) and is described in the following equation:

$$HarvestCost = f(DISTm, QMD, VOL, TPA, SLOPE)$$

where

DISTm = distance in miles to the nearest logging company, processing center, or city

QMD = quadratic mean diameter of the stand

VOL = volume removed

TPA = trees per ac removed

SLOPE = slope at the plot, which determines logging system availability

Equally important is the cost of moving logs the long distances to milling centers. The hauling costs are based on a rate of $50/hr and an average load of 5,000 bd ft. The round-trip time to each milling center is computed based on a 30-minute loading wait and a speed of 20 mph for the first 10 miles and 40 mph for the remaining distance.

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