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Forest Cover Dynamics in the Pacific Northwest West Side: Regional Trends and Projections

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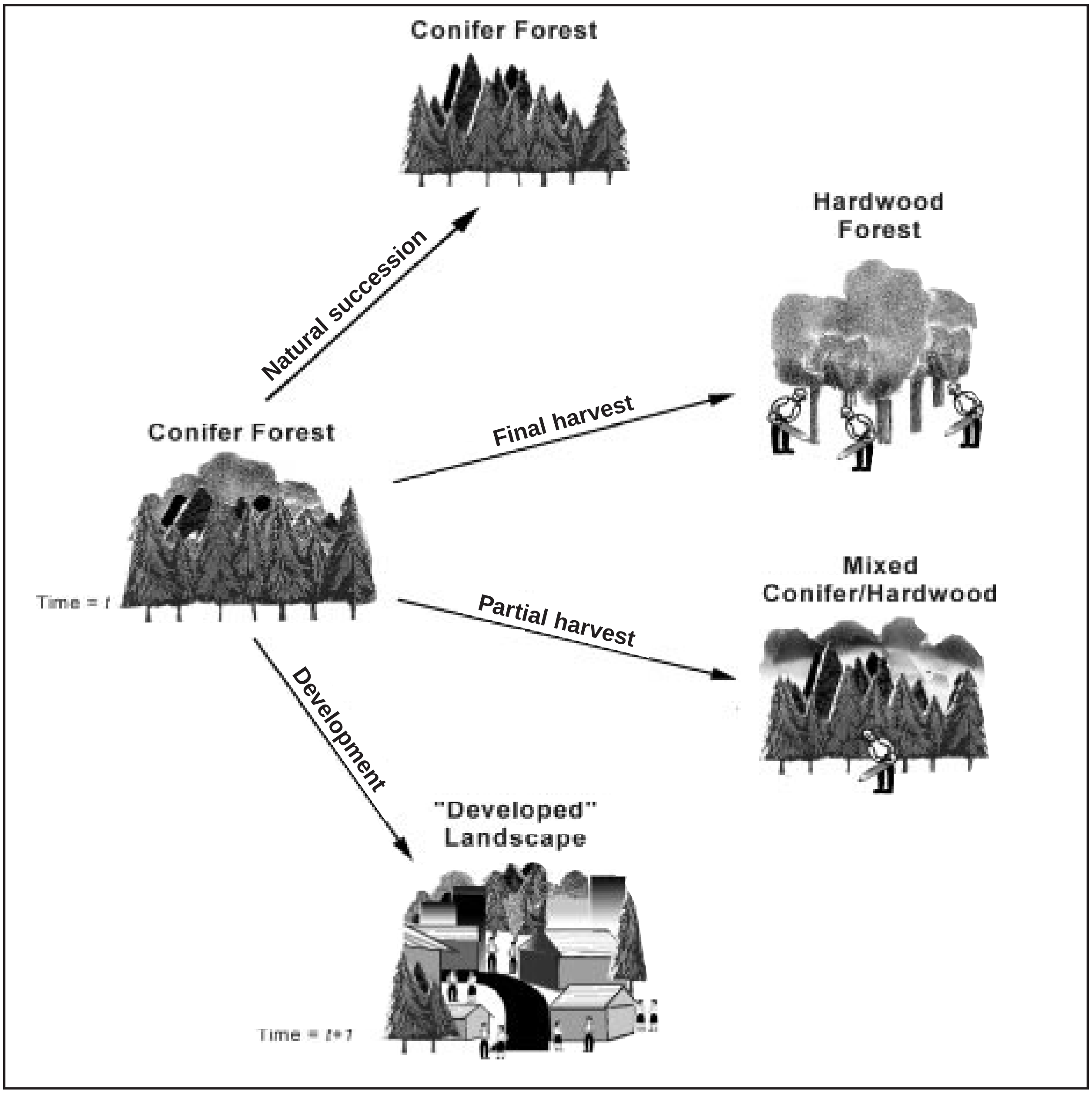

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Abstract

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The objectives of this paper were to (1) analyze recent rates of transitions among forest cover types on private timberland, (2) identify differences by ownership class, and (3) project future changes under different scenarios related to current policy issues in the Pacific Northwest. Timber harvests are the dominant class of disturbance on private timberland in western Oregon and Washington. Net changes in forest type areas depend on the relative mix of natural and human-related forces. Transitions among forest types after harvest may be planned, as in conversion of red alder (*Alnus rubra* Bong.) to the commercially preferred Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco.), or stochastic successional changes, such as reversion of disturbed areas to red alder in the absence of intervention. Projected areas of Douglas-fir and red alder were notably different under a scenario without harvests versus a scenario in which the rate of partial harvesting is increased. Areas of Douglas-fir were projected to increase under selected scenarios for both industrial and nonindustrial private ownerships. Conversely, areas of red alder are projected to decrease under selected scenarios and for both ownerships.

Keywords: Forest type transitions, forest land management, temporal analyses, periodic surveys.

Summary

We examined area changes for cover types on private forest land between the last two forest surveys in western Oregon and western Washington, the area west of the crest of the Cascade Range in both states. Periodic surveys by the USDA Forest Service indicate that forest cover changes and timber harvest activities are more frequent on private forest land than on public lands. A significant shift of timberlands from hardwoods and other softwood types to the Douglas-fir type was observed. The most frequent disturbance on private lands is some form of harvest, with clearcutting methods dominating on industry lands, and partial harvests most common on nonindustrial private lands.

Projected areas of Douglas-fir increase under several selected scenarios. These include baseline projections based on a continuation of trends observed for the last forest survey remeasurement period, a scenario where only natural succession forces are at work, and a scenario where all harvesting on private land is assumed to be partial harvesting.

Net changes in projected forest type areas depend on the relative mix of natural and human-caused forces. Failure to recognize the significant influence of human-caused disturbances could lead to underestimated amounts of Douglas-fir relative to other forest types. More intensive forest management would induce shifts in forest species on private timberlands to those better suited to disturbed forest conditions. An increase in the number of people on the regional landscape in the future will further affect forest type areas and will pose additional land management challenges. Future research should include investigation of socioeconomic causes of forest cover changes, including influences of timber markets and land management costs.

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Introduction

Projecting changes in forest vegetation composition over time is an important part of regional assessments of prospective forest conditions. Interest in landscape changes has increased, as pressures on the land base increase owing in part to a growing population and increasing personal incomes. Area changes in forest management types can significantly affect nontimber components, such as carbon sequestration, species abundance, and structure of wildlife communities. Regional landscape dynamics are influenced by ecological and socioeconomic forces that impact land ownership, use, and management. Environmental factors and market forces, along with policy influences, interact to affect the likelihood of disturbances that may alter forest cover. The relative importance of key determinants for land cover shifts differs among owners. To assess long-term policy options for forest and aquatic ecosystems, therefore, it is important to project changes in forest type areas under different ownership and land management scenarios.

We examine regional landscape dynamics to determine the relative influences of ecological and socioeconomic factors in area changes for forest cover types. Our analysis addresses three primary questions: (1) Do dynamics of regional forest cover changes differ by type of disturbance? (2) Do such dynamics differ by ownership? and (3) What are the long-term implications of recent disturbance trends in terms of resultant vegetation patterns? Projection models are developed in the context of large-area (e.g., several million hectares) forest and aquatic ecosystem assessments designed to provide long-term projections (typically 50 to 100 years) (e.g., Haynes and others 1995). In examining the questions regarding forest type dynamics, we focus on private timberland because private owners control two-thirds of timberland in Oregon and Washington west of the crest of the Cascade Range and have provided an increasing proportion of timber harvests since 1990.

Previous Research

In the Pacific Northwest west side (PNWW; see fig. 1),[1] modeling of changes in forest types has been oriented towards public lands and natural disturbance scenarios. For example, long-term forest succession has been modeled in response to wildfire, wind, and climate change (Dale and Franklin 1989, Dale and others 1986). Before European settlement, landscape dynamics in PNWW forests were driven primarily by patterns of wildfire (Agee 1993, Wallin and others 1996). Now, however, forest cutting and other human-caused disturbances throughout the region have been underway for over a century. Human-caused disturbances such as timber harvests now tend to dominate in most PNWW private forests.

Studies of changes in forest types can be separated into three categories according to emphases on driving factors: (1) forest succession and natural disturbances, with emphasis on natural forces; (2) planned changes, based primarily on expected financial returns from timber management; and (3) empirical studies based on observed regional trends, combining elements of forest succession and economics of human-caused disturbances. The first category of forest succession models is predicated on ecological theories of succession (e.g., Shugart 1984), where the forest is frequently

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[1] The PNWW includes the 38 counties that compose western Oregon and western Washington, the area west of the crest of the Cascade Range in both states.

Figure 1—The PNWW study area. It includes those counties of Washington and Oregon west of the crest of the Cascade Range.

viewed as essentially isolated from human influences (e.g., does not consider landowner behavioral tendencies). More recent ecological models now include natural disturbances such as wildfire and windthrow but typically do not include direct human manipulation and disturbances. Most models of forest development and succession assume a relatively stable, long-term steady-state community. Succession is viewed as tending toward a given stable environment, whereas disturbances are conceptualized as exogenous changes setting back succession. Some studies also concentrate on potential natural vegetation types, in contrast to actual or extant vegetation types. Scale of inquiry often has been at a small scale, such as at the "gap" level (Spies and Franklin 1989). Most research in the Northwest has concentrated on early successional changes in unmanaged Douglas-fir forests after catastrophic disturbances (Spies 1991). Those approaches generally stress ecological developments under equilibrium conditions, and give relatively little or no attention to timber harvests, other forest management practices, and effects of policies.[2] For policy analysis, this limits the utility of such succession models given that policies (e.g., government intervention such as cost-sharing or technical assistance programs) often are tied to likelihood of unassisted timber management regimes.

The second category of previous studies is characterized by emphasis on forest management options and planned activities. These studies bring in human-caused factors affecting forest dynamics, but in a normative way; i.e., what is optimal or prescribed, versus actual behavior. Forests are typically separated into those suitable for commercial operations (e.g., timberland) and other forests that have low productivity or constraints on timber operations (e.g., legislative restrictions or physical or economic inaccessibility). Analysis of forest dynamics on timberland is centered on human-caused manipulation of stand growth and renewal, with studies often assuming deterministic outcomes of actions. Most timber harvest scheduling models (e.g., FORPLAN) adhere to this structure. Eng (1992) provides an extension for harvest scheduling models, by incorporating stochastic elements in modeling of cover type changes for public forests. Capturing the effects of such disturbances on forest type areas results in a shift of the relative frequencies of regenerated cover types toward the high-yielding conifer type.

The third category of studies has combined elements of the other two categories, based on observations of actual long-term changes in forest types. These studies recognize that the role of disturbances in governing composition of forest management types is in the deflection of stand development from some successional pathway. The studies also recognize stochastic outcomes associated with ecological processes, such as uncertain stand establishment and progression in forests, with significant changes in cover types possible after disturbances. In a study of North Carolina forests, Wyant and others (1991) found that harvest and prescribed burning induce stand dynamics that are directionally nearly opposite those of developmental trends in undisturbed stands. Harvest disturbances were an increasing percentage of the disturbance regimes acting on Southeast U.S. forests. Intensive forest management activities will induce a shift in species composition to those better suited to highly disturbed conditions. Research drawing on socioeconomic factors has used conditional transition probability matrices to reflect the outcome of both land management practices and natural succession tendencies (e.g., Alig and Wyant 1985). Such models include a probability distribution for different possible destinations (future forest types) for each unit of area harvested in each forest cover type (e.g., Alig 1985). When associated models project forest type areas, key drivers are projections of economic and policy variables. Simulations of alternative policies reflect the increasing role of human-caused disturbances that alter forest successional pathways. Alig's (1985) model includes the total land base, where forestry is one of five major land uses. Areas of forest types result from a designated mixture of custodial care of forests, timber harvesting, and other miscellaneous forest management activities and forest succession.

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[2] Recent studies have considered possible effects of global climate change on forest succession (e.g., Franklin and others 1992) but have concentrated on changes in environmental variables and processes versus possible effects from human adaptation activities and policies.

Studies of landscape-level processes have increasingly relied on remotely sensed data to investigate spatial relations for forest cover changes. Wear and others (1996) examined how the landscape for a study site (about 100 000 hectares) in the southern Appalachians highlands could develop under several different scenarios designed to reflect historical land cover dynamics as well as hypothetical regulatory approaches to ecosystem management. Landscape change is driven by conditional transition probabilities, estimated as a function of independent variables by using multinomial logit models. An example of a spatially referenced relation is distance to roads or markets, which influences the probability of transition to another cover class. The relatively small size of the study site precluded analysis of variables such as timber prices, which in cross-section are essentially homogenous across small areas. Market-related variables such as price can vary in important ways over time, in contrast to physical variables (e.g., distance to market) that are typically constant over the time series. Turner and others (1996) studied land-cover transitions in the southern Appalachians and on the Olympic Peninsula. They found that land-cover transitions differ between historical time intervals, thereby suggesting that factors such as commodity prices or laws have an important influence over land management activities.

To our knowledge, no empirical study has examined large-scale changes in forest types associated with disturbance patterns on private land in the PNWW region. In particular, the link between human-caused disturbances with changes in forest types at a large scale is unknown. This is due, in part, to research gaps pertaining to models of harvest decisions and other causes of disturbance events. Landscape-level studies have increasingly investigated spatial relations involving physically based variables, but scale problems present difficulties in incorporating variables that vary over time, such as market-clearing prices and land rents. Further, no such study provides consistent, regionwide coverage. Such studies have not addressed the relative importance of driving factors for human-caused disturbances and their effects on forest cover changes. We will examine the effects of human-caused disturbances on changes in PNWW regional forest cover as a basis for projections over the next 50 years.

Methods

The PNWW study area, a region of 16 million hectares, is 80 percent forested and one of the world's most productive timber-producing regions. More than 90 percent of the private forest land is classified as timberland by forest survey standards (e.g., MacLean 1990); that is, it meets productivity standards of at least 1.6 cubic meters • hectare^{-1} • year^{-1} and is available for timber operations. We analyze forest type changes on timberland, excluding other forest land that is typically of low productivity.

Data

Periodic forest surveys by the Forest Inventory and Analysis (FIA) units (e.g., MacLean 1990) of the USDA Forest Service provide a time series of data for forest type areas on non-Federal timberland. Timberland areas for all private and other non-Federal ownerships for a particular state are estimated about every 10 years, with states sampled in sequence. Field methods used to collect data are discussed in a detailed field manual (USDA Forest Service 1985). The FIA data provide regional coverage of the timberland base and include estimates of different types of disturbances (e.g., harvest) by ownership, in contrast to databases constructed from remotely sensed data. Our analysis is based on direct observations of forest composition and change from about 1,500 stands located at environmentally diverse sites. We used data from the most comparable recent sets of FIA forest surveys—termed Time 1 and Time 2—for the western parts of Oregon and Washington (1970s and 1980s).

Forest stands are stratified by private ownership (forest industry and nonindustrial private forest [NIPF]), and forest cover type (Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco.), western hemlock [*Tsuga heterophylla* Raf. Sarg.], other conifers, red alder [*Alnus rubra* Bong.], and other hardwoods). Stands with 70 percent or more of the stocking in live conifer trees (e.g., *Pseudotsuga, Tsuga, Picea, Abies, Pinus*) are classified as pure conifer types; stands with 70 percent or more of the stocking in live hardwood trees (e.g., *Alnus, Acer, Populus, Quercus*) are classed as pure hardwood stands. Other stands represent a minority of the regional total and are classed as either conifer-hardwood or hardwood-conifer types, depending on relative stocking. We placed such stands into one of the five major forest types, depending on the plurality of stocking. In general, the specific forest type reflects the individual species of live conifer or hardwood tree with the greatest total stocking (USDA Forest Service 1985).

The years of Times 1 and 2, the forest survey period, were 1973-76 to 1984-86 for western Oregon and 1977-78 to 1988-89 for western Washington. For each sampled plot, species was recorded along with evidence of any disturbance since the last survey. Three disturbance classes were used: (a) none, (b) final harvest or clearcut, and (c) partial harvests and other miscellaneous disturbances (including any natural disturbances).

The latter two classes reflect aggregate measures of human-caused disturbances, which can differ notably in frequency by private ownership class. Ownership for each plot was determined from tax records in county courthouses. Lands designated as forest industry lands are owned by companies for the purpose of timber growing, including companies that either possess at least 2025 hectares or have more than 10 employees year-round.

Analysis Framework

Forest type transitions on land retained in timberland between Times 1 and 2 are represented by equation (1). Gains are represented by equation (1a), where the timberland remains in the same forest type or other timberland shifts to that type. Equation (1b) represents the opposite case for losses out of a particular forest type between field remeasurements.

$$FTG_{i,j,t\Delta} = \sum_{k=1}^{3} \sum_{j=1}^{5} FTA_{i,j,t} [P(D_{k_{i,j,t\Delta}})\ P(FT_{i,j^{\alpha},t+1} \mid D_{k_{i,j,t\Delta}}, FT_{i,j,t})] \quad \text{for each } i = 1, 2 \quad \text{(1a)}$$

(1)

$$FTL_{i,j,t\Delta} = \sum_{k=1}^{3} \sum_{j=1}^{5} FTA_{i,j,t} [P(D_{k_{i,j,t\Delta}})\ P(FT_{i,j^{\phi},t+1} \mid D_{k_{i,j,t\Delta}}, FT_{i,j,t})] \quad \text{for each } i = 1, 2 \quad \text{(1b)}$$

where:

FTG = area gains for forest type j on ownership i over survey interval;
t = time period (with t = 1 equal to Time 1, and t = 1, 2);.
FTA = initial area in forest type j on ownership i at time t;
P = probability of occurrence between surveys;
D = disturbance class (k = 1, 2, 3);
FT= classed as forest type j at time t; j^{α} refers to retention in same forest type; j^{ϕ} refers to transition to another forest type; i refers to private owner class (i = 1, 2); and
FTL = area losses for forest type j on ownership i over survey interval.

Equations (1a) and (1b) represent forest type transitions for an aggregate grouping of forest land (by strata representing region and ownership) and are conditional on major disturbance class *D.* Use of the three disturbance classes—no harvest, final or clearcut harvest (clearcut harvests have at least 75 percent of the trees removed in one operation, or are a harvest where residual trees now comprise less than 25 percent cover), and other harvest types—is based on observed frequency in FIA ground surveys of forest resources.

We hypothesize that different types of disturbances, partial and clearcut harvesting, can lead to distinct pathways of forest type transitions. Forest type transitions are the net outcome of successional forces and active management by man. This is depicted as the product of two probabilities—the probability of disturbance D_k and the type transition probability conditional on disturbance class. In a matrix of forest type probabilities, transition elements on the diagonal represent cases where the forest type j^{α} is in the same forest type at times t and $t + 1$, i.e., source and destination are the same. Disturbance and type transition probabilities are specific to ownership and forest type. The probabilities represent broad averages for aggregates of timberland areas that range in size from 1 to 5 million hectares; averaging was across age classes and productivity classes because of insufficient sample size.

Results

Likelihood of Disturbances

The major disturbance on private ownerships was harvesting of trees (tables 1 and 2). In the approximately 10 years between Times 1 and 2, timber harvests affected about 20 percent of the field plots on private timberland. Fire and significant natural disturbances were recorded on relatively few ground plots on private land. For example, fire affected less than 1 percent of private land in the Pacific Northwest during the last survey cycle. This is more than an order of magnitude less than the harvest frequency. Fire control efforts have been successful in limiting the average annual burned area to a small percentage of the total timberland base. Likewise, other natural causes of mortality affect relatively few PNWW private timber stands (MacLean and others 1992).

The likelihood of timber harvest differs by forest ownership and forest type. We discuss each one separately, although recognizing that in practice there are interactions.

Disturbances by Forest Ownership

The rate of harvest-related disturbances between Times 1 and 2 was higher for NIPF land (28 percent) compared to forest industry (22 percent). Although 10 percent more forest industry land was clearcut, the higher overall harvest rate on NIPF ownerships is due to partial harvests and other types of harvest (e.g., firewood removals). Partial harvests dominate on NIPF lands (21 percent of total timberland between Times 1 and 2), whereas clearcuts dominate on industry lands (18 percent). Although NIPF lands have more partial harvesting, thinning is most frequent on industry lands (9 percent vs. 1 percent), with many more precommercial thinnings by industry. Rates of harvest on both private ownerships are higher than on public ownerships, consistent with the findings of Alig and others (1986) and Wear and Flamm (1993) for the Southern United States.

Table 1—Forest type transitions on forest industry land between Times 1 and 2 from Forest Inventory and Analysis surveys in the Pacific Northwest west-side region

Forest type at time 1/ disturbance	Probability of disturbance	Probabiliy of destination by forest type at Time 2				
		Douglas-fir	W. hemlock	Other soft.	Red alder	Other hard.
Douglas-fir:		0.875[a]	0.055	0.012	0.039	0.019
No harvest	0.789	.881	.067	.011	.022	.019
Clearcuts	.157	.816	.012	.024	.123	.025
Others	.054	.959	.000	.000	.041	.000
W. hemlock:		.146	.799	.032	.023	.000
No harvest	.730	.097	.880	.016	.008	.000
Clearcuts	.228	.332	.500	.092	.075	.000
Others	.042	1.000	.000	.000	.000	.000
Other softwoods:		.129	.276	.539	.018	.038
No harvest	.808	.133	.318	.480	.022	.047
Clearcuts	.129	.063	.145	.792	.000	.000
Others	.063	.216	.000	.784	.000	.000
Red alder:		.301	.042	.025	.611	.021
No harvest	.778	.204	.055	.025	.690	.027
Clearcuts	.205	.693	.000	.027	.280	.000
Others	.017	.265	.000	.142	.460	.132
Other hardwoods:		.383	.000	.035	.057	.525
No harvest	.809	.371	.000	.000	.070	.558
Clearcuts	.104	.450	.000	.152	.000	.398
Others	.087	.410	.000	.220	.000	.370

[a] Top row for each forest type represents combined estimates across all disturbance classes.

Table 2—Forest type transitions on nonindustrial private forest lands between Times 1 and 2 from Forest Inventory and Analysis surveys in the Pacific Northwest west-side region

Forest type at time 1/ disturbance	Probability of disturbance	Probability of destination by forest type at Time 2				
		Douglas-fir	W. hemlock	Other soft.	Red alder	Other hard.
Douglas-fir:		0.791[a]	0.017	0.011	0.055	0.126
No harvest	0.686	.767	.025	.008	.059	.141
Clearcuts	.068	1.000	.000	.000	.000	.000
Others	.246	.800	.000	.022	.059	.119
W. hemlock:		.068	.825	.000	.000	.108
No harvest	.721	.000	.850	.000	.000	.150
Clearcuts	.199	.341	.662	.000	.000	.000
Others	.081	.000	1.000	.000	.000	.000
Other softwoods:		.150	.000	.631	.073	.146
No harvest	.735	.136	.000	.668	.076	.119
Clearcuts	.060	.000	.000	.714	.286	.000
Others	.205	.242	.000	.474	.000	.286
Red alder:		.127	.017	.039	.766	.050
No harvest	.698	.104	.017	.031	.788	.060
Clearcuts	.139	.272	.036	.049	.578	.064
Others	.163	.104	.000	.060	.836	.000
Other hardwoods:		.177	.000	.033	.047	.743
No harvest	.807	.185	.000	.032	.057	.725
Clearcuts	.047	.197	.000	.155	.000	.648
Others	.146	.124	.000	.000	.000	.876

[a] Top row for each forest type represents combined estimates across all disturbance classes.

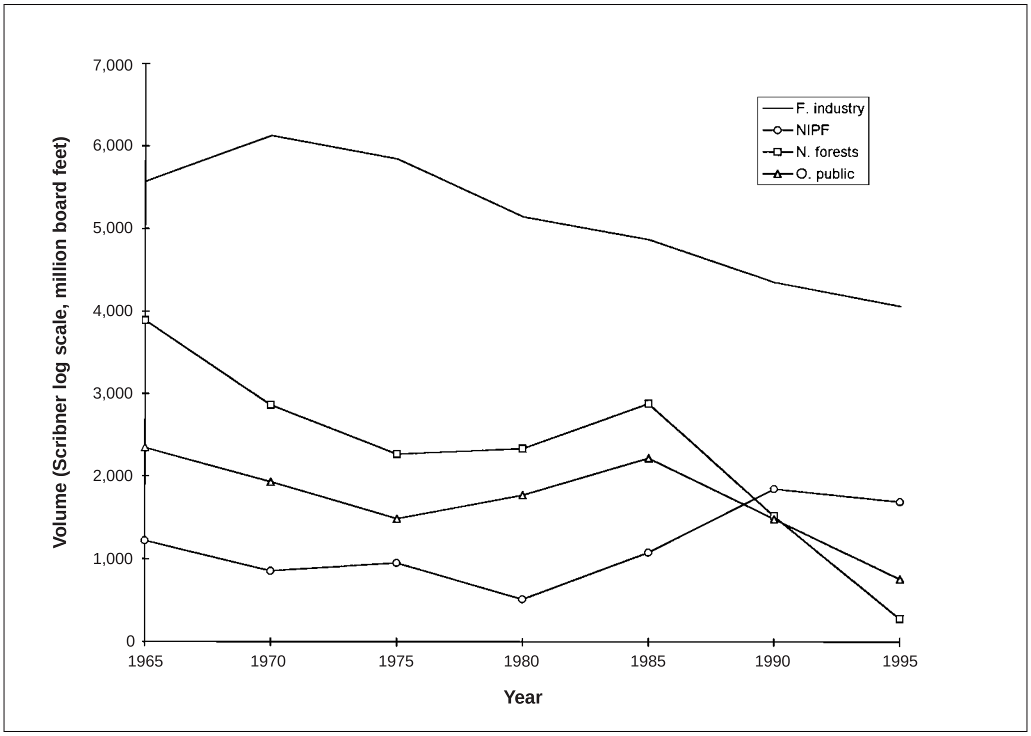

Figure 2—Timber harvests in the PNWW, 1965-95.

Although areas of clearcutting and partial cutting have been increasing, overall private harvest volumes have remained stable. Harvesting activities have disturbed more areas in order to remove about the same volume of timber.[3] The increase in area harvested includes more thinnings and clearcutting in younger stands with lower average volumes per area. Private PNWW timberlands have relatively young timber stands, compared to public lands, with 60 percent of stands less than 40 years old. Only 5 percent of private timberland stands are 90 years or older. With declining sales of timber from PNWW Federal lands since 1989, private harvests as a share of the total have increased, from 47 percent in 1988 to 85 percent in 1995 (Warren 1996) (fig. 2). Much of that timber is coming from private stands younger than 60 years old.[4]

Other harvest methods, such as incidental or firewood harvest, were relatively infrequent compared to clearcut and partial harvest methods. These harvests represented only 2 and 5 percent of harvested timberland for forest industry and NIPF, respectively, between Times 1 and 2.

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[3] Lettman, G.; Campbell, D. 1997. Timber harvesting practices on private forest land in western Oregon. 48 p. Unpublished report. On file with: Oregon Department of Forestry, 2600 State St., Salem, OR 97310.

[4] Harvest age estimates for the 1990s decade are based largely on personal communications with industry and nonindustrial private owners. Sample-based estimates will be available when the 1995-97 data from the most recent forest survey in Oregon are released.

Forest survey field crews also identify cases of other forestry treatments (nonharvest) between surveys, such as precommercial thinning or tree planting. For example, in western Oregon, forest industries treated their timberlands at a rate about double that for NIPF owners. The two most frequent forestry treatments were thinnings and tree planting. For example, in 1994, about 40 000 hectares were planted on private land in Oregon, about the same level as in 1980 and 1988 (USDA Forest Service, State and Private Forestry 1994). That area of annual planting represents about 1 percent of total private timberland area in Oregon, equivalent to about one-tenth of the private timberland base being planted each survey cycle. Forest industry has planted the greatest area. Most extant stands, however, have been naturally regenerated, most frequently as Douglas-fir.

Disturbances by Forest Cover Type

We examine disturbance rates for two forest cover types with interrelated area trends, Douglas-fir and red alder. In contrast to the management for commercially preferred Douglas-fir, red alder has typically not been favored by most owners at time of active forest regeneration. Although red alder will grow on a wide range of sites, it grows extremely well on highly productive Douglas-fir sites and, in its early years, can exceed conifer growth. Red alder is a prolific seeder and invades areas that have been disturbed by fire, logging, or other disturbances such as slumps or slides. The area of red alder in the PNWW region declined by 12 percent between 1977 and 1987, while Douglas-fir area increased by 19 percent (USDA Forest Service 1982, Waddell and others 1989). About 90 percent of the red alder is on private lands. The decrease in red alder area results from a mixture of disturbances. Active conversion of red alder stands to Douglas-fir stands, largely by forest industries, reduces red alder area. In contrast, passive timber management after harvest, primarily on NIPF lands, can increase the probability that conifer stands may revert to red alder.

The proportions of harvest-related disturbances on forest industry land were similar for Douglas-fir (21 percent) and red alder (22 percent). On NIPF lands, disturbance proportions were also similar for Douglas-fir and red alder but higher than the industry proportions (31 and 30 percent, respectively). The higher proportions for NIPF lands were due to partial harvesting, which affected 25 percent of Douglas-fir area and 16 percent of red alder area.

The NIPF owners partially harvested Douglas-fir stands at 5 times the rate of industry owners, and red alder stands at about 10 times the rate of their industrial counterparts. In contrast, the two owner groups clearcut red alder stands at more similar rates, in the range of 14 to 20 percent. Forest industry clearcut both Douglas-fir and red alder stands at a higher rate than NIPF owners (tables 1 and 2).

Forestry treatments were applied most frequently to the commercially preferred Douglas-fir type by both private ownership groups. The two most frequently applied nonharvest treatments for Douglas-fir stands were thinning and planting. In contrast, few red alder stands received forestry treatments.

Table 3—Softwood and hardwood volumes by forest type and ownership in the PNWW region[a]

	Forest industry		NIPF[b]	
Forest types	Soft.	Hard.	Soft.	Hard.
	Percent			
Douglas-fir	91.7	8.3	88.4	11.6
W. hemlock	94.8	5.2	88.7	11.3
Other soft	88.4	11.6	83.2	16.8
Red alder	37.4	62.6	34.4	65.6
Other hard	42.8	57.2	43.2	56.8

[a] PNWW = Pacific Northwest west side.
[b] NIPF = nonindustrial private forest.

Type Transitions

Forest types changed on many timberland areas, even during the relatively short forestry period represented by a survey cycle (tables 1 and 2). Given the diversity in types of stands classified as Douglas-fir stands, including some with substantial components of other species (table 3), 12 percent of Douglas-fir stands on industry lands and 23 percent of NIPF stands changed forest type in the absence of a disturbance. In the industry case, the proportion of transitions due to succession to western hemlock and other softwood types (8 percent) is higher than the percentage transitioning to hardwood types (4 percent). On NIPF lands, transition percentages to hardwoods (20 percent) are much higher than to conifer types (3 percent).

The frequency of type changes represented in tables 1 and 2 are consistent with earlier studies that indicate that more than 10 to 15 percent of conifer area may transition to mixed or hardwood types after harvest in western Oregon (e.g., Eng 1992). Similarly, close to one-half of hardwood area may regenerate back to conifer or mixed types. The net outcome in recent years has been that the area of Douglas-fir in the Pacific Northwest increased by more than 8 percent from 1987 to 1992 (Powell and others 1994, Waddell and others 1989). A recent survey indicates that active forest type conversion by NIPF owners took place on about 16 percent of ownerships (Johnson and others 1997). About two-thirds of those surveyed undertook brush control favoring conifers.

In the absence of disturbance, 88 percent of Douglas-fir stands on forest industry lands remained in the same type compared to 69 percent of red alder stands. The situation is different on NIPF lands, with similar retention percentages for undisturbed red alder stands (79 percent) and Douglas-fir stands (77 percent). Forest industry has a higher percentage of conifer stands and tends to promote more conifer stocking per hectare than NIPF owners.

Clearcutting Douglas-fir stands on industry lands resulted in a lower rate of regeneration back to Douglas-fir (82 percent) compared to partially cut stands (96 percent). The FIA survey estimates indicate that a substantial area (15 percent) of clearcut Douglas-fir stands were replaced by hardwood stands, primarily red alder. In more recent years, modified industry practices have led to higher rates of Douglas-fir retention, as evidenced by industry estimates that less than 5 percent of clearcut Douglas-fir stands are now replaced by other forest types in western Washington (e.g., Adams and others 1992).

The higher rate of Douglas-fir retention after partial harvesting compared to that after clearcutting on industry lands may indicate that competing species, especially hardwoods, are targeted in partial cuts. In contrast, partial cuts in NIPF Douglas-fir stands resulted in more transition to other forest types (20 percent), especially to hardwoods. Partial harvests on NIPF lands often are focused on timber value-extraction, and in many cases, the removed trees may be commercially preferred Douglas-fir, thereby shifting the species composition balance to hardwoods. Ninety percent of partially harvested Douglas-fir stands on NIPF lands that were replaced by other forest types shifted to hardwoods.

Clearcutting red alder stands on industry lands led to more type conversion (72 percent) than for NIPF lands (42 percent). Industry retention rates for alder under the undisturbed and partial harvest regimes are also lower than for NIPF stands. Although industry may actively manage some red alder stands, given the value of alder in furniture products and other uses (Raettig and others 1995), most harvested stands are converted to other types, particularly to Douglas-fir.

Partial harvesting red alder stands is an infrequent practice on industry lands (2 percent between surveys), but most affected stands transitioned to a different forest type. The more frequent partial harvests of red alder stands on NIPF lands resulted in 84-percent retention in red alder, with most of the remainder being replaced by Douglas-fir.

The higher retention rate of red alder in the NIPF case reflects more heterogenous stands in terms of species composition. Stands on NIPF lands have a greater diversity of species within the forest type grouping (table 3). For example, stands classified as part of the red alder type have a larger Douglas-fir component than counterparts on forest industry land.

Projected Futures

We projected forest type areas to examine outcomes under different assumptions about owner behavior, based on the historical vegetation dynamics described above that depend on ownership and forest cover type. Because transition probabilities reflect a mix of passive and active management, each of which can affect successional pathways differently, the projected outcome is not obvious a priori. We focus on the commercially preferred Douglas-fir and red alder that will grow on a wide range of sites.

We projected future areas in PNWW forest types on private timberland for the next 50 years. The projection of forest type areas involved summing gains and losses (FTG and FTL, respectively, in equation [1]) across all forest types on retained timberland, as shown in equation (2).

$$FTA_{i,\,j,\,t+1} = \sum_{j=1}^{5} (FTG_{i,\,j,\,t}\Delta + FTL_{i,\,j,\,t}\Delta) \quad \text{for each } i \wedge t. \qquad \textbf{(2)}$$

In equation (1) the *FTG* and *FTL* estimates were computed by using the *FTA* areas at time t, representing an initial vector of forest type areas, and these were multiplied by the transition probability matrices developed from tables 1 and 2. The resulting *FTA* at time $t + 1$, shown in equation (2), represents the net change resulting from the transitions into and out of a type along with hectares remaining in that type.

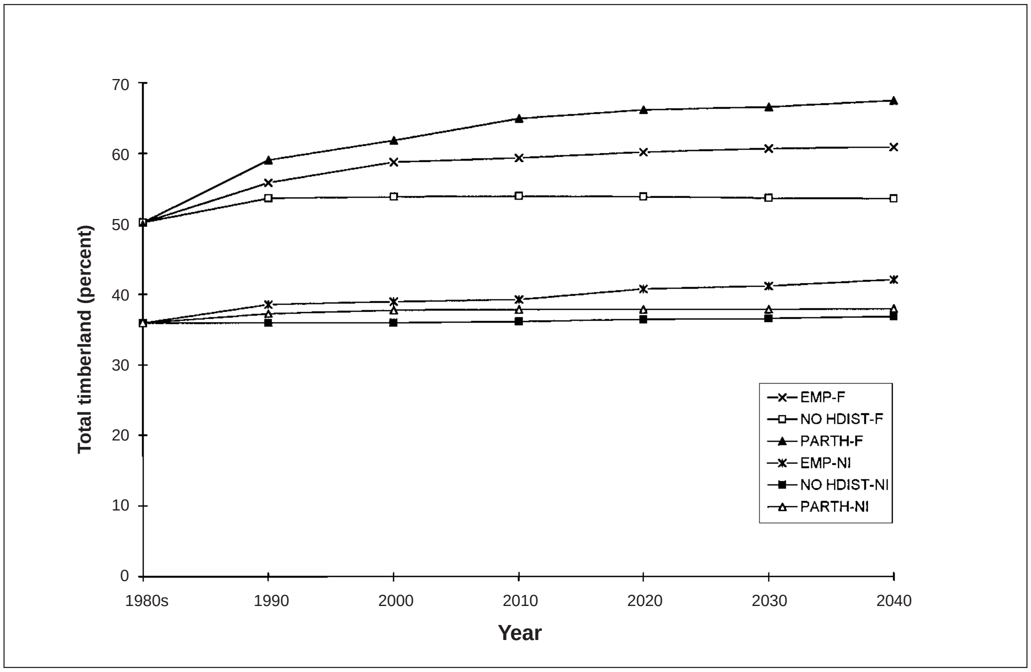

Figure 3—Projections of Douglas-fir area by private ownership in the PNWW region, under three scenarios.

For projections in our baseline case (which is the EMPIRICAL scenario described in the following paragraph), we assume that future rates of disturbance (*D* in equation [1]) will be the same as historical ones. Further, we use the Markovian assumption that the path over time to a current state is independent of future transitions among possible states of nature for a forest type aggregate. We made successive 10-year projections over the 50-year time horizon and held constant the total area of timberland by ownership over time.

We projected future areas in forest types under different assumptions regarding driving forces through three scenarios: (1) EMPIRICAL (EMP) or baseline—an assumed continuation of disturbance rates and type transition rates on private lands as observed over the last forest survey remeasurement cycle from tables 1 and 2; (2) NO HUMAN-CAUSED DISTURBANCE (NO HDIST)—scenario where only natural forces are at work; and (3) PARTIAL HARVEST (PARTH)—all harvesting on private lands is assumed to use partial harvest methods, as proposed under some recent policy alternatives. We used the total PARTH harvest rate as equal to the sum of partial and clearcutting rates in Times 1 and 2 and did not attempt to increase the harvest rate to compensate for total reliance on partially harvested hectares.

The baseline projections based on EMPIRICAL rates indicate that the area of Douglas-fir would increase on both ownerships (fig. 3). For forest industry lands, the area of Douglas-fir would increase from about 50 percent at Time 2 to about 60 percent by 2040. On NIPF lands, the percentage of area of Douglas-fir starts lower and would increase, but not as much as for the industry case.

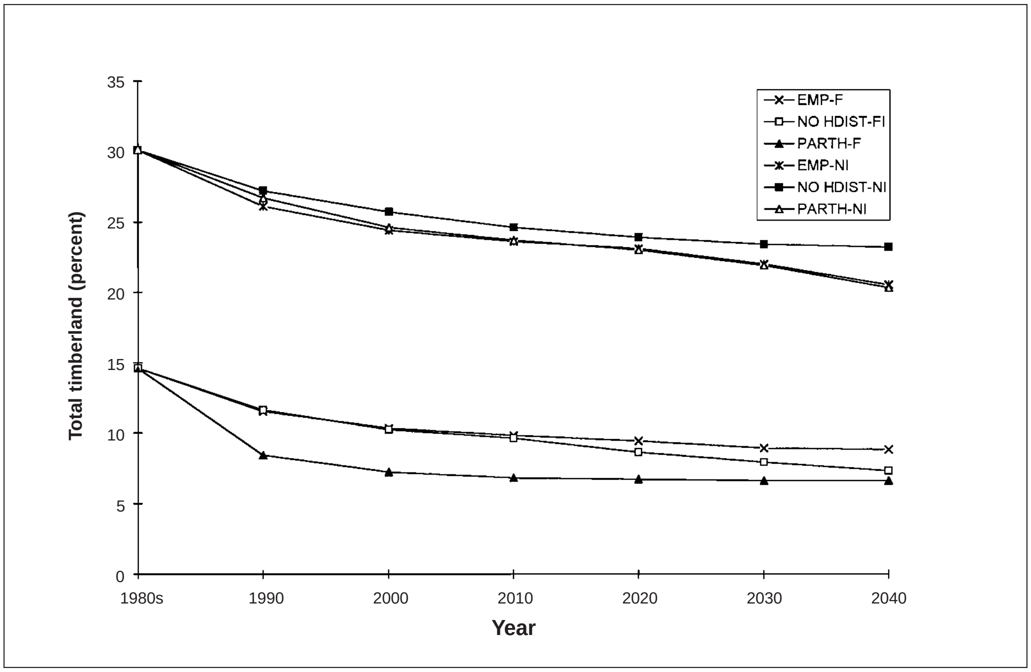

Figure 4—Projections of area of red alder by private ownership in the PNWW region, under three scenarios.

Projected changes in Douglas-fir are driven largely by assumed active management activities. This includes regeneration to Douglas-fir after harvest and conversion of the other four forest types. This is projected to be a more pronounced trend on industry lands. In contrast to the commercially preferred Douglas-fir, red alder is not typically favored at time of active regeneration.

Forest type projections under the EMPIRICAL scenario or baseline indicate that red alder area would continue to decrease for both private ownerships (fig. 4). This is the reverse of the Douglas-fir situation and is driven largely by conversion of red alder stands to the commercially preferred Douglas-fir. The larger extant area of red alder on NIPF lands means a larger relative projected decrease in area of that forest type on NIPF lands, from about 30 to 23 percent over the projection period.

Under the NO HUMAN-CAUSED DISTURBANCE scenario, the largest relative projected impacts relative to the baseline for red alder would be on NIPF lands and for Douglas-fir, on industry lands. Absence of harvests would lead to a slower increase in Douglas-fir area on both ownerships, compared to the baseline. One cause is natural succession to more shade-tolerant species, such as western hemlock. Area of red alder would increase relative to the baseline on NIPF lands because less would be converted to Douglas-fir, as planned conversions typically take place after harvests. Forest industry area of red alder would drop slowly over time relative to the baseline because of reductions in transitions of other harvested cover types to alder.

The projected impacts on area trends on industry lands are less pronounced under the NO HUMAN-CAUSED DISTURBANCE scenario than on NIPF lands. The projected increase in Douglas-fir area is tempered somewhat, as the shade-tolerant western hemlock type gains area compared to that projected under the EMPIRICAL scenario. Area of Douglas-fir would still increase, however, given the high conifer stocking of stands that would reduce transitions relative to stands on NIPF lands. Red alder area on industry lands would decline under both scenarios.

Under the PARTIAL HARVEST scenario, area of Douglas-fir would increase on both ownerships, similar to the EMPIRICAL scenario. Replacing clearcutting by all partial harvesting would result in less area of red alder area on industry lands compared to the baseline. Partial harvests on NIPF lands would result in a mix of projected area gains and losses for red alder. Ten percent of partially harvested red alder area would transition to Douglas-fir, but some harvested Douglas-fir areas also would revert to red alder stands.

Discussion

Human-caused disturbances are likely to be important influences on future areas of forest cover types on private land in the Pacific Northwest. Over the last FIA survey cycle, human-caused disturbances were more frequent, by at least an order of magnitude, than recorded natural disturbances. Further, increased proportions of total timber harvests coming from private lands are likely in the future because of reduced public harvest levels and higher stumpage prices.

Simulation of scenarios pertaining to types of future disturbances demonstrates the importance of harvest disturbances on future forest type areas. Increased demand for private timber and higher stumpage prices in recent years have contributed to relatively more private timber harvest (fig. 2). Shifting of harvests from public to private lands has been accompanied by substantial increases in conifer stumpage prices, which have doubled (in constant dollar terms) since 1980. This upward trend is expected to continue, as further increases in stumpage prices are projected (Haynes and others 1995). Further increases in harvest volumes on private lands may lead to proportionately more Douglas-fir area, if past trends continue.

The changes in forest type areas analyzed in this study have several implications for biological diversity in the PNWW region. First, the probability of harvesting on private lands was about 2 to 10 times more likely than full or partial stand-replacement disturbances from wildfire, the primary natural disturbance agent of the past (Agee 1993). Increased rates of disturbances will favor early successional plants and animals that have good dispersal capabilities and disfavor species such as some canopy lichens that have slow or weak dispersal capabilities (McCune and others 1997, Neitlich and McCune 1997). The rate and intensity of disturbances on private lands will also largely preclude the development of late-successional forest ecosystems and habitat for terrestrial and aquatic species that specialize in older forests or habitats created by large live and dead trees. On the other hand, rapid planting of clearcut sites to conifers could reduce the amount of time a site supports open, shrub-, and herb-dominated communities, affecting the availability of this habitat in a landscape (Adams and others 1992).

Second, if private land management continues to increase the amount of Douglas-fir in the landscape and decrease the amount of hemlock and alder, then shifts in composition of other plants and animals will probably occur. For example, some shrub and herbs associated with alder canopies (Pabst and Spies 1998) probably would decline over time. Locational aspects include a higher proportion of NIPF timberland in lower elevations (e.g., riparian zones) (Bettinger and Alig 1996), with many of the stands containing significant alder components. Third, increasing the percentage of Douglas-fir in the landscape and reducing the compositional diversity of the regional forest, may increase the risk of insect or disease outbreaks in the future. This phenomenon may be occurring already in coastal parts of the region. In the last few years, Swiss needle cast on Douglas-fir has affected some plantations, prompting some private industrial owners to convert precommercial stands to western hemlock.[5]

Conclusions

Land use and land cover dynamics can substantially affect the types of ecosystems available for resource production and environmental services. A key component of forest area changes involves shifts among forest management types, arising from a mixture of ecological and economic factors, as well as policy influences. Analyses of forest type transitions have evolved from ecologically oriented forest succession models to more recent ones that account for both natural and human-related forces on the landscape. Our study links human behavior and forest resource data, given that human decisions (e.g., harvesting) affect resources and ecological conditions. Empirical analysis for western Oregon and western Washington indicate that:

1. A substantial percentage of hectares shifted among forest types over a decade. The dynamics are accelerated by harvest events.

2. Dominant types of human-caused disturbances differed by private ownership, with clearcuts most frequent on industry lands and partial-other harvesting most frequent on NIPF lands.

3. Net outcomes of changes in forest type areas depend in part on the relative mix of natural and human-related forces at work. Projections of forest type areas under different assumed futures for land management and economic factors indicate that Douglas-fir area likely will increase. Failure to recognize the influence of human-caused disturbances, however, could lead to understated amounts of Douglas-fir relative to other types. Human-caused activities likely will encourage the continued expansion of area of Douglas-fir over the next several decades.

4. Forest type transitions in the Northwest differ notably by ownership, a situation similar to general patterns in the Southeastern United States. More intensive forest management will induce a shift in species to those better suited to highly disturbed conditions (e.g., Wyant and others 1991). The diversity of private owners results in a broad range of on-the-ground forest cover conditions across landscapes, reflecting the different sets of land management objectives pursued by the hundreds of thousands of owners.

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[5] Personal communication. 1999. Greg Filip, Professor, Oregon State University, Corvallis, OR 97331.

This study will be updated as new forest survey data are made available. In particular, the forest type transitions will be reexamined after the forest survey data collected by the regional FIA unit in 1995-97 in western Oregon are made available. That third remeasurement set of data also will allow temporal stationariness questions to be examined. Expanded data coverage also may allow improved analysis of "births" and "deaths," such as land use changes, that affect forest type areas. Type transition matrices also will be internalized in a forest resource projection model, following the approach of Alig (1992), to preclude the need for separate simulations of different modeling systems.

Spatial analysis of cover changes in western Oregon over the last several decades would supplement the empirical analysis of this broad-scale study. This could include locations of concentrations of forest cover changes and correlation of forest cover changes by distance-dependent factors such as proximity to streams, roads, and settlements. Increased availability of remotely sensed data may aid in overcoming sample size problems with extant forest survey data, such as augmenting age or size class data. Challenges still remain, however, in providing cost-effective and reliable remotely sensed data for large regions. Further, assessments of the accuracy of map-based attributes are sometimes lacking, including consideration of tradeoffs between cost and quality in a practical utility context.

Monitoring human-related activities (e.g., forest investment and timber harvesting) that affect forest ecosystems will require more direct information on owners and their behavior, as forest surveys to date have focused on forest resources. Future research also should include investigation of the socioeconomic causes of forest cover changes, including influences of timber markets and land management costs, and their effects on sustainability options. On a broader scale, human-caused factors have resulted in global change, and continued monitoring and analysis of forest survey data can aid in determining whether the relative importance of natural and human-caused forces may be changing over time with respect to forest type changes. Increases in population have led to continued deforestation for urban and developed uses, especially on NIPF lands (Alig and Adams 1995, Kline and Alig 1999, Zheng and Alig 1999). With populations of both Washington and Oregon projected to grow by more than a million people over the next 50 years, more people on the landscape will further affect forest type areas and will pose additional land management challenges.

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Appendix: Sampling Procedures

The Forest Inventory and Analysis Program (FIA) unit, formerly the Pacific Resource Inventory, Monitoring, and Evaluation Program, of the Pacific Northwest Research Station in Portland, Oregon, is responsible for inventories in Alaska, California, Hawaii, Oregon, and Washington. The FIA inventories are part of a nationwide project of the U.S. Department of Agriculture, Forest Service, authorized by the Forest and Rangeland Renewable Resources Act of 1978. Work units, located at Forest Service research and experiment stations, conduct forest resource inventories through-out the 50 States.

Periodic forest surveys by the program (e.g., MacLean 1990) provide a time series of area data for forest types on non-Federal land on a substate basis. Forest land area for all private and other non-Federal ownerships for a particular state are estimated about every 10 to 12 years, with the sampling of states staggered across the Pacific Northwest. The timing of survey cycles within a state can differ also over sequential remeasurement periods. Our analysis is based on direct observations of forest composition and change from about 1,500 stands located in environmentally diverse sites. We used data from the most comparable sets of the two recent forest surveys—termed Time 1 and Time 2—for the western parts of Oregon and Washington (1970s and 1980s).[1]

The FIA unit uses a two-phase sampling approach. For example, in western Oregon, the program interprets 24,000 photo points and then subsamples 1,465 field plots located on a fixed grid (MacLean 1990). Land classes include forest land, pasture land, crop land, and developed-urban uses. The urban-developed uses include town sites and areas of clustered suburbs, residential and industrial buildings, infrastructure (e.g., roads), pipelines, canals, powerlines, and railroads.

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[1] An interim survey or update in 1994 for western Oregon was conducted in cooperation with the Oregon Department of Forestry. Forest survey crews did not collect a full array of data; e.g., unclassified plots for clearcut plots, where forest type is not indicated.

Forest stands are stratified by private owner (forest industry and nonindustrial private forest), and forest cover type (Douglas-fir, western hemlock, other softwoods, red alder, and other hardwoods). Stands with 70 percent or more of the stocking in live conifer trees are classified as pure softwood types; stands with 70 percent or more of the stocking in live hardwood trees are classed as pure hardwood stands. Other stands represent a minority of the total and are classed as either softwood-hardwood or hardwood-softwood types, depending on relative stocking. The specific forest type reflects the individual species of live softwood or hardwood tree with the greatest total stocking (definitions as given by Adams and others [1992]).

The period between Times 1 and 2 or the forest survey period was 1973-76 to 1984-86 for western Oregon and 1977-78 to 1988-1989 for western Washington. For each sampled plot, species was recorded, along with evidence of any disturbance since the last survey.

Glossary

Forest industry lands—Lands are owned by companies for the purpose of timber growing, including companies that either possess 5,000 acres or more or have more than 10 employees year-round.

Forest land—Land at least 10 percent stocked by live trees, or land formerly having such tree cover and not currently developed for nonforest use. The minimum area recognized is 1 acre.

Forest types—Stands with 70 percent or more of the stocking in live conifer trees are classed as pure softwood types; stands with 50 to 69 percent of the stocking in live conifer trees are classed as softwood-hardwood types. Stands with 70 percent or more of the stocking in live hardwood trees are classed as pure hardwood types; stands with 50 to 69 percent of the stocking in live hardwood trees are classed as hardwood-softwood types. The specific forest type reflects the individual species of live softwood or hardwood tree with the greatest total stocking.

Hardwoods—Nonconiferous trees, usually broad leaved.

Industrial wood—All commercial roundwood products except fuel wood.

Land area—Area reported as land by the Bureau of the Census (MacLean 1990). Total land area includes dry land and land temporarily or partially covered by water such as marshes, swamps, and river flood plains; streams, sloughs, and canals less than 660 feet wide; and lakes, reservoirs, and ponds less than 40 acres in area.

Land class—A classification of land by major use. The minimum area for classification is 1 acre.

Nonforest land—Land that has never supported forests or formerly was forested and currently is developed for nonforest uses. Included are lands used for agricultural crops, Christmas tree farms, improved pasture, residential areas, city parks, constructed roads, operating railroads and their right-of-way clearings, powerline and pipeline clearings, streams more than 29 feet wide, and 1- to 40-acre areas of water classified by the Bureau of the Census, U.S. Department of Commerce, as land. If intermingled in forest areas, unimproved roads and other nonforest strips must be more than 119 feet wide, and clearings or other areas must be 1 acre or larger to qualify as nonforest land.

Nonindustrial private lands—Private lands not owned by forest industry. Native American lands, farmer-owned lands, and miscellaneous lands held by individuals or by companies holding forest lands for reasons other than timber production are included.

Nonstocked areas—Timberland less than 10 percent stocked with live trees.

Other forest land—Forest land incapable of growing 20 cubic feet per acre per year (mean annual increment at culmination) of industrial wood because of adverse conditions such as sterile soils, dry climate, poor drainage, subalpine sites, steepness, or rockiness.

Other land uses—Nonforest, marsh, roads, pipelines, canals, powerlines, and railroads, but also contains barren areas (e.g., rock) and streams 10 to 35 meters wide.

Reserved timberland—Land capable of growing 20 cubic feet or more per acre per year (mean annual increment at culmination) but withdrawn from timber utilization through statute, ordinance, or administrative order.

Site class—A classification of the potential productivity of forest land expressed as mean annual increment at culmination.

Site index—A measure of the productivity of forest land expressed as the average height of dominant and codominant trees at a specified age.

Softwoods—Coniferous trees, usually evergreen, with needles or scalelike leaves.

Timberland—Forest land capable of growing 20 cubic feet or more per acre per year (mean increment at culmination) of industrial wood and not withdrawn from timber utilization.

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