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Potential future dead wood dynamics in a multi-ownership region: The Coastal Province of Oregon, USA

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ABSTRACT

Dead wood is important to the processes, structural complexity, and biodiversity of forested ecosystems. Forest management may have unforeseen consequences to dead wood via the interaction of proposed activities with the legacy of past management, natural disturbance, and site productivity. We assessed the potential effects of future forest management for a 300-year period across a large (ca. 23,000 km^2) forested region that contains numerous ownerships and land management strategies. To do this, we used an ecological gap model (ZELIG), a dead wood decomposition dynamics model (CWDM), live and dead wood data from a physiographic province-wide plot database, and ownership- and land-allocation-specific management prescriptions. Dead wood amounts were projected to increase over the simulation period across the region, primarily because conservation-oriented management approaches utilized on federal lands increased the volume of large logs and snags and number of large snags on federal lands. Large snags and logs decreased on forest industry lands as legacy dead wood derived from historical natural disturbance events was not replaced through management. The results of this study provide an estimate of the maximum potential amounts of dead wood in the forests of the Coastal Province of Oregon, USA, under current policies and forest management, given model assumptions. In cases where current amounts of dead wood may be lower than those present historically, conservation-oriented policies designed to maintain or increase dead wood amounts, such as the Northwest Forest Plan, may have a strong positive influence on large dead wood abundance and related biodiversity in parts of a region that are also under intensive management.

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1. Introduction

In recognition of the contribution of dead wood (snags and logs) to ecosystem processes, forest structure, and biodiversity (Maser and Trappe, 1984; Harmon et al., 1986; Jonsson and Kruys, 2001), regional conservation planning and local forest management plans have increasingly incorporated dead wood considerations (U.S.D.A. Forest Service and U.S.D.I. Bureau of Land Management, 1994; Hagan, 1999; Laudenslayer et al., 2002). In practice, management effects on dead wood may be complex and highly variable over time and space, especially in multi-ownership landscapes. This complexity makes it difficult to evaluate potential cumulative or long-term effects, both within land ownerships and among them. It is important to understand dead wood patterns at landscape levels or across multiple ownerships because many species and ecological processes cross ownership boundaries.

The potential effects of forest policies on future dead wood amounts are mediated by the current status of living forest stands, their potential developmental trajectories, and the amount and condition of dead wood there. Current dead wood amounts have been shown to vary widely across ecoregions (Ohmann and Waddell, 2002) and ownerships (Kennedy et al., 2008), and future patterns may differ greatly from those of the present (Ranius et al., 2003), via the interaction of future management with the legacy of past management, natural disturbance, and site productivity. Because of this complexity, simulation modeling is one of the only ways we can investigate potential management effects on dead wood dynamics (Tinker and Knight, 2001).

Past research simulating dead wood dynamics has mainly focused on individual stand dynamics and/or relatively straightforward management scenarios. For example, in a study in which log dynamics were modeled in a simulated stand of even-aged Norway spruce (*Picea abies* (L.) Karst.) in Sweden (Ranius et al.,

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2003), the more biodiversity-oriented management approaches such as long rotations and the retention of live trees at harvest produced a higher volume of logs more continuously over the simulation period (one forest rotation). In another study simulating the effects of clearcutting, moderate intensity fire, and spruce-beetle outbreak on dead wood delivery to a stream in Wyoming, USA, clearcutting at year 50 to an individual stand reduced the volume of logs in streams for about 200 years relative to control (old-growth) conditions (Bragg, 1997, 2000). We aimed to expand the temporal and spatial scope of dead wood simulation modeling to examine questions of both short- and long-term, multi-ownership management effects on dead wood dynamics in large region of highly productive forests.

To do this, we used two simulation models – a dead wood decomposition dynamics model and a forest gap model – and data from a regional forest inventory to assess potential management effects on future dead wood dynamics across a large (ca. 23,000 km^2), forested, multi-ownership landscape in coastal Oregon. Ownership has been shown to be a key factor determining forest patterns including dead wood (Kennedy and Spies, 2004; Wimberly and Ohmann, 2004; Johnson et al., 2007; Spies et al., 2007). We have yet to know, however, how various components of dead wood might change in the future under current policies and how policy alternatives might affect long-term potential amounts of dead wood. Our objectives were to: (1) characterize potential future changes in dead wood amounts and characteristics; (2) determine the relative contributions of present-day dead wood vs. dead wood amendments from potential management and stand development; and (3) assess potential effects of various management practices on transitional dynamics and long-term patterns of dead wood. To assess spatial patterns, we compiled and used plot data from across the region as model input, then evaluated model output for regional dynamics and differences in dead wood among ownerships over the simulation period.

2. Study area

The Coastal Province of Oregon, USA, the study area, is an area of productive coniferous forests of about 23,000 km^2 characterized by a mild, maritime climate with mild wet winters and cool dry summers (average annual precipitation 150–300 cm, by elevation; average January temperature 2.4 8C, average July temperature 16.6 8C), steep, mountainous terrain, and a dense network of perennial and intermittent streams. The coastal margin, which occurs in the Sitka spruce (*Picea sitchensis*) vegetation zone (Franklin and Dyrness, 1988), is cooler and wetter than the interior, which falls within the western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) vegetation zone (Franklin and Dyrness, 1988). Forests are dominated by Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) (PSME), western hemlock (TSHE), and western redcedar (*Thuja plicata* Donn) (THPL), with Sitka spruce (PISI) along the coast. Hardwood trees such as red alder (*Alnusrubra* Bong.) (ALRU) and bigleaf maple (*Acer macrophyllum* Pursh) (ACMA) also occur, with red alder frequently dominating near-stream areas (Hibbs et al., 1994; Kennedy and Spies, 2005). In some locations, quantities of dead wood that are legacies of past old-growth forests and disturbance (legacy wood) are larger than quantities produced by present-day stands (Kennedy et al., 2008). However, current total amounts of dead wood in the Coastal Province may be toward the lower end of the region's historical range of variability (Nonaka et al., 2007).

Land ownership of the area includes federal (USDA Forest Service (FS) and USDI Bureau of Land Management (BLM)), State of Oregon, forest industry (FI), and non-industrial private (NIP)) (Fig. 1). Forested lands are managed mainly for timber production (private and state) or for old-growth-related biodiversity and aquatic habitat (federal). In recent decades, most land ownership changes have occurred within, not among, these ownership types (Azuma et al., 2002). Hence, for our simulations, we assumed spatial coherence of future management with current ownership patterns. Urban areas near the coast and within the Willamette Valley just east of the Coastal Province are projected to expand locally into forestlands through the next century but these changes are not expected to be regionally large, so we did not include land use change in our modeling effort (Kline et al., 2003).

Historically, the major disturbances in this region were windthrow, other gap-forming disturbances such as laminated root disease (*Phellinusweirii*), and, infrequently, large stand-replacement fires with mean return interval of 200–300 years (Agee, 1993; Impara, 1997; Weisberg and Swanson, 2003). Prior to fire suppression's advent in the early- to mid-1900s, fires occurred most recently on what are today State of Oregon and US Forest Service landholdings, temporarily increasing dead wood amounts there (Levesque, 1985; Fick and Martin, 1992; Kennedy and Spies, 2007). However, fire suppression has been highly effective in this maritime, extensively roaded region, and no large fires have occurred since that time. For this study, therefore, we assumed continued effective fire suppression in the future, with the primary disturbances being windthrow and other gap-forming disturbances. These and other ecosystem processes and components were incorporated into the parameters and dynamics of the gap model (Pabst et al., 2008).

3. Methods

We simulated snag and log production and decomposition for 300-years given present-day amounts and distributions of live and dead trees and landowner-specific forest management practices. For each management scenario, we generated data on the amount of snags and logs produced over time. We used a gap model (ZELIG) (Urban and Shugart, 1992; Hansen et al., 1995; Garman et al., 2003; Pabst et al., 2008) to simulate forest growth and development and a dead wood dynamics model to simulate dead wood decomposition over time (Coarse Wood Dynamics Model; CWDM)(Mellen and Ager, 2002) (see below (Sections 3.2 and 3.3) and Appendices).

3.1. Source data

We used current regional dead and live vegetation data to initialize the model simulations. Current vegetation data were derived from surveys of a systematic grid of field plots established for regional forest inventories: Current Vegetation Survey (CVS) (Siuslaw National Forest, measured 1993–1996), Forest Inventory and Analysis (FIA) (non-federal lands, measured 1997), Natural Resources Inventory (NRI) (Bureau of Land Management, measured 1997) (total $n = 930$) (Fig. 1). The distribution of plots by category of ownership was as follows: Forest Service, $n = 309$; Bureau of Land Management, $n = 118$; State of Oregon, $n = 84$; forest industry, $n = 274$; non-industrial private, $n = 145$. All plots were located on a systematic 5.5 km grid excepting CVS plots (2.75 km spacing), about 1 ha in size, and forested. We combined data from the three sources into a consistent format and summarized individual records to a unit per hectare basis for the uniform land cover condition classes in each plot. The minimum size of snags in the input data was 12.5 cm diameter at breast height (dbh); the minimum size of logs was 12.5 cm large-end diameter (led) because those were the minimum sizes that were uniform across source datasets. Output from the forest stand development model was used as input to the dead wood dynamics model to assess relationships of future management and stand development with future dead wood production.

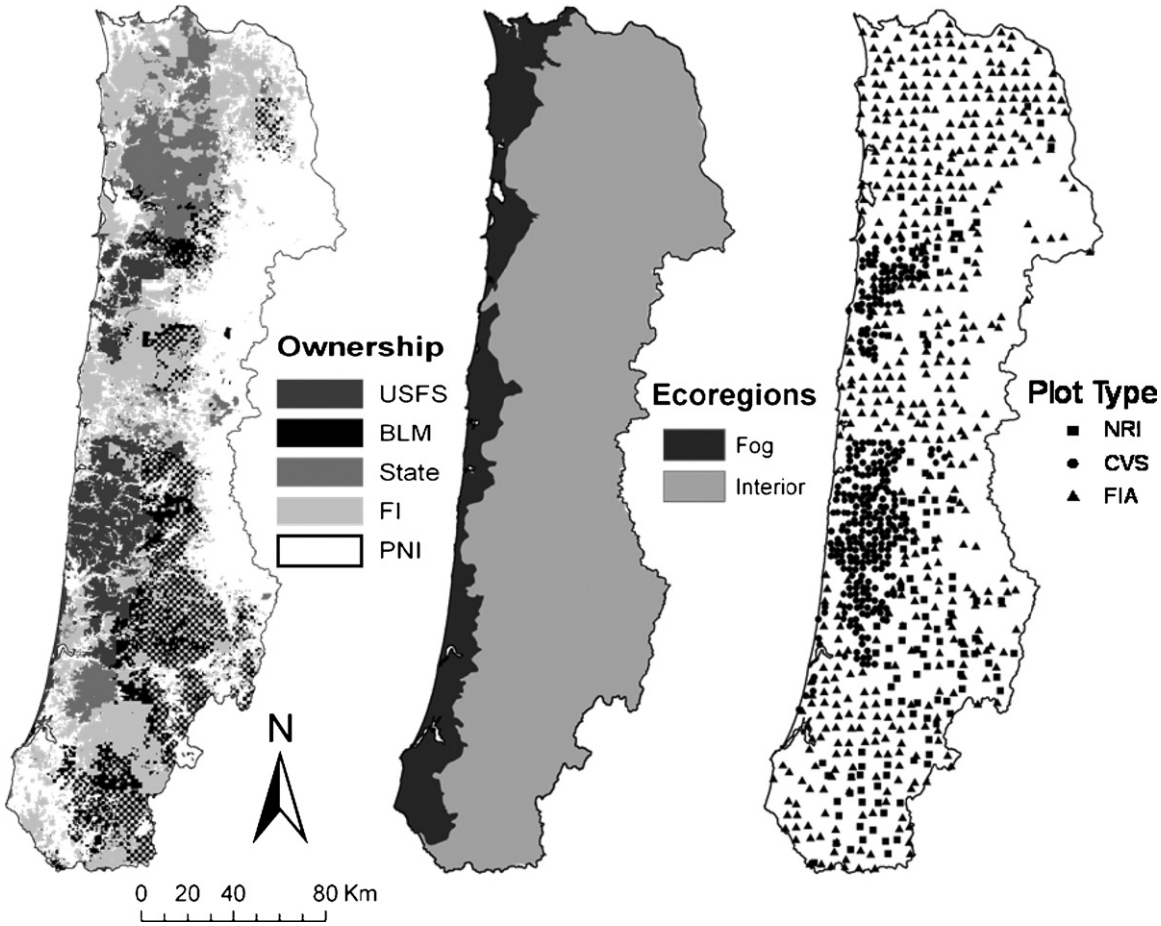

Fig. 1. Characteristics of the Coastal Province in Oregon, USA. (a) Distribution of main ownership groups (FS = USDA Forest Service, BLM = USDI Bureau of Land Management, State = State of Oregon, FI = forest industry. NIP = non-industrial private); (b) generalized ecoregion types used in forest growth modeling; and (c) location of current vegetation reference plots whose live tree and dead wood characteristics were used in simulation modeling of dead wood dynamics (NRI is Natural Resourcs Inventory; CVS is Current Vegetation Survey; FIA is Forest Inventory and Analysis).

For ownership and ecoregion data, plot locations (1 ha in area) were superimposed on 30-m-resolution GIS grids of each variable and maximum values for ownership and ecoregions obtained. Land ownership data originated from a GIS coverage that included fire protection district maps and county assessor plats and was considered current for 1990–1996. Ecoregions originated from a digitized map of Pacific Northwest Ecoregions (Woods et al., unpublished data).

3.2. Simulating snag and log dynamics

We updated the Coarse Wood Dynamics Model (CWDM) (Mellen and Ager, 2002) to simulate changes in amounts and characteristics of snags and logs over time in the Coastal Province study area (For CWDM updates and parameter settings, see Appendix A). CWDM simulates the dynamics of individual pieces of dead wood using species- and size-specific decay rates. The model predicts fall, height loss and decay of snags, and decay and decomposition of logs based on reported literature values and has been validated using field data (Mellen and Ager, 2002). The model is parameterized for two species types: slow-decaying (Douglas-fir type) and fast-decaying (western hemlock type). We ran the model using a 5-year timestep for a 300-year period because this was the maximum time allowed by the model. We tabulated output for initial and newly produced dead wood for various size classes for log volume (m^3 ha ^{1}), snag volume (m^3 ha ^{1}) and number of snags (minimum height 5 m). The model has a minimum size requirement for snags of 10 cm diameter at breast height (dbh) and height of 1.4 m. Model decomposition parameters were set based on average values from the literature, and the model was developed for use across broad areas such as landscapes (Mellen and Ager, 200 2).

3.3. Simulating stand development and mortality

To simulate stand growth and yield, we used a version of the gap model ZELIG that was developed and parameterized to study the growth of stands and the production of dead wood in the Coastal Province of Oregon. ZELIG was calibrated using local long-term plot data, stand chronosequences, and an empirical growth-and-yield model (Pabst et al., 2008). (For ZELIG parameter values and simulation output from individual stands, see Appendix B). Our version of ZELIG modeled individual tree regeneration, growth, and mortality. Tree regeneration and growth were modeled by estimating maximum potential behavior and then constraining this potential by limiting light, soil moisture, soil fertility, and ambient temperature. Two model variants (fog and interior; Fig. 1) were used to differentiate among generalized ecoregions occurring in the study area. ZELIG mortality modeling included both density-dependent (suppression) and -independent (ambient) mortality. We also simulated the effects of management including the retention of live trees and snags and the creation of logs at harvest. Densities and species compositions of post-harvest plantations were specific to each management scenario. The model was run on

a 1-year timestep, for a period of 300 years, five times. The output of the five runs was averaged for each 5-year increment of the 300-year period. We summarized mortality output by species, size class, height or length class, and an expansion factor for pieces per unit area. Log and snag lengths were averaged by 3 m increments and diameters by 5 cm increments.

3.4. Management scenarios

We evaluated management effects in two ways. First, we simulated changes based on current dead wood conditions, which varied among ownerships. Second, we controlled for initial conditions by assuming the same starting conditions for all ownerships. We developed and applied land-use-allocation-specific scenarios for each ownership type after consultation with representatives of each landowner group (see Appendix C for details). All plots ($n = 930$) were simulated based on their ownership and land allocation in the landscape. Second, to control for potential effects of different initial conditions among ownerships, we created uniform starting conditions by randomly selecting a subset ($n = 100$) of the 930 plots and then simulating only these plots. Management prescriptions specific to each land allocation type and owner were applied at random to the 100 plots, in proportion to their full sample population of plots. We applied each ownership's management regime to the same set of 100 plots and projected this over a 300-year period. The landowner-specific scenarios were constructed as follows:

The FS scenario had two land allocation types: (1) reserves (97% of FS plots): no action on forests > 80 years old, with mixed species composition, or with low conifer densities, thin other reserves; (2) matrix (non-reserves) (3%): harvest on a 70-year rotation with moderate amounts of green-tree retention. Prescriptions for both of the FS allocation types created at least twice as much dead wood relative to non-federal ownerships.

The BLM scenario had three land allocation types: (1) Matrix General Forest Management Areas (GFMs) (34% of BLM plots): harvest on an 80-year rotation with two thinnings, a high amount of snag and log creation, and a medium-high amount of green-tree retention at harvest; (2) Matrix Connectivity Diversity Blocks (CDBs) (8%): harvest on a 150-year rotation, heavier thins during later thinnings, GFM-type snag and log creation amounts, and higher green-tree retention; and (3) LSR Riparian (63%), with 4 regimes: no action (42%) and three levels of thinning (20%). BLM thinnings involved high amounts of snag and log creation relative to non-federal ownerships.

We modeled State of Oregon forests using four main management approaches: two for upland sites (75% of State plots), one for riparian areas (13%), and one for withdrawn areas (12%). The two upland regimes were approximately equally applied to the upland plots. Both required harvest on a 110-year rotation, with three thinnings prior to harvest. The first upland regime had a slightly higher amount of green-tree retention than the second, and the first required snag creation at the last thinning and log creation at both the last thinning and at harvest, whereas the second required snag and log creation only at harvest. Both had fairly high amounts of snag and log creation in relation to the private ownerships, and high levels of green-tree retention at harvest.

We simulated FI lands as managed primarily for timber production on a 40-year rotation with no thinning (99% of forest industry plots). All snag and log creation for industrial and non-industrial private owners followed the rules established by the Oregon Forest Practices Act (Oregon Department of Forestry., 2001), with a low amount (volume) of logs created and snags produced via post-harvest green-tree mortality. Riparian plots (1%) were thinned without manual log or snag creation. Due to model constraints, no snags were felled during harvest on this or any other ownership, so the number of snags is probably not underestimated on forest industry lands.

Most NIP lands (90%) were simulated as uplands managed on a 60-year rotation with one thinning at age 45. Snag and log creation and green-tree retention were identical to that of the forest industry upland regime. Riparian plots (10%) were managed under a no-action approach.

3.5. Data analysis

For each 5-year increment of the 300-year simulation period, we summarized the number and volume of snags and volume of logs of various sizes for each plot. We differentiated between dead wood present at model initiation ("initial") and that produced during the simulation period ("new"). We calculated weighted mean values for area-based measures of dead wood because plot sampling densities were not uniform across ownerships. We calculated mean and median values by plot, dead wood type, and location. We performed two-sided Wilcoxon rank-sum tests on the medians to test for differences among ownerships because dead wood data are often skewed and tests of difference between means may not meet normality assumptions (Ohmann and Waddell, 2002). Reporting dead wood amounts as means is common practice (Spies et al., 1988; Green and Peterken, 1997; Ohmann and Waddell, 2002; Rouvinen et al., 2002), so we reported means to facilitate cross-study comparisons, and results for median-related tests of difference.

4. Results

4.1. Province-wide trends

The average volume of logs and snags increased, by about three and nine times, respectively, over the 300-year simulation period across the Coastal Province. All sizes of dead wood showed marked increases early in the simulation period (e.g. 50–100 years). Province-wide, the mean volume per hectare of large snags and logs increased greatly (Table 1).

Most dead wood volume was comprised by large snags and logs (> 50 cm dbh or led) (Fig. 2). 'New' logs, or non-legacy logs, comprised the majority of the volume of dead wood over the simulation period (Fig. 3). The residence time of large pieces of dead wood was long and reflected decomposition processes in mesic coastal forests (maximum of about 225 years for large logs and 175 years for large snags from simulation year 0). This combined with management and stand development led to increases in the mean volume of large snags and logs across the Province. The proportion of dead wood that was present as snags increased over time on all ownerships, as new snag volume inputs exceeded the loss of initial snags over the first century of the simulation period (Fig. 3). The largest sizes of snags were lowest at model initiation and were most rarely created via management or stand development. Small snags were most commonly produced and had great fine-grained temporal variation, as forest stands went through cycles of development and harvest (Fig. 2).

4.2. Ownership-related patterns

Land management had a great impact on dead wood dynamics and amounts (Table 1; Figs. 3 and 4). Federal ownerships (FS and BLM) showed steady increases in both log and snag volumes and consistently had among the highest amounts of both total dead wood and large piece sizes (Fig. 4). On FS lands, where management consisted mainly of thinning or no action (natural development), the volume of medium-sized (30–50 cm dbh) snags declined as stands matured and larger trees died. State of Oregon

Table 1
Projected future mean snag and log volume ($m^3 ha^{-1}$) and snag number(ha^{-1}), and differences among median amounts by ownership, over a 300-year simulated management period in the Coastal Province in Oregon, USA. Differences among medians ($p < 0.05$, from paired Wilcoxon Rank-Sum Tests) are indicated by different letters after means. Numbers in left column indicate simulation years. FS = USDA Forest Service. BLM = USDI Bureau of Land Management. State = State of Oregon. FI = forest industry. NIP = non-industrial private. For more description of ownership classes, see text. For management prescriptions, see Appendix C.

	FS			BLM			State			FI			NIP			Coastal Province	
	Mean		s.e.	Mean		s.e.	Mean		s.e.	Mean		s.e.	Mean		s.e.	Mean	s.e.
	Volume of all snags																
0	68.4	a	4.2	39.5	b	7.1	29.1	b	4.4	14.3	c	1.8	13.1	c	3.2	26.74	1.75
50	183.8	a	6.5	144.7	b	9.5	125.9	b	7.2	48.5	c	2.5	86.0	d	6.5	97.81	2.94
100	277.5	a	7.9	227.6	b	11.2	167.4	c	8.6	48.0	d	1.9	85.3	e	5.6	129.07	3.93
150	374.0	a	8.3	312.6	b	12.9	186.6	c	11.0	47.0	d	1.8	81.7	e	6.4	157.87	5.16
200	468.8	a	8.2	387.4	b	15.4	219.4	c	13.9	49.1	d	2.1	92.5	e	8.5	189.76	6.39
250	554.6	a	8.7	445.5	b	18.0	233.2	c	16.9	52.7	d	2.7	96.1	e	10.6	214.49	7.56
300	612.4	a	8.9	504.0	b	19.6	256.7	c	19.2	55.3	d	2.7	98.8	e	11.7	236.67	8.43
	Volume of snags > 50 cm dbh																
0	56.0	a	3.7	33.3	b	7.0	19.0	b	4.0	8.9	c	1.6	7.4	c	2.8	19.69	1.62
50	143.9	a	6.5	103.3	b	9.3	76.1	b	6.7	17.1	c	1.9	41.1	d	5.8	58.98	2.74
100	244.7	a	8.0	184.2	b	11.4	132.8	c	8.6	15.2	d	1.7	39.4	e	5.7	91.75	3.92
150	349.7	a	8.2	279.0	b	13.2	144.2	c	11.7	14.5	d	1.5	34.4	d	6.8	122.30	5.27
200	454.6	a	8.2	361.7	b	15.9	191.0	c	14.6	17.0	d	1.6	38.6	e	9.1	157.52	6.66
250	547.0	a	8.7	425.6	b	18.8	194.7	c	18.5	21.0	d	2.1	43.3	e	11.2	183.27	7.93
300	607.6	a	8.9	488.6	b	20.6	228.7	c	20.4	23.6	d	2.1	46.5	e	12.4	207.98	8.86
	Number of snags > 50 cm dbh																
0	7.7	a	0.6	3.7	b	0.6	2.4	c	0.5	1.0	d	0.2	0.8	d	0.3	2.39	0.18
50	12.1	a	0.5	9.1	b	0.5	9.0	b	0.6	1.7	c	0.2	4.2	d	0.4	5.62	0.21
100	16.6	a	0.4	14.3	a	0.6	11.2	b	0.6	1.2	c	0.1	3.0	d	0.4	6.98	0.26
150	20.4	a	0.4	18.0	b	0.8	11.4	c	0.8	1.0	d	0.1	2.9	e	0.5	8.07	0.32
200	22.7	a	0.5	20.4	b	0.9	15.4	c	0.8	1.1	d	0.1	2.8	e	0.5	9.26	0.37
250	22.3	a	0.4	20.2	b	1.1	12.5	c	0.9	1.0	d	0.1	2.6	e	0.5	8.76	0.37
300	20.2	a	0.4	19.3	b	1.1	15.8	b	0.8	1.0	c	0.1	2.4	d	0.4	8.68	0.35
	Volume of all logs																
0	206.8	a	10.2	204.7	ac	21.7	253.5	b	20.3	169.4	c	8.7	76.1	d	7.9	172.57	5.73
50	404.3	a	10.8	373.4	a	19.7	396.3	a	21.6	203.7	b	7.6	208.1	b	13.0	281.08	6.20
100	560.0	ab	12.8	520.6	a	18.3	566.7	ab	16.3	204.4	c	5.8	250.0	d	10.9	356.06	7.24
150	705.8	a	13.9	673.9	a	18.2	582.4	b	15.3	202.8	c	4.6	258.3	d	10.6	405.20	8.66
200	853.8	a	14.9	794.2	ab	20.0	731.3	b	17.5	204.5	c	4.3	296.5	d	13.1	471.54	10.64
250	975.4	a	15.7	872.7	b	24.4	726.8	c	17.4	197.1	d	4.2	313.2	e	14.9	500.24	12.03
300	1074.9	a	16.6	976.5	b	26.0	837.8	c	20.8	202.3	d	4.7	327.1	e	17.0	549.56	13.64
	Volume of logs > 50 cm led ($m^3 ha^{-1}$)																
0	144.0	a	9.2	150.1	a	20.1	198.4	b	18.7	113.3	a	7.7	44.6	c	6.5	120.26	5.13
50	246.2	a	10.4	234.7	a	18.4	236.1	a	17.5	92.8	b	5.7	89.9	b	10.6	151.68	5.23
100	385.1	ab	12.7	344.7	a	18.5	395.3	b	15.1	65.8	c	4.2	89.6	d	10.0	197.76	6.70
150	542.0	a	13.2	491.4	a	18.3	395.5	b	14.3	45.1	c	3.4	74.5	c	11.2	233.43	8.41
200	709.6	a	13.4	612.1	b	19.4	539.2	c	15.8	39.2	cd	3.7	81.2	d	15.0	292.80	10.66
250	864.1	a	13.9	708.6	b	23.9	529.3	c	18.0	38.1	c	3.9	83.7	d	17.5	327.90	12.41
300	976.3	a	14.8	820.1	b	25.7	628.1	c	20.7	44.1	c	4.6	91.8	d	20.0	377.91	14.14

lands commenced the simulation period with the highest volume among ownerships of all logs and large logs but quantities fluctuated more because of that ownership's tendency toward a long-rotation harvest (110 years), their non-reserve approach to management, and because many of their forests were of similar age so were harvested at similar times. By the end of the simulation they were ranked third after the federal owners for these variables. The largest numbers of large snags occurred on FS, BLM, and State lands, in that order. The State lands started with the highest total number of snags among ownerships but numbers fluctuated widely and by the end of the simulation period the State had intermediate numbers of snags.

Private lands (FI and NIP) had the lowest dead wood amounts through the course of the simulation period. Given that, the two private ownerships showed differing trajectories through the simulation period. FI commenced the simulation period with dead wood amounts similar to FS and BLM amounts but by 50 years they were much less than on federal lands and continued to diverge over the simulation period. NIP lands, on the other hand, started out with the lowest amounts of dead wood and then increased fairly rapidly to levels that were significantly larger than FI lands by 50–100 years (Figs. 3 and 4; Table 1). Total log volume decreased on FI lands as legacy logs initially present decayed away, and number and volume of large snags and logs (> 50 cm) there remained very low. FI lands contained moderate amounts of medium-sized logs consistently through the simulation period. NIP lands had fairly high amounts of medium-sized logs and snags. FI and NIP lands also had higher numbers of small snags than other ownerships.

4.3. Effects of controlling for initial conditions

The potential effects of management were highlighted when variation in initial conditions was removed. The policies of the State of Oregon resulted in the production of more large logs up to about 75 years in the simulation period (Fig. 5). In addition, the cyclic pulses of dead wood produced by the State in the first simulation strategy were dampened, as the age of live trees in the random sample of plots was of a wider range than the plots currently under State ownership. This meant that for the State, harvests were more spread out over time in the random sample than in the first scenario. The trends in dead wood resulting from FS and BLM practices were nearly identical (Fig. 5), indicating that effects of initial conditions can persist for long time periods. Large

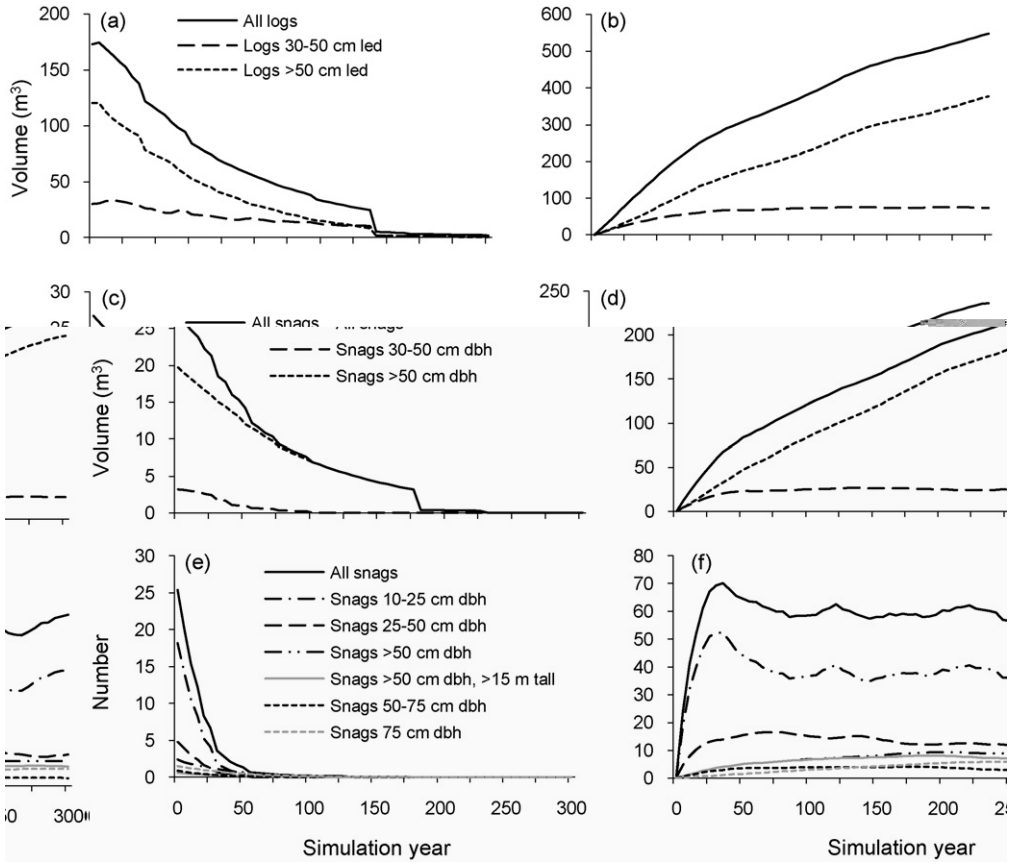

Fig. 2. Projected future patterns of dead wood in the Coastal Province of Oregon per hectare by dead wood type, given that forest management is applied according to current land ownership patterns: (a) initial log volume; (b) new log volume; (c) initial snag volume; (d) new snag volume; (e) number of initial snags; and (f) number of new snags. Legend for figures (a) and (b) is in (a); legend for figures (c) and (d) is in (c); legend for figures (e) and (f) is in (e).

increases in medium-sized snags on BLM lands observed in the first simulation strategy were not observed in the scenario wherein initial conditions were controlled. More large snags were produced by the midpoint of the simulation period on State, FS, and BLM lands. However, these amounts declined to levels similar to the first simulation strategy by the conclusion of the 300 years.

Patterns of dead wood amounts on FI and NIP lands were similar for the most part with those of the first simulation strategy. There were greater declines in large logs for both of these ownerships because there were more large logs initially in the controlled initial conditions scenario. These large logs were not replaced after they were lost via decomposition (Fig. 5).

5. Discussion

5.1. Policy effects

Cumulatively, dead wood quantities in the Coast Range were projected to increase over time due to the conservation-focused management strategies on public lands, which compensated for the drawdown effects of intensive management on forest industry lands. Managing for older forest structure and aquatic habitat such as under the NWFP – including creating snags and logs during young stand thinning, and treating older stands and riparian areas as no-action areas – appears to have strongly positive effects on dead wood abundance. Lands under intensive management, such as those regulated by the State of Oregon Forest Practices Act (OFPA), may maintain current dead wood total volumes, but are likely to show declines in large piece sizes. In our study, with green-tree retention under the intensive management scenario, very low levels of large snags and logs were maintained through the simulation period. This study enumerates how differences in forest policy can have dramatic effects on dead wood abundance and its spatial distribution across landscapes, even within short periods of time.

Likewise, our simulation results quantify the concept that differences in initial conditions can obscure the effects of forest management over decades and centuries. Pre-existing (legacy) dead wood masked the effects of dead-wood-insensitive management practices. This effect may prevail particularly in landscapes where dead wood decomposition times are long relative to the management cycle. With the same initial conditions, differences in forest management can result in widely divergent patterns of abundance of dead wood. With the same initial conditions across ownerships, the Forest Service lands ended the 300-year period with about six times as much dead wood volume as forest industry lands (1610 vs. 262 m^3 ha^{-1}), and this trend was apparent even in the early years of the application of the forest management scenarios.

5.2. Projected potential future changes in dead wood: spatial and temporal context

Projected increases on federal and state lands combined with declines on industrial lands mean that there is likely to be increased spatial divergence of dead wood amounts (number of snags and volume of snags and logs), types (snags vs. logs), and size classes across the region. The timing of spatial divergence is projected to commence in the first few decades and carry through for centuries thereafter. Thus, management effects on dead wood