Forest Ecology and Management 330 (2014) 183–191

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Effects of rural residential development on forest communities in Oregon and Washington, USA

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ARTICLE INFO

Article history:
Received 19 March 2014
Received in revised form 14 July 2014
Accepted 19 July 2014
Available online 7 August 2014

Keywords:
Forest structure
Development metrics
Land use change
Forest inventory and analysis

ABSTRACT

Rural residential development in forests of Oregon and Washington continues to be a key driver of land use change. This type of development can have a variety of effects on the goods and services forests provide to the region. We used structure density from photo-interpreted points around forest inventory and analysis plots to examine differences in forest attributes with respect to varying development metrics. Our results demonstrate that forest ownership (public vs. private), structure density, and proximity of development are critical factors in explaining variation in forest attributes. Small-scale fragmentation, standing dead tree volume, coarse woody debris, and the propensity for introduced species are all affected by development close to the borders of public land. Differences in coarse woody debris, small-scale fragmentation, and propensity for introduced species are also affected by the density and proximity of development on private ownership.

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1. Introduction

Forest communities of the United States provide a variety of goods and services to the American public. Some of these include fresh water, wildlife habitat, wood and wood products, recreational opportunities, and carbon storage and sequestration. As populations grow and rural residential development occurs in forested communities, some of these goods and services may be at risk (Brown et al., 2005; Stein et al., 2010). The most extreme example of this risk is the conversion of forest land to other land uses, such as residential.

Oregon and Washington have some of the most productive forest lands in the United States, having 17.1 million hectares, roughly 14% of this forest land is capable of producing greater than 11.5 cubic meters-per-hectare-year of wood at culmination of mean annual increment (Donnegan et al., 2008; Campbell et al., 2010). High population growth and concern for preserving both forest and agricultural land caused both states to enact legislation addressing development, the Land Conservation and Development Act passed in Oregon in 1973, and Washington's Growth Management Act in 1990. The major concern for development involved private lands in both states, public lands are generally exempt from development, but may have development in close proximity to their borders. Although laws in both states address land use conversion, there are still concerns about the effects of rural residential development intermingling in resource areas and at the edges of public lands.

The most obvious and damaging effect of development in forested landscapes is seen when a stand of trees becomes a community of houses. On a lesser scale, a grove of trees might turn into a house and yard, with a transportation corridor creating access. Less obvious effects are those created at the edges of a site and its transportation corridor. Effects from roads can be tied to the amount of traffic, but even secondary roads may have effects that extend for more than 200 m (Forman, 2000; Trombulak and Frissell, 2000; Saunders et al., 2002). The edge may attract more of the species that thrive there as opposed to those that like large tracts of continuous forest. The more edges there are in a forested landscape, the more fragmented habitat becomes. Roads also have an effect on natural water pathways that drain forested land to streams. Once a road is installed, the impervious or semi-impervious surface directs runoff differently than a forested landscape by focusing runoff to collection points. Some of the impacts from development may be minor; others while minimal for a single developed site, could be cumulative with increasing development.

Human disturbance to forested landscapes increases as development increases. In addition to wildlife habitat fragmentation, disturbances can include introduced vegetation species, interactions

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http://dx.doi.org/10.1016/j.foreco.2014.07.018
0378-1127/Published by Elsevier B.V.

between pets and wildlife, increased sediment runoff, alterations in biodiversity, and disruption of ecosystem processes. There are multiple studies that address effects on avian (Fraterrigo and Wiens, 2005; Marzluff, 2005) and mammalian habitat changes (Odell and Knight, 2001; Gibeau et al., 2002; Fairbanks and Tullous, 2002). Several studies investigate disruption of ecosystem processes (McDonnell et al., 1997; Hansen et al., 2005). In many areas in Oregon and Washington, private lands occupy the valley bottoms where development is most likely, focusing development effects in riparian areas. Major urban centers in Oregon are found along waterways in the Willamette Valley and in the Puget Sound area in Washington. Transportation corridors, rail lines, and roads are often located in valley floors and pose direct effects on riparian areas.

Forest management decisions can be affected by ownership changes and fragmentation on surrounding forest land. As development encroaches into privately owned forested areas, active management such as harvesting, site preparation, and thinning are less likely (Barlow et al., 1998; Wear et al., 1999; Munn et al., 2002; Kline et al., 2004). Others have hypothesized that development brings in newer owners who value forest land for purposes other than timber production, thus creating a management conflict with timber producers and that perceived impermanence of land use may discourage investment in timber production (Wear et al., 1999; Kline et al., 2004). As development occurs, forest ownership becomes more fragmented and tract sizes decrease, resulting in increases in management costs per unit area (Harris and DeForest, 1993).

Wildfire suppression and pre-fire fuels management are greatly affected by the amount of development on forest land (Radeloff et al., 2005; Gill and Stephens, 2009). Increasing development will generally result in greater potential for ignitions (Syphard et al., 2009; Narayanaraj and Wimberly, 2012; Chas-Amil et al., 2013). Also, federal wildland fire policy lists protection of human life as its first priority followed by property and resource values (USDA Forest Service, 2005). Therefore areas that have houses will receive suppression efforts before other resource areas, and public land owners may focus funds for fuel reduction in areas that have adjacent homes. Knowledgeable owners of individual houses will strive to maintain a defensible space around their homes, which may include structural changes to the immediate forest surroundings. Finally, prescribed fire will be difficult to implement in forested areas with intermixed housing, thus forest land owners may be forced to use more costly measures such as mechanical or manual treatments to reduce fuel around their homes (Calkin and Gebert, 2006).

There is adequate research focusing on changes in forest area, forest management, and wildlife habitat resulting from urban development, but few studies have investigated differences in forest attributes due to small amounts of development (Russell et al., 2011).

Our study uses USDA Forest Service Forest Inventory and Analysis (FIA) plot data along with data from land use change studies in Oregon and Washington to examine how forest attributes can change with increasing development in close proximity. A broad scale of development is examined here; in some cases the development is extremely minor such as a single house within 2000 m of the plot center, in other cases there is urban development in close proximity. The objective of this study is to identify various development metrics that show an effect on properties of forested or partially forested FIA plots. A second objective is to identify what levels of development might be associated with a change in forest attributes.

2. Methods

2.1. Study area

The study area consists of all forested land in Oregon and Washington as represented by FIA field plots collected between 2001 and 2010. Elevation ranges from sea level to over 4200 m. The majority of the population in both Oregon and Washington occurs on the western side of the Cascade Range, with smaller population centers on the east side. In both eastern Oregon and eastern Washington, forest land is associated with increasing elevation. Both states have a considerable area of "non-forest" zone at lower elevations on the east side of the Cascade Range. Forests are dominated by Douglas-fir and spruce/fir/hemlock types on the west side and Douglas-fir and ponderosa pine types on the east side. The ownership of forest lands in Oregon and Washington is almost evenly distributed between public and private ownership, with the major public owners being the US Forest Service (NFS), the Bureau of Land Management (BLM), the National Park Service (NPS), the Oregon Department of Forestry (ODF), and Washington's Department of Natural Resources (DNR). Private ownership is split roughly evenly between corporate and non-corporate. Public ownerships tend to have higher average elevation with both the NFS and the NPS having the highest elevations.

2.2. Photo-interpreted points

We used 44.5 thousand photo-interpreted points in Washington with a latest image date of 2006 and 37 thousand points in Oregon with an image date of 2005. Points were placed on a systematic grid to estimate structure density. The imagery consisted of 1-m resolution color digital imagery from the National Agriculture Imagery Program acquired from the Farm Service Agency. Imagery for earlier dates was based on digitally scanned aerial photos that were georegistered in a geographic information system (GIS). The original use of the grid was for stratification for inventory estimates and was later used in land use change studies (Lettman et al., 2011; Gray et al., 2013). Structure density information was not collected on federal lands because land use change and development rarely occur there. Data collected at each of the photo-interpreted points includes, but was not limited to, land use that the point fell in, the number of structures in the surrounding 32.4 ha, and the area of various land uses within the 32.4 ha.

Due to varying grid intensities between the field plot and photo-interpreted grids, there could be as many as nine photo-interpreted points within 2 km of a field plot (Fig. 1). We averaged the structure density (DEN), the increase in structure density from the 1970s to the 2000s (DCHG), and the structure density divided by the distance from point to the plot (DEND) for all the photo-interpreted points that fell within a 2-km radius circle of each forested FIA field plot. We also computed the minimum distance from the field plot to a point that had at least one structure (MDP). The occurrence of a low-density residential or urban zone on any point within 2 km of the plot was also recorded (URB). These various development metrics were used in linear regression and generalized linear models to explain variation in forest attributes computed from FIA field plots as described in the next section.

2.3. FIA field plots

FIA plots represent a spatially balanced sample of field measured plots on a rough 4.8 km grid across the landscape where ten percent are sampled each year (Bechtold and Patterson, 2005). The information collected on each plot included, but was not limited to, tree information, understory vegetation, coarse woody debris, forest land conditions, ownership, tree damages, disturbances, and non-forest land uses. FIA plots can be segmented in several different conditions, for example a plot could have two distinct tree size classes or owner groups. Plots can also be segmented for non-forest conditions, the most common being a road intersecting the plot. This study included only those plots that contain a piece of forest land, defined by FIA as being at least 0.4 ha in

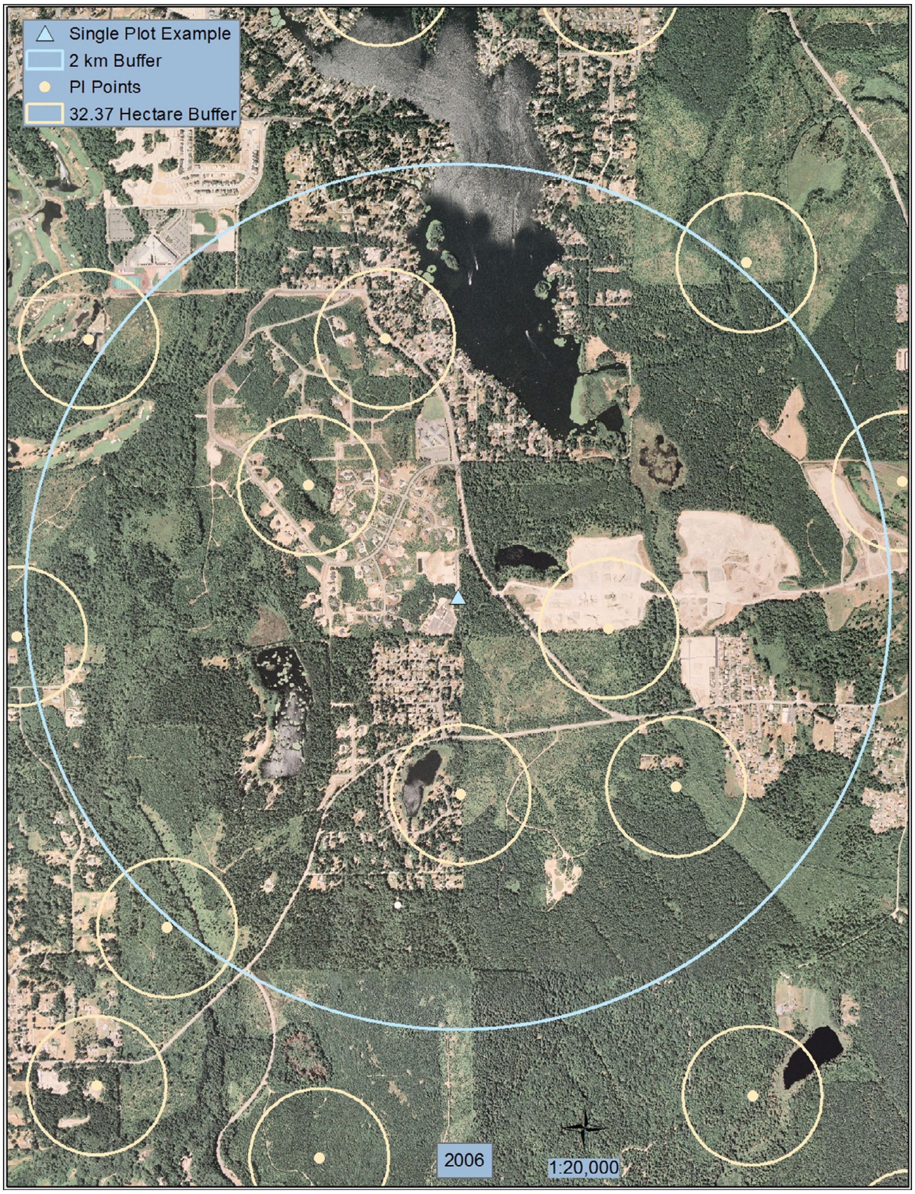

Fig. 1. Example of photo-points and a forest inventory and analysis plot with 2 km buffer.

size and 36 m in width, and having at least 10% canopy cover of live trees or having had at least 10% cover in the past. Additionally, the land cannot be subject to non-forest uses that prevent normal tree regeneration such as intensive grazing, regular mowing, or recreational activities.

FIA plots consist of a cluster of four 0.017 ha (7.32 m radius) subplots that are distributed over a 1 ha area, with larger trees sampled on a 17.9 m radius circle (Bechtold and Patterson, 2005). Understory vegetation and trees less than 12.5 cm are sampled on a 2 m radius circle offset from the center of the subplot. Course woody debris is sampled on two 7.3 m transects per subplot. Because the plot design is fixed around systematically-located points, plots can sample multiple land-use conditions and vegetation types, termed "condition classes" which are distinguished in the field using an elaborate set of criteria.

FIA plot measurements were used to calculate forest attributes (Table 1) such as the amount of softwood (SWBA), hardwood (HWBA), and large tree basal-area-per ha (LTBA); the volume of coarse woody debris (CWD) and standing dead wood per ha (STDVL); proportion of trees with physical damage (PDAM); and stand age (AGE). Other attributes such as a non-forest condition, the occurrence of a treatment, or introduced vegetation species were based on the existence of the attribute on the plot as determined by the field crew. The proportion of the plot with an introduced species (IVEG) was based on the proportion of subplots measured that have an introduced species present. Fragmentation in this paper was represented by the presence of a non-forest condition break (NFBK) that was measured on the plot and was representative of small-scale forest fragmentation. A treatment (TREAT) was considered a forestry operation such as, thinning, site preparation, planting, harvesting, or removal of unwanted trees and brush.

2.4. Analysis

Using generalized linear models, we tested the influence of various development metrics, elevation, and ownership on multiple attributes for the forested plots in our study region (see Table 1 for detailed description of response variables). For the two binary response variables (NFBK and TREAT) we used binomial models; for IVEG and PDAM, which are proportions, we used weighted

Table 1
Descriptions of response and explanatory variables in generalized linear models.

Response variables:	Descriptions:
Proportion of subplots with an introduced species (IVEG)	Count of subplots with an introduced species/number of subplots sampled
Occurrence of a non-forest break on the plot (NFBK) (0, 1)	Zero/one variable, 1 if there is a non-forest break on the plot
Volume of coarse woody debris (CWD)	Accumulated plot volume per hectare of down wood over 7.5 cm in diameter
Volume of standing dead (STDVL)	Volume per hectare of standing dead trees
Softwood basal area (SWBA)	Accumulated softwood basal area per hectare
Hard wood basal area (HWBA)	Accumulated hardwood basal area per hectare
Large tree basal area (50 cm plus) (LTBA)	Accumulated basal area per hectare for trees over 50 cm
Stand age (AGE)	Estimated field stand age call
Proportion of trees with physical damage (PDAM)	Count of trees with a physical damage/total trees on plot
Treatment since 1990 (TREAT) (0, 1)	Occurrence of a treatment since 1990
Explanatory variables:	Descriptions:
Density (DEN)	Average density in structures per hectare for point within 2 km of plot
Density change (DCHG)	Average change structure density change for points within 2 km, 1970s–2000s
Distance to point (MDP)	Minimum distance to a point with a structure
Ownership, public or private (OWN)	Majority plot ownership, 0 private and 1 public
Elevation (ELEV)	Elevation in meters
Density/distance (DEND)	Average (density/distance to point from plot)
Urban (URB)	Presence of an urban or low density residential polygon around any of the points within 2 km

binomial models; and for the continuous response variables (volume of coarse woody debris and standing dead wood; basal area of softwood, hardwood, and large trees; and stand age) we used a generalized Poisson model with log-link and variance proportional to the mean. This model type allowed accounting for the abundance of zero values for response variables due to various phenomena (McCullagh and Nelder, 1989; Moisen and Edwards, 1999).

Possible explanatory variables were five development metrics (DEN, DCHG, MDP, DEND, and URB) as well as ownership and elevation (see Table 1 for detailed description of explanatory variables). All generalized linear models were fit using backwards regression, with significance within the model being determined by the *t*-statistic with an α of .05.

The minimum distance to a point with a structure (MDP) was divided into four groups (<1 km, 1–2 km, 2–7 km, $\geqslant$7 km) to examine spatial patterns of effects. The structure density metric (DEN) was divided into three groups (0, $\leqslant$1, and >1 per km^2). Statistical comparisons between groupings of structure density or minimum distance to a point with a structure were based on *t*-tests with unequal variances using an α of 0.05.

3. Results

Ownership was a significant explanatory variable for all ten forest attribute response variables (see Table 2 for *P*-values). The most important development metrics were structure density and distance to a point with a structure, which occurred in most of the models. In a few models the occurrence of an urban zone and density change appeared when structure density dropped out (Table 2).

Differences between public and private lands were highly variable for the ten forest attributes. There tends to be more coarse woody debris, softwood, standing dead wood, and large trees; greater proportion of trees with physical damage; lower occurrence of treatment; fewer introduced species and non-forest breaks; and more older forests on public lands (Fig. 2). In many models, elevation was also significant when ownership is accounted for within the model (Table 2). Average hardwood basal area was relatively even between the two ownerships. With the ownership variable being significant in the models for all forest attributes examined, we ran separate models for both ownership groups (Table 2).

All forest attribute models for public ownership, except physical damage and hardwood basal area, had either the structure density or distance to a point with a structure variable, or both, as being significant (see Table 2 for *P*-values). Both structure density and distance to a structure were significant in the models for coarse woody debris, non-forest breaks, softwood, and standing dead volume, with coarse woody debris, amount of softwood, and standing dead volume all decreasing as structure density increased, and all increasing as distance to a structure increased. Presence of a non-forest break tended to increase with structure density and decrease with distance to a structure, although it appeared that only the greatest density class and the closest distance were different from the others ($P < 0.05$). Difference in coarse woody debris, standing dead volume, and amount of softwood basal area could be seen between the two smallest density classes and also existed between the two lowest distance classes (Figs. 2c–e and 3c–e). Non-forest breaks were more prevalent when closer than 1 km than when greater than 1 km and were only different in the largest structure density class. Although neither structure density nor minimum distance to a point with a structure were significant in the hardwood model, we found that presence of an urban zone and elevation were significant explanatory variables. Introduced vegetation and treatment occurrence had distance to a structure significant in their models, with both tending to decrease as distance increased. Large tree basal area tended to increase as the distance to a structure increased but did not change much with density, although the model had density change being significant (Table 2).

On private lands, all but one of the models for forest attributes, treatment occurrence, had minimum distance to a point with a structure being significant, and of these models, eight also had either structure density or urban zones being significant (Table 2). The model for treatment occurrence did not have either structure density or distance to a structure being significant, but did contain density change. Unlike the public ownership group, standing dead volume and amount of softwood only showed significant differences between the smallest and largest density groupings; in both cases the urban zone parameter was significant within their respective models (Table 2). Introduced vegetation, non-forest breaks, and hardwood basal area all increased with increasing structure density (Fig. 2a, b and f) and all tended to decrease with an increasing distance to a structure (Fig. 3a, b, and f). Coarse woody debris decreased with structure density and increased with distance to a structure, with major differences between the smallest and largest classes (Figs. 2c and 3c). There seemed to be no pattern for treatment occurrence, trees with physical damage, or stand age with structure density ($P > 0.05$); however, treatment

Table 2
Estimates of coefficient, significance levels,[a] and model statistics for generalized linear models of forest attributes with development metrics as explanatory variables.

Response Variables[b]	Explanatory variables[b] Intercept	OWN	DEN	DCHG	MDP	ELEV	DEND	URB	N	F
Age(log transform)	3.80^{***}	$-.494^{***}$	$.0020^{***}$	–	$-.00005^{***}$	$.0006^{***}$	–	–	5287	222^{***}
Public	3.96^{***}	–	$.0014^{*}$	–	–	$.0003^{***}$	–	$-.117^{**}$	1863	24^{***}
Private	3.25^{***}	–	$.0028^{***}$	–	$-.00004^{***}$	$.0007^{***}$	–	–	3421	135^{***}
CWD (log transform)	3.72^{***}	$-.695^{***}$	$-.0068^{***}$	–	$.00022^{***}$	$-.0011^{***}$	–	$.191^{**}$	5301	151^{***}
Public	3.85^{***}	–	$-.0054^{***}$	–	$.0002^{***}$	$-.0011^{***}$	–	–	1866	51^{***}
Private	3.02^{***}	–	$-.0015^{***}$	$.011^{*}$	$.0003^{***}$	$-.0013^{***}$	$.0029^{*}$	$.228^{**}$	3429	72^{***}
NFBK (0, 1)		$.277^{***}$	$.120^{***}$	$.0011^{**}$	–	$-.00002^{***}$	–	–	–	5306
Public	-1.44^{***}	–	$.0062^{***}$	–	$-.00007^{**}$	$.00003^{*}$	$.065^{*}$	–		1870
Private	$-.319^{***}$	–	$.009^{***}$	–	$-.0001^{***}$	–	–	–		3435
SWBA (log transform)	2.84^{***}	$-.811^{***}$	$-.0048^{***}$	–	$-.0001^{***}$	$-.0003^{***}$	–	$.096^{*}$	5301	104^{***}
Public	3.05^{***}	–	$-.0069^{***}$	–	$.0001^{***}$	$-.0005^{***}$	–	–	1867	48^{***}
Private	1.89^{***}	–	–	–	$.0001^{***}$	$-.0002^{*}$	–	$.016^{*}$	3431	23^{***}
STDVL (log transform)	$.484^{***}$	-1.56^{***}	-0046^{**}	–	$.0002^{***}$	$-.0011^{***}$	–	–	5301	299^{***}
Public	$.475^{***}$	–	$-.0052^{*}$	–	$.0003^{***}$	$-.0014^{***}$	–	–	1867	42^{***}
Private	-1.16^{***}	–	–	–	$.0002^{***}$	$-.001^{***}$	–	$.259^{**}$	3484	24^{***}
IVEG	-1.20^{***}	$.67^{***}$	–	–	$-.0002^{***}$	$.0003^{***}$	$.004^{**}$	$-.09^{*}$	5306	
Public	$.205^{***}$	–	–	–	$-.00003^{***}$	$.00006^{***}$	–	–	1870	
Private	$-.480^{***}$	–	–	–	$-.0002^{***}$	$.0002^{**}$	$.004^{**}$	$-.124^{**}$	3435	
HWBA (log transform)	1.08^{***}	$-.219^{***}$	–	$.0046^{*}$	$-.00005^{***}$	$-.002^{***}$	–	$-.039^{***}$	5301	330^{***}
Public	3.09^{***}	–	–	–	–	$-.002^{***}$	–	$-.367^{***}$	1866	138^{***}
Private	$.920^{***}$	–	–	$.0054^{*}$	$-.00007^{***}$	$-.0031^{***}$	–	$-.405^{*}$	3431	276^{***}
PDAM	-1.912^{***}	$-.134^{***}$	$.0015^{***}$	$.0032^{***}$	-0.00003^{***}	$.0006^{***}$	$-.001^{*}$	–	5077	
Public	-1.89^{***}	–	–	$.003^{**}$	–	$.0004^{***}$	–	–	1823	
Private	-2.018^{***}	–	$.0057^{***}$	–	$-.00005^{***}$	$.0008^{***}$	–	–	3259	
TREAT (0, 1)		$-.917^{***}$	$.68^{***}$	$-.007^{***}$	–	$-.00004^{***}$	–	–	–	5306
Public	$-.88^{***}$	–	–	–	$-.00005^{*}$	–	–	–	1807	
Private	$-.237^{*}$	–	–	$-.014^{***}$	–	$-.0002^{**}$	–	–	3435	
LTBA (log transform)	2.11^{***}	-1.19^{***}	–	$.0031^{*}$	$.000006^{***}$	$-.0008^{***}$	–	–	5302	202^{***}
Public	2.23^{***}	–	–	–	$.00007^{***}$	$-.0009^{***}$	–	$-.262^{**}$	1866	30^{***}
Private	$.902^{***}$	–	–	$.006^{***}$	$.00005^{***}$	$-.0007^{***}$	–	–	3432	53^{***}

N – sample size for the model.
$\hat{\phi}$ = Pearson's Chi-square/degrees of freedom-estimate of dispersion parameter.
[a] The *, **, and *** indicate the probability of the *t*-statistic exceeding the critical of 90%, 95% and 99%.
[b] See Table 1 for variable acronym descriptions.

occurrence and stand age seemed to differ with distance to a structure ($P < 0.05$). It is also interesting to note that large tree basal area seemed to be greater with increasing structure density and decreasing distance to a structure ($P < 0.05$).

4. Discussion

Ownership is a key variable when investigating various forest attributes in the Pacific Northwest. It is also essential when investigating development, as most public land is exempt from development. The major public owner is the NFS with roughly 9.1 million ha (22.6 million acres) or 42% of forest land in the two states. Management on NFS lands shifted away from producing timber in the late 1980s and early 1990s, resulting in different forest attributes on NFS lands than on the more intensively managed privately owned lands. The NFS lands tend to be at higher elevations, include wilderness areas, and barring disturbance, tend to have older stands with larger trees, more coarse woody debris, more damages, and more standing dead volume than privately owned forests (Donnegan et al. 2008, Campbell et al., 2010). With the NFS having older stands, the proportion of trees with physical damage would be expected to be higher than on private lands.

It is of interest that public lands show less coarse woody debris, standing dead volume, and amount of softwood between the two extreme structure density groups with 45%, 45%, and 22% decreases respectively, along with a pattern of increases with increasing distance to a structure with 138%, 220%, 60% increases respectively, showing the effect of development (Figs. 2 and 3). Most public land is protected from development; however, it can attract development on its borders. While NFS lands can be buffered by other forestland owners, other public owners like DNR and BLM in southwestern Oregon can have high amounts of development adjacent to their lands (Azuma et al., 2013), which affects various forest attributes.

Both non-forest breaks and introduced vegetation are indicative of human influence on the forest environment. One reason for the increasing frequency of introduced species in United States forests is the development pattern of human populations (Moser et al., 2009). Numerous studies have investigated effects of forest fragmentation on ecosystem processes and avian populations (Saunders et al., 1991; Theobald et al., 1997). Our treatment of non-forest breaks as micro fragmentation is a unique approach representing breaks within the forest from a ground perspective. Both the non-forest breaks and introduced vegetation attributes show patterns of increase with increasing density. On private lands, both introduced vegetation and non-forest breaks show increases with even small amounts of development. As development occurs closer to a plot, the probability increases that a road could intersect the foot print. As roads increase, access to forest land also increases, especially on public lands. This may be due to the possibility of development occurring throughout the ownership, compared to public lands where development occurs only at the edges and a greater density of development may be required to show an increase in these attributes.

The introduced vegetation attribute shows a steady decrease as the distance to a structure metric increases for both ownership

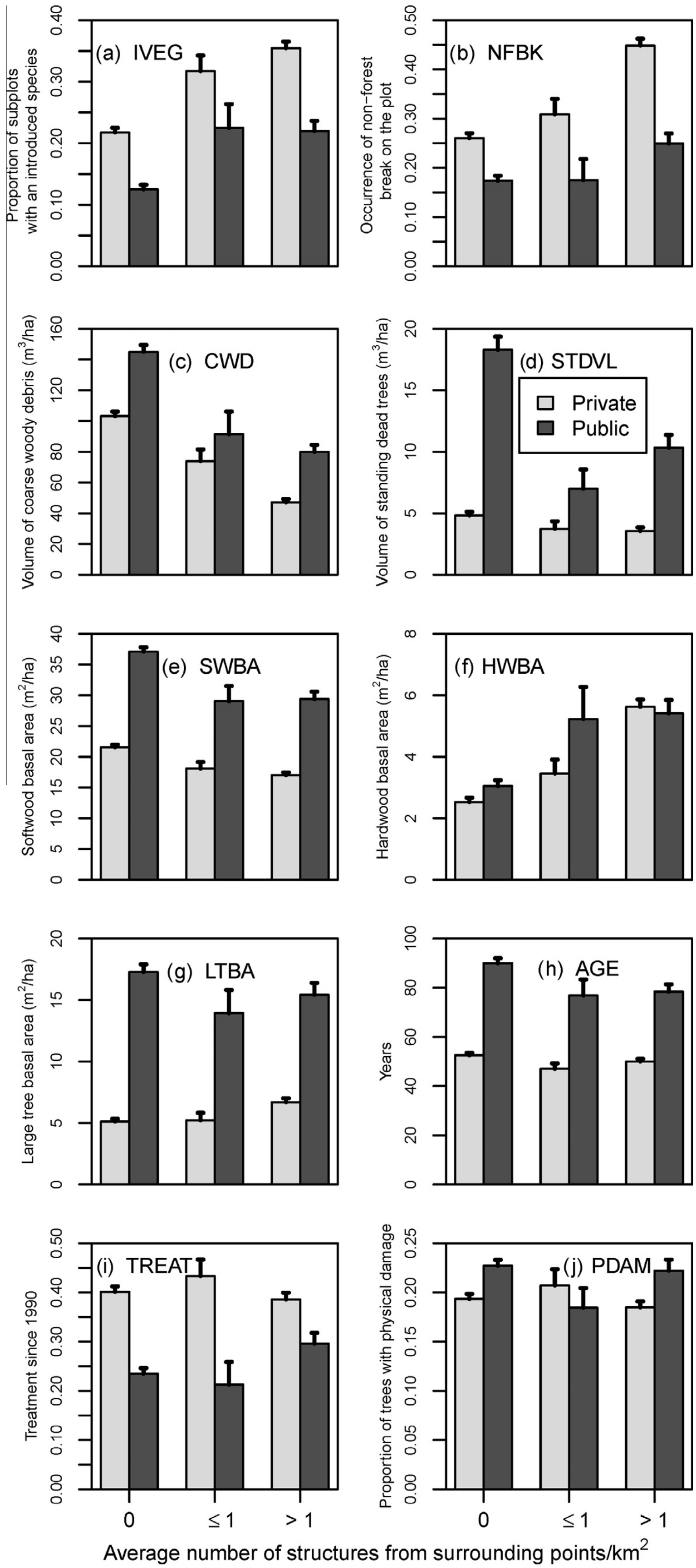

Fig. 2. Mean and standard errors for various forest attributes by ownership (private vs. public) and structure density (divided into four groups: 0, ⩽1, and >1 per km^2).

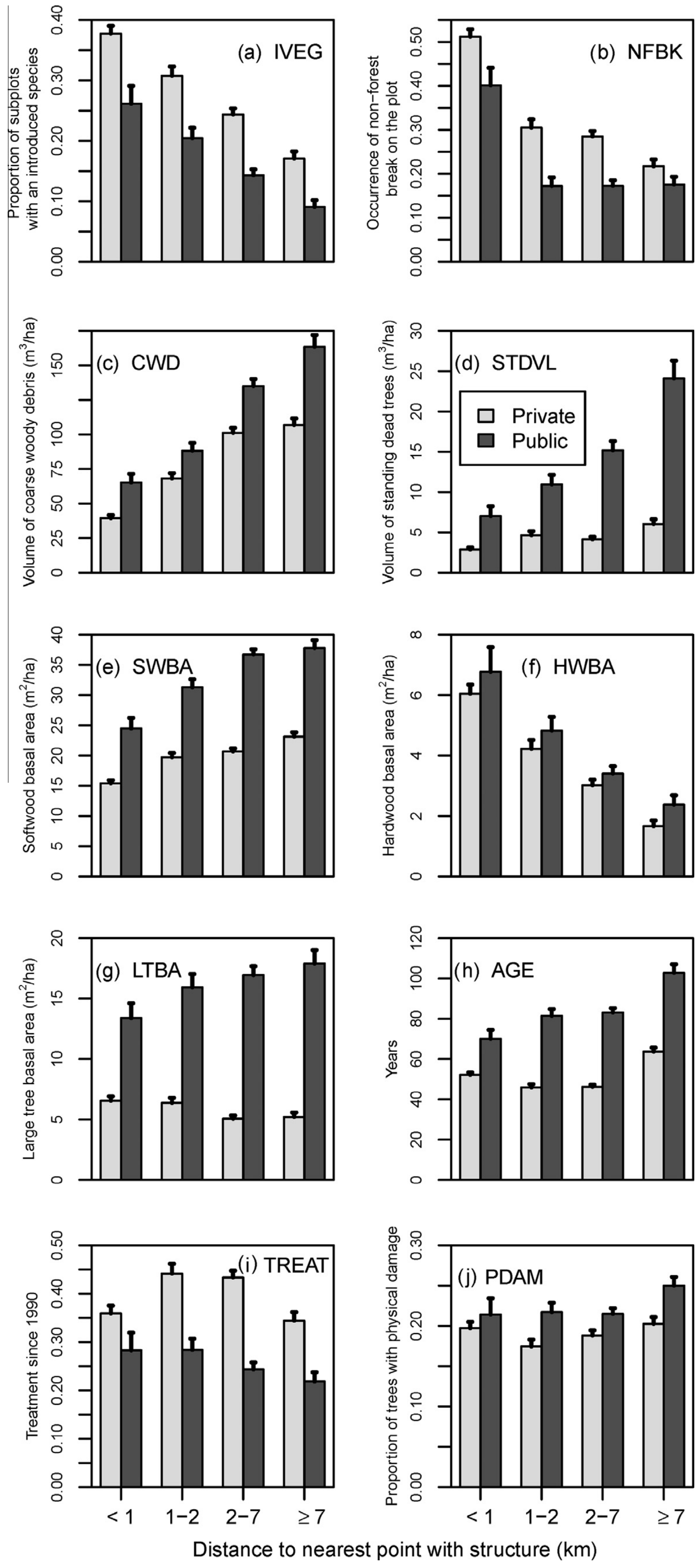

Fig. 3. Mean and standard errors for various forest attributes by ownership (private vs. public) and minimum distance to a point with a structure (divided into three groups: 1<, 1–2, 2–7, and ⩾7 km).

groups, whereas for non-forest breaks, the pattern is less evident for public owners (Fig. 3a and b). The distance to development seems to be a key driver for non-forest breaks in the shortest class for public lands, and once outside the 1 km band, the number of non-forest breaks seems to be relatively constant. The introduced vegetation component on public land seems to be less influenced by small increases in density once development has occurred; the difference between the two smallest density classes is 80% while there is no difference the mid and upper classes, while the trend on private lands shows steady increases (Figs. 2a and 3a).

Softwood harvest dominates the timber industry in Oregon and Washington; in 2008, softwoods accounted for roughly 95% of region's harvest (Gale et al., 2012; Washington, DNR, 2008). A key attribute when considering sustained forest productivity in the Pacific Northwest is the amount of softwood basal area. Therefore, change in softwood basal area with respect to development is an important indicator for development's effect on timber resources. Our results suggest this is especially true for private lands. On private lands, amount of softwood is roughly 20% lower when development is within 1 km as opposed to over 7 km away. A similar decrease is seen between the smallest and largest structure density group on private lands. The differences seen here may be an indication of private owners putting less into restocking softwoods after harvest when development is close, or possibly a decrease in stocking levels for fuel management purposes. There is also a minor effect shown on public lands with respect to density groupings.

Deadwood in forests is of interest to ecologists, foresters, and fuel specialists, for its effects on fire and fuels, habitat, nutrients, and carbon storage (Rondeux and Sanchez, 2010). Coarse woody debris and standing dead wood are two critical components of deadwood in forests, and therefore changes with development would be of interest to multiple parties. Even without development occurring on public lands there is a marked decrease between plots with no structures around them and those that average less than 1 structure per km^2 in the surrounding 2 km. Both coarse woody debris and standing dead wood are affected on public lands by stand age, which tends to increase as the distance to development increases. While stand age does not have the same influence on private lands as it has on public, development density and distance certainly affect the amount of coarse woody debris, yet have little effect on standing dead wood. The marked difference between public and private lands for standing dead wood is indicative of stand age differences and to a lesser extent of management differences, where private owners are more likely to take down dead trees either for safety or to prepare the site for the next generation of trees. The differences for both coarse woody debris and standing dead wood along the distance to development metric on public lands may be a result of adjustments to fuel management practices when development is close to the forest.

There are some interesting relationships between elevation, ownership, hardwood basal area, and development. In general, as elevation increases there will be less development due to slope limitations as well as increasing proportion of public land. Hardwoods as a percentage of stand basal area will tend to decrease as elevation increases, with the vast majority of hardwoods accumulated in valley bottoms. So it is not surprising that hardwood basal area is related to development. It is surprising, however, that the hardwood basal area is relatively similar between public and private lands (Figs. 2f and 3f). This is an artifact of the limiting distance of 2 km used to calculate development metrics. Many of the public plots on federal lands (NFS and NPS), have no photo points within 2 km and are not used in the analysis, and these plots are probably highly skewed to having more softwoods.

Stand age and large tree basal area tend to be related, although the relationship is stronger at higher elevations. It is curious to note that for private lands there is an increase in large tree basal area with density increase, and that large tree basal area tends to be highest closest to development. It may be that on private lands there is a tendency to retain larger trees for aesthetic values when development is near.

5. Conclusions

This study demonstrates that development in close proximity to forested stands in Oregon and Washington can affect forest structure. Development metrics such as distance to the closest point with development and development density within a 2 km circle influence various forest attributes. The propensity for introduced species, degree of small scale fragmentation, standing dead volume, and the amount of coarse woody debris are all affected by development in proximity to the stand. Interestingly, effects are seen on both public and private forests. Public lands, where the development only occurs at or near the boundaries, can have as much as a 130% increase in coarse woody debris, 220% increase in the standing dead volume, and 60% decrease in proportion of subplots with an introduced species when development is further away. Even small amounts of development (less than 1 structure per km^2) affect forest conditions on public lands, such as increases in introduced species, coarse woody debris, and standing dead volume. Private lands also show differences in coarse woody debris, propensity for introduced species, and small scale fragmentation with both distance to development and density changes.

Acknowledgments

We thank Rachel White and Sharon Stanton for their helpful reviews of earlier versions of this manuscript.

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