Population Growth, Urban Expansion, and Private Forestry in Western Oregon

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ABSTRACT. Private forestlands in the United States face increasing pressures from growing populations, resulting in greater numbers of people living in closer proximity to forests. What often is called the "wildland/urban interface" is characterized by expansion of residential and other developed land uses onto forested landscapes in a manner that threatens forestlands as productive socioeconomic and ecological resources. Prevailing hypotheses suggest that such forestlands can become less productive, because forest owners reduce investments in forest management. We develop empirical models describing forest stocking, thinning, harvest, and tree planting in western Oregon, as functions of stand and site characteristics, ownership, and building densities. We use the models to examine the potential impacts of population growth and urban expansion, as described by increasing building densities, on the likelihood that forest owners maintain forest stocking, precommercial thin, harvest, and plant trees following harvest. Empirical results support the general conclusion that population growth and urban expansion are correlated with reduced forest management and investment on private forestlands in western Oregon (USA). Results have potential implications for both economic outputs and ecological conditions, as well as for wildfire risks at the wildland/urban interface. FOR. SCI. 50(1):33–43.

Key Words: Urbanization, wildland/urban interface, nonindustrial private forest owners.

AN INCREASINGLY IMPORTANT FACTOR in forestry is the potentially significant impact that population growth and resulting land use change will have on forestlands as they are converted to residential and other developed uses. What often is referred to as the wildland/urban interface is characterized by expansion of residential and other developed land uses onto traditionally forested landscapes in a manner that threatens forestlands as productive socioeconomic and ecological resources. Prevailing hypotheses suggest that forestlands located at the wildland/urban interface can become less productive due to their fragmentation into smaller and smaller management units, changes in the characteristics and management objectives of newer more urban-minded forest owners, potential conflicts arising from conducting forestry in closer proximity to people, and increasing uncertainty among forest owners regarding prospects for maintaining forest productivity in the future. There is also increasing awareness that locating homes on predominantly forested landscapes may carry unacceptable risks associated with wildfire. All of these concerns have motivated national conferences and workshops, and special journal issues, examining the impacts of population growth and urban expansion on forests in recent years (for example, KAG 1999, DeCoster 2000, Sampson and DeCoster 2000).

Declining forest productivity resulting from forestland development itself may not necessarily justify significant

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management or policy concern, and in fact could simply reflect the workings of efficient land markets. However, changes in management could effect changes in the characteristics of remaining forests, with resulting management- and policy-relevant economic and ecological consequences. Previous empirical studies suggest that increasing human population densities are negatively correlated with the likelihood that forest owners harvest timber (Barlow et al. 1998, Munn et al. 2002) and the likelihood that forestlands are managed for commercial timber production (Wear et al. 1999). Regarding forests as economic resources, forest managers and policymakers want to anticipate how much timber likely will be supplied from private forests in a future in which timber harvest rates and forest management may be changing. From an ecological perspective, changes in management and harvesting resulting from population growth and urban expansion can affect forests as ecological resources that provide wildlife habitat and other benefits. These changes also can play a significant role in determining potential fuel loads that will influence wildfire risks in new wildland/urban settings.

Anticipating the impacts of population growth and urban expansion on forests can facilitate developing management and policy strategies appropriate to future forest/urban landscapes. Although previous studies have begun to examine these impacts, Barlow et al. (1998) and Munn et al. (2002) are restricted to examining harvesting, and Wear et al. (1999) is based on expert opinion rather than actual forest owner behavior. We build on these studies by examining harvest, thinning, tree planting, and forest stocking, and how each might vary with population growth and urban expansion using data describing actual private forest owner behavior in western Oregon. We develop empirical models describing forest stocking, precommercial thinning, harvesting, and tree planting following harvest, and, as functions of stand and site characteristics, ownership type, and building densities. Data for analysis come from the USDA Forest Service Forest Inventory and Analysis Program's forest inventories and aerial photographs. We use the empirical models to test hypotheses regarding the potential impacts of population growth and urban expansion, as described by building densities, on forest management at the wildland/urban interface.

Hypothetical Effects of Population Growth and Urban Expansion on Forestry

There are several hypotheses regarding why we might expect less forestry investment on private forestlands as residential and other developed uses expand onto forest landscapes. First, research regarding specifically nonindustrial private forest owners suggests that forest management intensity tends to diminish with declining forest parcel size. Row (1978) suggests that economies of scale in timber production associated with diminishing average fixed costs yield greater marginal net returns to larger forest tracts. Dennis (1990) suggests that nonindustrial private owners are more likely to manage and harvest timber as tract size increases, because the marginal utility of forestland producing nontimber values, such as aesthetics and recreation, is decreasing. Empirical studies tend to confirm that forest owners on smaller tracts are less likely to manage their forestland for timber production (Thompson and Jones 1981, Cleaves and Bennett 1995). If population growth and urban expansion tend to fragment forestlands into smaller and smaller parcels (Mehmood and Zhang 2001), forest management intensity on remaining forest parcels may decline.

Second, it is thought that residential development on forest landscapes leads to changes in the characteristics of forest owners. Research suggests that urbanites increasingly are moving into rural areas seeking to improve their quality of life. These new residents tend to value forestland for aesthetic and recreational purposes, rather than for timber production (Egan and Luloff 2000). Nonindustrial private forest owners long have been noted for their tendency to base their forest management decisions on nontimber values in addition to or in place of timber production (Binkley 1981, Max and Lehman 1988, Hyberg and Holthausen 1989, Dennis 1989, 1990, Newman and Wear 1993, Kuuluvainen et al. 1996). In western Oregon and western Washington, it has been estimated that 40% of nonindustrial private forest owners primarily have recreation or passive ownership objectives rather than timber production objectives (Kline et al. 2000a, 2000b). These owners tend to own smaller parcels and are less likely to harvest timber. If residential development on forestland increases the proportion of nonindustrial forest owners motivated more by nontimber values than by timber production, management of remaining forestland could shift from timber production to nontimber objectives.

Third, some forestry analysts believe that the proximity of residential development to productive forestlands can lead to conflicts between forestry and new more urban-minded residents, reducing forestry profitability in populated settings. This concern is similar to the "edge effect" hypothesized to exist where residential development exists in close proximity to agriculture, creating rural/urban conflicts that reduce farm profitability (for example, Sorensen et al. 1997, p. 19–20). For agriculture, potential conflicts might include vandalism, trespass, and complaints about odors, noise, dust, or pesticide drift. For forestry, conflicts might arise from vandalism of gates or logging equipment, trespass leading to liability issues associated with equipment or forest management activities, and complaints about particular forest practices such as clearcutting or prescribed burning. Few studies, however, have documented such conflicts or linked them to lower forest productivity. Schmisseur et al. (1991) find no statistically significant relationship between population density and the likelihood of forest/urban conflicts in Oregon, but do find that estimated costs associated with forest/urban conflicts are higher for smaller forest parcels than for large. Related to forest/urban conflicts are growing concerns that residential development near forests may increase the likelihood of wildfire and draw firefighting resources away from fighting forest fires to save homes.

A final hypothesis involves expectations among forest owners in rapidly urbanizing areas that their forestlands eventually will be converted to urban uses. Such expectations may deter forestry investment, because forest owners may perceive a limited productive future for their land. This process is similar to the "impermanence syndrome" often cited in agriculture: expanding urban areas raise land values and increase the opportunity costs of farming, resulting in less investment in new farm technology and slower responsiveness to agricultural market conditions (for example, Lopez et al. 1988, p. 347). As human populations expand onto forest landscapes, remaining forest owners may reduce or forego more expensive management prescriptions and investment opportunities as they anticipate continued population growth and eventual conversion of their land to residential uses (Wear et al. 1999).

To our knowledge, Barlow et al. (1998), Munn et al. (2002), and Wear et al. (1999) are the only empirical studies that have tested whether population growth and urban expansion are correlated with reduced investment in forest management on private forestlands. Barlow et al. (1998) and Munn et al. (2002) combined data describing plot-level harvest activities and stand characteristics in Mississippi and Alabama, with data describing human population densities and distances to urbanized areas. They found the likelihood that forest owners harvest timber is negatively correlated with population density and urban proximity, with potential impacts on forest density, age class, species composition, and successional stage. Wear et al. (1999) used expert opinion to identify the likelihood that forestlands in five Virginia counties were managed for commercial timber production. They combined this information with data describing plot-level forest characteristics and population densities, and found the likelihood that forestlands are managed for commercial timber production is negatively correlated with population densities. We build on these studies by examining the potential impact that population growth and urban expansion have on forest stocking, precommercial thinning, harvest, and tree planting using data describing actual forest owner behavior in western Oregon.

Modeling Stocking, Thinning, Harvest, and Planting

Similar to the Pacific Northwest in general, western Oregon comprises some of the most productive forests in the world. The region includes the forested Coast Range bordering the Pacific Ocean to the west and the western slope of the Cascade Range to the east. In between are the fertile agricultural lands of the Willamette Valley, encompassing the growing cities of Portland, Salem, Corvallis, and Eugene, among others. Currently, 70% of Oregon's 3.4 million people live in the Willamette Valley, and the population is expected to grow by 1.3 million new residents in the next 40 yr (McGinnis et al. 1996, Franzen and Hunsberger 1998). A forest policy interest that is increasingly important region-wide is identifying where and how resulting land use changes likely will affect forests and the goods and services they provide. Research has examined historical and future changes in the spatial distribution of people in western Oregon, and suggests that future population growth will bring more people in closer proximity to forests (Kline et al. 2003). We examine how these changes are likely to affect forests and the manner in which they are managed.

We combined plot-level data describing forest conditions, management, and harvest activities with photo-point data depicting historical building densities, to examine the potential impacts of population growth and urban expansion on forest management. We used these data to estimate empirical models describing forest stocking, precommercial thinning, harvesting, and tree planting following harvest, as functions of stand and site characteristics, ownership, and building densities. Based as they are on plot-level data, the models cannot directly address hypothetical management effects regarding declining tract size, changing owner characteristics, forest/urban conflicts, and owners' development expectations. However, the models can be used to test whether changes in forest management in locations experiencing population growth and urban expansion are consistent with these hypotheses, by examining how forest stocking, precommercial thinning, harvesting, and planting might vary as building densities increase. If population growth and urban expansion have reduced the intensity of forest management in western Oregon, we would expect lower forest stocking levels, and less likelihood of thinning, harvesting, and tree planting in areas comprised of higher building densities.

Forestry and Building Density Data

Plot-level forestry data were obtained from the USDA Forest Service Forest Inventory and Analysis Program's regular inventories of forestland in western Oregon (Azuma et al. 2002). The inventories consist of periodic nationwide assessments of nonfederal land in the United States, as authorized by the Forest and Rangeland Renewable Resources Research Act of 1974. Inventory data are gathered in western Oregon using photo-interpretation and ground-truthing on a systematic sampling of nearly 1,500 field plots. The inventories gather detailed information regarding forest characteristics, as well as information about any evidence of precommercial thinning, harvesting, and tree planting observed from one inventory to the next, as well as forest stocking. Western Oregon inventories are conducted on roughly a 10 yr cycle. Data used for this study were gathered during inventories initiated in 1974, 1984, and 1994.

Building density data were developed by the Oregon Department of Forestry in cooperation with the Forest Inventory and Analysis Program. The data consist of building densities (numbers of buildings) on nonfederal land observed in the 640 ac vicinity of sample points located on aerial photographs taken in 1974, 1982, and 1994 (Azuma et al. 1999). With nearly 24,000 sample points, the data provide nearly 72,000 observations of building densities varying in space and time. Building densities for 1984 were estimated by interpolating between 1982 and 1994 values. Resulting data for 1974, 1984 (interpolated), and 1994 roughly coincide with the 1974, 1984, and 1994 forest inventory data. Cross-referencing between building density sample points and forest inventory field plots enable simultaneous analysis of building densities and the forest stocking, thinning, harvest, and planting variables.

Empirical Modeling Issues

Two types of data comprise dependent variables available in this study: (1) discrete data consisting of dummy variables describing evidence of whether or not precommercial thinning, harvesting, or tree planting activities occurred from one forest inventory to the next; and (2) continuous data describing forest stocking at each inventory. Typically, the potential impacts of various factors on each dependent variable could be analyzed using the structural model

$$y_i^* = \beta' x_i + \varepsilon_i \tag{1}$$

where x is a vector of explanatory variables describing factors hypothesized to affect each dependent variable y, β is a vector of estimated coefficients, ε is an error term, and $i = 1,..., n$ identifying individual observations comprising the sample. However, our data consist of multiple observations of individual sample plots at multiple points in time. For example, harvest data consist of harvest activity observed on individual plots from 1974 to 1984 and from 1984 to 1994. The structural model can be modified to account for panel structure of the data using fixed or random effects models (Greene 1998, p. 318).

Fixed effects models include an individual constant term for each cross-sectional grouping of time-series observations to account for potential parametric shifts or "fixed effects" associated with and specific to each cross-sectional group included in the analysis—each inventory plot in this case. Estimation of fixed effects models is not feasible when explanatory variables are included describing plot characteristics that remain constant across all time series observations. This is the case here because potentially important independent variables, such as site characteristics, do not vary across time.

Alternatively, random effects models assume that there is a stochastic term specific to individual sample plots, and are more appropriate when the sample of cross-sectional observation groups are drawn from a larger population. The structural model (1) is modified to account for random effects across sample plots as

$$y_{it}^* = \beta_*' x_{it} + \varepsilon_{it} \tag{2}$$

where $t = 1, \ldots, T$, $\varepsilon_{it} = u_{it} + v_i$, and

$$Var[u_{it} + v_i] = Var[\varepsilon_{it}] = \sigma_u^2 + \sigma_v^2 \tag{3}$$

This modified structural model features the error term ε_{it} in place of the ε_i in (1). This new term includes error u_{it} specific to individual observations of plots i at time t, and error v_i specific to individual plots i that remains constant across time (Greene 1998, p. 318).

Precommercial thinning, harvesting, and tree planting activities occurring between successive forest inventories are described by discrete data, and we define the probability that evidence of each activity was observed as y_i^*. Although y_i^* is unobservable, observed evidence of each activity can be described as a vector of binary variables y_i defined by

$$y_i = 1 \text{ if } y_i^* > 0, \quad 0 \text{ otherwise.} \tag{4}$$

For example, when examining the likelihood of harvesting, y_i equals 1 for plots i observed as harvested since the previous inventory, and 0 if harvesting was not observed. We assume that error in the model is normally distributed and use the binary variable y_i to estimate a random effects probit model. The model describes the likelihood that evidence of a harvest was observed from one forest inventory to the next and is described as

$$P(y_i = 1) = \Phi(\beta' x_i) \tag{5}$$

where Φ is the standard normal distribution (Greene 1998, p. 443). Additional probit models describe the likelihood that evidence of thinning and tree planting was observed. The probit models with random effects result in estimated coefficients β_* such that $\beta = \beta_* / \sigma_\varepsilon$, as well as an estimated coefficient of correlation among plot-specific errors

$$Corr[\varepsilon_{it}\varepsilon_{is}] = \rho = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2) \tag{6}$$

that can be evaluated using a *t*-test to evaluate potential correlation among plot-specific errors across time (Greene 1998, p. 454).

Forest stocking at successive forest inventories is described by a continuous dependent variable—average basal area per acre of sample plots—and can be examined using ordinary least squares regression. As before, however, we must account for the panel structure of the data. For this, we used generalized least squares regression with random effects to estimate an empirical form of the structural model (2) (Greene 1998, p. 318).

Testing the Influence of Building Density on Forestry

Several factors reasonably could be expected to influence forest stocking, thinning, harvesting, and planting on private forestlands. We analyzed each of these dependent variables by considering as many potential factors as possible, using the best data available. The first empirical model describes forest stocking, as represented by basal area, as a function of explanatory variables describing stand and site characteristics including stand age, site index, forest type, nonindustrial private ownership, and building density. The next three empirical models describe the likelihood that private forest owners precommercial thinned, harvested, and planted trees following harvest, as functions basal area, site index, slope, road access, nonindustrial private ownership, and building density. Explanatory variables tested in each of the four empirical models are described in Table 1.

Forest Stocking Levels

We examined the basal area of forest stands during the 1974 and 1984 inventories, and whether basal area varied by building densities. Changes in procedures used during the 1994 inventory prevent us from conducting a comparable analysis for 1994, because plot-level data describing stand age, a key explanatory variable, are unavailable. Stocking may not necessarily be treated as a choice variable by forest owners; however, less intensive management of forest stands could lead to lower stocking levels. We estimated two ordinary least squares regres-

Table 1. Descriptions of explanatory variables tested in the empirical models.

Variable	Description
BASAL AREA$_{t-1}$	Basal area (ft^2/ac) of the plot stand at preceding forest inventory occasion.
BASAL AREA$_t$	Basal area (ft^2/ac) of the plot stand at current forest inventory occasion.
SITE INDEX	Site index of the plot.
SLOPE	Percent slope at the plot.
ROAD DISTANCE	Distance of the plot to the nearest road in meters (100s).
HARDWOOD	Variable equals 1 if plot is hardwood stand; 0 otherwise.
AGE	Age of plot stand in years at current forest inventory occasion.
NIPF	Variable equals 1 if nonindustrial private-owned; 0 otherwise.
BUILDING DENSITY$_{t-1}$	Number of buildings within a 640 ac circle (Azuma et al. 1999) surrounding plot at preceding forest inventory occasion.
BUILDING DENSITY$_t$	Number of buildings within a 640 ac circle (Azuma et al. 1999) surrounding plot at forest inventory occasion.
1984	Variable equals 1 if observation was taken at 1984 forest inventory occasion; 0 otherwise.
1994	Variable equals 1 if observation was taken at 1994 forest inventory occasion; 0 otherwise.

sion models describing average basal area per acre as a function of stand age, site index, nonindustrial private ownership, and building density (Table 2). The stocking models describe how average basal areas might vary by building density, after accounting for stand and site characteristics. Although past management practices, such as thinning, likely affect current stocking levels, including explanatory variables describing these is not possible because such data were not collected on a consistent basis in previous inventories.

We restricted the analysis to even-aged stands because of difficulties posed by modeling the basal area of uneven-aged stands. Inventory data for 1974 and 1984 indicate average basal areas of 101 ft^2/ac for even-aged conifer stands, and 94 ft^2/ac for even-aged hardwood stands. We estimated two models: one including both conifer and hardwood stands, and a second model including conifer stands alone. We estimated two additional models using generalized least squares to account for random effects associated with potential correlation among plot-specific errors across time. We found the random effects models to be superior (Lagrange multiplier test statistic = 72.97 and 49.16, $df = 1$, $P < 0.0001$) (Table 2).

We found stand age, site index, and whether stand consists of conifers or hardwoods all to have had a statistically significant influence on average basal area per acre (Table 2). We also found ownership by nonindustrial private owners to be a statistically significant factor contributing to lower basal areas for conifer stands. The statistically insignificant coefficient for the dummy variable 1984 suggests that average stocking levels did not differ between the 1974 and 1984 inventories. In all four basal area models, estimated building density coefficients are negative and statistically significant ($P < 0.10$), suggesting that forest stocking tends to be lower

Table 2. Estimated coefficients of ordinary and random effects models describing the basal area of even-aged stands, 1974 and 1984.

	Conifer and hardwood stands		Conifer stands alone	
Variable	Est. OLS coefficient	Est. GLS coefficient[a]	Est. OLS coefficient	Est. GLS coefficient[a]
Constant	–70.407***	–63.065***	–75.461***	–72.073***
	(–5.87)	(–4.86)	(–6.31)	(–5.59)
AGE	4.315***	3.938***	5.112***	4.799***
	(26.29)	(24.00)	(25.77)	(23.90)
AGE^2	–0.021***	–0.018***	–0.029***	–0.026***
	(–15.56)	(–13.59)	(–16.55)	(–14.99)
SITE INDEX	0.486***	0.475***	0.424***	0.434***
	(5.05)	(4.50)	(4.44)	(4.17)
HARDWOOD	66.943***	63.489***	—	—
	(3.40)	(3.15)		
HARDWOOD * AGE	–0.946***	–1.021***	—	—
	(–7.05)	(–7.96)		
HARDWOOD * SITE INDEX	–0.332**	–0.284*	—	—
	(–2.05)	(–1.70)		
NIPF	–4.332	–3.301	–8.198*	–7.618
	(–1.20)	(–0.82)	(–1.87)	(–1.61)
1984	0.513	3.396	–2.184	–0.222
	(0.16)	(1.30)	(–0.59)	(0.07)
BUILDING DENSITY$_t$	–0.098**	–0.085*	–0.108**	–0.097*
	(–2.03)	(–1.72)	(–2.18)	(–1.95)
Summary statistics	$N = 1{,}258$ Adj. $R^2 = 0.46$ $F = 122.33$ $df = 9, 1{,}248$ $P < 0.0001$	$N = 1{,}258$ Adj. $R^2 = 0.47$ LM test = 72.97 $df = 1$ $P < 0.0001$	$N = 901$ Adj. $R^2 = 0.54$ $F = 180.67$ $df = 6, 894$ $P < 0.0001$	$N = 901$ Adj. $R^2 = 0.55$ LM test = 49.16 $df = 1$ $P < 0.0001$

NOTE: The *, **, and, *** indicate that the probability of the t-statistic (in parentheses) exceeding the critical t-value is greater than 90%, 95%, and 99%. Explanatory variables are defined in Table 1.

[a] Estimated using generalized least squares.

in more densely populated areas, as characterized by greater numbers of buildings.

Likelihood of Precommercial Thinning

Forest inventory data indicate that 9% of sample plots were precommercially thinned. We estimated a probit model describing the likelihood that forest owners precommercially thinned between the forest inventory years of 1974 to 1984 and 1984 and 1994, as a function of basal area, site index, slope, road distance, ownership, and building density. We estimated an alternative specification using predicted values of the generalized least squares basal area model (Table 2, second column) to account for the endogenous nature of basal area in the stocking and thinning models. In this case, thinning observed at 1984 and 1994 inventories is specified partly as a function of basal areas and building densities observed in 1974 and 1984. As we have shown, 1974 and 1984 basal areas can be a function of 1974 and 1984 building densities. The alternative model includes only even aged plots, consistent with plots used in the basal area models. Additional thinning models estimated using probit with random effects (results not shown) resulted in estimated correlation coefficients (ρ) that were statistically insignificant ($P > 0.5$), suggesting no significant correlation among plot-specific errors across time.

For the model estimated using actual basal area and all sample plots, we found basal area, road distance, and ownership by nonindustrial private forest owners all to have had a statistically significant negative influence, and site index to have a statistically significant positive influence on the likelihood of precommercial thinning (Table 3). The coefficient for the dummy variable 1994 is statistically significant and positive, suggesting greater precommercial thinning during the 1984 to 1994 period than the 1974 to 1984 period. We found the signs, magnitudes, and statistical significance of coefficients estimated for the model based on predicted basal area values and even aged plots to be similar. In both models, estimated building density coefficients are negative and statistically significant ($P < 0.05$), suggesting that the likelihood of precommercial thinning on private forestland decreases as building density increases. This result is consistent with the hypothesis that investment in active forest management might become less likely in more densely populated areas, as characterized by greater numbers of buildings.

Likelihood of Harvesting

Forest inventory data for 1974 to 1994 indicate that 27% of sample plots had experienced some type of harvest more significant than firewood cutting or other incidental harvest; 16% had experienced clearcutting. We examined the likelihood that forest owners harvested between the inventory years of 1974 to 1984 and 1984 and 1994, and whether harvesting varied by building densities. Conversion of forestland to residential uses often involves harvesting existing forest stands prior to new construction. However, such harvests are not explicitly reported in Forest Inventory and Analysis Program inventories, because they occur on plots considered to have converted to nonforest uses, and the inventories do not report forestry data for such plots. Also, the potential number of plots experiencing pre-urban-conversion harvesting likely is small, because the actual total number of forest plots converting to urban uses has been few. For these reasons, we restrict our analysis to inventory plots on which forest use continued.

Table 3. Estimated coefficients of probit models describing precommercial thinning, 1974 to 1984 and 1984 to 1994.

	Model estimated using actual basal area and all plots		Model estimated using predicted basal area on even-aged plots	
Variable	Est. coefficient	Marginal effect	Est. coefficient	Marginal effect
Constant	–1.449***	–0.152	–1.431***	–0.170
	(–4.83)		(–4.33)	
BASAL AREA $_{t-1}$	–0.005***	–0.001	—	—
	(–7.35)			
Pred (BASAL AREA $_{t-1}$*)*[a]	—	—	–0.010***	–0.001
			(–7.51)	
SITE INDEX	0.006**	0.001	0.008***	0.001
	(2.40)		(3.18)	
SLOPE	0.000	0.000	–0.000	–0.000
	(0.10)		(–0.04)	
ROAD DISTANCE	–0.028*	–0.003	–0.024	–0.003
	(–1.84)		(–1.59)	
NIPF	–0.530***	–0.056	–0.475***	–0.056
	(–3.78)		(–3.11)	
1994	0.357***	0.038	0.525***	0.062
	(3.58)		(4.67)	
BUILDING DENSITY $_{t-1}$	–0.024**	–0.002	–0.029**	–0.004
	(–2.05)		(–2.20)	
Summary statistics	$N = 1{,}563$ Log–L = –403.76 $\chi^2 = 139.73$ $df = 7$; $P < 0.0001$		$N = 1{,}258$ Log–L = –360.90 $\chi^2 = 131.56$ $df = 7$; $P < 0.0001$	

NOTE: The *, **, and *** indicate that the probability of the t-statistic (in parentheses) exceeding the critical t-value is greater than 90%, 95%, and 99%. Explanatory variables are defined in Table 1.

[a] Predicted values from stocking equation for conifer and hardwood stands (Table 2).

We estimated two probit models: one describing the likelihood of any harvest activity more significant than firewood cutting or other incidental harvest (PRIME 1997); and a second describing the likelihood of clearcutting. As with the thinning models, we estimated alternative specifications of these models using predicted values of the basal area model for even-aged stands (Table 2, second column) to account for the endogeneity of basal area in the stocking and thinning models (results not shown). Alternative model results differed little from the two base models estimated using the full sample of even and uneven aged plots. Additional models using probit with random effects (results also not shown) again resulted in estimated correlation coefficients (ρ) to be statistically insignificant ($P > 0.5$), suggesting no significant correlation among plot-specific errors across time in either of the harvest models.

We found basal area to have had a statistically significant positive influence, and slope and road distance a statistically significant negative influence on the likelihood of any harvest activity (Table 4). We found ownership by nonindustrial private forest owners to have had a statistically insignificant effect on any harvest. The statistically significant positive coefficient for the dummy variable 1994 suggests greater harvest activity during the 1984 to 1994 period than the 1974 to 1984 period. One explanation for greater harvesting between 1984 and 1994 are higher stumpage prices, which averaged $140/mbf ($1982) from 1985 to 1992, compared to $126 from 1974 to 1984 (Sohngen and Haynes 1994). Although the negative estimated building density coefficient is consistent with a reduced likelihood of any harvest as building density increases, the coefficient is statistically insignificant ($P > 0.50$), suggesting that increasing building densities have not affected harvests on private forestlands from 1974 to 1994.

Regarding the likelihood of clearcutting, we found basal area and site index to have had a statistically significant positive influence, and road distance a statistically significant negative influence (Table 4). We found ownership by nonindustrial private forest owners to have a statistically significant negative effect on the likelihood of clearcutting ($P < 0.01$). As with any harvest, the statistically significant positive coefficient for the dummy variable 1994 suggests greater harvest activity from 1984 to 1994 than from 1974 to 1984. Again the estimated building density coefficient is negative, but statistically insignificant ($P > 0.50$), suggesting that increasing building densities have not affected the likelihood of clearcutting on private forestlands from 1974 to 1994. Harvest model results are not consistent with the hypothesis that harvesting is less likely in more densely populated areas, characterized by greater numbers of buildings.

Likelihood of Tree Planting Following Harvest

Forest inventory data indicate that 50% of sample plots on which any harvesting had occurred had been planted in trees by the successive inventory. Oregon's Forest Practices Act has evolved over time, but generally has required reforestation following harvest (ODF 1997). Rules do allow natural regeneration in place of planting, as well as other exemptions. We estimated a probit model describing the likelihood that forest owners planted trees following harvest between the inventory years of 1974 to 1984 and 1984 and 1994. An additional planting model estimated using probit with random effects (results not shown) again resulted in an estimated correlation coefficient (ρ) that was statistically insignificant ($P > 0.5$), suggesting no significant correlation among plot-specific errors across time.

Data were restricted to plots on which any harvesting had occurred since the preceding inventory. Basal area observed

Table 4. Estimated coefficients of probit models describing the likelihood of harvesting, 1974 to 1984 and 1984 to 1994.

	Likelihood of any harvest[a]		Likelihood of clearcutting	
Variable	Est. coefficient	Marginal effect	Est. coefficient	Marginal effect
Constant	–1.630***	–0.490***	–3.031***	–0.553***
	(–7.03)	(–7.21)	(–10.48)	(–10.88)
BASAL AREA $_{t\text{-}1}$	0.007***	0.002***	0.007***	0.001***
	(13.77)	(14.04)	(12.80)	(12.63)
SITE INDEX	–0.000	–0.000	0.008***	0.001***
	(–0.04)	(–0.04)	(3.72)	(3.94)
SLOPE	–0.006***	–0.002***	–0.002	–0.000
	(–3.19)	(–3.20)	(–1.17)	(–1.18)
ROAD DISTANCE	–0.021*	–0.006*	–0.023*	–0.004*
	(–1.94)	(–1.95)	(–1.76)	(–1.76)
NIPF	0.088	0.026	–0.265***	–0.048***
	(1.09)	(1.09)	(–2.73)	(–2.72)
1994	0.742***	0.223***	0.717***	0.131***
	(9.66)	(9.86)	(7.77)	(8.13)
BUILDING DENSITY $_{t\text{-}1}$	–0.001	–0.000	–0.000	–0.000
	(–0.65)	(–0.65)	(–0.25)	(–0.25)
Summary statistics	$N = 1{,}551$ Log-L = -739.27 $\chi^2 = 329.19$ $df = 7$; $P < 0.0001$		$N = 1{,}551$ Log-L = -531.40 $\chi^2 = 287.18$ $df = 7$; $P < 0.0001$	

NOTE: The *, **, and *** indicate that the probability of the t-statistic (in parentheses) exceeding the critical t-value is greater than 90%, 95%, and 99%. Explanatory variables are defined in Table 1.

[a] Includes any harvest activity more significant than firewood cutting and other incidental harvest as defined by Forest Inventory and Analysis field instructions (PRIME 1997, p. 64).

at the current (postharvest) inventory, rather than the preceding (preharvest) inventory, was used as a proxy for stocking following harvest and prior to planting. Basal area measurements include only trees having a minimum 2.5 cm dbh—recently planted seedlings generally would not be included (PRIME 1997). On recently harvested stands, inventory-observed basal areas would indicate the amount of postharvest restocking needed. Actual rather than predicted basal areas were used in the planting model, since postharvest basal area likely is more a function of harvest intensity than historical building densities so that basal area in this case is exogenous. We found basal area, road distance, and ownership by nonindustrial private forest owners all to have had a statistically significant negative influence, and site index to have a statistically significant positive influence on the likelihood of tree planting following harvest (Table 5). We found that the likelihood of planting following harvest was greater from 1974 to 1984 than from 1984 to 1994. The estimated building density coefficient is negative and statistically significant ($P < 0.10$), suggesting that the likelihood of tree planting following harvest decreases as building density increases.

We estimated an alternative planting model to account for potential sample selection bias (Heckman 1979) resulting from restricting the model to recently harvested plots. The bivariate probit model examines the likelihood of postharvest planting conditional on the likelihood of harvesting (Table 5). The model is comprised of two equations: one describing the likelihood of planting as specified in the previous planting model, and one describing the likelihood of any harvest as specified in previous harvest models. In this case, we used predicted rather than actual basal area values in the harvest equation shown, so this alternative model is restricted to even age plots. However, results using actual basal area values in the harvest equation and all plots were similar. Again we found basal area, road distance, and ownership by nonindustrial private forest owners to have had a statistically significant negative influence, and site index to have a statistically significant positive influence on the likelihood of tree planting following harvest (Table 5). The estimated building density coefficient is negative, but is not highly statistically significant ($P \sim 0.20$). Taken together, results of the planting models regarding building densities are somewhat consistent with the hypothesis that forestry investment becomes less likely in more densely populated areas as characterized by greater numbers of buildings. However, empirical evidence provided by the bivariate probit model is somewhat weak.

Discussion

The empirical results suggest that increasing building densities have had no statistically significant effect on the likelihood that private forest owners harvested timber in western Oregon from 1974 to 1994. However, empirical results do suggest that increasing building densities are correlated with reduced forest stocking, and reduced likelihood of precommercial thinning and tree planting following harvest. To illustrate the estimated impacts of increasing building densities on thinning, planting, and stocking in western Oregon, we used the estimated model coefficients (Tables 2, 3, and 5) to compute predicted values based on

Table 5. Estimated coefficients of probit and bivariate probit models describing likelihood of planting on recently harvested plots, 1974 to 1984 and 1984 to 1994.

	Probit planting model		Bivariate probit planting|harvest model[a]		
Variable	Est. coefficient	Marginal effect	Planting est. coefficient	Harvest est. coefficient	Combined marginal effect
Constant 1	–1.125** (–2.51)	–0.449	–1.149 (–1.35)	—	–0.895
Constant 2	—	—	—	–2.552*** (–8.26)	—
$\mathit{BASAL\ AREA}_{t}$	–0.010*** (–8.15)	–0.004	–0.010*** (–6.42)	—	–0.004
$\mathit{Pred}(\mathit{BASAL\ AREA}_{t\text{-}1})$[b]	—	—	—	–0.011*** (–11.55)	0.002
SITE INDEX	0.015*** (4.18)	0.006	0.019*** (3.46)	0.002 (0.90)	0.008
SLOPE	0.002 (0.58)	0.001	0.008 (1.60)	–0.005** (–2.14)	0.002
ROAD DISTANCE	–0.042* (–1.82)	–0.017	–0.057** (–1.99)	–0.015 (–1.11)	–0.027
NIPF	–0.472*** (–3.08)	–0.188	–0.368* (–1.94)	0.118 (1.20)	–0.140
1994	0.551*** (3.24)	0.212	0.494* (3.24)	0.842*** (8.94)	0.345
$\mathit{BUILDING\ DENSITY}_{t\text{-}1}$	–0.009* (–1.66)	–0.004	–0.010 (–1.27)	–0.001 (–0.32)	–0.004
Summary statistics	$N = 416$, Log-L = –218.41 $\chi^2 = 139.84$ $df = 7$; $P < 0.0001$		*N* planting = 298, *N* harvest = 1,254 Log-L = –699.50 *Rho* = –0.455 ($P < 0.05$)		

NOTE: The *, **, and, *** indicate that the probability of the *t*-statistic (in parentheses) exceeding the critical *t*-value is greater than 90%, 95%, and 99%. Explanatory variables are defined in Table 1.

[a] Estimated using full information maximum likelihood.

[b] Predicted values from stocking equation for conifer and hardwood stands (Table 2).

varying building density levels (Table 6). In areas having 16 buildings per square mile, for example, nonindustrial private forest owners are 44% as likely to conduct precommercial thinning and 88% as likely to plant trees following harvest, than owners located in areas having 0 buildings per square mile. Nonindustrial private forest owners in areas having 32 buildings per square mile are 17% as likely to conduct precommercial thinning and 77% as likely to plant following harvest, than owners located in areas having 0 buildings per square mile.

The results imply that when there is standing merchantable timber, private forest owners in western Oregon have tended to harvest that timber—the likelihood of harvests has not varied due to population growth and urban expansion. However, the results provide some evidence that investment in forest management by private forest owners, as represented by thinning, tree planting, and stocking, may diminish as population growth and urban expansion increase. Taken together, we feel that the empirical results do support the general conclusion that population growth and urban expansion may be reducing the intensity with which private forest owners manage their forestlands in western Oregon. Although results suggest that harvesting by private forest owners has not been affected by population growth and urban expansion during the time period examined, the question remains what the future likelihood of harvests might be. Will those forestlands currently subject to lower thinning and planting rates and stocking ripen for economically viable harvest in the future? Will those forest owners have any interest in harvesting? It is conceivable that the impacts of population growth and urban expansion on harvesting in western Oregon may not yet be apparent given the historical data analyzed.

A relatively small proportion of all forestland in western Oregon currently is located in places where significant residential and other development has taken place. Of sample plots evaluated in this analysis, 12% of plots were located in areas having a building density over 10 buildings per square mile. Only 1% of plots were located in areas having a building density over 64 buildings per square mile. Although results suggest that forestry in western Oregon seems to be changing with increased population growth and urban expansion, only a small proportion of forestland in the region currently is affected. This is not to say that residential and other development on forest landscapes should be of little interest to forest managers and policymakers in the state. On the contrary, population growth rates projected for western Oregon suggest that greater change could be forthcoming. Rather, it indicates that identifying strong empirical relationships between forestland development and forestry in western Oregon is hampered somewhat by the relatively small number of places where those potential relationships can be observed. Stronger relationships might be found in the future, as human populations increase and urban land uses expand further onto forest landscapes with potentially greater impact.

Conclusions and Policy Implications

The results of previous studies by Barlow et al. (1998) and Munn et al. (2002) for Alabama and Mississippi, and Wear et al. (1999) for Virginia suggest that harvesting and commercial forest management decline as forest landscapes become more populated. Our results generally are consistent with previous studies, and suggest that precommercial thinning and planting following harvest are less likely, and forest stocking somewhat lower on forest landscapes comprised of higher population densities in western Oregon. Our result regarding timber harvest is not consistent with those of previous studies, and suggests that the likelihood of harvesting is not adversely affected by increasing population densities. However, this result could be due to the relatively low number of observations located in areas having higher building densities. Forest landscapes in western Oregon still are relatively undeveloped in comparison to many forests in the eastern United States. Changes in harvesting resulting from increasing population densities may not yet be observable from data collected for the 1974 to 1994 time period and used in our analysis.

Prevailing hypotheses suggest that increasing population densities reduce the productivity of private forestlands, through parcelization, changing forest owner characteristics,

Table 6. Reduction in the estimated likelihood of pre-commercial thinning and planting following harvest, and basal area per acre on private forestland as building density increases in western Oregon.

	Basal area/ac*		Precommercial thinning†		Planting following harvest††	
Buildings/mi^2	Industrial owners	Nonindustrial owners	Industrial owners	Nonindustrial owners	Industrial owners	Nonindustrial owners
0	1.00	1.00	1.00	1.00	1.00	1.00
4	1.00	1.00	0.86	0.83	0.98	0.97
8	0.99	0.99	0.74	0.68	0.96	0.94
16	0.99	0.98	0.53	0.44	0.92	0.88
32	0.97	0.97	0.25	0.17	0.84	0.77
64	0.94	0.94	0.04	0.02	0.67	0.56

NOTE: For example, the basal area on nonindustrial-owned forestland in an area having a building density of 64 buildings/mi^2 is 94% of the basal area on nonindustrial-owned forestland in an area having a building density of 0 buildings/mi^2, all other factors equal. An industrial owner in an area having a building density of 4 buildings/mi^2 is 86% as likely to precommercial thin as an industrial owner in an area having a building density of 0 buildings/mi^2, all other factors equal.

* Computed using estimated GLS coefficients reported in Table 2 (fourth column) for even-aged conifer stands alone, and age of 35 yr and site index of 100.

† Computed using estimated coefficients reported in Table 3 (first column), and basal area of 70 ft^2/ac, site index of 100, and a slope of 30%.

†† Computed using estimated coefficients reported in Table 5 (first column), and basal area of 40 ft^2/ac, site index of 100, and a slope of 30%. Note that the planting projections are based on a building density coefficient that is statistically significant at the 10% level.

forest/urban conflicts, and reducing owners' expectations regarding the future productive potential of their forestlands. Although we are unable to confirm any one of these specific hypotheses, our results do suggest that potential relationships exist between the increasing presence of people on forest landscapes and the manner in which forests are managed. Forestland development may imply more than greater numbers of houses located on forest landscapes—it may involve accompanying changes in forest characteristics. This should be of interest to forest managers and policymakers concerned about the impact of population growth and urban expansion on private forestry.

From an economic perspective, if such changes lead to less investment in forest management and lower productivity over time, we might expect lower quantities of timber supplied by private forestlands in the future. Potential ecological impacts are less certain. Urban expansion on forest landscapes undoubtedly will have some adverse ecological consequences as some forestlands and the habitats they provide are converted to residential and other developed uses. On the other hand, less intensive management and less frequent harvesting of remaining private forestlands could alter or improve certain habitat conditions on some private forestlands. As Munn et al. (2002) suggest, such changes might be brought about by resulting changes in forest density, age class, species composition, and succession. Also less certain are the long-term effects of reduced thinning and planting, and lower stocking, on fuel loads and wildfire risks associated with forestland development. Evaluating the net ecological and wildlife-risk implications of the increasing presence of people on forest landscapes will require anticipating how resulting changes in forest management are likely to affect ecological conditions and processes, and forest stand characteristics in future years.

Maintaining and improving the productivity of private forestlands traditionally has been one concern of forest managers and policymakers. However, some forestry impacts resulting from population growth and urban expansion are inevitable. Even absent potential changes in forestry investment and management, continued population growth and urban expansion onto forest landscapes undoubtedly will increase land prices and raise the opportunity costs of production forestry to a point where forestry's commercial viability may yield to development in more populated locations. This possibility is in addition to growing concerns that new development on forest landscapes is increasing wildfire risks and potential property losses to unacceptable levels. In such places, managers and policymakers may find it fruitful to focus less on waning forest productivity, and more on facilitating new forms of stewardship consistent with the evolving landscape objectives of new forest owners. For some owners, this might involve fostering habitat and aesthetics in addition to or in place of timber production, to preserve or enhance positive externalities provided by remaining forests. For managers and policymakers, it necessarily may also include encouraging actions among private forest owners and public land use planning agencies that minimize wildfire risks in fire-prone landscapes.

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