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Evaluating empirical evidence for housing development effects on the management of remaining private-owned forest in the U.S.

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ABSTRACT

Forest ecosystems are notably influenced by: 1) the rate and spatial distribution of forest land development, and 2) how remaining undeveloped forest lands are managed. Regarding this second factor, economics and ecology research conducted in different locations in the U.S. suggests that increasing housing development can reduce the profitability of commercial timber production and thus the intensity with which landowners manage their forest lands. Some studies, however, suggest that in some locations these effects are not evident. We sought to consider what contextual factors might influence where and when development effects on forest management might become evident. We began with a critical review and synthesis of existing research addressing the degree to which housing development influences private forest management. We followed that with an empirical (logit) analysis of the likelihood of "active" (e.g., thinning) and extractive (e.g., harvesting) management on nonindustrial private forest lands in Oregon and Washington (U.S.), as a function of stand, site, and other factors, including nearby housing development. From our review and synthesis of previous research literature, we conclude that the varying results of previous studies likely owe to a combination of biophysical and socioeconomic contextual factors that influence both how prevalent development impacts might be in different locations and how easily they can be observed in empirical analyses. The results of our analysis of active and extractive management in Oregon and Washington are largely consistent with this finding, with some regions showing statistically significant negative effects owing to housing development, and other regions remaining largely unaffected. We conclude that policymakers and managers need to consider the biophysical and socioeconomic context of different study areas when evaluating the implications of individual study results.

1. Introduction

The dynamic nature of forests and their management are of persistent policy concern worldwide as forest lands increasingly are recognized for their role in providing numerous ecosystem services that benefit people. Specific policy concerns within individual countries vary depending on the prevailing factors influencing forest change. Europe, for example, has experienced significant expansion of forest land area in recent decades, with policy concerns there largely focused on ensuring sustainability of expanding forest ecosystems in the face of climate change and related disturbance (e.g., European Environment Agency, 2018). Recent decades in the United States (U.S.), on the other hand, have seen increasing policy concern about the loss of private forest land to housing and other development and what those changes might mean for how remaining private forest lands are managed (e.g. Gobster and Rickenbach, 2004; Stein et al., 2005, 2009). An important element in these forest policy concerns, whether in the U.S. or Europe, is anticipating the potential roles that private forest lands can play toward achieving national-level forest policy and management goals. This includes anticipating the evolving manner with which private forest landowners manage their forest lands as they adapt to changing socioeconomic and biophysical factors.

Research in both the US and Europe has long focused on examining why some private forest landowners manage their forest lands more intensively for forest commodity production, while other forest landowners either manage less intensively or manage for other noncommodity objectives altogether (e.g., Kuuluvainen et al., 1996, Kline et al., 2000a, 2000b, Van Herzele and Van Gossum, 2008, Fischer et al., 2010, Lidestav and Arvidsson, 2012, Fischer et al., 2013). The emergence of ecosystem services as a forest policy concern has extended research interest toward also examining the degree to which private forest lands can augment public lands in the production of socially desirable ecosystem services, if only forest landowners could be adequately incentivized to do so (e.g., Kline et al., 2000a, 2000b; Mutandwaa et al., 2019; Hashida et al., 2020). More recently, climate change and associated risks such as wildfire have increased concerns about the juxtaposition of housing development and fire-prone forest landscapes (e.g., the wildland-urban interface). These concerns motivate policy interest in understanding whether private forest landowners would be willing to conduct management activities that sequester

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carbon to mitigate climate change (e.g., Latta et al., 2016) or augment wildfire risk mitigation efforts on public lands with similar efforts on private lands (e.g., Fischer et al., 2014; Ager et al., 2015; Olsen et al., 2017).

Pursuing any such policy interests on private forest lands in the U.S. has long been viewed as more feasible when private forest landowners continue to actively manage their forest lands (e.g., KAG (Keep America Growing)., 1999). The idea that such "working" forest lands—those under active management—ensure various ecosystem services and other public benefits, such as wildfire risk mitigation or carbon sequestration, derives in part from an assumption that private forest lands managed for some level of commercial return provide landowners with greater financial incentive to maintain forest land in the face of increasing development pressure from urbanization (e.g. DeCoster, 2000; Sampson and DeCoster, 2000). Loss of forestland to development and associated forest fragmentation is considered one of the most significant "stressors" affecting forests in the U.S. (e.g., Kerns et al., 2016). Forest development was cited along with climate change as a major factor in ecological change (Collins and Larry, 2007:9), leading to the USDA Forest Service's adoption of its Open Space Conservation Strategy which outlined a federal purpose and plan for "conserving working lands," among other objectives (USDA Forest Service, 2007:5). These conservation rationales for maintaining "working" forest lands in the US expand on a long-standing federal policy goal of maintaining and improving the active management and productivity of especially nonindustrial private forest lands to augment national timber supplies (Robbins, 1985:249–259).

These policy concerns in the U.S. underlie a growing research literature examining the potential adverse effects of development on the management of nonindustrial private forest lands (e.g. Wear et al., 1999; Munn et al., 2002; Kline et al., 2004b; Kline and Azuma, 2007; Vickery et al., 2009; Thompson et al., 2017). A premise of this research literature is that development reduces the intensity with which private landowners manage remaining forest lands, thereby reducing forest commodity production, as well as the potential for producing ecosystem services and addressing increased wildfire risk and the desire for greater carbon sequestration. A fear is that reductions in forest commodity production may result in further forest land development if financial returns to forestry lag potential returns from development. Empirical evidence does suggest that in some locations proxy variables representing development—including population, housing, road, and building densities, and proximity to urban areas—are negatively correlated with "commercial management" (e.g., Wear et al., 1999) and more intensive forestry activities such as harvesting (e.g., Munn et al., 2002). Other studies, however, suggest that in some locations these effects are less significant or absent altogether (Kline et al., 2004b; Kline and Azuma, 2007). Do such anomalies suggest that development does not always reduce forest management? Under what circumstances might concern among policymakers and public officials about forest land development and its impact on private forest management be warranted?

In this paper, we consider what contextual factors might influence where and when development effects on forest management might become evident. We begin by providing a critical review and synthesis of existing research literature concerning development effects on private forest management. We then add to that literature by examining correlations between development and both "active" and "extractive" forest management in Oregon and Washington (U.S.), using logit regression models and data from the USDA Forest Service's Forest Inventory and Analysis Program. Although we focused on evaluating studies and data from the US concerning specifically the potential influence of forest land development on private forest management, our results have implications for how analysts might conceive of and approach examining the evolving manner in which private forest landowners elsewhere manage their forest lands in response to changing socioeconomic and biophysical conditions.

2. Critical review and synthesis of previous studies

A body of research literature has examined the forest management activities, preferences, and motivations of private forest landowners (for reviews, see Amacher et al., 2003, Hodgdon and Tyrrell, 2003, and Beach et al., 2005). We consider forest management to be any type of manipulation of the forest stand via cutting, planting, and other silvicultural practices, to achieve a particular outcome desired by the landowner, whether that is financial return, aesthetics, wildlife habitat, or something else. To our knowledge, there have been only seven empirical studies in the U.S. that have examined the degree of correlation between variables characterizing private forest management and proxy variables for development. Prior to these seven studies, research interest concerning such effects had largely focused on how development influences the productivity and profitability of agriculture (Kline and Alig, 2005:711). By the 1990s in the U.S., these policy interests extended to forest lands as continued expansion of the wildland-urban interface increasingly extended into forested locations, coinciding with increased concern about wildfires in especially fire-prone areas.

Two studies—Wear et al. (1999) and Vickery et al. (2009)—were conducted in the southeastern U.S. and New York State, and examined primary data drawn from expert opinion surveys of forestry professionals who reported their perceptions of private forest landowner behavior. Five other studies—Munn et al. (2002), Sabor et al. (2003), Kline et al. (2004b), Kline and Azuma (2007), and Thompson et al. (2017)—examined secondary data from the USDA Forest Service's Forest Inventory and Analysis (FIA) Program, which reports actual observed forest landowner behavior (Table 1). Although these studies differ in their approaches to defining "forest management" and "development," their shared goal has been testing the hypothesis that development leads to reductions in the prevalence or intensity of private forest management.

We note that there also has been additional work examining private forest landowners' perceptions of and responses to development using landowner and other surveys (e.g., Gobster and Rickenbach, 2004; Rickenbach and Steele, 2006). We have opted to omit these from our review so that our review does not become too unwieldy and to focus on those studies that share the commonality of using secondary data to describe forest management behavior or development, and in most cases, both. We feel that the use of secondary data allows for greater confidence in objectively determining the degree of development taking place for different landowners, over and above what might be possible from the responses of landowners themselves to survey questions about development. We feel that such a review of survey-based studies would be highly beneficial for augmenting and expanding on our present analysis.

2.1. Expert opinion surveys

Wear et al. (1999) used expert opinion to examine whether population density was negatively correlated with the location of "commercial" forest land in five Virginia counties. Field foresters were shown county-level forest maps and asked to identify those lands they felt were managed as commercial forests. This information was combined with population densities reported from the US Census and other data. Logistic regression indicated that the likelihood that forest lands were identified by field foresters as being managed as commercial forests was negatively correlated with population density. Results suggested that the predicted likelihood of commercial management declined from 87% at zero people per square mile to 0% at 170 people per square mile (Wear et al., 1999:114). At 45 people per square mile, the predicted likelihood that private lands were managed as commercial forests was 50%. The study has been frequently cited by federal and state agencies and other organizations concerned about protecting forest land as evidence that development and resulting forest fragmentation lead to declines in commercial (or "working") forests (e.g. Stein et al., 2005, 2009;

Table 1
Studies examining correlation between housing development variables and private forest management.

Study	Location	Forestry data source	Evidence of forest management	Development variable examined	Statistically significant
Wear et al. (1999)	Five Virginia counties	Professional forester survey	Managed commercially	Population density	Yes
Munn et al. (2002)[a]	South central states (AL, AR, LA, MS, OK, TN, TX)	FIA[b]	Harvest	Population density	Yes
			Harvest	Proximity to cities	Yes
			Harvest	Contiguous forest area	Yes
Sabor et al. (2003)	Upper Midwest (MI, MN, WI)	FIA[b]	Harvest	Housing density	Yes
Kline et al. (2004)	Western Oregon	FIA[b]	Stocking	Building density	Yes
			Harvest	Building density	No
			Pre-commercial thinning	Building density	Yes
			Post-harvest planting	Building density	Yes
Kline and Azuma (2007)	Eastern Oregon	FIA[b]	Stocking	Building density	No
			Harvest	Building density	No
			Pre-commercial thinning	Building density	No
			Post-harvest planting	Building density	No
Vickery et al. (2009)	Central New York	Professional forester survey	Sustained-yield managed	Population density	Yes
			Sustained-yield managed	Road density	Yes
Thompson et al. (2017)	20 northeastern states	FIA[b]	Harvest	Population density	No
			Harvest intensity	Population density	Yes

[a] A study by Barlow et al. (1998) is cited by Munn et al. (2002) as their pilot study and so is not listed here.
[b] The USDA Forest Service's Forest Inventory and Analysis (FIA) program conducts periodic inventories of the nation's forest resources.

Lettman, 2009; Hanson et al., 2010).

Similarly, Vickery et al. (2009) used a survey of professional foresters to examine whether development—represented by both population and road density—was negatively correlated with the location of forest lands "managed for sustained yield" in five New York counties. Professional foresters were shown a map of the five-county study region and asked to identify those townships likely "to support sustained yield management now and into the future" (Vickery et al., 2009:45). Logistic regression indicated that the likelihood that townships were identified as supporting sustained yield management was negatively correlated with both population and road density, with road density the better predictor. Results suggested that the predicted likelihood of sustained yield management declined from 90% at a road density of about 2 road miles per square mile of area, 50% at 2.5 road miles per square mile, and 10% at a road density of 3 road miles per square mile (Vickery et al., 2009:47). For population density, results suggested that the predicted likelihood of sustained yield management declined from 90% at about 17 people per square mile to 10% at 150 people per square mile, roughly paralleling (and slightly above) the Wear et al. (1999) relationship. At 75 people per square mile, the likelihood that private lands were managed for sustained yield was 50% (Vickery et al., 2009:48).

2.2. Observed behavior studies

In research using secondary data describing observed forest landowner behavior, Munn et al. (2002) combined FIA data describing landowners' timber harvest activities and other variables to examine correlations between development and private forest management in south central states. Development variables included US Census-reported population densities, distance to urbanized areas, and the contiguity of stands with surrounding forest lands. Logistic regressions indicated that the likelihood that forest owners had harvested timber was negatively correlated with population density and positively correlated with forest contiguity. Harvest likelihood also was found to increase with greater distance from urban areas up to 50 to 60 miles, at which point harvest likelihood declined with greater distance. Similarly, Sabor et al. (2003) also combined FIA data with US Census housing density data to show a negative correlation between harvest rates and housing density, with correlation varying by forest type.

Building on Munn et al. (2002), Kline et al. (2004) used FIA data to examine whether building density—their proxy for development—was correlated with basal area, pre-commercial thinning, harvest, and post-harvest tree planting in western Oregon. Building densities (or structure counts) were obtained from aerial photographs (e.g., Lettman, 2009). Regression analyses indicated no correlation between building density and harvest likelihood, but did indicate negative correlations between building density and forest stocking, pre-commercial thinning likelihood, and post-harvest planting likelihood. Taken together, their results support the general conclusion that forest land development may be reducing the intensity with which private forest landowners in western Oregon manage their forest lands, but that these effects are found on only a small proportion of lands (Kline et al., 2004b:41). Follow-up work by Kline and Alig (2005) suggest that this is because only a fraction of productive forest land in western Oregon actually exists at building densities sufficient to adversely influence management (p. 717). In a duplicate study conducted for eastern Oregon, Kline and Azuma (2007) found no correlation between building density and forest stocking, pre-commercial thinning, harvest, and tree-planting following harvest. Their results suggest that either adverse development effects on stocking, thinning, harvest, and post-harvest planting are not prevalent in eastern Oregon or they are not yet observable using FIA data because of generally sparse development the region.

Most recently, Thompson et al. (2017) used FIA data to examine harvest likelihood and intensity, and its correlation with population densities reported by the U.S. Census for 20 northeastern states. A key departure from earlier studies was the inclusion of public forest land along with corporate and nonindustrial private (or family) owned land in the analysis. Thompson et al. (2017) found population density, along with other "social context" variables including local home prices, income, and distances to roads, were correlated with harvest intensity on private forest lands, while key biophysical variables, including basal area, forest type, and distance to roads better explained harvest likelihood. Private-owned forest lands were found to be the least intensely harvested, followed by public and then corporate-owned forest land.

2.3. Evaluating results from previous studies

Taken together, these previous study results would seem to support the general conclusion that the prevalence and intensity of private forest management for timber production appears to decline with greater levels of development, but that these effects may not necessarily be universal (e.g., Kline et al., 2004b; Kline and Azuma, 2007). Moreover, closer examination of individual study results indicates that the magnitudes of development effects found by different studies greatly varies by study location. We suggest that these differing magnitudes likely owe at least in part to differences in the biophysical and socioeconomic contexts of different study locations, and whether individual studies relied on expert opinion or observed behavior.

Most notable are differences in the estimated magnitudes of development effects found by studies based on expert opinion versus observed behavior. Taking the results of Wear et al. (1999) and Munn et al. (2002), for example, the predicted likelihood that forest lands were identified by field foresters as being managed as commercial forests in Wear et al. (1999) shows a steep downward-sloping negative relationship with increasing population density—from 87% at zero people per square mile to 0% at 170 people per square mile (Fig. A1). This relationship has been used, in part, to rationalize federal and state policies to address forest land development (e.g., USDA Forest Service, 2006:27, Lettman, 2009:46). In contrast, the empirical results of Munn et al. (2002) regarding the influence of population density, urban proximity, and forest fragmentation on actual observed harvest likelihood suggest "flatter" relationships. Regarding population density, for example, Munn et al.'s predicted intermediate harvest likelihood declines from 21% at zero people per square mile to 17% at 170 people per square mile, and their predicted final harvest likelihood declines from 10% to 8% (Fig. A1). The correlation between population density and harvest intensity found by Thompson et al. (2017) using similar methods suggests a similarly flat relationship (Thompson et al., 2017:950).

One possible explanation for these differences between the Wear et al. (1999) results based on expert opinion versus those based on observed behavior—besides that the results come from different study areas—could be the fairly general "commercial management" dependent variable examined by Wear et al. (1999) versus the more specific activity-based (final and intermediate harvest) dependent variables examined by Munn et al. (2002). For example, commercial management may have been perceived by the professional foresters who completed the Wear et al. (1999) survey as encompassing a wide range of activities, while "intermediate" and "final harvest" examined by Munn et al. (2002) are fairly specific activities identified in the FIA data. We might also ponder the degree to which "expert opinion" surveys might be more or less reliable for evaluating changes in private forest management, compared to direct observations of management activities found in FIA data, given that they depend on the accuracy of perceptions of the experts surveyed—a question beyond the scope of our analysis.

A second possible explanation for magnitude differences is that the biophysical and socioeconomic context of different study areas can influence the degree to which development effects on private forest management are found to be statistically significant. In Oregon, for example, the biophysical conditions found in the typically dry eastern forest lands examined by Kline and Azuma (2007) differ substantially from the moist western forest lands examined by Kline et al. (2004). These differences conceivably could lead to differences in landowners' expectations regarding their forest landownership objectives. Lower average site indices (or productivity) on eastern Oregon forest lands likely inspire less intensive management generally among eastern Oregon's nonindustrial private forest landowners, compared to those in western Oregon (Kline and Azuma, 2007). Land designated by FIA as "timber land"—the most productive forest land—accounted for 70% of the forest land in eastern Oregon versus 90% in western Oregon, for example. Basal areas found on FIA plots in eastern Oregon also tended to be lower than those found in western Oregon, likely providing less incentive for pre-commercial thinning. Likewise, post-harvest stocking rates in eastern Oregon were found to be higher than post-harvest stocking rates in western Oregon, likely providing less incentive for post-harvest tree planting. These conditions suggest that it may be more difficult to detect development-induced changes in forest management in places where forest management has not been all that prevalent, owing to subpar growing conditions and potentially lower profitability.

We suspect too that socioeconomic conditions also can vary among study areas and influence both study results and the policy implications that might reasonably be drawn from them. For example, lower average building densities found on forest land in sparsely populated eastern Oregon examined by Kline and Azuma (2007), relative to those found on western Oregon (Kline et al., 2004b) generally provide fewer opportunities to observe potential development effects on private forest management. Similarly, although Kline et al. (2004b) did find empirical evidence of negative development effects on basal area, pre-commercial thinning, and post-harvest planting in western Oregon, their inability to find such an effect on harvest likelihood as Munn et al. (2002) did, could reflect the low building densities found among western Oregon forest lands, relative to population densities found among forest lands examined by Munn et al. (2002) in the south-central U.S. Related to this could be differences in the ways development was characterized among different studies—using population density from the U.S. Census in the case of Wear et al. (1999) and Munn et al. (2002), and building density (or counts) from aerial photos in the case of Kline et al. (2004b) and Kline and Azuma (2007). We suspect that building counts taken from aerial photos provided the later studies in Oregon with greater spatial precision than population densities provided by the U.S. Census, especially in largely forested rural areas where Census observational units (e.g., Census tracts) are likely to be fairly large and may not accurately reflect actual population density at the measured forest plots.

A final socioeconomic context factor is land-use history, which can influence how we might interpret the findings of different analyses, and thereby formulate their policy implications. For example, the message that many forest advocates arguably have taken from the negative correlation between population density and commercial management found by Wear et al. (1999) is that development has reduced the likelihood that forest landowners maintain "working forests" in the five Virginia counties studied—that productive forest land is being taken out of production as places become more developed. Indeed, the five-county study area has experienced rather significant population growth, from 36 to 58 people per square mile between 1970 and 1990 (Fig. A2). However, as far back as 1910 area-wide population already was fairly high at 37 people per square mile—the point at which Wear et al. (1999) predict that only 58% of forest land would be commercially managed. But agricultural census data indicate that in 1910 most land (91%) in the Wear et al. study counties was in agriculture (Table A1) and it remained mostly agricultural until about the 1950s when rapid farm abandonment occurred following World War II (Fig. A3). By 1992—the date of land cover data used by Wear et al. (1999)—agricultural lands comprised just 32% of all land in the five-county study area, with forest land conceivably accounting for the balance (less those areas that had transitioned to urban uses) (Table A1). However, former agricultural lands would not necessarily have transitioned immediately to forest. Rather, abandoned farmland simply would not have been reported in the agricultural census, and may have sat for years before actually succumbing to tree cover.

This land-use history suggests that a significant proportion of forest land examined by Wear et al. (1999) may not have ever had a long-term legacy of commercial forest management. Across the five counties examined, at least 71% of the forest land Wear et al. (1999) examined was in agriculture at some point in the 80-year period prior to the study, much of it as recently as the 1950s. Although these lands likely became more fragmented by more recent population growth and development, their agricultural legacy suggests that they could also have been fairly fragmented by past farming. A similar analysis of the five Vickery et al. (2009) study area counties suggests a similar story. In all but one county—Onondaga, including the city of Syracuse—population growth has been fairly flat since 1910 (Fig. A4). For the 5-county study area, 80% of the forest land evaluated by Vickery et al. (2009) for "sustained yield management" had been in agriculture in 1910 (Table A1), and much of it remained in agriculture until it declined more rapidly decline during the 1950s (Fig. A5). An alternative interpretation that emerges from the Wear et al. (1999) and Vickery et al. (2009) results is not necessarily that development is causing forest land to go out of production, but rather that the gradual idling and abandonment of farmland over the past century has led to steady increases in forest land, which now either may or may not eventually be managed for timber production. These land-use transitions likely occurred not because private landowners felt that production forestry might be economically viable, but rather because they at one time felt that production agriculture was not.

3. Methods

The varied results of previous studies suggest to us that differences in the biophysical and socioeconomic contexts of different study areas can lead to researchers finding varying influences on forestry and alternative land uses, and that these should factor into any analysis of development effects on private forest management as well as the policy implications drawn from research results. We sought to evaluate the influence of biophysical and socioeconomic context by conducting new analysis of development effects on private forest management in Oregon and Washington. Our primary goal of this empirical portion of our study was to test and demonstrate the role that context plays in influencing the variability in results that previous studies have found regarding the influence of development on forest management.

3.1. Theoretical framing

Beach et al. (2005) among others have suggested that private forest management is a function of several factors, including market drivers, policy variables, landowner characteristics, and land and resource conditions. We suspect that the potential for housing development to influence private forest management can also involve each of these factors, separately or in combination. Previous research on nonindustrial private forest landowners suggests that landowners in developing locations might reduce their forest management activities focused specifically on timber production for four possible reasons: (1) Development leads to fragmentation of remaining forest land into smaller and less profitable management units; (2) Related changes in the characteristics and management objectives of newer more urban-minded forest landowners lead them to focus less on timber and more on aesthetics, and other nontimber objectives; (3) Continued timber production in developing locations can lead to conflicts arising from conducting forestry in closer proximity to people; and (4) Development creates increasing uncertainty among remaining forest landowners regarding the future of forestry in their locality (Kline et al. 2004: 34–35). Each of these hypotheses touches on one or more of the factors outlined by Beach et al. (2005). Ideally, studies would account for the variety of factors involved, and recognize that different biophysical and socioeconomic contexts may influence the degree to which researchers are able to observe hypothesized effects.

However, we also suggest the need to consider the broader biophysical-socioeconomic context in which private forest management occurs in given locations. Specifically, we propose that biophysical and socioeconomic factors may combine to create landscape feedbacks which also influence the evolving manner with which landowners manage forest lands. Research conducted in both the U.S. and Europe, for example, has long suggested that private forest landowners are heterogeneous in their forest landownership objectives, with some landowners motivated largely by timber and other commodity production interests, some landowners motivated by natural amenities or ecosystem services interests, and some landowners motivated by both of these (e.g., Kuuluvainen et al., 1996, Kline et al., 2000a, 2000b, Van Herzele and Van Gossum, 2008, Fischer et al., 2010, Lidestav and Arvidsson, 2012, Fischer et al., 2013). Research also suggests that these differences in forest landownership objectives can be correlated with parcel sizes and the degree of forest fragmentation in the vicinity where landowners are located, with forest landowners who own smaller parcels in more fragmented landscapes more likely to favor natural amenity or ecosystem services objectives over forest commodity objectives compared to owners on larger parcels in less fragmented landscapes (e.g., Kline et al., 2000b). Given these findings, it is conceivable that as development and fragmentation progress over time, forest landowners' management objectives likely change.

Taking a broader socioecological-systems view, we can imagine other ways to in which forest landowners are likely to be influenced, causing their forest landownership objectives to further evolve. Research in the U.S., for example, suggests that people in urbanizing areas tend to become more supportive of protecting landscapes from further urban development, consistent with an increasing marginal utility for undeveloped land as landscape develop (Kline, 2006). For forest landowners, such factors potentially may act as landscape feedbacks that influence how remaining forest landowners in urbanizing locations might evolve in their forest management objectives in response to changing forest landscapes. We can imagine such changes to include gradual evolution in management focus, from commodity production interests toward greater interest in nontimber objectives such as aesthetics, wildlife habitat, and recreation. Any changes that researchers observe in the intensity with which private forest landowners manage their forest lands may owe in part to changes occurring on the forest landscape as a whole and how those changes are perceived by forest landowners themselves. This is in addition to the influence that encroaching development opportunities may have in terms of acting as a financial incentive to shift land use from forest management toward eventual development.

Accounting for each of the factors noted by Beach et al. (2005) in applied research can be difficult. Accurate data regarding different factors tend to be available from different sources. Data about landowner characteristics, for example, are most easily gathered using surveys of landowners themselves, while accurate data about land and resource conditions are better gathered from land inventories. The disparity among data sources in the ability to provide data about different influential factors often leads researchers to focus on those factors than can best be examined using the data collection methods at hand. Our study is no different. Given our interest in exploring influential factors in the varying results of studies that have examined forest management and development, we chose to focus our analysis on examining similar types of factors considered in previous studies, including biophysical (e.g., site productivity, slope) and socioeconomic factors (e.g., population or housing density, road access), and their potential influence on active forest management. However, we also sought to structure our analysis to consider the potential role of varying biophysical and socioeconomic contexts, and the degree to which they may be associated with differences we might observe in how influential the prevalence of development might be on private forest landowners' management.

3.2. Study area

Oregon and Washington comprise distinct forest regions contrasting in their biophysical and socioeconomic characteristics. West of the Cascades in both states are moist and temperate forests that are among the most productive in the world. Douglas-fir (*Pseudotsuga menziesii*) is a primary species, along with western hemlock (*Tsuga heterophylla*) and silver fir (*Abies amabilis*), among others. "Westside" forests comprise 68% of all non-federal land, with 80% of that privately owned (Lettman, 2011; Gray et al., 2013). The westside also includes most of the largest and fastest growing cities in the Pacific Northwest, including Seattle, WA, and Portland, OR, and smaller cities located along Interstate 5 corridor. Urban and low-density residential land uses comprise 15% of non-federal westside land. In contrast, forests east of the Cascades in both states tend to be drier, more fire-prone, and feature tree species more suitable to these conditions, with ponderosa (*Pinus ponderosa*) and lodgepole pine (*Pinus contorta*) most prevalent. Forests account for 23% of all "eastside" non-federal lands, with 83% of that privately owned. More prevalent, however, are non-federal rangeland (39%) and agricultural lands (31%) (Lettman, 2011, Gray et al., 2013). The eastside also features fewer large cities. Urban and low-density residential uses comprise just 4% of non-federal land.

Additionally, Oregon and Washington differ in the size and geographic distribution of their populations relative to forest land. Oregon's 41 people per square mile (U.S. Census Bureau, 2015) are mostly located west of the Cascades in the Willamette Valley, where agricultural lands tend to buffer much forest land from development. Washington's 107 people per square mile are also mostly located on the westside, but with less agricultural land there, development has more often extended onto forest lands. The two states also differ in their land-use planning histories, potentially resulting in differing rates of forest land conservation. Oregon enacted statewide land-use planning in 1973, requiring all cities and counties to prepare comprehensive plans to conserve forest and farmlands, and concentrate future development within urban growth boundaries. The program largely is credited with reducing development of forest and farmlands since its inception (Gosnell et al., 2010). Washington did not implement statewide planning until 1990—17 years later than Oregon. Washington's approach has been comparatively less centralized, leaving local governments free to develop and enforce land-use plans as they see fit. Although Washington's program seemingly too has begun to conserve forest and farmlands, some evidence suggests that its decentralized approach may be allowing more extensive forest and farmland development than in Oregon (Kline et al., 2014).

Our Oregon and Washington study area thus can be thought of as comprised of four distinct regions: (1) western Washington, with productive forests, higher population density, and less restrictive land-use planning; (2) western Oregon, with productive forests, higher population density, and more restrictive land-use planning; (3) eastern Washington, with less productive forests, lower population density population, and less restrictive land-use planning, and (4) eastern Oregon, with less productive forests, lower population density, and more restrictive land-use planning. The juxtaposition of these four regions enables comparisons of the varying influences that development might have on private forest management under these differing biophysical and socioeconomic contexts.

3.3. Data

We examined plot-level forestry data obtained from the USDA Forest Service FIA Program's annual inventories of forest land in Oregon and Washington (Bansal et al., 2017; Holgerson et al., 2018) for plots initially measured 2001–2006 and remeasured 2011–2016. We chose this sample because it encompasses plot remeasurements following the FIA Program's 2001 shift from a periodic to an annualized inventory, enabling consistency in the number of years between individual plot remeasurements. Although earlier inventories to exist, use of prior inventories would have prevented such consistency because the time period between plot remeasurement would vary across plots. Together, the data describe a period of robust housing growth from 2001 to 2006, and a period of slower but recovering housing growth following the 2008 recession.

The data describe forest conditions at each inventory and forest management activities landowners have conducted in the 10 years since the previous measurement. Activities include harvesting of varying intensities, pre-commercial thinning, improvement cutting, and site preparation. Additional plot information included live tree basal area, site productivity (Hanson et al., 2002), slope, steepness, and distance to the nearest improved road. We combined these data with data describing the numbers of buildings on nonfederal land observed within 640-acre circles surrounding FIA plots (Lettman, 2011; Gray et al., 2013). The combined data set provided 1734 observations of actual forest management activities conducted by private forest landowners in Oregon and Washington for the time period examined.

We note that our focus on plot-level data provided by periodic forest inventories owes to our interest in comparing our results to those of previous studies that also relied on similar forest inventory data. Such inventories are good at providing data concerning the characteristics of forest land. They are not, however, very good at providing data concerning the characteristics of private forest landowners. Data concerning forest landowners more typically would be gathered from focus groups or surveys of landowners themselves. We chose to focus our analysis on forest inventory data, to enable comparisons of our results with previous studies that have also relied on forest inventory data. Ideally, future studies might try to combine use of forest inventory data with survey data, to best take advantage of the informational advantages of each data collection method.

3.4. Empirical analysis

Using methods similar to those of previous studies based on FIA data (e.g., Munn et al., 2002; Kline et al., 2004b; Kline and Azuma, 2007), we used logistic regression models to evaluate the likelihood that private forest landowners conducted various forest management activities, as a function of stand and site characteristics, and nearby development. We defined two dependent variables to describe two degrees of forest management intensity over the 10-year measurement period: (1) "Extractive management" included clearcutting, partial cutting, firewood cutting, and incidental cutting (Table 2); and (2) "Active management" included pre-commercial thinning, improvement cutting, and site preparation, as well as the extractive management activities. Each of the two dependent variables were assigned a value of "1" if during the second (2011–2016 inventory) evidence of extractive or active management activities had been found as occurring since the previous (2001–2006 inventory). They were assigned a value of "0" if evidence of management had not been found.

Our independent variables represented stand and site conditions typically found to influence forest management (e.g., Kline et al., 2004b). These include basal area of the stand, slope of the site, mean annual increment as a measure of site productivity, the presence of roads as a proxy for stand access, and ownership by nonindustrial versus industrial owners. We characterized development using the 640-acre building counts. We used dummy variables to account for state and regional differences in how much development might influence forest management on private forest lands (Table 2). Although there likely are

Table 2
Dependent and independent variables examined in the logit models ($N = 1734$).

Variable	Definition	Mean
Dependent variables		
Extractive management	Equal to 1 if plot experienced a clearcut, partial cut, firewood cut, or incidental cut; 0 otherwise.	0.25
Active management	Equal to 1 if plot experienced a precommercial thin, improvement cut, site preparation, or any of the extractive management activities; 0 otherwise.	0.29
Independent variables		
Basal area	Total live basal area at time 1.	90.04
Slope	Mean percent slope.	26.88
Mai	Mean site productivity (cubic feet per acre per year).	123.80
Road 0 to 300	Equal to 1 if plot located within 300 ft of an improved road; 0 otherwise.	0.35
Road 301 to 1000	Equal to 1 if plot located from 301 to 1000 ft of an improved road; 0 otherwise.	0.31
Road >1000	Equal to 1 if plot located over 1000 ft of an improved road; 0 otherwise.	0.35
Nipf	Equal to 1 if plot located on land owned by a nonindustrial (versus an industrial) owner; 0 otherwise.	
WA	Variable equal to 1 if plot is located in Washington State; 0 otherwise.	0.43
West	Variable equal to 1 if plot is located west of the crest of the Cascades; 0 otherwise.	0.35
Buildings	Average number of buildings counted within a 640-acre circle surrounding plot during the measurement period.	10.71

a variety of factors other than stand and site conditions, and housing developments that influence the behavior of forest landowners, including landowners' age, landownership objectives, personal finance needs, and expectations about timber prices, among other factors, the individual characteristics of landowners remain largely unknown. While this does lead to the likelihood that some potentially influential variables are omitted, our analysis does retain comparability with previous analyses, which was one of the objectives of our analysis.

4. Results

The logit models describing the likelihood of active and extractive management are highly statistically significant, indicating that collectively the explanatory independent) variables help to explain variation in in the likelihood of management of private forest lands. Many of the individual explanatory variables are statistically significant at a 95% level of confidence ($P < 0.05$) or better, indicating that we are at least 95% certain that their effect on the likelihood of particular management activities is greater than zero (or no effect).

Estimated model coefficients indicated that stand and site characteristics, including basal area, mean annual increment, and distance to roads, are correlated with both active and extractive forest management likelihood among private forest landowners at a high level of statistical significance ($P < 0.05$) (Table 3), consistent with previous studies (Munn et al., 2002; Kline et al., 2004b, and Kline and Azuma, 2007). Statistically significant negative coefficients for WA and WEST dummy variables in the extractive management model indicate less likelihood of extractive activities in Washington relative to Oregon, and west of the Cascades relative to east, after controlling for other influencing factors (Fig. 1). Estimated coefficients for NIPF, distinguishing nonindustrial from industrial private forest landowners, were not statistically significant ($P > 0.10$) and so were dropped from final models. Estimated coefficients for BUILDINGS—our independent variable representing development—fell just outside our chosen statistical significance threshold ($P < 0.10$), indicating fairly weak evidence for measurable adverse development impacts on active ($P = 0.13$) and extractive ($P = 0.16$) forest management across the study area. However, an estimated interaction coefficient denoting development specifically in western Washington (BUILDINGS*WA*WEST) was statistically significant, indicating less likelihood of active ($P < 0.01$) and extractive ($P < 0.05$) management in more developed western Washington locations. Alternate logit models estimated for individual regions (Appendix) indicate some differences in these basic results across regions, but did not alter our general findings concerning development influence on active and extractive forest management.

Table 3
Estimated coefficients of logit models describing the likelihood of "active" and "extractive" management on private forest land in Oregon and Washington (N = 1734).

Variable	Active management		Extractive management	
	Estimate coefficient	Wald chi-square	Estimate coefficient	Wald chi-square
Intercept	−0.759***	19.66	−0.945***	27.77
Basal area	0.003***	19.51	0.006***	54.75
Slope	−0.002	0.77	−0.004	2.23
Mai	0.003**	4.79	0.003**	6.07
Road 301 to 1000	−0.543***	17.04	−0.492***	12.44
Road >1000	−1.006***	49.79	−1.016***	44.36
WA	−0.103	0.75	−0.294**	5.31
West	−0.221	1.65	−0.632***	11.82
Buildings	−0.004	2.26	−0.004	1.96
Buildings * WA * West	−0.022***	7.77	−0.019**	5.35
Summary statistics:	Log-likelihood = 1970.1 $\chi^2 = 116.6$, df = 9, $P < 0.0001$		Log-likelihood = 1794.6 $\chi^2 = 143.4$, df = 9, $P < 0.0001$	

Dependent and independent variables are described in Table 2.
** Indicate statistical significance at the 5% level.
*** Indicate statistical significance at the 1% level.

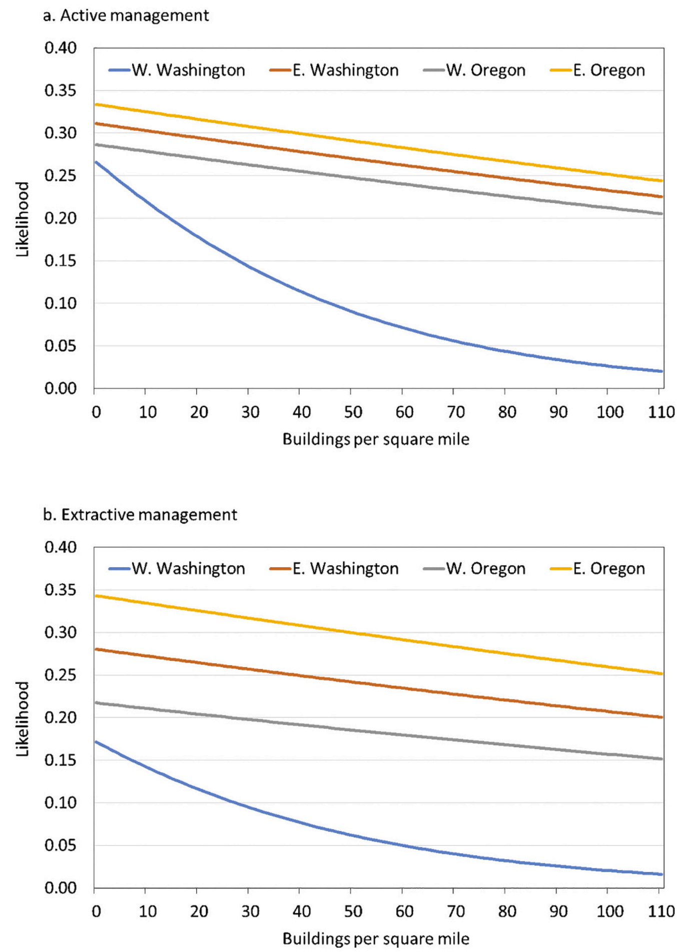


Fig. 1. Estimated likelihood of active and extractive management at varying building densities, computed from estimated coefficients reported in Table 3 holding other variables at mean values.

5. Discussion

Taken together, the results of previous studies along with our new results concerning private forest management in Oregon and Washington, suggest that development effects on private forest management can vary across different biophysical and socioeconomic contexts, and potentially by the data and methods used to examine these processes. There are likely a variety of possible explanations for these differential effects which factor alone or in combination to influence the results that researchers find pertaining to how private forest management is influenced by forest land development, and we consider each in turn.

A first set of potential factors involve the inherent productivity potential of forest land examined and the degree and prevalence of development taking place in different study regions. These factors likely combine to influence how much change in forest management researchers might observe with increasing development. In our Oregon and Washington case study, for example, development is more strongly correlated with reduced intensity of private forest management in more developed locations, such as western Washington. These effects were found to be less prevalent in less developed locations or in locations where active forest management itself was less likely due to less favorable growing conditions, such as eastern Oregon. One possible explanation for these differences is lower inherent productivity of forest land east versus west of the Cascades (e.g., Kline and Azuma, 2007), which tends to reduce the likelihood of intensive management generally (Zhang and Nagubadi, 2005), coupled with greater distances to markets for harvested eastern timber. Also factoring are differences in the land-use planning approaches that Oregon and Washington have taken, which can influence rates of development. Oregon's approach typically is viewed as somewhat more restrictive and thus conceivably more protective of forest land than Washington's approach (e.g., Kline et al., 2014), which conceivably would lead to fewer development impacts on Oregon forests, and therefore fewer or less prevalent changes in private forest management.

A second potential factor is the likely increasing marginal utility of natural amenity or ecosystem service values among both forest landowners and the public, associated with remaining forest land as locations develop (e.g., Kline, 2006). The growing scarcity of undeveloped forest lands in developing locations could cause some private forest landowners to forego intensive forest management activities that culminate in eventual harvest, in favor of managing or habitat, aesthetics, and other nontimber values (Kline et al., 2004a). Many nonindustrial private forest landowners in both the U.S. and in Europe have long been shown to base their management decisions on nontimber values in addition to or in place of timber values (e.g., Kuuluvainen et al., 1996; Kline et al., 2000a, 2000b; Fischer et al., 2010; Lidestav and Arvidsson, 2012; Fischer et al., 2013), and most surveys of nonindustrial private forest owners find a class of owners with little interest in commercial timber production (Dhubhain et al., 2007). These "nontimber" owners tend to own smaller forest parcels, which may be becoming more common in places experiencing development. Shifts in forest management focus from active management for timber production, toward amenity and other nontimber values could reflect increasing marginal utilities for nontimber values among forest landowners, particularly on smaller forest parcels on which the profitability of active management and timber production may be waning.

A third potential factor is the historical land-use legacy of different study areas, which appears to influence what land uses and management activities are prevalent in the present. For example, a fairly recent history of widespread agricultural use prior to the advent of forest cover in a region, as is clearly evident in the Wear et al. (1999) and Vickery et al. (2009) study areas, conceivably could reduce the likelihood that researchers would observe active forest management, if existing forest cover has resulted more from the idling or abandonment of agricultural land and farming operations, rather than any deliberate or intentional transition of agricultural land to production forestry on the part of landowners. Previous studies of development effects on private forest management do not appear to have considered this possibility. Related to the role of historical legacy is the relative prevalence of nonindustrial versus industrial owned forest land, with nonindustrial forest land tending to be managed less intensively than industrial forest land generally.

In addition to the potential roles that biophysical and socioeconomic context might play in influencing the results found by studies that have examined development effects on forestry, is the likely influence of study methodology itself. Specifically, we are thinking here of the distinction between "expert" opinion studies versus those drawing on data describing observed forest landowner behavior. From our review, there appears to be a tendency for studies that have relied on "expert" opinion (e.g., Wear et al., 1999; Vickery et al., 2009) to find developed effects of much greater magnitude than those studies that have relied on field data describing observed (or actual) forest management activities. A possible explanation for these differences is the more generalized nature of dependent variables examined by the expert opinion studies—"commercial management" (Wear et al., 1999) and "sustained yield management" (Vickery et al., 2009), for example—which arguably describe general management philosophies rather than specific management activities. Experts taking part on such studies may find it fairly easy to assign a variety of land to such categories. Alternatively, the dependent variables constructed and examined by studies that have relied on field data describe fairly specific management activities—harvest and thinning, for example—which conceivably would be prevalent only among landowners whose forest lands had conditions favorable for such activities, such as merchantable timber or overstocked stands.

A second consideration regarding methodology is the degree to which expert opinion survey responses might reflect preconceived notions (or biases) on the part of the "experts" concerning development effects on private forest management, and yield study results that simply reflect these biases, despite what actual field data might show about actual landowner behavior. Whatever the reason, researchers, policymakers, and managers will want to weigh the results that arise from different data and methodologies and consider what different studies add to the body of evidence available concerning development effects on private forestry.

Ideally, researchers would focus on examining the actual process at play, to the extend that data and analytical methods allow. If the hypothetical processes associated with development potentially involve fragmentation of forest parcels into management units that are too small to be economically viable, or changes in landowners, or increasing conflicts with newer residents who are unwilling to tolerate forest practices, or the increasing opportunity costs of forest production, all implied by Kline et al. (2004), then perhaps future studies could be framed to directly examine the reasonableness of these explanations. We suggest choosing empirical strategies purposefully to enable examining the dynamics and interactions of interest so that hypothesized causal relationships can be reasonably tested. In some cases, a mix of approaches, including econometric analysis of both secondary data and interview or survey data—whether gathered from forestry experts or forest landowners themselves—might provide a richer understanding of what and why forest management changes are taking place and whether they might be of policy concern. Given that context appears to matter, policymakers are cautioned to not base policy decisions solely on research findings from studies conducted in regions with noticeably different forestry-related and socioeconomic conditions and trends.

6. Conclusions and implications for policy and research

There remains long-standing interest in and concern about the presumedly negative influence that housing and other development might have on how remaining private forest landowners manage their remaining forest lands. The body of research addressing these effects using secondary data describing development in different locations in the U.S. has shown mixed results concerning the presence and magnitude of correlations between development and the degree of management occurring on private forest land. From our critical review and synthesis of this body of research, as well as our own new analysis using field data for Oregon and Washington, we conclude that varying study contexts—including both biophysical and socioeconomic—as well as study methodology likely contribute to producing varying results among studies conducted in different locations. Conceivably, these differences also can lead to varying policy implications that researchers, policymakers, and managers will want to consider when seeking to address forest land development issues in the wildland-urban interface and similar contexts. More broadly, researchers in the U.S., Europe, and elsewhere are reminded not to lose sight of the fact that individual studies of forest landowner behavior are conducted within a specific biophysical and socioeconomic context that is defined by the study area. While individual studies may lead to research results that suggest specific policy implications, whether those implications are relevant to locations characterized by distinctly different biophysical or socioeconomic circumstances from the study area sometimes remains an open question until additional studies find corroborating results.

Whether correlations found between development and private forest management alone justify significant public policy concern likely depends on the biophysical and socioeconomic context of changes affecting forestry in given locations, and how these are perceived by landowners both spatially and temporally. There has been a tendency to advocate for open space conservation based in part on the perceived need to protect "working lands,"—for forest lands, those continue to produce merchantable timber and other commercial commodities. By generating revenue for landowners, working forests are believed to better compete with other land-use opportunities faced by landowners, such as development. For this reason, previous studies often have focused on the degree to which forest landowners continue to pursue more active forest management practices, such as harvesting and thinning, as development increases.

Persistent concern about whether forests are producing timber or other commercial commodities, and whether population growth, development, and fragmentation are creating forests that are not "working" in this way, tends to avoid broader consideration of public preferences concerning how best to conserve and manage remaining forest lands in the face of development and other landscape level policy concerns including providing a variety of desired ecosystem services and landscape values. The influence of socioeconomic change on private forestry, and in turn national timber supplies and ecosystem conditions and processes, justifiably is of significant public policy concern. However, researchers, policymakers, and managers must not lose sight of the possibility that forests need not always be intensively or actively managed for eventual commercial harvest to generate benefits for both landowners and the public. This is because private forests also produce valued ecosystem services and in urbanizing locations, the marginal values that both landowners and the public hold for these ecosystem services may be rising as development reduces and fragments remaining forest land. Too myopic a focus on commercial production risks overlooking the broader implications these studies may have regarding the provision of public goods from remaining private forest lands as development draws near.

This is not to say that there are not situations where the public may be better off if private forest lands were more actively or intensively managed. Management to provide ecosystem services may depend too on some thinning and harvest. Also, in fire-prone forests where housing and other development are prevalent, there can be significant public interest in encouraging private forest landowners to thin, prune, plant fire-adapted species, and otherwise manage to reduce wildfire risk, if not actually conduct commercial harvests. In such cases, more active or intensive forest management can help to reduce landscape-level wildfire risk, especially if encouraged and conducted with strategic consideration of the comparative advantages that particular forest parcels may have in reducing overall landscape-level risk (e.g., Ager et al., 2015). Circumstances involving insects or disease may offer other examples.

By considering a broader socioecological-systems view of forests and people, we may find that as forest landscapes experience greater development, fragmentation, and loss of forestland, there may be landscape feedbacks associated with biophysical and socioeconomic changes that influence remaining landowners to shift their thinking about what forest values they are most interested in producing. Potential shifts in forest landowners' objectives from forest commodity production toward protection and enhancement of natural amenities including aesthetics, habitat, and recreation, aligns with research suggesting increasing marginal utilities for landscape amenities among people living in rapidly developing locations where such amenities are becoming increasingly scarce (e.g., Kline, 2006). We acknowledge that we have only examined the one-way effect that increasing development may have on influencing private landowners' forest management activities. However, we hypothesize that there could be landscape feedbacks that arise from people's changing relationships to landscapes as they become more developed. In addition to examining the effects of development on private forest management, research seems warranted to examine whether and how landscapes change, such as via declines in forest land or its fragmentation into smaller parcels, might influence interest among remaining forest landowners to maintain remaining undeveloped forest lands and the nontimber values they provide.

Our conclusions have potential implications for future research. Most noteworthy is the need to consider the biophysical and socioeconomic (including historical) context of different study areas when evaluating the implications of individual study results, and how these varying contexts may influence observed forest landowner behavior. A thorough review and synthesis of survey-based studies that have gathered data directly from landowners concerning their management objectives and practices, and the factors including development that influence them, may be a logical next step and would likely be of significant value. Ideally, new surveys would be geo-coded for location, so that survey responses align with land-use data for characterizing development. Our analysis relied solely on secondary data, which has the advantage of providing detailed information about forest land and its characteristics, but a disadvantage in that it does not typically tell us much about forest landowners, their landownership objectives, and details about their forest land management activities. Researchers pursuing additional studies might consider combining secondary (e.g., forest inventory) data with surveys or interviews of forest landowners, to gain the benefits of both secondary and primary forms of data. Also important is considering how development and accompanying fragmentation of remaining forest land may be leading to both stand- and landscape-level changes, and how these changes influence supplies of valued natural amenities and ecosystem services beyond forest commodities alone.

Lastly, we suggest a need to consider the potential influence of methodological and data differences among studies when examining development effects on private forest management, as these appear, at least anecdotally, to be influencing the magnitudes of development effects on private forestry found by different studies. Examining development effects on forestry is challenging in part because of potential limitations in the variation in variable describing development. There often are few observations of "working forests" along the full gradient of development from very rural to wildland-urban interface, especially when using cross-sectional data. Researchers planning future studies might consider the use of alternative data and approaches to see if they yield contrasting or new results. Greater collection and use of panel data specifically designed to measure both development and forest management activities would help. Also, useful would be the application of different empirical methods, such as difference-in-difference or other approaches, that may better highlight the potential causal effects of development occurring over specific time periods.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Appendix

Table A1. Computed minimum acres of forest land once in agriculture for Wear et al. (1999) and Vickery et al. (2009) study counties.

Study/ county	All land[a]	1910 land in agriculture[b]	Forest land at time of study[c]	Minimum acres forest land once in agriculture[d]	Proportion forest land once in agriculture[e]
Five Virginia counties from Wear et al. (1999)					
Albemarle	462,720	386,492	278,205	201,977	0.73
Fluvanna	183,680	151,554	137,348	105,222	0.77
Greene	100,480	87,525	53,599	40,644	0.76
Louisa	318,080	235,370	228,537	145,827	0.64
Nelson	302,080	240,824	231,868	170,612	0.74
All	1,367,040	1,101,765	929,557	664,282	0.71
Five New York counties from Vickery et al. (2009)					
Chenango	572,160	539,084	257,266	224,190	0.87
Cortland	320,000	299,707	175,787	155,494	0.88
Madison	419,840	381,434	168,544	130,138	0.77
Oneida	776,320	690,431	361,322	275,433	0.76
Onondaga	499,200	437,658	206,788	145,246	0.70
All	2,587,520	2,348,314	1,169,707	930,501	0.80

[a] U.S. Bureau of the Census (2000).
[b] National Agricultural Statistics Service (2009).
[c] For Wear et al. (1999): 1992 forest land areas reported in the paper. For Vickery et al. (2009): 2006 private-owned forest land reported by the USDA Forest Service's Forest Inventory and Analysis program (https://www.nrs.fs.fed.us/fia/).
[d] Computed as: forest land at time of study – (all land – 1910 land in agriculture).
[e] Computed as: minimum acres of forest land once in agriculture divided by forest land at time of study.

Table A2. Estimated coefficients of region-specific logit models describing the likelihood of "Active" management on private forest land for western Washington, eastern Washington, western Oregon, and eastern Oregon

Variable	Estimate coefficient	Wald chi-square	Estimate coefficient	Wald chi-square
	Western Washington		*Eastern Washington*	
Intercept	−1.029**	5.22	−0.154	0.10
BASAL AREA	0.004***	8.45	0.000	0.02
SLOPE	0.004	0.66	−0.025***	8.92
MAI	0.001	0.22	−0.001	0.02
ROAD 301 to 1000	−0.495*	3.79	−0.298	0.52
ROAD >1000	−0.851***	7.39	−0.673**	3.97
BUILDINGS	−0.026***	10.83	−0.001	0.16
Summary statistics	$N = 426$		$N = 315$	
	Log-likelihood = 465.9		Log-likelihood = 329.0	
	$\chi 2 = 40.7$, df = 6, $P < 0.0001$		$\chi 2 = 16.8$, df = 6, $P < 0.01$	
	Western Oregon	*Eastern Oregon*		
Intercept	−1.154***	11.52	−1.117**	6.05
BASAL AREA	0.003***	9.03	0.005*	3.62
SLOPE	0.000	0.00	−0.007	0.72
MAI	0.004**	4.84	0.007	1.37
ROAD 301 to 1000	−0.674***	12.63	−0.380	1.04
ROAD >1000	−1.215***	25.63	−0.894***	7.70
BUILDINGS	−0.005	1.59	−0.003	0.25
Summary statistics:	$N = 693$		$N = 300$	
	Log-likelihood = 820.6		Log-likelihood = 336.6	
	$\chi^2 = 53.1$, df = 6, $P < 0.0001$		$\chi^2 = 15.3$, df = 6, $P < 0.02$	

* Indicate statistical significance at the 10% level.
** Indicate statistical significance at the 5% level.
*** Indicate statistical significance at the 1% level.

Table A3. Estimated coefficients of region-specific logit models describing the likelihood of "extractive" management on private forest land for western Washington, eastern Washington, western Oregon, and eastern Oregon.

Variable	Estimate coefficient	Wald chi-square	Estimate coefficient	Wald chi-square
	Western Washington		*Eastern Washington*	
Intercept	−2.118***	16.59	−0.274	0.28
BASAL AREA	0.008***	30.30	0.000	0.04
SLOPE	0.001	0.05	−0.025***	8.35
MAI	0.002	0.75	0.001	0.07
ROAD 301 to 1000	−0.407	2.04	−0.312	0.55
ROAD >1000	−0.985***	7.02	−0.918***	6.76
BUILDINGS	−0.024***	8.20	−0.007	0.79
Summary statistics:	N = 426		N = 315	
	Log-likelihood = 394.1		Log-likelihood = 308.6	
	$\chi^2 = 56.5$, df = 6, $P < 0.0001$		$\chi^2 = 20.0$, df = 6, $P < 0.003$	
	Western Oregon		*Eastern Oregon*	
Intercept	−1.730***	22.92	−1.206***	6.98
BASAL AREA	0.006***	25.56	0.005**	3.93

(continued on next page)

(*continued*)

Variable	Estimate coefficient	Wald chi-square	Estimate coefficient	Wald chi-square
SLOPE	−0.001	0.10	−0.008	0.84
MAI	0.004**	4.90	0.007	1.54
ROAD 301 to 1000	−0.624***	9.65	−0.330	0.78
ROAD >1000	−1.093***	18.35	−0.837***	6.69
BUILDINGS	−0.003	1.05	−0.003	0.21
Summary statistics	N = 693		N = 300	
	Log-likelihood = 752.4		Log-likelihood = 334.9	
	$\chi^2 = 61.7$, df = 6, $P < 0.0001$		$\chi^2 = 15.0$, df = 6, $P < 0.02$	

** Indicate statistical significance at the 5% level.
*** Indicate statistical significance at the 1% level.

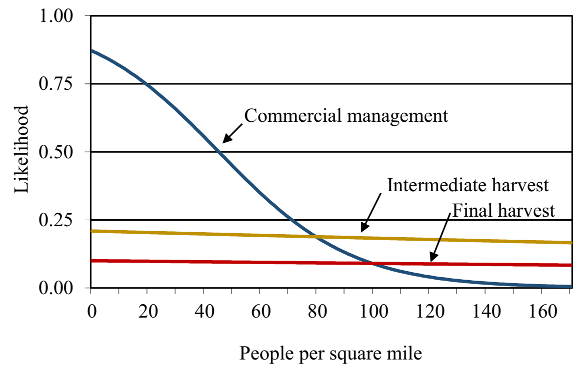


Fig. A1. Population density and predicted likelihoods of commercial management (Wear et al., 1999) and intermediate and final harvest (Munn et al., 2002).

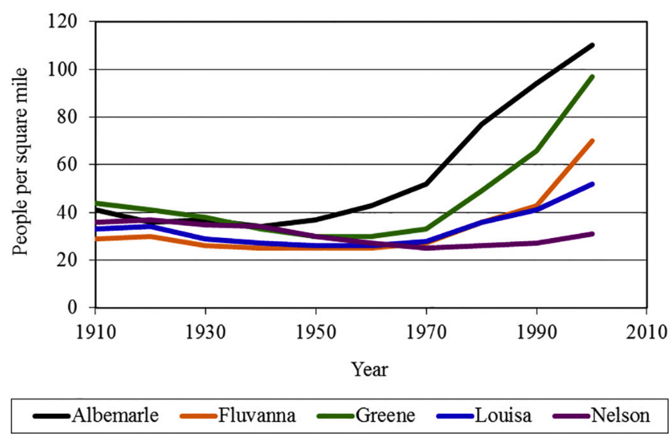


Fig. 2A. Historical population densities in five Virginia counties studied by Wear et al. (1999).

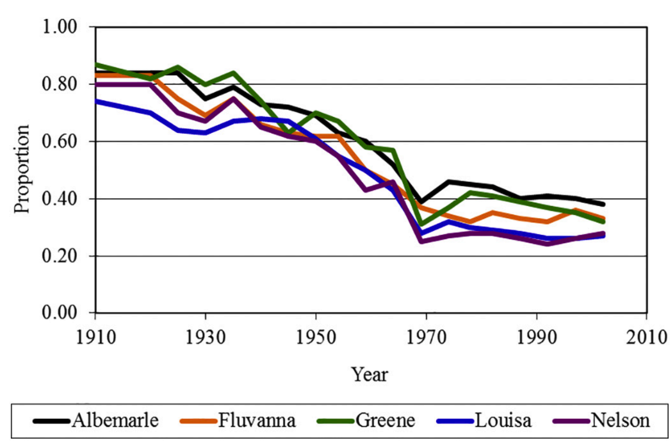


Fig 3A. Proportion of land in agriculture in five Virginia counties studied by Wear et al. (1999).

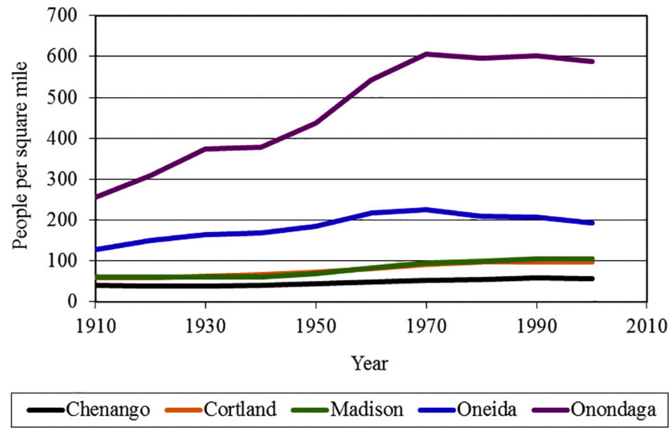
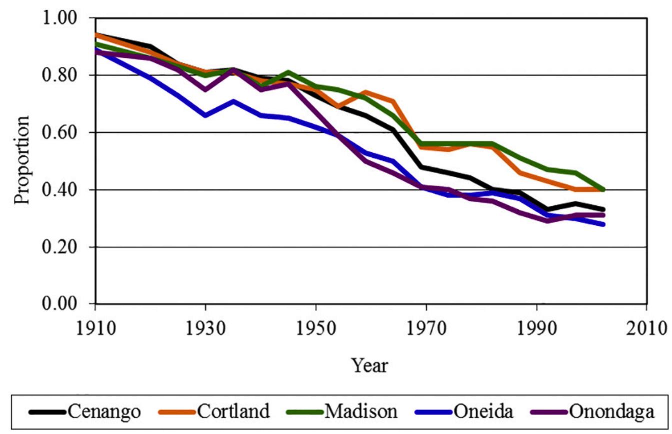


Fig 4A. Historical population densities in five New York counties studied by Vickery et al. (2009).



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