# Changes In Land Use, Forest Fragmentation, And Policy Responses

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## Introduction

Land-use conversion is a primary determinant of environmental change in terrestrial ecosystems. Projections are for more than 50 million acres of U.S. forest to be converted to developed uses (e.g., parking lots) over the next 50 years (Alig et al. 2004, Alig and Plantinga 2004), as the population grows by more than 120 million people. Land use change can lead to forest fragmentation--the transformation of a contiguous patch of forest into disjunct patches. Forest fragmentation is considered to be a primary threat to terrestrial biodiversity. We examine underlying behavioral factors affecting landowner decisions, and analyze the effects of land use policies on forest fragmentation.

More attention to date has been focused on biophysical aspects of forest fragmentation, in contrast to socio-economic and policy matters. If the country is facing the prospect of considerably more forest fragmentation, more attention to socio-economic and policy factors can aid in exploring the efficiency of options for addressing effects of land-use conversion and allowing society sufficient lead time to implement land conservation measures. A central part of this is better understanding of socio-economic determinants of land use conversion leading to forest fragmentation and the importance of land use decisions.

## Impacts of Forest Fragmentation

Forest fragmentation has a multitude of effects on forest ecosystems. On the negative side, forest fragmentation is considered to be a primary threat to terrestrial biodiversity (Armsworth et al. 2004). In the United States, approximately twenty percent of resident bird species have experienced significant population declines in recent years (National Audubon Society 2002). Although there are many possible causes of these declines, one central factor is thought to be the fragmentation of forested habitat (Askins 2000). Particularly at risk are migratory songbirds, many of which nest in forests of the eastern U.S. These species are of significant conservation interest because they serve as indicators of ecosystem quality and are of considerable value to recreationists. Human health may also be impacted by forest fragmentation, as Jackson and Gilborn (2005) indicate that Lyme disease may increase with increased contact with wildlife as vectors because of more forest edge. Possible positive impacts include increased tree growth of many species if additional sunlight reaches trees that are closer to forest edges. Some wildlife species in forest ecosysems benefit from forest fragmentation, e.g., whitetail deer.

Our intent in this section is to point out examples of the many possible impacts of forest fragmentation, recognizing that not all are negative, depending on one's point of view. The overall or aggregate impacts of forest fragmentation depends in part on the social weighting given to the different components of forest ecosystems. Such aggregate analysis is outside the scope of our paper. Our findings can be used in analyses where others desire to examine impacts and would be useful for policy analyses.

## Forest Ecosystem and Land Use Setting

A recent GIS analysis of the fragmentation of contiguous U.S. forests indicates that most forested parcels are in fragmented landscapes (Ritters et al. 2002). Heavily fragmented landscapes have fewer interior parcels, i.e., forested parcels that are a certain minimum distance from the nearest edge. Such interior parcels provide the best habitat for many sensitive species (e.g., Askins 2002). For example, some species of interior-forest songbirds require habitat that is at least 200m from the nearest non-forest edge (Temple and Cary 1988). However, approximately 62% of forest in the contiguous 48 states is located within 150m of the nearest edge, which suggests that fragmentation of U.S. forests is so pervasive that edge effects influence ecological processes on most forested lands (Ritters et al. 1995, 2002).

We are interested in the future forest ecosystem setting, which will reflect the substantial further development of U.S. forests and a considerable exchange of land between forest and agricultural uses (Alig and Plantinga 2004). Overall, more than 200 million acres of U.S. forest land are projected to be involved in changes among land uses over the next 50 years (Alig and Plantinga 2004). Given that such land use changes will materially affect forest

ecosystems, including forest fragmentation, what policies should society be considering now? We draw upon findings from several related studies to outline an approach for analyzing the spatial structure of forest landscape change under alternative market conditions and policy scenarios.
o help set the stage for outlining our approach, we define relationships among land use change, forest fragmentation, parcelization, land management investment, and timber harvest. *Land use change* involves changes among human-defined uses of the land bases, such as urbanization (e.g., Alig et al. 2004, Kline and Alig 1999, Kline et al. 2001). Conversion of rural land uses to other developed uses has been the major cause of recent deforestation in the United States, as well as leading to fragmentation of remaining forested acres. U.S. developed area increased by 34% between 1982 and 1997, and is projected to increase by more than another 75 million acres by 2025 (Alig et al. 2004). Land use change can also be passive, as with afforestation due to seeding in old field succession. *Forest cover* pertains to the biophysical cover on forest land and can be affected notably by land use changes (e.g., Alig and Butler 2004 a,b).

*Forest fragmentation* is the transformation of a contiguous patch of forest into disjunct patches. Forest fragmentation results from land use conversion of forests to other uses. For example, conversion of forests to developed uses can fragment forests, and environmental and socio-economic factors are key predictor variables and next we highlight land quality as one of those determinants. *Forest parcelization* is the breaking up of retained forest land among smaller ownerships (Butler and Leatherberry 2004). Thus, forest parcelization can occur with or without forest fragmentation, although remaining forest may be managed differently by new owners. *Land management investment* can impact forest fragmentation by planned afforestation through investment, either by individuals or society. The latter means can be part of deliberate poicies, either focused singly on the fragmentation issue or in a multiple issue mode, such as considering related impacts on global change mitgation. *Timber harvest* can be one form of land management disinvestment or divestiture in a forstry context. It is important to point out that while timber harvest can remove trees and lead to "age class fragmentation" (Alig et al. 2000), which we do not consider necessarily to be forest fragmentation because the land is still classified as forest until conversion to another use such as parking lots.

## Determinants of Forest Fragmentation

Fragmentation of forestland is a consequence of human land use decisions. Thus, an understanding of the causes of fragmentation can begin by examining factors which influence land use decisions. The usual starting point is Ricardo and von Thunen's land rent theories (van Kooten and Folmer 2004), which state that land use is allocated to maximize the present value of the flow of net revenue (or rent) from a land parcel of particular quality. Using land rent theory as a foundation, Butler et al. (2004) estimated determinants of human-caused forest fragmentation, which accounts for 20% of the total forest edge in the western portions of Oregon and Washington. They used a multiple metric approach involving percentage nonforest, percentage edge, and average interspersion metrics. Separate regression models for each metric and a composite index produced similar, but not identical, results. Results of the empirical models conformed to the hypotheses based on land rent theory that socio-economic (e.g., population density) and physical factors (e.g., slope) proved to be important predictors of forest fragmentation.

Research in progress is examining the importance of the spatial configuration of land quality in forest fragmentation processes. Land quality is an all-encompassing term, which can include many factors which would influence the value of land to different uses. For example, parcels that are further from urban centers are generally considered to be of lower quality for urban development than parcels which are close to urban centers. Likewise, parcels with high soil fertility and moderate slopes are generally considered to be more suitable to agricultural production than parcels with low soil fertility and steep slopes. Most aggregate land use models specify shares of land in forest/non-forest as functions of net-returns to different land uses (e.g., forest, agriculture, urban) and average levels of soil quality. A roadblock to including land quality in past studies has been assembling sufficient data. Our preliminary tests indicate that including land quality spatial pattern, based on soils properties, as an explanatory variable for western Oregon forest fragmentation increases the fit of the regressions substantially. The fit of the regressions is improved most when the dependent variable represents spatial pattern (e.g., percent edge, interspersion) rather than aggregate land use (e.g., percent nonforest). Specifically, the adjusted $r^2$ for a model of percent edge (interspersion) increases from 0.756 to 0.841 (0.673 to 0.751) upon inclusion of land quality spatial pattern as an explanatory variable. The influence of the spatial structure of land quality on forest fragmentation is consistent with Ricardian land rent theory. These results suggest that regions with significant spatial variation in land quality will be more likely to have heavily fragmented landscapes than regions that are mostly homogeneous in land quality. Soil quality is only one possible component of the broader concept of land quality, and avenues for future research could explore alternative measures of the spatial structure of land quality, particularly as pertains to urban development.

## Policy Considerations

The ecological and economic effects of policies to address forest fragmentation have seen relatively little theoretical or empirical analysis. However, fragmentation concerns are reflected in the design of conservation policies in the most recent U.S. Farm Bill. For example, reducing forest fragmentation is a primary goal in the Wildlife Habitat Incentives Program (WHIP) as administered by several states. Likewise, many wildlife conservation plans adopted by non-governmental agencies such as Partners-In-Flight have explicit goals related to the reduction of forest fragmentation. Managing forest fragmentation poses many challenges, particularly in regions dominated by private landownership. Landscape-level fragmentation on private landscapes is the result of thousands of individual land-use decisions and private landowners typically have insufficient incentives to coordinate decisions that affect landscape pattern. Land-use policies provide a mechanism for aligning private incentives with broader public goals, but there are several factors that need to be considered in the design of efficient policies.

Because the ecological effects of fragmentation are particularly important in the midwestern and eastern U.S., regions dominated by private landownership, a method is needed to analyze the effects of land use policies on the fragmentation of private lands. We describe ongoing research that develops a method to examine the effects of market-based incentives on forest fragmentation in the U.S. southeast (Lewis and Plantinga 2005). First, the study uses econometrics to model the effects of economic incentives on the probability of private land use conversion at the parcel level. Second, the econometrically estimated conversion probabilities are linked with GIS through a series of Monte Carlo simulations to depict the effects of alternative market conditions and policy scenarios on alternative measures of forest fragmentation. Results include distributions of landscape outcomes defined over various fragmentation indices.

The effects of alternative policy designs on the efficiency of reducing fragmentation are considered in this study. In particular, two principal land use policies were considered. First, a spatially uniform policy was simulated that offers a subsidy to any landowner who converts land into forest. This approach maximizes the area of agricultural land converted for a given outlay by the government (Plantinga and Ahn 2002). Second, a spatial subsidy was simulated that pays landowners to convert land into forest only if their parcel shares a border with a forested parcel, similar to an agglomeration bonus (Smith and Shogren 2002). The spatial subsidy offers a tradeoff relative to the uniform subsidy. For a given number of parcels converted, the spatial subsidy is more likely to reduce fragmentation. However, it is more expensive to convert parcels under the spatial subsidy because the set of parcels to select from is smaller than under the uniform subsidy. Therefore, the efficiency of reducing fragmentation under such policies is an empirical question. Lewis and Plantinga (2005) find that the marginal costs of increasing average forest patch size are lower under the spatial subsidy than the uniform subsidy, and the marginal costs of increasing core forest are lower under the uniform subsidy than the spatial subsidy. So, if efficiency is an important consideration in policy design, then the desired measure of fragmentation must be explicit. Lewis and Plantinga (2005) also find that the marginal costs of reducing all measures of fragmentation are lower on landscapes with a larger share of the landscape in forest.

If policy makers wish to alter fragmentation trends, private landowner behavior and incentives are major considerations (Butler et al. 2004, Lewis and Plantinga 2005). Looking ahead, most U.S. afforestation opportunities are in the South (Alig et al. 2003), but that region also has substantial projected population growth and deforestation (Alig et al. 2004). Coordinating multiple policies, such as for climate change, open space, and forest fragmentation, could increase the efficiency of incentives for inducing land use changes to help address forest fragmentation and fostering other co-benefits of afforestation (e.g., Matthews et al. 2002). However, a complete understanding of designing policies to reduce fragmentation requires multiple research components. First, there is little theoretical foundation for designing economic incentives to achieve spatial outcomes. Research is needed to identify the factors that will potentially affect efficiency. Second, econometric modeling of parcel-level land use transitions would benefit greatly from improvements in the modeling of spatial autocorrelation in discrete-choice models. Third, application of the methodology created in Lewis and Plantinga (2005) to other regions will help understand regional differences in reducing fragmentation. However, this methodology is extremely data-intensive and requires land-use GIS data rather than land cover GIS data. At this time, land cover data are much easier to obtain than land use data.

## Literature Cited


Alig, R.; Butler, B.; Swenson, J. 2000. Fragmentation and national trends in private forest lands: Preliminary findings from the 2000 RPA Assessment. Pp. 34-46, In : Sampson, N.; DeCoster, L. eds. Proceedings, Forest Fragmentation 2000. September 17-20, 2000, Annapolis Maryland. American Forests, Washington, DC.

Alig, R., A. Plantinga, S. Ahn, and J. Kline. 2003. Land use changes involving forestry for the United States: 1952 to 1997, With Projections to 2050. USDA Forest Service Gen. Tech. Report 587, Pacific Northwest Research Station. Portland, OR.

Alig, R. and B. Butler. 2004a. Area changes for forest cover types in the United States, 1952 to 1997, with projections to 2050. USDA Forest Service Gen. Tech. Report 613, Pacific Northwest Research Station. Portland, OR. 106pp.

Alig, R. and B. Butler. 2004b. Projecting large-scale area changes in land use and land cover projections for terrestrial carbon analyses. *Environmental Management* 33(4): 443-456.

Alig, R., J. Kline, and M .Lichtenstein. 2004. Determinants of developed area, with projections to 2025. *Landscape and Urban Planning* 69: 219-234.

Alig, R. and A. Plantinga. 2004. Future forestland area: Impacts from population growth and other factors that affect land values. *J. of Forestry* 102(8): 19-24.

Armsworth, P.R., B.E. Kendall, and F.W. Davis. 2004. "An Introduction to Biodiversity Concepts for Environmental Economists." *Resource and Energy Economics,* 26: 115-136.

Askins, R.A. 2002. *Restoring North America's Birds.* Yale University Press, New Haven, CT.

Butler, B. and E. Leatherberry. 2004. America's family forest owners. *J. of Forestry* 102(7): 4-14.

Butler, B., J. Swanson, and R. Alig. 2004. Forest fragmentation in the Pacific Northwest: Quantification and correlations. *Forest Ecology and Management* 189: 363-373.

Jackson, L. and B. Gilborn. 2005. Lyme disease and forest fragmentation. This volume.

Kline, J.D., and R.J. Alig. 1999. "Does Land Use Planning Slow the Conversion of Forest and Farm lands?" *Growth and Change*, 30: 3-22.

Kline, J.D., A. Moses, and R.J. Alig. 2001. "Integrating Urbanization into Landscape-level Ecological Assessments," Ecosystems 4: 3-18.

Lewis, D.J., and A.J. Plantinga. 2005. "Policies to Reduce Forest Fragmentation: Integrating Econometric Land-Use Models with GIS-Based Landscape Simulations." Working Paper, Department of Agricultural and Resource Economics, Oregon State University.

Matthews, S., R. O'Connor, and A.J. Plantinga. 2002. "Quantifying the Impacts on Biodiversity of Policies for Carbon Sequestration in Forests." *Ecological Economics*, 40(1): 71-87.

National Audubon Society. 2002. Audubon Watchlist 2002. Available Online at http://www.audubon.org/bird/watchlist/index.html

Plantinga, A.J., and S. Ahn. 2002. Efficient Policies for Environmental Protection: An Econometric Analysis of Incentives for Land Conversion and Retention. *Journal of Agricultural and Resource Economics* 27(1):128-45.

Ritters, K.H., R.V. O'Neill, C.T. Hunsaker, J.D. Wickham, D.H. Yankee, S.P. Timmins, K.B. Jones, and B.L. Jackson. 1995. "A Factor Analysis of Landscape Pattern and Structure Metrics." *Landscape Ecology*, 10(1): 23-39.

Ritters, K.H., Wickham, J.D, O'Neill, R.V., Jones, K.B., Smith, E.R., Coulston, J.W., Wade, T.G., and J.H. Smith. 2002. "Fragmentation of Continental United States Forests." *Ecosystems*, 5: 815-822.

Smith, R.B.W., and J.F. Shogren. 2002. "Voluntary Incentive Design for Endangered Species Protection." *Journal of Environmental Economics and Management*, 43(2): 169-187.

Temple, S. A., and J. R. Cary. 1988. Population dynamics of habitat-interior birds in fragmented landscapes. *J. Conserv. Biol.* 2:340-347.

van Kooten, G.C., and H. Folmer. 2004. *Land and forest economics*. Cheltenham, UK: Edward Elgar.

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