Forests on the Edge: A GIS-based Approach to Projecting Housing Development on Private Forests

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Abstract—*The private working land base of America's forests, farms, and ranches is being converted at the rate of nearly 1,620 ha (4,000 acres) per day with tremendous economic, ecological, and social impacts. The United States Department of Agriculture (USDA) Forest Service is sponsoring the "Forests on the Edge" project to develop a better understanding of the contributions of America's private forests to timber, wildlife, and water resources and the pressures exerted on these resources from development, fire, air pollution, and insects and diseases. The project uses Geographic Information Systems (GIS) techniques to construct a series of maps depicting pressures and opportunities on America's private forests in the lower 48 states. Phase I of the project identifies fourth-level watersheds with private forests that are projected to experience increased housing density by 2030. The majority of these watersheds are in the eastern United States, although some that are projected to experience the greatest percent change are in the West. The methodology, results, and planned uses of Phase I products are presented, as are examples of the potential impacts of increased housing density on forest attributes such as wildlife, timber, and water.*

Introduction

Comprising over 57 percent of total forest cover, America's private forests make enormous contributions to water quality, biodiversity, timber, recreation, and essential ecological and economic functions. However, the conversion of private forest lands to urban uses threatens to reduce forests' ability to provide these functions.

Although there are many areas of the country that are experiencing an increase in private forest land, overall private forest land area is declining slightly (Smith and others 2004). Between 1982 and 1997, over 4 million ha (10 million acres) of non-Federal forests were converted to developed uses across the conterminous United States (USDA 2000) and an additional 9.3 million ha (23 million acres) may be lost by 2050 (Alig and others 2003).

The effects of development on private forest management have been documented in several localized studies. These studies have illustrated both short and long-term negative impacts of population growth and urban expansion on forest management for economic functions, such as timber production. In western Virginia, increasing human population densities affected long-term timber management capabilities by reducing timber land area and growing stock volumes by approximately 40 percent (Wear and others 1999). Private forest stakeholders in Wisconsin indicated that parcelization caused by development makes timber production less profitable and can result in a shift from commercially valued aspen, pine, and oak to less valued species such as red maple (Gobster and Rickenbach 2004). In Mississippi and Alabama, proximity to urban land uses and higher population densities led to a net decrease in harvesting rates (Barlow 1998).

Population growth and urban expansion are also related to reductions in non-timber forest management and investment in private forest lands. A 2004 study focused in western Oregon concluded that increased building densities are correlated with reduced forest stocking and pre-commercial thinning, as well as a reduced likelihood for tree planting following thinning (Kline and others 2004). Private forest landowners in Georgia's metropolitan counties were less likely to participate in government incentive programs for protecting soils and tree planting than landowners in more rural counties (Harris and DeForest 1993).

The objective of this project, denoted Forests on the Edge and sponsored by the Forest Service, was to identify areas in the conterminous United States where private forests are likely to experience increases in housing density between 2000 and 2030. The project focused on lands projected to shift from rural or ex-urban use to urban use, and from rural use to ex-urban. These levels of "use" are based on housing density levels and are defined in the Analyses section.

Methods

Data

A 100-m spatial resolution dataset of the conterminous United States differentiating combinations of land cover and land ownership was constructed from the 1992 National Land Cover Dataset (NLCD) (Vogelmann and others 2001) and the Protected Areas Database (PAD) (DellaSala and others 2001). NLCD is a 30-m resolution, 21-class, land cover classification derived from nominal 1991 Landsat Thematic Mapper imagery and ancillary data by the U.S. Geological Survey. Forest/non-forest data were obtained from NLCD by collapsing its Transitional (33), Deciduous Forest (41), Evergreen Forest (42), Mixed Forest (43), and Woody Wetlands (91) classes into a forest class and the remaining classes into a non-forest class. PAD is an ArcInfo polygon coverage compiled by the Conservation Biology Institute (CBI). PAD contains boundaries of most Federal and State-owned/managed protected areas in the conterminous United States and Alaska, and includes county, city, and private reserves where data were available. Recoded NLCD data were re-sampled and recoded PAD data were rasterized to 100-m spatial resolution. The two resulting grid layers were combined, forming a single forest/non-forest ownership grid dataset that was denoted FOROWN100M and consisted of six land cover/ownership categories: public non-forest, public forest, protected private non-forest, protected private forest, unprotected private non-forest, and unprotected private forest. The area of land identified in FOROWN100M as forest is within a 95 percent confidence interval for the estimate of Conterminous United States (CONUS) forest land in the draft 2002 tables of the Resource Planning Act (RPA) Forest Resources of the United States (http://ncrs2.fs.fed.us/4801/fiadb/rpa_tabler/2002_rpa_draft_tables.htm). No formal accuracy assessment was conducted on the ownership attributes in FOROWN100M.

Watersheds were delineated using the HUC250 database (http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml), which is based on hydrologic unit maps published by the U.S. Geological Survey, Office of Water Data Coordination. Hydrologic units are encoded with an eight-digit Hydrologic Unit Code (HUC); with the first two digits indicating the hydrologic region, the second two digits indicating the hydrologic subregion, the third two digits indicating the accounting unit, and the fourth two digits indicating the cataloging unit. Watersheds corresponding to these hydrologic units are characterized as eight-digit HUC watersheds and are 1,735 sq. mi. (1,110,400 acres) on average. These data were digitized generally at a scale of 1:250,000 but with some portions at a scale of 1:100,000 and some at a scale of 1:2 million.

Housing density was estimated by drawing from historical and current housing densities at a fine resolution to examine spatial patterns of development. Using the historical and current housing density patterns as data inputs, a forecast simulation model of future housing density patterns was developed based on county-level population projections.

Nationwide estimates of population and housing density were computed from the U.S. Census Bureau's block-group and block data for 2000 (U.S. Census Bureau 2001a). To estimate current housing density patterns, housing density was computed using dasymetric mapping techniques (Theobald 2001a, in review). Census blocks were refined using public land information from FOROWN100 and water polygons from Census Bureau data. Because privately-owned houses are not allowed on public land, portions of blocks on public land were removed, as were portions of blocks identified as streams, rivers, ponds, lakes, and reservoirs. Using these refined census block geographies, the number of housing units per block, obtained from the 100 percent data of the 2000 Census STF1 (U.S. Census Bureau 2001b), were allocated throughout the refined blocks and weighted to reflect the likely heterogeneity of the placement of houses that are more likely to be located near roads and less likely in portions of blocks distant (greater than 1 km) from roads. The allocation of housing units is weighted based on road density (computed using an 800 m radius moving neighborhood).

Road density was classified into four arbitrary categories that distinguished different levels of development and were used to allocate housing density values to cells within a block: very low (0.0 - 0.25 km/km^2), low (0.25 - 1.0 km/km^2), medium (1.0 - 5.0 km/km^2), and high (>5.0 km/km^2). Housing density estimates for 1990 were generated from the "Year Housing Built" question from the sample data Summary File 3 dataset (US Census Bureau 2001c). These data are provided at the block-group level and were adjusted to ensure that the sum of units by block-groups in a county equaled the counts from decadal census using established methods (Hammer and others 2004; Radeloff and others 2001; Theobald 2001a).

The Spatially Explicit Regional Growth Model (SERGoM v1) was used to model the full urban-to-rural spectrum of housing densities. It uses a supply-demand-allocation approach and assumes that future growth patterns will be similar to those found in the past decade. Four basic steps are used in SERGoM v1 to forecast future patterns on a decadal basis. First, the number of new housing units in the next decade is forced to meet the demands of the projected county-level population. Population growth was converted to new housing units by the county-specific housing unit per population ratio for 2000. Population estimates were obtained from a demographic-econometric model (NPA Data Services 2003). Second, a location-specific average growth rate from the previous to current time step (for example, 1990 to 2000) was computed for each of four density classes: urban, suburban, exurban, and rural. These growth rates were computed for each 100 m cell using a moving neighborhood (radius = 1.6 km) that allows within-county heterogeneity and cross-county and State boundary growth patterns to be captured. Also, new housing units were spatially allocated based on these locally determined growth rates, which assumes that areas of future growth are likely to be near current high-growth areas or "hot spots."

Third, the distribution of new housing units was adjusted according to accessibility to the nearest urban core area. That is, urbanization and conversion to urban and exurban land use typically occurs at locations on the fringe of urban core areas where land is undeveloped. Accessibility is computed in terms of minutes of travel time from urban core areas as one would travel along the main transportation network. An urban core area is defined as a contiguous cluster of greater than 100 ha at urban housing density. The distribution of housing density was then adjusted by creating a weight surface based on travel time from urban areas and is used to modify the location of new housing units computed in the first step. Fourth, the new housing density was added to the current housing density, which makes the assumption that housing density does not decline over time, which is reasonable to represent patterns of expansion in suburban and exurban areas, but may under represent areas that are in fact declining in housing density through urban decay or expansion of commercial land use into residential areas.

Analyses

Watersheds were selected as the unit of analysis to focus on the contributions provided by forests to water and watershed quality and condition. Geographic Information System (GIS) techniques were used with the FOROWN100M and the eight-digit HUC watershed layers to select watersheds that satisfied two criteria: 10 percent or greater forest cover, and 50 percent or more of the lands with forest cover in private ownership. GIS techniques were also used with the housing density layer to create maps depicting the percentages of each selected watershed containing private forest projected to experience increases in housing density between the years 2000 and 2030. Note that the maps displayed conversion of private forest land as a percentage of all land within the watershed, not just private forest land in the watershed. The study was conducted in this way to focus on the potential impacts of housing development on the watersheds themselves.

Housing density projections displayed in the final maps reflect projections for private forest land only. All public lands and all non-forested lands were excluded from the analyses, as were private forest lands with conservation easements recorded in the PAD.

Housing density was used to characterize the most likely and widespread type of development and land use conversion facing private forests. There was no attempt to depict other types of development or conversion resulting from commercial development, road building, mining, or conversion of forest to farms or pastures.

Three categories of private forest land were defined based on three housing density thresholds: rural, ex-urban, and urban. For the purposes of this study, private forest lands were denoted "rural" if they contained 6.2 or fewer housing units per km^2 (16 or fewer housing units per sq. mi.). Forest lands with this housing density can generally support a diversity of economic and ecological functions commonly associated with private forests such as management for timber, most wildlife species, and water quality. Private forest lands were denoted "ex-urban" if they contained from 6.2 to 24.7 housing units per km^2 (16 to 64 housing units per square mile). Lands with these higher housing densities can still support many wildlife species and other ecological functions, although perhaps at a reduced level. However, management for commercial timber may be less likely. Private forest lands were denoted "urban" if they contained 24.7 or more housing units per km^2 (64 housing units per sq. mi.). Such lands are unlikely to be used for timber production and, in many States, do not qualify for favorable property tax assessments or technical or financial assistance through State or Federal forest management programs. Forest lands with this housing density are less likely to contribute to wildlife habitat and water quality because of increased road density, infrastructure, and human population levels associated with this level of development.

Shifts in private forest lands among these categories can have strong implications, with respect to management for timber, wildlife, and other values. In western Virginia, the transition from rural to urban use occurs over a range from 7.7 people per km^2 (approximately 20 people or 8 housing units per sq. mi.) to 27 people per km^2 (70 people or 28 housing units per square mile). The chance of commercial forestry drops from 75 percent down to 25 percent over this range (Wear and others 1999). Similar results have been found for western Oregon where pre-commercial thinning and planting following harvest are less likely, and forest stocking levels are somewhat lower on forest landscapes with higher population densities (Kline and others 2004).

Such shifts in land use can also lead to a decrease in wildlife habitat quantity and quality. The cumulative effects of removing native vegetation, constructing fences, increasing human contact, and increasing presence of small-sized predators (cats and dogs) associated with residential development in formerly rural areas can all contribute to the displacement of native wildlife populations (Theobald and others 1997).

Results

Maps based on the selected thresholds are displayed in figures 1 to 5. The criteria that watersheds have at least 10 percent total forest cover, of which at least 50 percent is in private ownership, focused the analyses on the eastern United States where forest cover is more extensive and most forest land is in private ownership.

Figure 1 displays the percentage of each watershed that contains private forests that are projected to shift from rural or ex-urban to urban. Our definition of "ex-urban" for this map is any forest land containing 6.2 housing units to 12.7 housing units per km^2 (16 to 33 housing units per sq. mi.), as opposed to the previous definition of 6.2 to 24.7 housing units per km^2 (16 to 64 housing units per sq. mi.). This was done to ensure that we were not including forest lands experiencing only small increases in housing density (for example an increase from 64 to 65 or 66 housing units per sq. mi.). By 2030, 8,773,847 ha (21.7 million acres) of private forest is projected to experience this type of increase in housing density.

Two watersheds, one in Maine and one in California, are projected to shift from rural or ex-urban to urban on 20 to 30 percent of their areas. Thirty-eight watersheds are projected to experience this shift on 10 to 20 percent of their area. Most of these watersheds are scattered across the eastern United States, although some are located in the Sierra Nevada foothills of California, and northern Washington State.

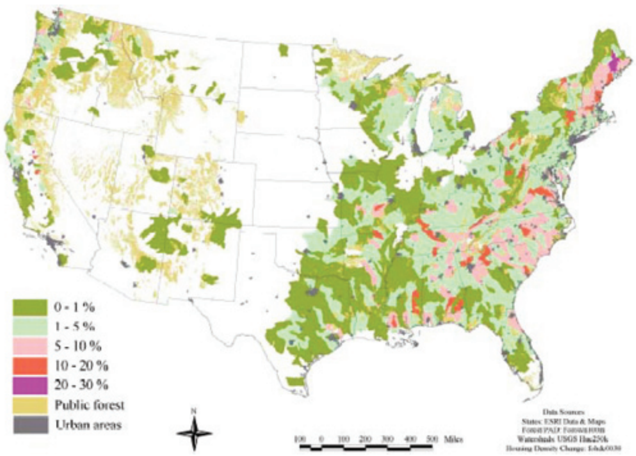

Figure 1. Percentage of watersheds with private forests projected to shift from rural or ex-urban to urban use.

The project also identified the number of acres of private forest projected to shift from rural or ex-urban to urban use by watershed. The top 20 watersheds are presented in figure 2 and table 1. The Lower Penobscot watershed in Maine ranks number 1, with 107,671 ha (266,066 acres) of private forest projected to experience this shift. This is followed by the Etowah watershed in Georgia with 84,928 ha (209,866 acres), the Middle Hudson watershed in New York with 76,436 ha (188,880 acres), and the Upper Oconee watershed in Georgia with 67,210 ha (166,084 acres). The Piscataqua-Salmon Falls watershed, covering parts of southern Maine and southeastern New Hampshire, ranks 20th, with 42,427 ha (104,842 acres) of private forest expected to shift from rural or ex-urban to urban.

Figure 3 depicts the percentage of each watershed containing private forest projected to shift from rural

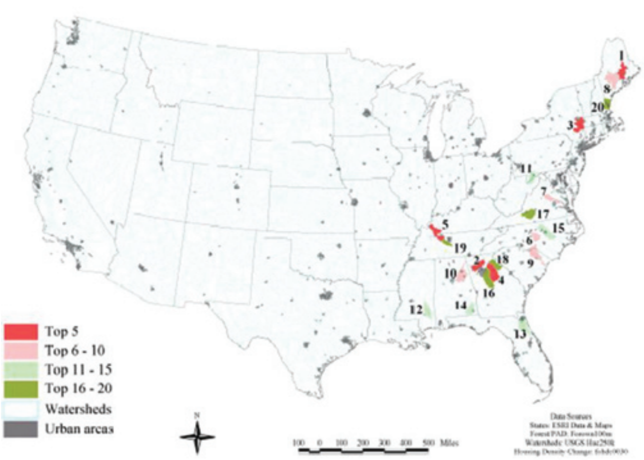

Figure 2. Top 20 watersheds with greatest acreage of private forests projected to shift from rural or ex-urban to urban use.

Table 1. Top 20 watersheds projected to shift from rural or exurban to urban use.

Watershed rank	8-digit HUC Identifier	Hydrologic Unit Name	Acres
1	01020005	Lower Penobscot	266,006
2	03150104	Etowah	209,866
3	02020006	Middle Hudson	188,880
4	03070101	Upper Oconee	166,084
5	05130205	Lower Cumberland	158,945
6	03030003	Deep	157,342
7	02080106	Pamunkey	156,015
8	01030003	Lower Kennebec	146,437
9	03040201	Lower Pee Dee	145,705
10	03150106	Middle Coosa	138,895
11	02070002	North Branch Potomac	138,829
12	03170005	Lower Leaf	134,499
13	03080103	Lower St. Johns	132,162
14	03140201	Upper Choctawhatchee	127,575
15	03020201	Upper Neuse	124,403
16	03070103	Upper Ocmulgee	120,375
17	03010101	Upper Roanoke	117,686
18	03060104	Broad	110,026
19	05130204	Harpeth	107,026
20	01060003	Piscataqua-Salmon Falls	104,842

to ex-urban. Our definition for "rural" for this map is any forest land containing less than 4.9 housing units per km^2 (12.8 housing units per sq. mi.), as opposed to the stated definition of less than 6.2 housing units per km^2 (16 housing units per sq. mi.). Just over 9 million ha (22.5 million acres) of private forest land is expected to experience this type of shift. About 20 watersheds contain forest projected to experience this shift on over 10 to 20 percent of their area. These watersheds are located in about 12 States in the Northeast and South. They include New Hampshire, Vermont, Pennsylvania, Virginia, West Virginia, North Carolina, Tennessee, Missouri, and Arkansas.

Results for the top 20 watersheds with the most private forest land projected to shift from rural to ex-urban are presented in figure 4 and table 2. The top watershed in this category is the Little Kanawa watershed in West Virginia, with 58,871 ha (145,476 acres) of private forest expected to experience this change. This is followed by the Upper Roanoke watershed in Virginia with 56,422 ha (139,424 acres), the Upper Green watershed of Kentucky with 55,874 ha (138,070 acres), and the Upper Susquehanna watershed in New York with 55,792 ha (137,867 acres). The Upper Alabama watershed ranks 20th with 42,292 ha (104,508 acres) projected to experience this change.

A map depicting the percentage of each watershed projected to experience either type of shift (from rural or ex-urban to urban and/or from rural to ex-urban) is presented in figure 5. A total of 17,882,073 ha (44.2 million acres) of private forest land is expected to experience

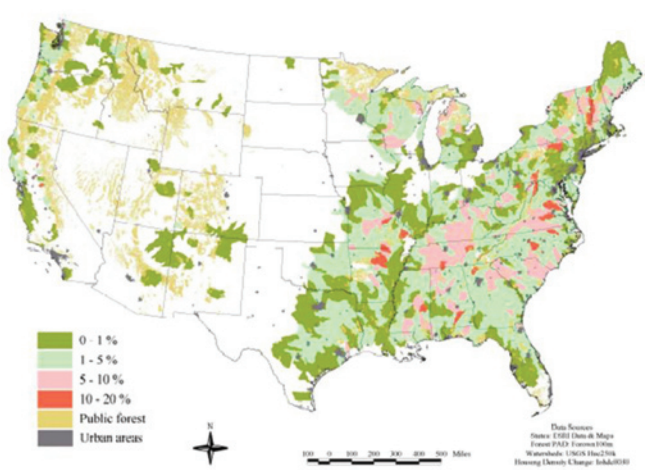

Figure 3. Percentage of watershed with private forests projected to shift from rural to ex-urban use.

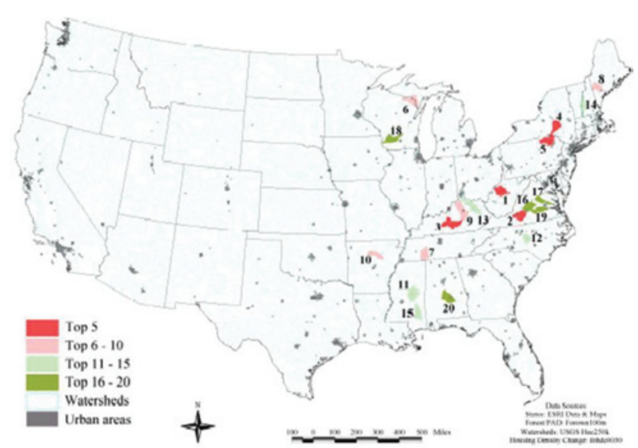

Figure 4. Top 20 watersheds with greatest acreage of private forests projected to shift from rural to ex-urban use.

Table 2. Top 20 watersheds projected to shift from rural to exurban use.

Watershed rank	8-digit HUC Identifier	Hydrologic Unit Name	Acres
1	05030203	Little Kanawha	145,476
2	03010101	Upper Roanoke	139,424
3	05110001	Upper Green	138,070
4	02050101	Upper Susquehanna	137,867
5	02050106	Upper Susquehanna - Tunkhannock	135,129
6	04030108	Menominee	133,753
7	06040001	Lower Tennessee – Beech	123,869
8	01040002	Lower Androscoggin	118,129
9	05100205	Lower Kentucky	117,822
10	11010014	Little Red	116,940
11	03180001	Upper Pearl	113,179
12	03030003	Deep	112,475
13	05100101	Licking	112,361
14	01080104	Upper Connecticut – Mascoma	109,176
15	03170005	Lower Leaf	108,259
16	02080203	Middle James – Buffalo	107,375
17	02080106	Pamunkey	105,988
18	07070005	Lower Wisconsin	104,958
19	02080207	Appomattox	104,632
20	03150201	Upper Alabama	104,508

one or both of these shifts by the year 2030 in watersheds that meet the forest coverage and ownership criteria. About 20 watersheds are projected to experience one or both of these changes on private forest covering at least 20 percent of their areas. Again, these watersheds are scattered primarily across the East (particularly across the Northeast and Southeast), with some occurring also in the northern Midwest, California, and the Pacific Northwest.

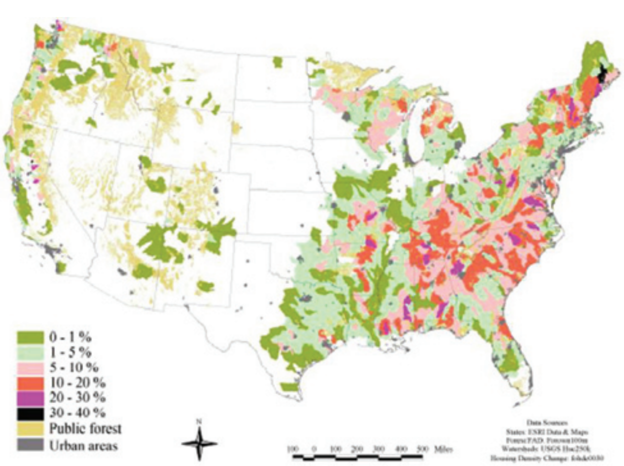

Figure 5. Percentage of watershed with private forests projected to experience increased housing density by 2030.

Discussion

The results of this project indicate that many of the private forest lands likely to experience increased housing density from 2000 to 2030 are located in the eastern United States. This makes sense as a majority of our private forests are located in this area. Much of the private forest projected to experience change is located in watersheds in the southeastern United States. This is consistent with the finding by Alig and others (2004) that development has been high in the South and will continue to be high due to above average population and income growth coupled with above average marginal consumption rates of land.

Private forests in certain areas of the Northeast (Maine, New Hampshire, Vermont, and New York) are also projected to experience housing density increases. Additional study of the possible causes of this would be useful. It may be that housing densities are increasing in these areas as a result of second home development because of the attractive recreational and aesthetic amenities they provide. A recent study of development in the north central United States indicates growth rates in attractive rural areas are among the highest and that this has major implications for forest ecology and management (Hammer and others 2004).

Although a number of watersheds in the Southwest met the selection criteria of forest coverage and private ownership, the private forests they contain were not projected to experience significant housing density increases. This does not mean that housing development will not occur in these watersheds or other areas of the Southwest. It only means that the development is not occurring on private forests that meet the selection criteria.

Private forests in the majority of the western watersheds that met the selection criteria are not projected to experience high housing density increases. It may be that in some localized areas, private forests will be developed, but those areas do not occur in watersheds containing at least 10 percent forest cover or where at least 50 percent of the forest is private. Private forests in a few watersheds in California and northwestern Oregon are projected to experience housing density increases. It is likely that many of these watersheds show up on our map because they will experience some level of housing development and because they are fairly small (thus, even change on a small amount of land makes them show up on the maps showing percent change in a watershed). The fact that none of these watersheds show up on either "top 20" acreage list indicates that the acreage projected to be affected is less than 40,000 ha (approximately 100,000 acres).

Conclusions

Private forests in watersheds across the eastern United States and particularly in the Northeast and Southeast, as well as in California and the Pacific Northwest are projected to experience a shift from rural or ex-urban use to urban use, or a shift from rural to ex-urban use between the years 2000 and 2030. While most watersheds meeting the forest coverage and private ownership criteria are projected to experience these types of development on less than five percent of their surface area, over 30 watersheds will experience one of these changes on 10 to 20 percent of their area. This has implications for the condition and management of the private forests projected to be affected and the watersheds in which they occur. Increasing housing density in forested areas can be associated with decreases in native wildlife populations, alterations in forest structure and function, decreases in timber production and active forest management, and increases in fire risk. Depending upon the location of the affected forest, the quality of water run-off could also be affected.

Admittedly, this study is but one chapter in the story of constant flux experienced by our Nation's private forest lands. The method used focuses on the quantity, rather than quality of private forest land in each watershed. Although this type of analysis can be important for targeting efforts to conserve functions and values bestowed by private forests, it will inevitably disregard some forest types, such as riparian areas in the Southwest, where quantity does not occur on the same scale as forest lands in the East.

While projections of this scope and nature do not necessarily provide accurate predictions of the future in all parts of the study area, spatial information about land use changes resulting from this and similar studies is a crucial input for scientists, resource managers, and communities in their efforts to plan for future growth and implement resource plans and policies. Furthermore, the results of this study can be used to identify watersheds for possible future research.

Future work in this area should focus on four areas: (1) validation of data identifying watersheds as having private forest most likely to experience housing density increases; (2) impacts of various levels of housing density on timber, wildlife, water quality, and other forest amenities; (3) projected shifts among the lower density categories (for example, from 0.5 to 1.5 housing units per square mile); and (4) a more in-depth look at private forests in the West and the pressures they face.

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