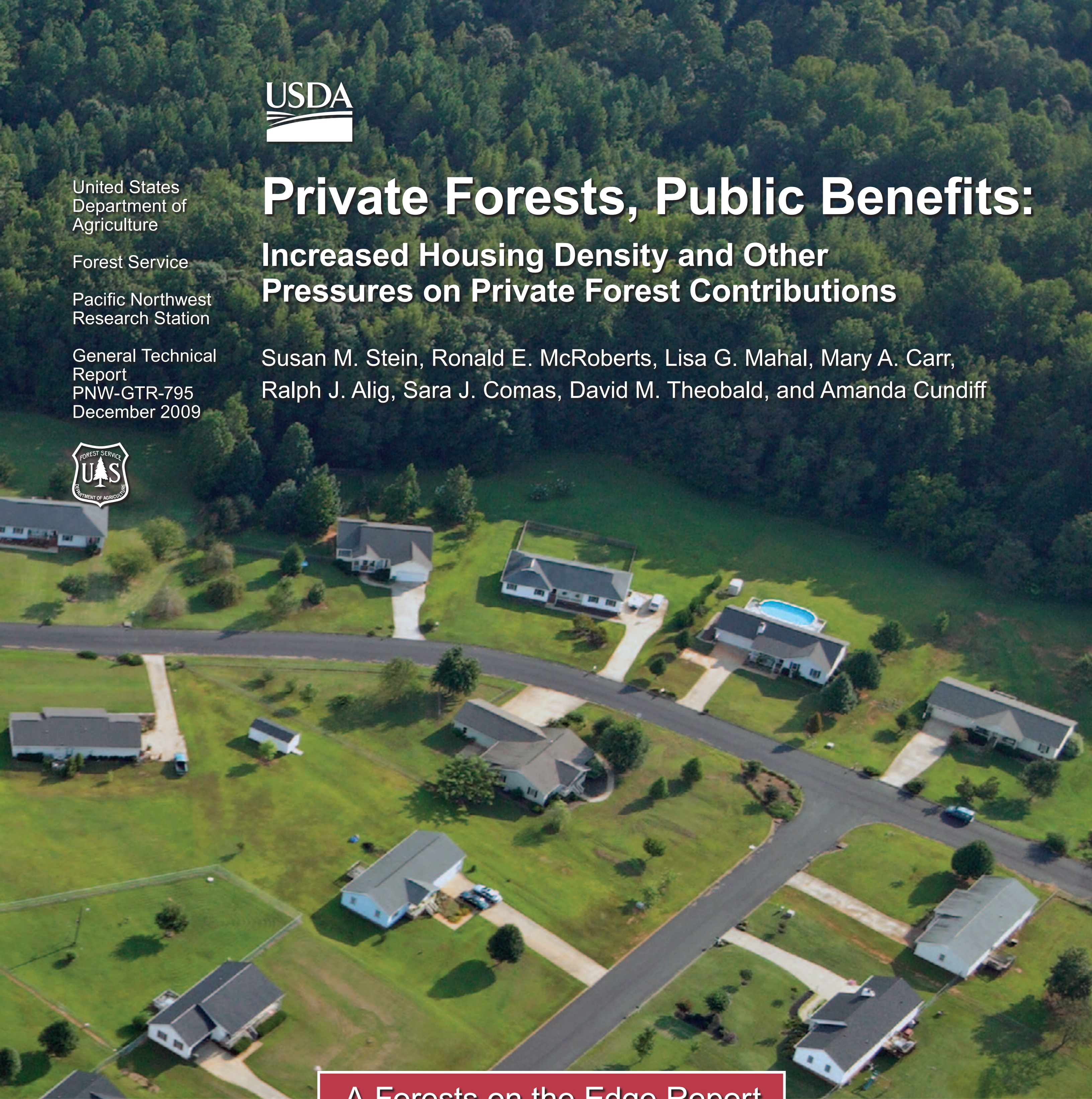

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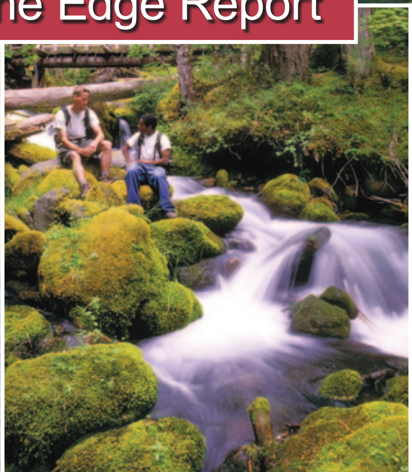
Private Forests, Public Benefits:

Increased Housing Density and Other Pressures on Private Forest Contributions

Susan M. Stein, Ronald E. McRoberts, Lisa G. Mahal, Mary A. Carr, Ralph J. Alig, Sara J. Comas, David M. Theobald, and Amanda Cundiff

A Forests on the Edge Report



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Cover photos: (top) housing development, ©Harrison Shull, Aurora Photos; (bottom) red trillium ©Hamiza Bakirci, iStockPhoto.com; red squirrel, Michael Mengak, University of Georgia, Bugwood.org; Oregon hikers, Tom Iraci; logs, U.S. Forest Service.

Back cover photos: Key deer (*Odocoileus virginianus clavium*), U.S. Fish and Wildlife Service; chanterelle mushrooms, U.S. Forest Service.

Abstract

Stein, Susan M.; McRoberts, Ronald E.; Mahal, Lisa G.; Carr, Mary A.; Alig, Ralph J.; Comas, Sara J.; Theobald, David M.; Cundiff, Amanda. 2009. Private forests, public benefits: increased housing density and other pressures on private forest contributions. Gen. Tech. Rep. PNW-GTR-795. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 74 p.

Over half (56 percent) of America's forests are privately owned and managed and provide a vast array of public goods and services, such as clean water, timber, wildlife habitat, and recreational opportunities. These important public benefits are being affected by increased housing density in urban as well as rural areas across the country. The Forests on the Edge project, sponsored by the U.S. Department of Agriculture, Forest Service, seeks to improve our understanding of where across the country housing density increases, as well as other threats, might affect these critical goods and services. For this study, we map and rank watersheds across the conterminous United States to analyze the relative contributions of private forest land to water quality, timber volume, at-risk species habitat, and interior forest. In addition, we rank watersheds according to the pressures on private forest contributions from increased housing density, wildfire, insect pests and diseases, and air pollution. Results indicate that private forest land contributions to forest cover, clean water, and timber volume are greatest in the East, but are also important in many Western watersheds. Private forests making substantial contributions to interior forest and at-risk species are more uniformly distributed across the country. Development pressures on these contributions are concentrated in the Eastern United States but are also found in the north-central region, parts of the West and Southwest, and the Pacific Northwest; nationwide, more than 57 million acres of rural forest land are projected to experience a substantial increase in housing density from 2000 to 2030. Private forests in both the Eastern and Western United States are under pressure from insect pests and diseases. The bulk of private forests most susceptible to wildfire are located in the West and parts of the Southeast. Lastly, ozone pollution affecting private forests is localized in California and several areas of the East.

Keywords: Private forest, housing density, ecosystem services, water quality, at-risk species, interior forest, wildfire, insect pests, diseases, ozone.

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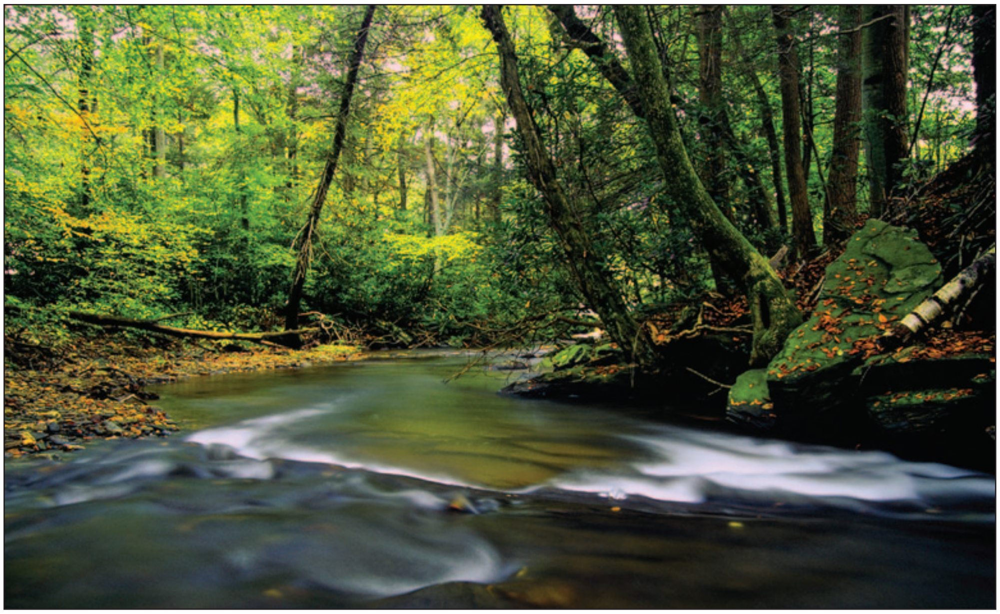
Introduction



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AMERICA'S FOREST LANDS provide a wealth of goods and services to the public—from helping ensure clean water and abundant forest products, to providing wildlife habitat, open spaces, and opportunities for outdoor recreation and education. Private forest contributions to these goods and services can be affected by increased housing density. Additional threats, such as fire and forest pests, can further exacerbate the effects of increased housing density. Although the focus of this report is on increased housing density, housing density increases are typically associated with additional development, including increases in related infrastructure, such as roads and other transportation networks, which also have environmental impacts. In fact, in some urban areas, a 10-percent increase in population growth can, in certain periods, lead to a 40- to 60-percent increase in urban land cover (Daniels 1999).

America's private forests provide many public benefits, including clean water.

This report is one of several produced by the U.S. Department of Agriculture, Forest Service as part of the Forests on the Edge project. It displays and describes information at a national level that can improve understanding of forest land development issues and can help answer such questions as:

- Where, nationwide, do private forests make substantial contributions to clean water, timber volume, habitat for at-risk plant and animal species, or interior forest?
- Where are these contributions likely to change because of increased housing density in rural private forests? Our use of term "increased housing density" refers to a very specific change in housing density such that land shifts out of a rural housing density category to a higher density category (see page 9).

- Where is change from increased housing density likely to be exacerbated by other factors such as insect pests and diseases, wildfire, or air pollution?
- Where are private forest lands that are making the most important contributions also facing the greatest pressures?


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We analyzed selected contributions and pressures for which nationally consistent data were available. The pressures analyzed represent only a sampling of the numerous factors that affect private forests across the country. Similar to other Forests on the Edge reports and other national assessments, our findings may not completely capture changes at all scales or in specific watersheds.

The data are analyzed by watershed—an area of land that drains into a river, stream, or other body of water—to emphasize the vital connection between private forests and clean water. Summarizing detailed data by a larger entity such as a watershed also is a useful way to organize and communicate our results.

The first section of this report focuses on identifying areas where contributions provided by private forests could be affected by increased housing density.

About the Forests on the Edge Project

SPONSORED BY the State and Private Forestry, Cooperative Forestry staff of the USDA Forest Service, in cooperation with Forest Service Research and Development, the Forests on the Edge project uses data prepared and analyzed by scientists across the country to increase understanding of the many public benefits derived from private forests and of the pressures that might affect these benefits.

The Forests on the Edge project is one of several efforts to assess the status, condition, and trends of forests across the United States. The number, scope, and complexity of these efforts reflect the critical importance of conserving and maintaining global forest resources. Major efforts include work by the Forest Service Eastern and Western Wildland Threat Centers (USDA FS, n.d.); Resource Planning Act assessments (USDA Forest Service 2007b); national work in climate change and policy analysis; and international guidelines for sustainable forest management such as the United Nations Framework Convention on Climate Change (http://unfccc.int/2860.php), the Montréal Process (criteria and indicators) (http://www.rinya.maff.go.jp/mpci/), and the Ministerial Conference on the Protection of Forests in Europe (MCPFE) (http://www.mcpfe.org/) .


Chris Evans, River to River CWMA, Bugwood.org

Following this, we identify areas where the detrimental effects of increased housing density may be compounded by or may intensify the effects of additional pressures from insects and diseases, wildfire, and ozone pollution. An appendix provides details on methods used in each assessment.

Additional maps can be found on the Forests on the Edge Web site (http://www.fs.fed.us/openspace/fote), including completed maps and digital data that can be used to make individualized maps showing various combinations of layers.

America's Private Forests

About 56 percent, more than 420 million acres, of America's forests are privately owned (Smith et al. 2004) (fig. 1). About three-quarters of these private forests are located in the Eastern United States, but ecologically valuable private forest lands are also found in the West, where some of the fastest population growth in the country is taking place.

Fifty-six percent of U.S. forests are privately owned.

For the purpose of this study, we define forest as land with at least 25 percent tree crown cover from trees that are greater than 20 feet tall. We chose this definition because it is the one used by the U.S. Geological Survey (USGS) in creating the forest cover data used for this report (see "About the National Land Cover Data" on page 5).

Private forest is forest land owned by individuals, families, corporations, organizations, tribes, or the forest industry. Public lands—that is, lands owned by federal, state, or local governments—were not included in this study because they are not typically available for development.

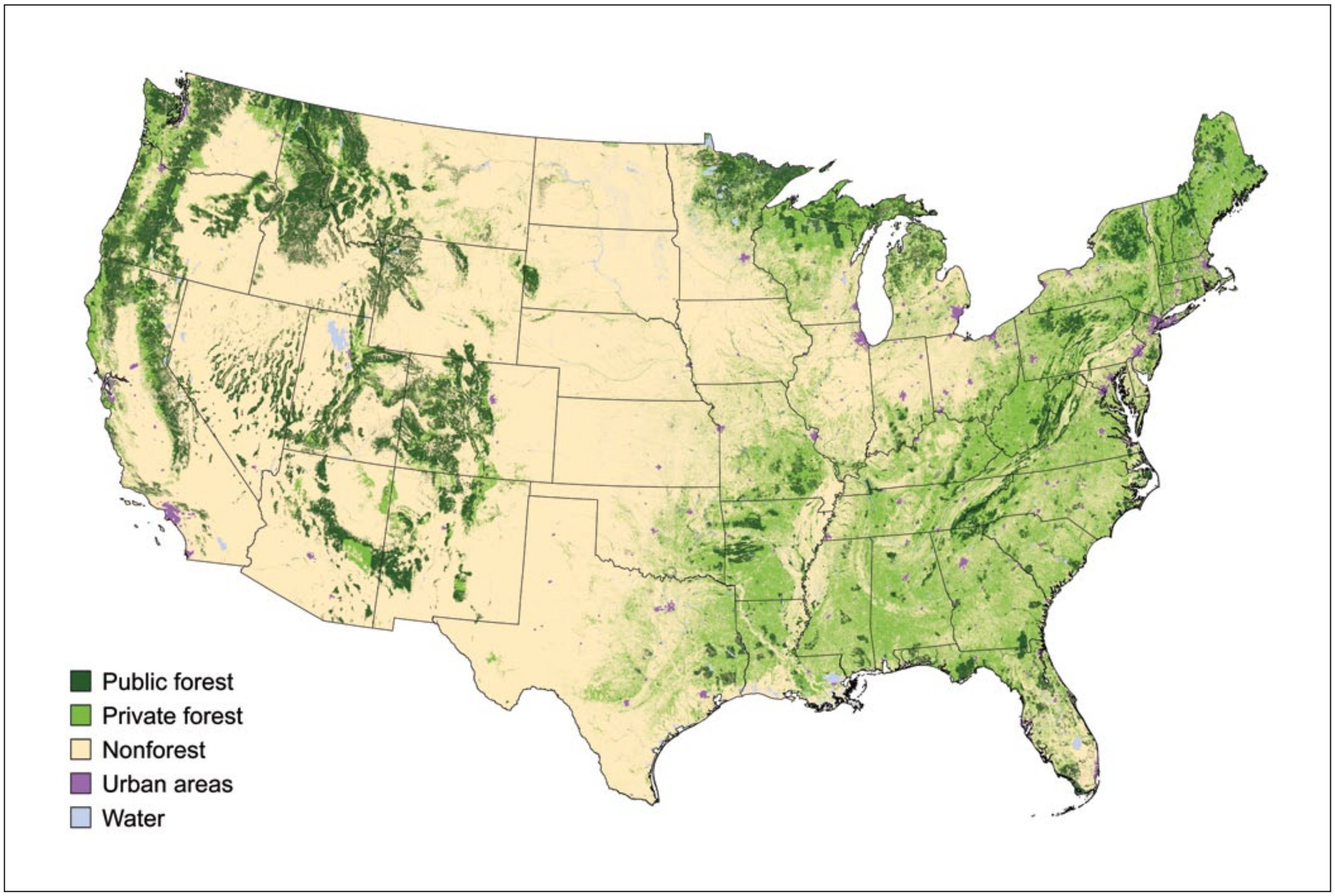

Figure 1—Location of private and public forest, nonforest, and urban areas. About three-quarters of America's private forests are in the East.

Private forests play a key role in protecting water quality, furnishing diverse habitats for fish and wildlife, providing the raw materials for timber products and other forest goods or services, and sustaining valuable ecological functions across the landscape such as flood and climate regulation (see sidebar on page 6). These benefits are often characterized as ecosystem goods or services and are subject to alteration because of housing development and environmental pressures.

Private Forest Owners

America's private forests are owned and managed by approximately 11 million private landowners, most of whom (close to 8 million landowners) have relatively small holdings of fewer than 50 acres each (Butler 2008). A quarter of private forest land acres are owned by corporations, other private organizations, and individuals who have large holdings of 5,000 acres or more (fig. 2).

About the National Land Cover Data

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THE 2001 NATIONAL Land Cover Data (NLCD) database was recently released and forms the basis for our forest cover layer (Homer et al. 2007). The NLCD database provides 21 land cover classes from Landsat satellite imagery and ancillary data for the conterminous 48 states (also referred to as the "Lower 48"). The detailed data are widely used for an array of applications including national environmental reporting, climate change investigations, clean water studies, and biodiversity and conservation assessments. This Forests on the Edge report uses three categories of forest vegetation as defined by the NLCD:

- **Deciduous forest**—Areas dominated by trees where 75 percent or more of the trees shed foliage in response to seasonal change.
- **Evergreen forest**—Areas dominated by trees where 75 percent or more of the trees retain their leaves all year.
- **Mixed forest**—Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.

—Sources: Homer et al. 2007; USGS, n.d.; US EPA, n.d.

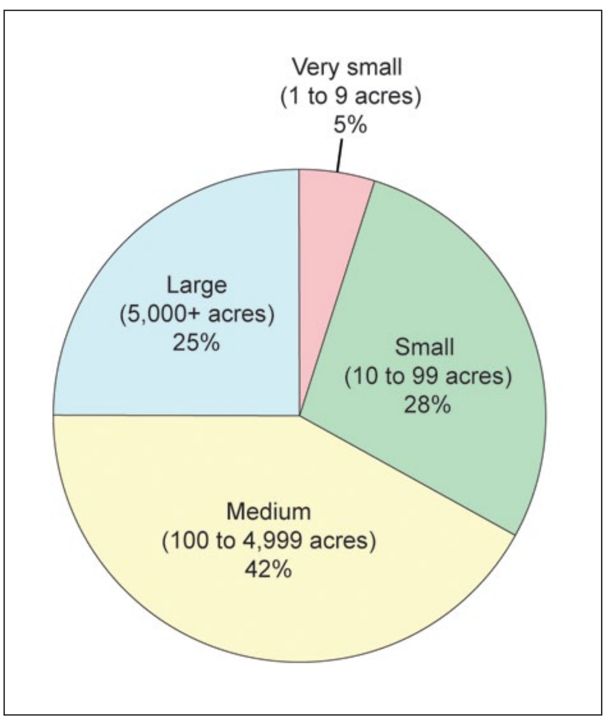


Figure 2—Percentage of private forest acres by parcel size. Source: Butler (2008).

Private landowners are key stewards of our forests, but costs for conserving and maintaining their forests can be high. Private forest landowners in many parts of the country are under pressure to sell their land for development or other uses (Alig 2007). The Forest Service and other agencies and organizations are working to find market-based approaches that provide landowners with economic incentives to retain and conserve these lands. More information on ecosystem services can be found at http://www.fs.fed.us/ecosystemservices.

Forest Ownership Changes

Millions of acres of large tracts of private forest once owned by traditional forest industry companies have been sold since the mid-1990s, owing in part to changes in tax codes, shifts in forest land market values, and business decisions (Butler 2008). The South has seen the most substantial changes—of the 23 million acres of industrial timberland sold in the United States from 2000 through 2004, approximately 18 million were in the South—but such transactions have also occurred in major timber-growing regions elsewhere in the country (Clutter et al. 2005). In northern Maine, for example, industrial landowners have subdivided and sold most of their timberland properties; one timber industry firm alone transferred 2.3 million acres to 15 owners during and since the 1990s (LeVert et al. 2008). Such a change in ownership patterns—where larger forested tracts are divided into multiple parcels owned by several owners—is known as parcelization.

David Cappaert, Michigan State University, Bugwood.org

Forests and Climate Change

FORESTS SEQUESTER (store) carbon and thereby help to reduce the amount of carbon dioxide (CO_2) in the atmosphere. Carbon dioxide is a greenhouse gas that enters the atmosphere from the burning of fossil fuels, solid waste, trees, and wood products, and also as a result of other chemical reactions. The U.S. Environmental Protection Agency (US EPA 2009b) defines a greenhouse gas as "any gas that absorbs infrared radiation in the atmosphere," such as CO_2, water vapor, methane (CH_4), and nitrous oxide (N_2O). Greenhouse gases lead to the greenhouse effect, in which heat is trapped and accumulated in the atmosphere near the Earth's surface. This in turn leads to global warming, which EPA defines as "an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns." United States forests currently sequester about 10 percent of U.S. carbon emissions (Woodbury et al. 2007). Therefore, the maintenance and proper management of private forests are critical to mitigating greenhouse gas emissions and global climate change.

Gordon Bradley, University of Washington

The impact of industry sales on forest parcelization is being studied but may not be completely understood for decades. Much of this land has been sold to institutional investors whose objective is to turn a profit in a shorter period than that pursued by traditional industrial owners. Although many timberlands sold do continue to be managed for timber production, changing ownership has led to and will likely continue to lead to the sale of some commercial timberland for real estate purposes (Clutter et al. 2005, Mendell et al. 2005). In Minnesota, for example, timber and mining industry landowners are selling thousands of acres to financial investors who value both large and small forest parcels in part for their potential to be subdivided and sold for real estate development (Johnson and Stone 2008).

Turnover in land ownership can lead to forest parcelization.

Accelerated changes in the ownership of smaller tracts that are **not** owned by forest industry or institutional investors are also likely to occur in coming decades as an aging generation of owners disposes of or transfers landholdings. More than 60 percent of current private forest landowners are age 55 or older and own a total of 170 million acres of private forest. More than 15 percent of private forest land owners are age 75 or older and own about 52 million acres of forest (Butler 2008). Although many of these older generations own land for reasons largely unrelated to finances, these owners or their heirs may be compelled to subdivide and sell their property if confronted by daunting economic and social challenges (Butler 2008).

Susan Stein

Smaller, more fragmented (or disconnected) parcels can lead to a host of changes in water quality and aquatic species diversity, timber volume and management, native wildlife populations, forest structure and function, wildfire risk, and scenic quality and recreational opportunities (Sampson and Decoster 2000, Smail and Lewis 2009, Stein et al. 2005). The size of forest holdings is also highly correlated with behaviors and attitudes of forest owners, such as their management objectives, plans to transfer the property to others, and willingness to prepare forest management plans (Butler 2008).

Assessing Housing Density Increases and Other Pressures on Private Forest Contributions

To assess the potential for increased housing density and other factors that affect private forests, nationally consistent data layers were constructed and then summarized at the spatial scale of 4th-level watersheds (see "What Is a Watershed?" below) (Steeves and Nebert 1994). Only watersheds with at least 10 percent forest cover and containing at least 10,000 acres of private forest were considered for the study (fig. 3).

Lynn Betts, USDA Natural Resources Conservation Service

What Is a Watershed?

A WATERSHED generally is an area of land that catches rainfall and other precipitation and funnels it into a network of marshes, streams, rivers, lakes, soils, or groundwater. Watersheds also are specific hydrological units defined by the U.S. Geological Survey. The 2,108 fourth-level (also known as 8-digit) watersheds in the conterminous United States average approximately 1 million acres in size but range from approximately 22,000 acres to approximately 13 million acres.

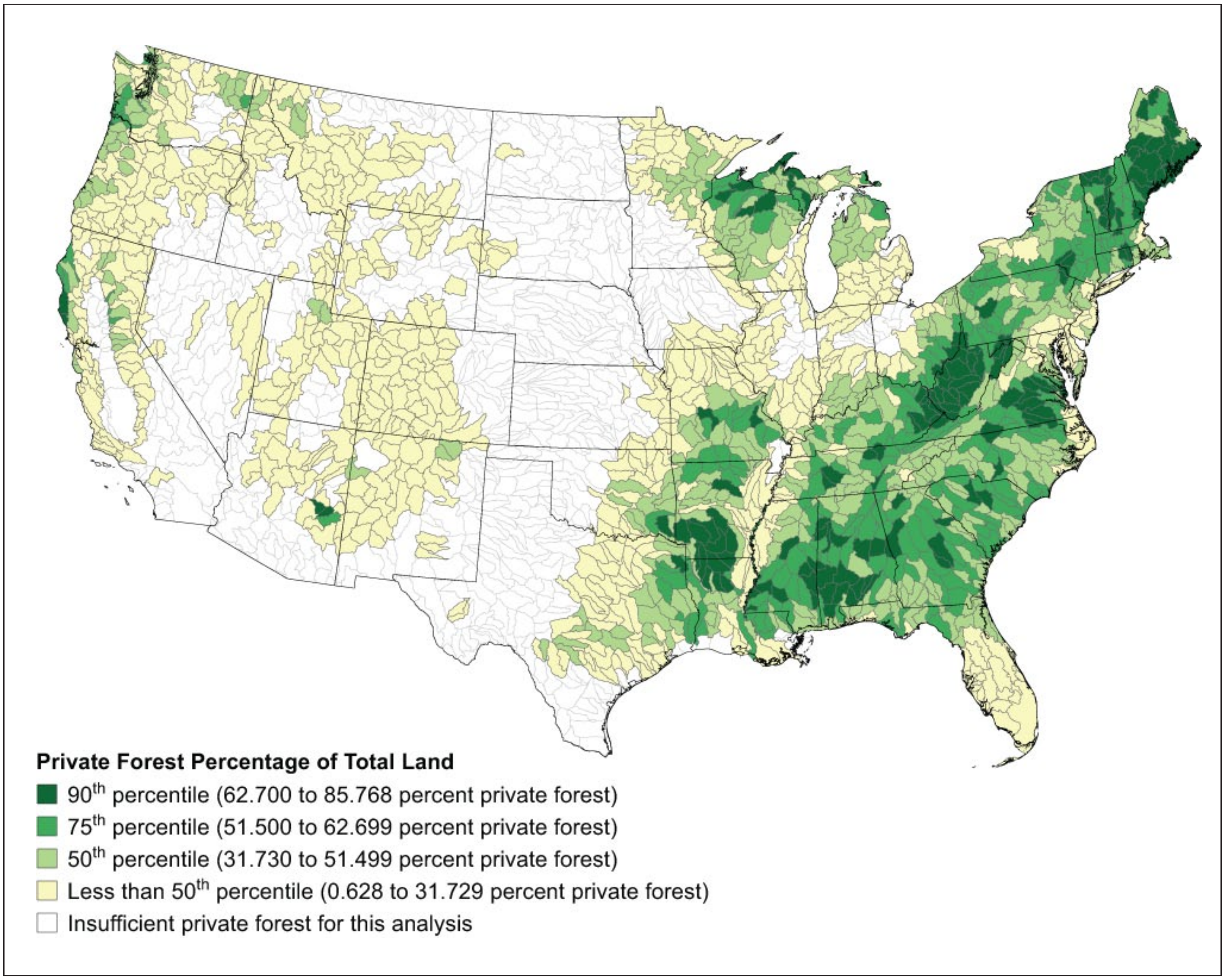


Figure 3—Watersheds by percentage of private forest cover. This map displays watersheds according to the percentage of each watershed containing private forest land. The highest ranked watersheds are found in the East and are concentrated in Maine, Vermont, West Virginia, Arkansas, and Alabama. Most of West Virginia's watersheds are also ranked in the 90th percentile.

As in previous Forests on the Edge studies, increased housing density here refers to a projected increase in housing density between 2000 and 2030—that is, an increased number of housing units per unit area on rural lands such that the housing density category would shift to a higher-level category (Stein et al. 2005, 2007; Theobald 2005). **Rural I** lands are defined as those with fewer than 16 housing units per square mile; **rural II** refers to lands with 16 to 64 housing units per square mile; and **exurban/urban** lands support more than 64 housing units per square mile. Housing density projections are based on several factors including past and current statistics on housing density and population, past growth patterns, road densities, and locations of urban areas (Theobald 2005). Our housing density projections excluded

Faces of Private Forest Owners

Bill Hull

This northern hardwood, hemlock, and oak forest owned by Hull Forest Products has extensive frontage on the federally designated "wild and scenic" Westfield River in Huntington, Massachusetts. Owner Bill Hull has used a variety of options to protect and manage the land as working forest.

"You Can't Make a Living Growing Trees in New England Anymore."

Bill Hull bought his first woodlot—12 acres of hardwoods—when he was 15 years old. Over time he created the largest and most progressive hardwood sawmill in southern New England and founded two family-owned forest products and resources companies. Hull aims to conserve working forest lands and to help preserve New England-style communities. To that end he placed the 12,000 acres of company lands in two states under conservation easements, thus protecting them from development and increasing the funds he has available to conserve more land. He also created a limited partnership to assure that the companies he established will continue, even if his children choose not to continue in the family business. Management of the Hull forests meets the Forest Stewardship Council's (FSC) management standard as certified by the FSC-accredited auditing firm, SmartWood.

Stating that "you can't make a living growing trees in New England anymore," Mr. Hull has found other ways to supplement his income and hold onto the land—such as offering recreational leases to private groups who use the properties for activities ranging from hunting and fishing to hiking, stargazing, and pure enjoyment of nature.

Primary threats facing the Hull forest properties include development and fragmentation related to increasing human population growth in the region. Countless brochures arrive from real estate companies as far away as California urging Mr. Hull to "cash in" on his land. Trespass and unauthorized all-terrain vehicle (ATV) use are related problems, resulting in substantial road damage and increased maintenance costs.

lands recorded in a national database as being protected from development by conservation easements (CBI 2007, DellaSalla et al. 2001, Theobald 2007).

For each data layer analyzed (for example, water quality, at-risk-species, increased housing density, or fire) a percentile ranking was assigned to each watershed. For example, watersheds in which private forests provide habitat for the greatest number of at-risk species fall in the highest (90^{th} percentile) category, whereas watersheds containing the fewest at-risk species fall in the low (0 to 50^{th} percentile) category.

To identify areas where contributions might be most likely to decline as a result of future increases in housing density, we re-ranked each watershed according to the average of the percentile categories of the two layers. For example, if a watershed was in the 96^{th} percentile for at-risk species and the 82^{nd} percentile for housing density increase, it would be placed in the 89^{th} percentile for at-risk species and housing density increase.

White watersheds on each map represent areas that did not meet this study's screening criteria (10 percent forested with at least 10,000 acres of private forest). This does not mean that private forest holdings in these watersheds are not important; the white areas may actually contain small acreages of private forests of high local significance. Several maps contain white watersheds with cross-hatches. These are watersheds for which there were no data for that layer.

For a brief description of data constraints, see "Data and Analysis Considerations" on page 15. A description of how each data layer was constructed is provided in the appendix and in Stein et al. (in press). Data used to create these maps represent more up-to-date information than was available for previous Forests on the Edge papers and studies.

See the appendix for a detailed description of the methods used to make the maps in this section.

Faces of Private Forest Owners

Sandy LeTourneaux

Jim LeTourneux and his family derive a living and a lifestyle from their forest.

An Unclear Future

More than 40 years ago, **Jim Letourneux** bought the Oregon land his parents had acquired when he was a child, becoming owner of 400 acres that he and his wife Sandy now manage as the Tripletree LLC timber farm. LeTourneux family members raise trees that will become saw logs and poles, and they also enjoy the property for recreation. They take pleasure in the long-term goals and aspirations that go along with growing trees that can take decades to reach their full potential.

Some of their neighbors have begun to file claims to subdivide their land into small lots, where homes will be built on what has been private forest land for generations. The impending development and wildfire danger—which Mr. LeTourneux believes go hand-in-hand—are the main pressures on the LeTourneux property today, along with invasive species.

Although their sons are not interested in owning and running a farm, Jim and Sandy LeTourneux don't want their land partitioned—a goal that may be difficult to achieve in the face of the development trend around them.

Go to Part 2

Return to Part 1

Private Forest Benefits and Housing Density Increases

THIS SECTION describes maps that rank watersheds across the conterminous United States according to the relative contributions of their private forests to water quality, timber volume, habitat for at-risk species, and interior forest. We also provide a ranking of watersheds relative to the prospect that these goods and services might be altered by future increases in housing density between 2000 and 2030. Watersheds receiving the highest rankings are those that make the greatest contributions and also have the greatest percentages of private forest projected to experience increased housing density.

Descriptions of each contribution include discussions of the implications of increased housing density. The actual impacts of the housing density increases projected in our analysis will be influenced by many factors, including the level of housing density increase and local environmental and socioeconomic characteristics. For example, a shift from the rural I to the rural II category will likely have different impacts than a shift from the rural I category to the urban-exurban category. The same shift in two ecologically different areas will likely have different impacts as well.

According to our analysis, over 57 million acres of rural forest land could experience a substantial increase in housing density from 2000 to 2030. As displayed in figure 4, watersheds with the highest percentages of private forest to be developed are concentrated in the East—in particular in Michigan, in the southern Appalachians (at the intersection of North Carolina, South Carolina, northern Georgia, and Tennessee), in North Carolina, and in Florida. Western States with highly ranked watersheds include Washington, Colorado, and California. Many of the highest ranking watersheds are adjacent to large metropolitan areas such as Denver, Albuquerque, Phoenix, Washington DC, Atlanta, and Knoxville.

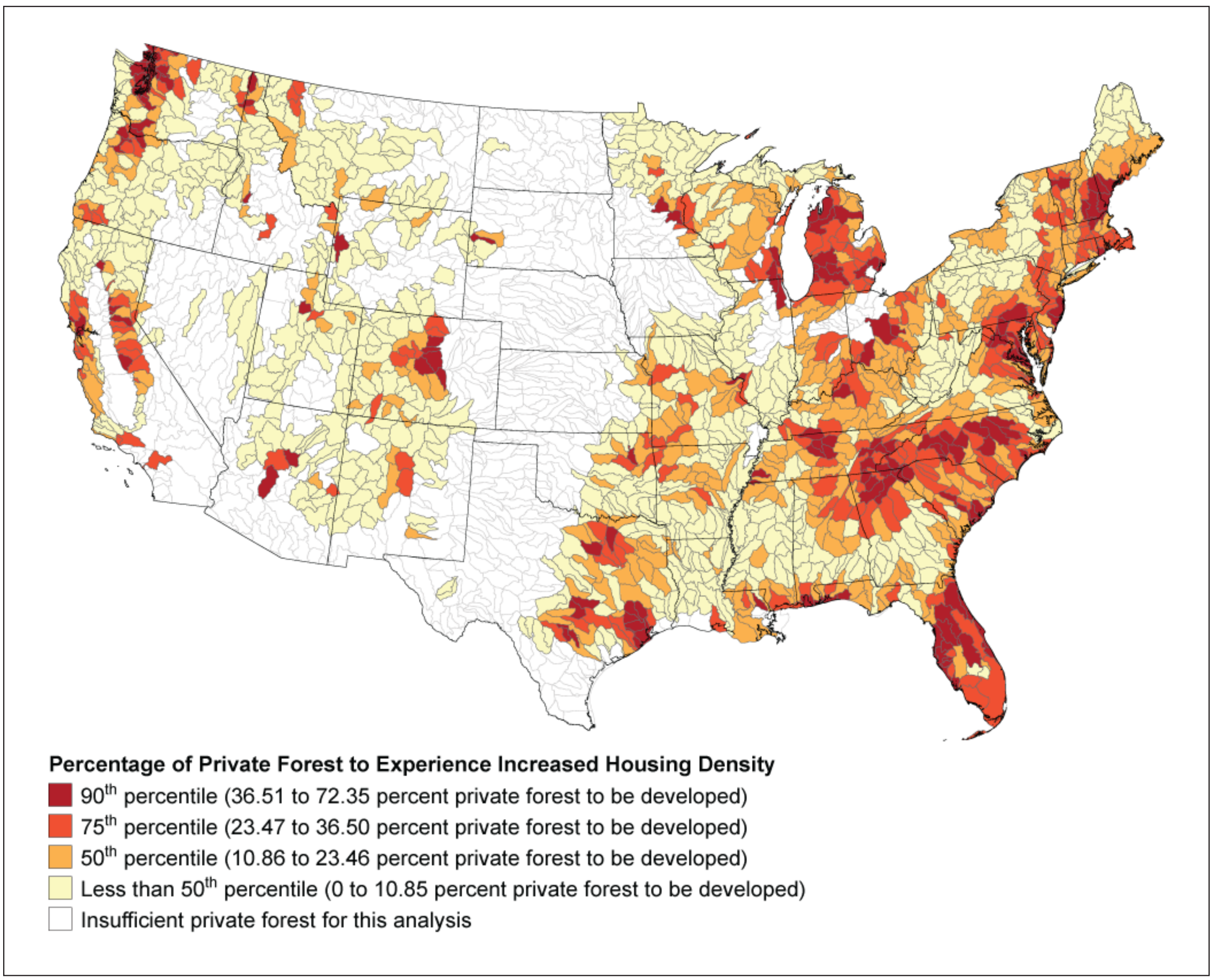


Figure 4—Watersheds by percentage of private forest projected to experience increased housing density.

Jeff Kline

The top 15 watersheds in terms of total acreage of private forest projected to experience increased housing density are located in the East (see fig. 5). The Merrimack watershed of Massachusetts and New Hampshire is at the top of the list, with over 400,000 acres of private forest projected to shift out of one of our two rural categories to the next highest density category. Eight of the top watersheds form an arc extending from northern Alabama through Georgia and South Carolina, to North Carolina. Others are located in north Florida, Kentucky, and New England.

	Watershed	Acres	State(s)
1	Merrimack	416,192	Massachusetts, New Hampshire
2	Middle Chattahoochee–Lake Harding	346,163	Alabama, Georgia
3	Piscataqua–Salmon Falls	345,070	Maine, Massachusetts, New Hampshire
4	Etowah	330,625	Georgia
5	Upper Neuse	323,468	North Carolina
6	Upper Broad	320,688	North Carolina, South Carolina
7	Lower St. Johns	314,466	Florida
8	Lower Kennebec	308,017	Maine
9	Upper Ocmulgee	306,174	Georgia
10	Saluda	294,915	North Carolina, South Carolina
11	Upper Catawba	280,136	North Carolina, South Carolina
12	Upper Oconee	277,620	Georgia
13	Saco	259,896	Maine, New Hampshire
14	Middle Coosa	257,556	Alabama
15	Lower Kentucky	244,192	Kentucky

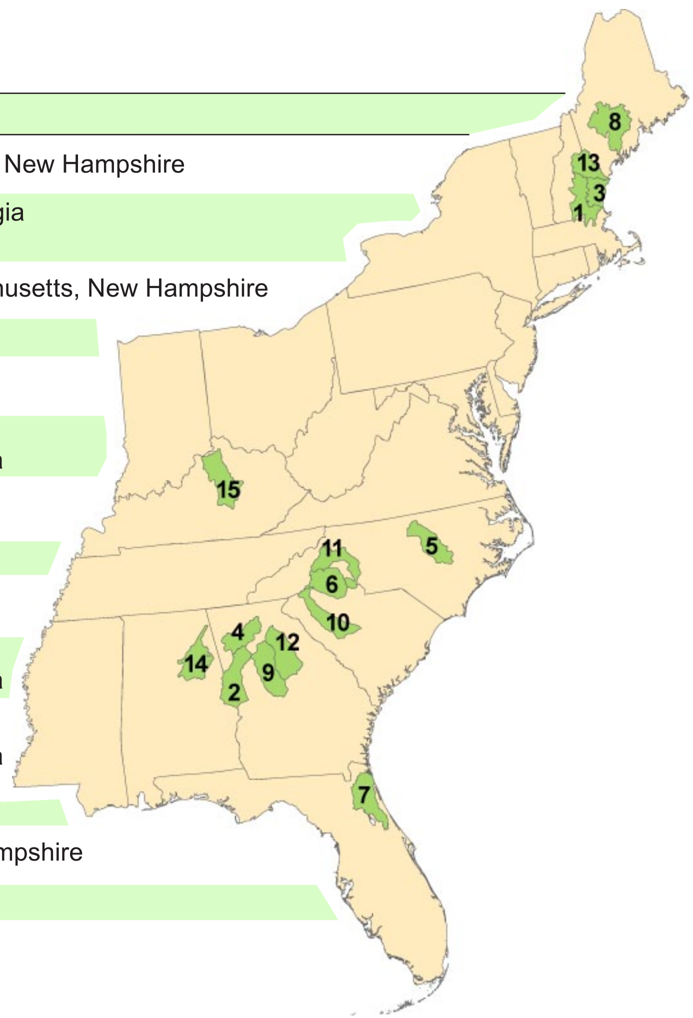


Figure 5—Top 15 watersheds in terms of total acreage of private forest projected to experience increased housing density. Note: Because of the use of updated data and analysis, the top 15 watersheds presented in this table are different than the top 15 watersheds shown in a similar table in Stein 2005.

Data and Analysis Considerations

DATA USED for this report represent the most recent and nationally consistent data available. As with all large-scale geographic information system analyses, this analysis has a number of constraints. For example, many western woodlands were not included in our analysis because they do not meet the tree height or canopy cover requirements needed to be identified as forest in the National Land Cover Data. The same is true of many riparian forests located in the Plains States. Our study focused on identifying lands that would shift out of the rural I or rural II housing density categories, into the next highest category. However, housing density shifts within each of our housing density categories also could create important impacts. Housing density increases within the rural I category in particular are of increased concern in many Western States.

Jeff Kline

Water Quality

Tom Iraci

Assessment of Current Situation

More than a quarter of America's water is filtered by private forests.

Approximately 53 percent of the water supply in the conterminous 48 states originates on forests (Brown et al. 2005)—and that water is widely recognized as clean compared to waterflow from other sources. Watersheds with more forest cover have been shown to have higher groundwater recharge, lower stormwater runoff, and lower levels of nutrients and sediment in streams than do areas dominated by urban or agricultural uses (Brett et al. 2005, Crosbie and Chow-Fraser 1999, Matteo et al. 2006). With more than half the Nation's forests in private ownership, the contribution of private forests to the supply of high-quality water in the conterminous United States is exceptional: more than a quarter of our fresh water flows from and is filtered by private forest lands.

Private forests provide other vital water-related ecological goods and services, including protection from soil erosion (especially during floods); filtration of fertilizers and pesticides; prevention of sediment runoff to streams; and support of riparian and wetland habitat for many fish and wildlife species. Although the contributions of public forests to water quality are not considered in this analysis, public forests also play a critical role in providing clean water.

Figure 6 depicts watersheds according to the relative contribution of private forests to the production of clean water. Rankings are based on a combination of factors including the percentage of each watershed in private forest as well as the percentage of all forest that is private. Watersheds whose private forests are providing relatively high contributions to the production of clean water are located primarily in the East. Watersheds in the 90th percentile are concentrated in Maine, West Virginia, Virginia, Georgia, and Alabama.

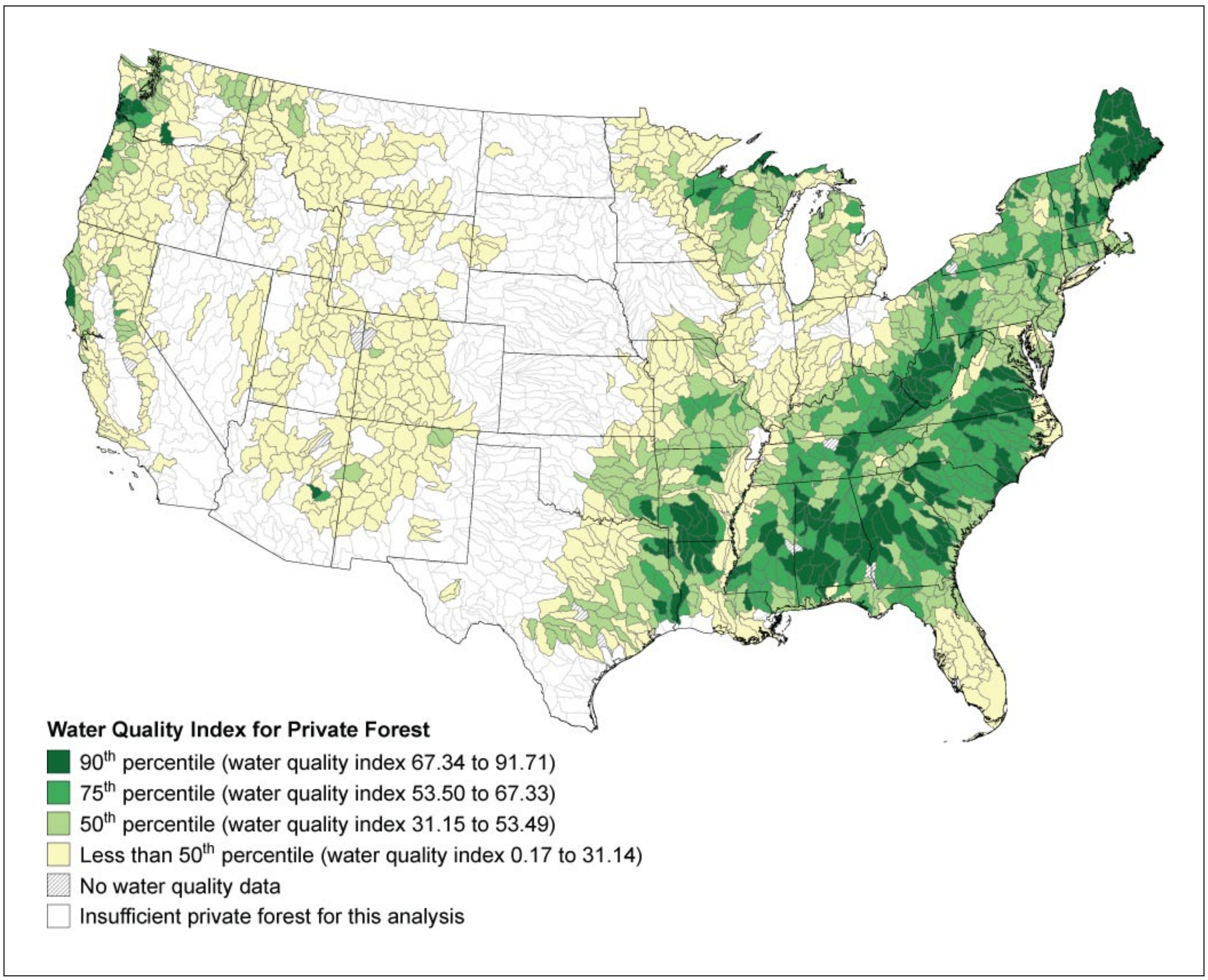


Figure 6—Watersheds by relative contribution of private forests to the production of clean water.

Identifying Areas of Future Change in Water Quality Associated With Projected Increases in Housing Density

Watersheds where water quality contributions could be most affected by increased housing density are in the East.

Figure 7 displays watersheds according to the contributions of private forests to water quality combined with the potential for increased housing density. Not surprisingly, watersheds in the East have the highest potential for future change in water quality as a result of future housing density increase. Areas with the largest concentrations of high-ranked watersheds include central New England and an area stretching from the North Carolina coast through the southern Appalachians. Highest ranking watersheds in the West are in the Pacific Northwest, central California, and northern Idaho.

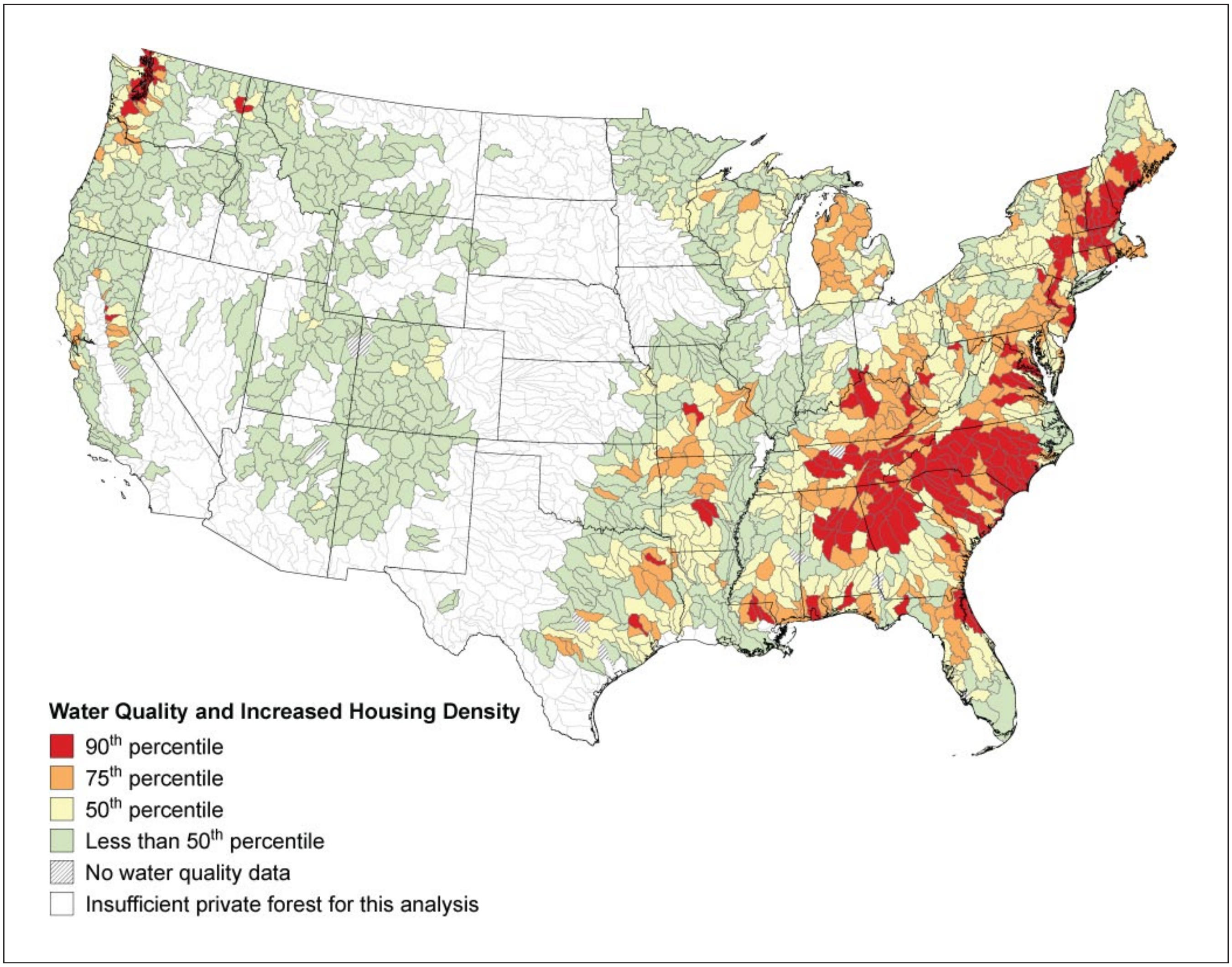


Figure 7—Watersheds by potential for changes in water quality as a result of projected increases in housing density on private forest lands.

Table 1 presents the 15 watersheds that could experience the largest changes in water quality as a result of increases in housing density on private forest land; 3 of the 4 highest ranked watersheds occur at least partially in New Hampshire, and 7 of the 13 highest ranked watersheds are located, either entirely or in part, in North Carolina.

Table 1—The 15 watersheds projected to experience the most change in water quality as a result of increases in housing density on private forest lands

Numerical rank	Watershed	State(s)	Water quality index[a]	Private forest to experience increased housing density
				Percent
1	Piscataqua-Salmon Falls	Maine, Massachusetts, New Hampshire	74.6	63
2	Contoocook	New Hampshire	75.5	55
3	Etowah	Georgia	68.1	51
4	Merrimack	Massachusetts, New Hampshire	66.3	50
5	Seneca	North Carolina, South Carolina	68.5	46
6	Deep	North Carolina	74.4	35
7	Coosawattee	Georgia	65.8	45
8	Haw	North Carolina	65.1	46
9	Upper Bear	California	63.7	47
10	Upper Cape Fear	North Carolina	61.3	51
11	Upper Broad	North Carolina, South Carolina	69.9	36
12	Saluda	North Carolina, South Carolina	70.9	34
13	Upper Neuse	North Carolina	60.6	50
14	Four Hole Swamp	South Carolina	69.1	35
15	Rivanna	Virginia	68.3	36

[a] Water quality indices are based on a combination of factors including the percentage of each watershed in private forest and the percentage of all forest that is private (see appendix for details).

Implications

Water quality and quantity can be altered when forest vegetation is replaced by housing and associated roads, parking lots, driveways, and rooftops. When urbanization increases, volume and peak rate of runoff also increase (Im et al. 2003); furthermore, depending on the land use, urban runoff can carry pesticides, fertilizers, oils, and metals (Stein and Butler 2004). The size of the forested area is important—wetlands adjacent to large forested tracts have lower levels of harmful nutrients and pollutants than do wetlands adjacent to smaller forested tracts (Houlahan and Findlay 2004).

Lynn Betts, Natural Resources Conservation Service

Timber Volume

Steve Nagy/DesignPics

Over 90 percent of U.S. timber comes from private forests.

Assessment of Current Situation

Private forest land makes a substantial contribution to America's timber resources, accounting for 92 percent of all timber harvested in the United States in 2001 (Smith et al. 2004). Trends and projections for coming decades show the forest products sector changing in response to several factors, including shifting populations, increased timber production in the South, and substantial changes in the types and intensities of forest management for private timberland owners (Egan et al. 2007, Haynes et al. 2001). The bulk of the Nation's timber harvest is expected to occur in the Southeast. Forecasts indicate that, by 2050, roughly two-thirds of the softwood timber harvest will come from plantations on less than 20 percent of the timberland base (Alig and Butler 2004, Haynes et al. 2001).

Chris Evans, River to River CWMA, Bugwood.org

In addition to timber, private forests also provide a host of other economically and culturally valuable specialty products such as mushrooms, nuts, medicinal herbs, syrup, basketry materials, and floral greens.

Figure 8 displays the importance of watersheds according to the relative contribution of private forest land to growing stock volume[1] (hereafter called timber volume), and is based on the most recent estimates by the Forest Service's Forest Inventory and Analysis (FIA) Program, which conducts the U.S. national forest inventory (see appendix for more details). Watersheds in the 90th percentile are located throughout the East, as well as in northern California and in western Washington and Oregon.

[1] Growing stock volume is defined as the volume of trees of commercial species with diameters of at least 5 inches d.b.h. (diameter at breast height) growing on forest land.

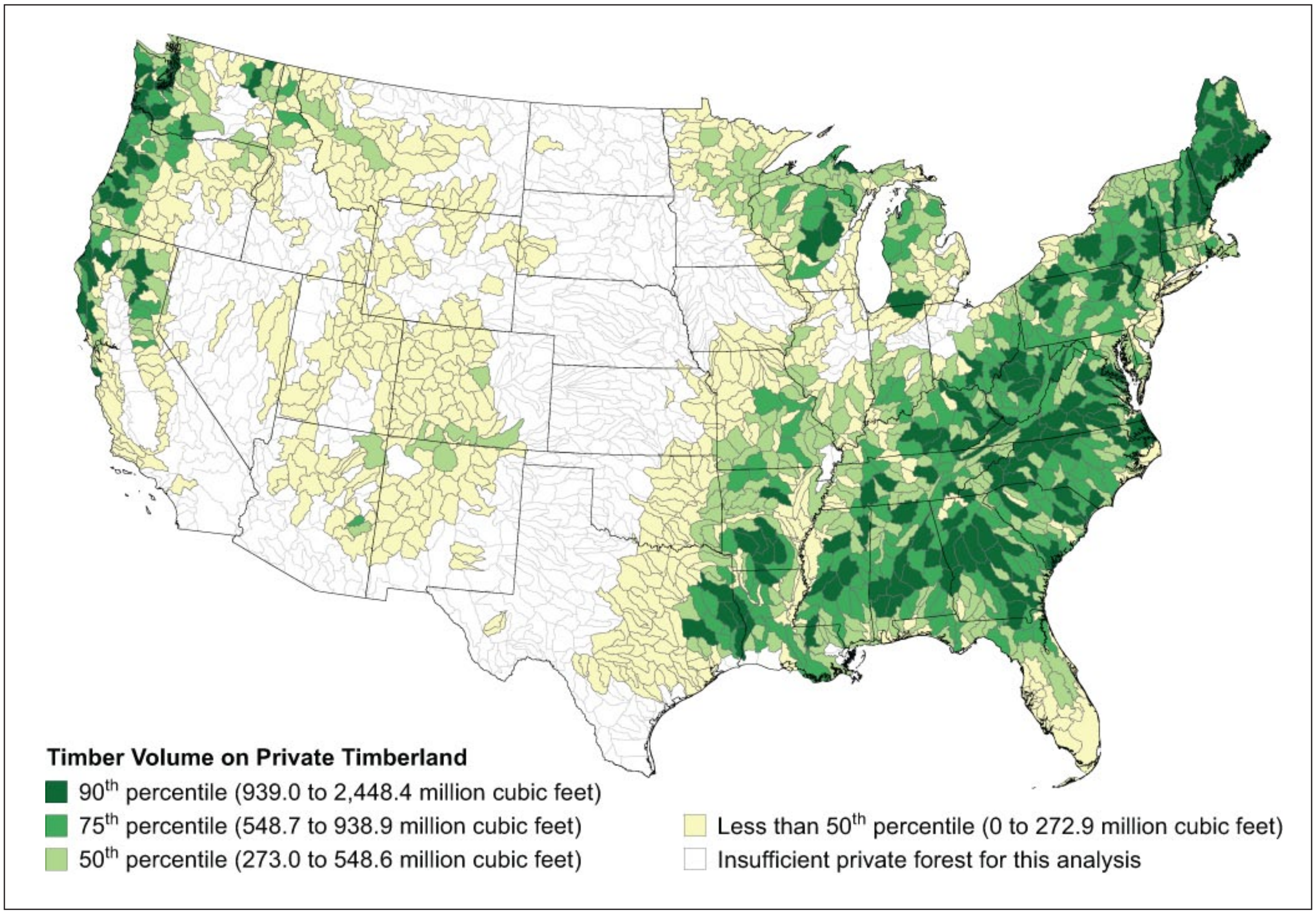


Figure 8—Watersheds by relative contribution of private forests to the production of timber volume.

U.S. Forest Service

Privately held pine plantation acreage in the South increased by more than 25 million acres between 1952 and 1997, more than a tenfold increase. An additional 14 million acres of private lands in the South are projected to be in pine plantation by 2050 (Alig and Butler 2004).

Watersheds where future increases in housing density could most affect timber volume are in the East and west-coast states.

Identifying Areas of Future Change In Timber Volume Associated With Projected Increases in Housing Density

Figure 9 displays watersheds according to the potential for changes in the amount of private timber volume as a result of future housing density increases. This map was produced by combining the growing stock volume and projected housing density increase layers using the method described on page 11. High-ranking watersheds are found throughout the East, especially in New England and the southern Appalachians. High-ranking watersheds in the West are scattered across western Washington, Oregon, and northern California.

Table 2 presents the 15 watersheds projected to experience the most changes in timber volume on private forest land as a potential result of increases in housing. As with the water quality findings, a number of watersheds occur at least partially in New Hampshire (4 of the 9 highest ranked) and North Carolina (7 of the 15 highest ranked).

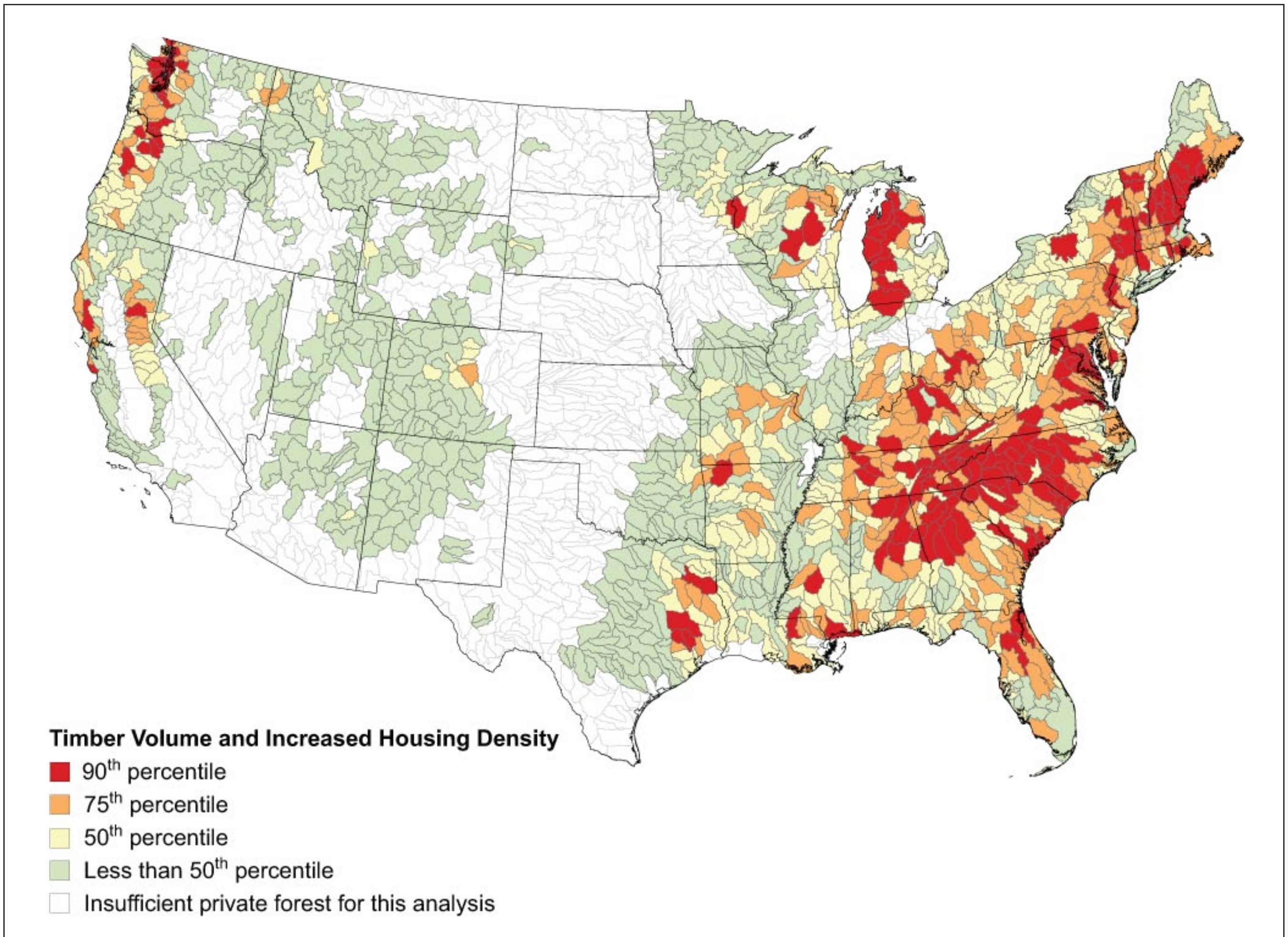


Figure 9—Watersheds by potential for changes in timber volume as a result of projected increases in housing density on private forest lands.

Table 2—The 15 watersheds projected to experience the most change in timber volume as a result of increases in housing density on private forest lands

Numerical rank	Watershed	State(s)	Estimated private timber volume	Private forest to experience increased housing density
			Million cubic feet	*Percent*
1	Merrimack	Massachusetts, New Hampshire	1,867	50
2	Piscataqua-Salmon Falls	Maine, Massachusetts, New Hampshire	1,094	63
3	Puget Sound	Washington	1,754	42
4	Etowah	Georgia	1,103	51
5	Lower Potomac	Maryland, Virginia	1,229	47
6	Saco	Maine, New Hampshire	1,134	45
7	Upper Catawba	North Carolina, South Carolina	1,319	40
8	Haw	North Carolina	1,048	46
9	Contoocook	New Hampshire	919	55
10	Upper Broad	North Carolina, South Carolina	1,378	36
11	Saluda	North Carolina, South Carolina	1,439	34
12	Upper Neuse	North Carolina	853	50
13	Upper French Broad	North Carolina, South Carolina, Tennessee	1,346	34
14	Presumpscot	Maine	797	55
15	Hiwassee	Georgia, North Carolina, Tennessee	1,008	38

Implications

The relationship between timber production and housing density is complex and not entirely predictable. Timber production and active forest management might decline or change in some areas as a consequence of increased housing density, generating a concern about wood supply (Egan et al. 2007) and price (LeVan 1995). One study in the South (Munn et al. 2002) concluded that urbanization led to lower rates of timber harvesting and to an overall decrease in regional short-term timber supply. Another study in the South documented expert opinions about a continuous, negative relationship between population density and commercial forestry; as population increased, commercial forestry decreased (Wear et al. 1999). A study of timberland in New Hampshire concluded that declining parcel size made forest management less profitable and that it was generally not profitable to harvest timber on parcels smaller than 10 to 20 acres (Thorne and Sundquist 2001). Such findings have been less conclusive in the Pacific Northwest, but researchers there did find a relationship between development and reduced private forest management and investment (Kline et al. 2004). However, in some places, changes in the management and harvest of private forests may be due to a variety of interacting factors, including geography, inherent site productivity, national and international markets, stumpage prices, and regulation (Egan et al. 2007, Kline and Alig 2005).

Habitats for At-Risk Species

Assessment of Current Situation

Approximately 60 percent of "at-risk" (see sidebar below) vertebrate and invertebrate animals and plants in the conterminous United States are associated with private forests, and two-thirds of the watersheds in the conterminous United States include private forests identified as having at-risk species (Robles et al. 2008). In most watersheds identified as having the greatest number of at-risk species, at least one species is found **only** on private land, and these forests are often isolated and particularly vulnerable to development (Robles et al. 2008). Private forests are especially critical for wide-ranging animals that cross patchworks of public and private lands at different seasons or life stages, such as the endangered Florida panther (*Puma concolor coryi*) or the grizzly bear (*Ursus arctos horribilis*) (Robles et al. 2008). Land use conversion owing to development has contributed to the decline of approximately 35 percent of all imperiled species nationwide (Wilcove et al. 2000).

Private forests provide critical habitat for at-risk species.

Figure 10 displays watersheds based on the number of at-risk species associated with private forests. Data on at-risk species were provided by NatureServe and its member Natural Heritage Programs and Conservation Data Centres in mid 2007. Watersheds in darkest green (90th percentile) provide habitats for up to 79 at-risk

Valerie Abbott

Red wolf (*Canis rufus*).

What Are At-Risk Species?

AT-RISK SPECIES include those plants and animals that are listed under the Endangered Species Act (ESA) or that are designated as critically imperiled, imperiled, or vulnerable according to the NatureServe Conservation Status Ranking system.

The ESA defines an endangered species as one that is in danger of extinction throughout all or a substantial portion of its range; a threatened species is one that is likely to become endangered in the foreseeable future. Also considered at-risk are species that are candidates or proposed for possible addition to the federal ESA list.

The NatureServe ranking system is slightly different. Species that have 5 or fewer populations are labeled critically imperiled; those with 20 or fewer populations are designated as imperiled; and those with 80 or fewer populations are identified as vulnerable.

Natural Heritage databases are maintained by every state to record the presence of plants and animals. NatureServe is a nonprofit organization that works with each State Natural Heritage office to collect and display this information at larger scales.

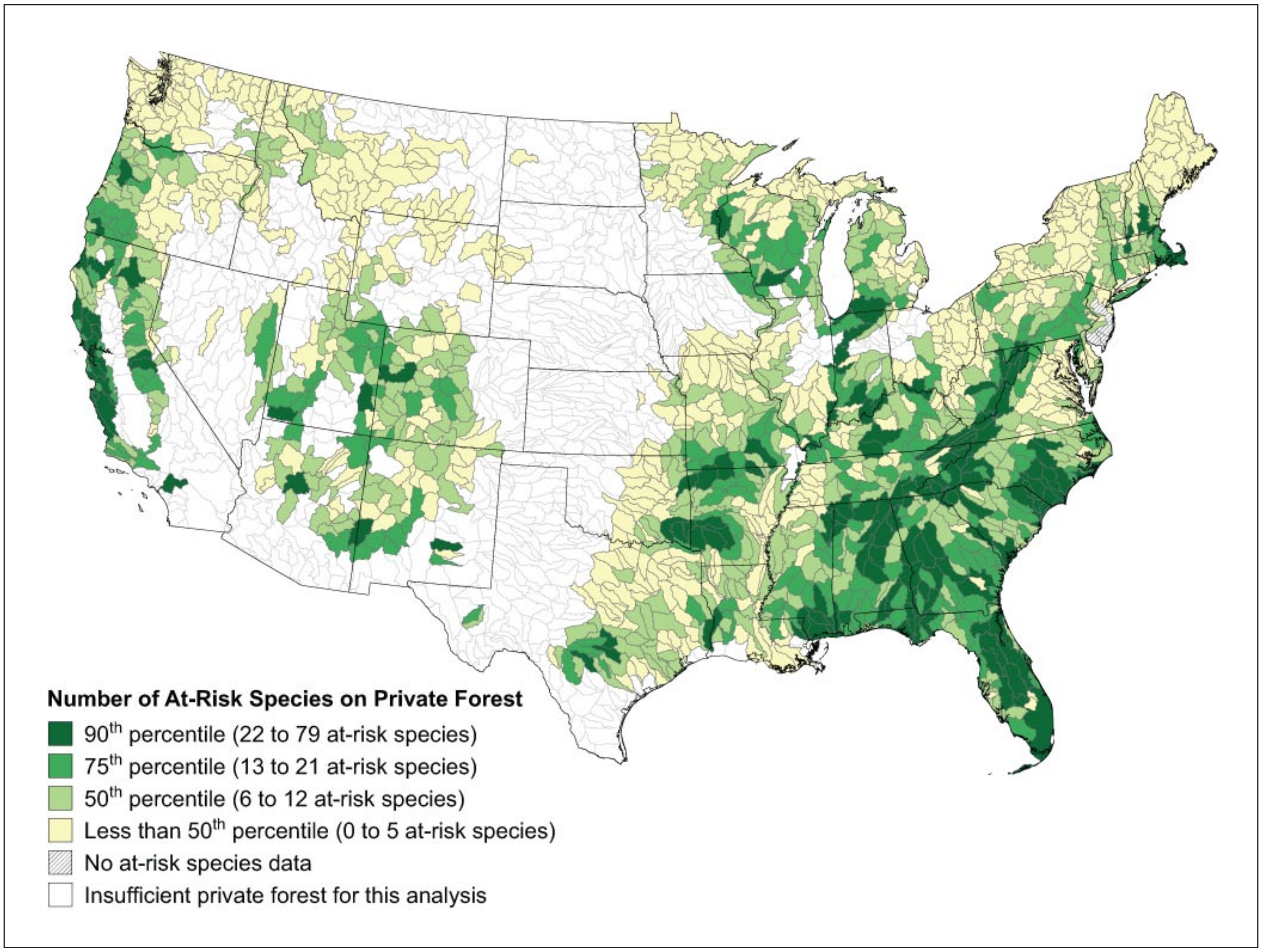


Figure 10—Watersheds by relative contribution of private forests to habitats for at-risk species.

species. Much of the Southeast and Mid-Atlantic have high concentrations of these watersheds. High numbers of at-risk species are also found in watersheds along the California coast and the Sierra Nevada range. The Southwest contains a few high-ranking watersheds and a large number with private forests providing habitat for 6 to 21 at-risk species—relatively significant numbers considering that these areas have a lower diversity of species in general, relative to coastal areas.

Larry Richardson, U.S. Fish and Wildlife Service

Florida panther (*Puma concolor coryi*).

Identifying Areas of Future Change in At-Risk Species Habitats Associated With Projected Increases in Housing Density

Figure 11 depicts watersheds according to the number of at-risk species associated with private forests and the percentage of private forest projected to experience increased housing density. Watersheds in red (upper 10th percentile) cover much of

Florida and are also found along the Maine–New Hampshire border, in southern New Jersey, and in and around the Southern Appalachians, as well as in Michigan, eastern Texas, western Oregon, and central California. The highest ranking is the Upper Cape Fear watershed, located in central North Carolina and home to 37 at-risk species associated with private forests. The San Pablo Bay watershed, the second-highest ranking watershed for this category, is located north of Berkeley, California, and contains 35 at-risk species associated with private forests.

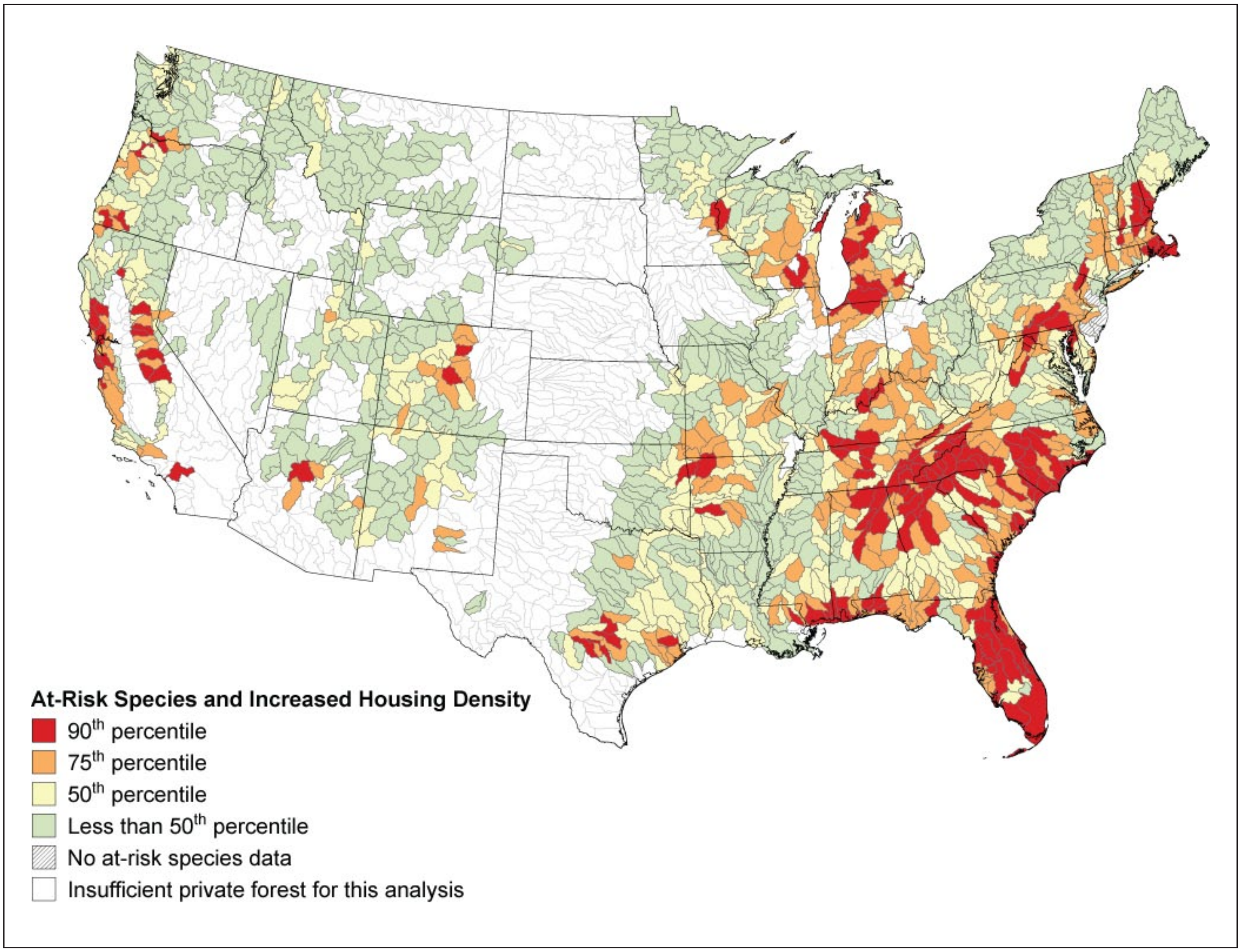


Figure 11—Watersheds by potential for changes in at-risk species habitats as a result of projected increases in housing density on private forest lands.

Table 3 presents the 15 watersheds projected to experience the most changes in habitat for at-risk species as a result of projected increases in housing density on private forest lands; all but 2 watersheds are located in the South, including parts of North Carolina, South Carolina, Florida, and Georgia.

Table 3—The 15 watersheds projected to experience the most change in at-risk species habitats as a result of increases in housing density on private forest lands

Numerical rank	Watershed	State(s)	Number of at-risk species associated with private forests	Private forest to experience increased housing density
				Percent
1	Upper Cape Fear	North Carolina	37	51
2	San Pablo Bay	California	35	51
3	Withlacoochee	Florida	33	52
4	Seneca	North Carolina, South Carolina	45	46
5	Tugaloo	Georgia, North Carolina, South Carolina	32	47
6	Upper Catawba	North Carolina, South Carolina	58	40
7	Merrimac	Massachusetts, New Hampshire	28	50
8	Kissimmee	Florida	48	42
9	Oklawaha	Florida	40	42
10	Upper Neuse	North Carolina	26	50
11	Upper Little Tennessee	Georgia, North Carolina, Tennessee	44	37
12	Conasauga	Georgia, Tennessee	28	41
13	Austin-Travis Lakes	Texas	27	42
14	Lower St. Johns	Florida	24	44
15	Upper Broad	North Carolina, South Carolina	40	36

Implications

Changes in the presence and distribution of private forest habitats could cause populations of at-risk species to disappear, decline, or become more vulnerable to disturbance (Robles et al. 2008). Loss of habitat is highly associated with at-risk species that have declining populations, and is seen as the primary obstacle for their recovery (Donovan and Flather 2002, Kerr and Deguise 2004).

Watersheds with the highest at-risk species counts and potential for increased housing density are in California and the East.

Decreases in habitat quality and quantity associated with increases in houses, roads, fences, powerlines, and other factors related to development can lead to declines in terrestrial biodiversity (Findlay and Houlahan 1997, Graham 2007, Houlahan and Findlay 2003, Houlahan et al. 2006, USDA NRCS 2007); increases in invasions by exotic (nonnative) species along forest edges (Meekins and McCarthy 2001); creation of barriers to movement (Jacobson 2006); increases in predation (Coleman and Temple 1993, Engels and Sexton 1994, Kurki et al. 2000, Sieving and Willson 1999, Woods et al. 2003); declines in pairing success (Lampila et al. 2005); and reproductive failures or mortality from parasitism and other factors (Hartley and Hunter 1998). Habitat degradation also has been determined to contribute to declines in fish numbers that could result in extinction within a century if trends continue (Ratner et al. 1997). The presence of roads alone can have impacts even tens to hundreds of yards away, including interruption of wildlife movement and modification of habitat, microclimate, and the chemical environment (Riitters and Wickham 2003).

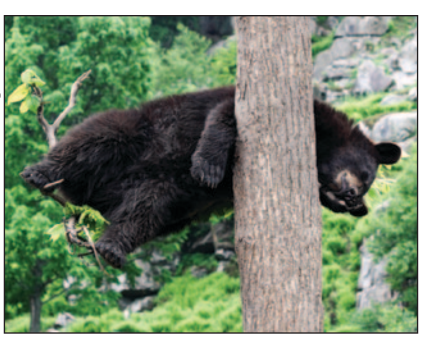
Interior Forests

Eric Foltz, ©iStockphoto.com

Assessment of Current Situation

Interior forest generally refers to an area of forest land that is surrounded by other forest (see the appendix for the detailed definition used for this study). Interior forests provide numerous public services including habitat for wildlife species. Interior forest is inversely related to the degree that a forested landscape is fragmented, or separated, into disconnected patches; as forests are fragmented, the relative amount of forest edge increases. More than 40 percent of all forests in the United States are estimated to be located within 90 meters (295 feet) of a forest edge (Riitters et al. 2002, Riitters and Wickham 2003). The amount of interior forest required by many species is not well-understood (Riitters et al. 2004); however, certain species are known to require larger expanses of interior forest than others, and the amount of interior forest can serve as an indicator of available habitat for species that are sensitive to fragmentation. For example, some bird species such as the red-bellied woodpecker (*Melanerpes carolinus*) and the white-breasted nuthatch (*Sitta carolinensis*) show substantial preferences for foraging in interior forest rather than at forest edges (Whelan and Maina 2005), and small mammals such as the eastern chipmunk (*Tamias striatus*) spend substantially more time pausing (and less time foraging) at the forest edge than they do in interior forest, presumably because of increased predation risk (Mahan and Yahner 1999). The survival of many larger mammals—such as the black bear (*Ursus americanus*), bobcat (*Lynx rufus*), and river otter (*Lutra canadensis*)—in some places can hinge on the maintenance of large expanses of interior forest (Phelps and Hoppe 2002).

Interior forests are essential to the survival of many large mammals.



Bev McConnell, ©iStockphoto.com

Figure 12 displays watersheds according to the percentages of private forest categorized as interior forest, based on NLCD forest cover data (Homer et al. 2007). This analysis involved dividing all private forests across the United States into pixels (30 by 30 meters [98.4 by 98.4 feet] each). To qualify as interior forest, each pixel had to be forested as did 90 percent of a surrounding 65-hectare (160.6-acre) window. Watersheds in the 90th percentile are concentrated along an axis running from northern Maine through southern Louisiana (particularly in Maine, New Hampshire, Vermont, northern New York, and West Virginia). High-ranking watersheds are also found in Arkansas, southern Missouri, northern Wisconsin and Minnesota, northern California, northern Idaho, western Montana, and scattered locations across the Southwest.

Terry Spivey Photography, Bugwood.org

Some small mammals spend substantially more time pausing (and less time foraging) at the forest edge than they do in interior forest (Mahan and Yahner 1999, USGS 2006).

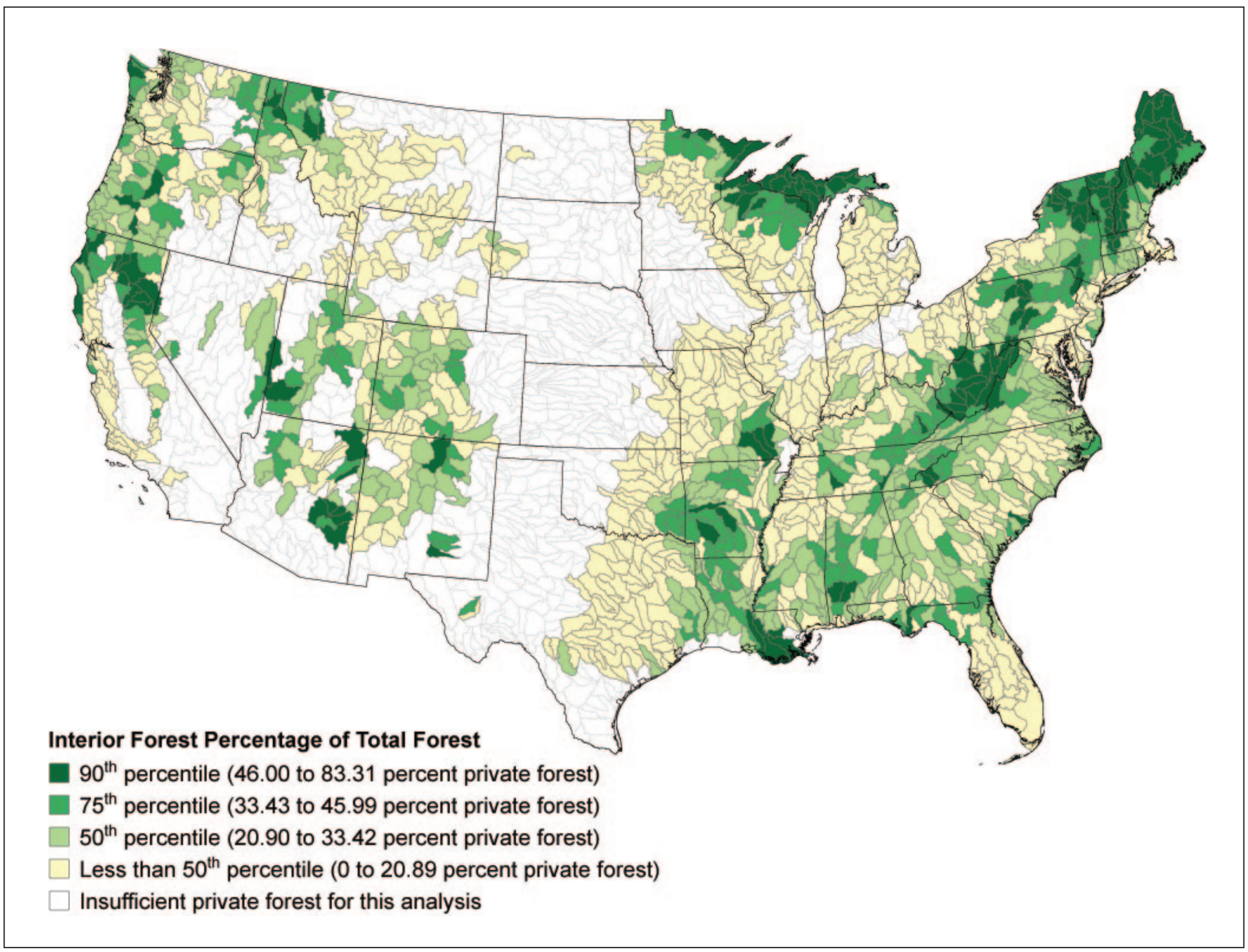


Figure 12—Watersheds by relative contribution of private forests to interior forest cover.

Jack Jelly, ©iStockphoto.com

Identifying Areas of Future Change in Interior Forest Associated With Projected Increases in Housing Density

Figure 13 identifies areas where private interior forest may be reduced by future housing density increases based on a combined ranking of the private interior forest and housing density data layers. Watersheds in the 90th percentile are again located along the Maine-Louisiana axis and are particularly concentrated in central New England, central Pennsylvania, and the southern Appalachian area. High-ranking watersheds are also found along the coasts of South Carolina, Georgia, and northern Florida; along Puget Sound in Washington state; in the Sierra Nevada range of California; and outside Denver, Colorado.

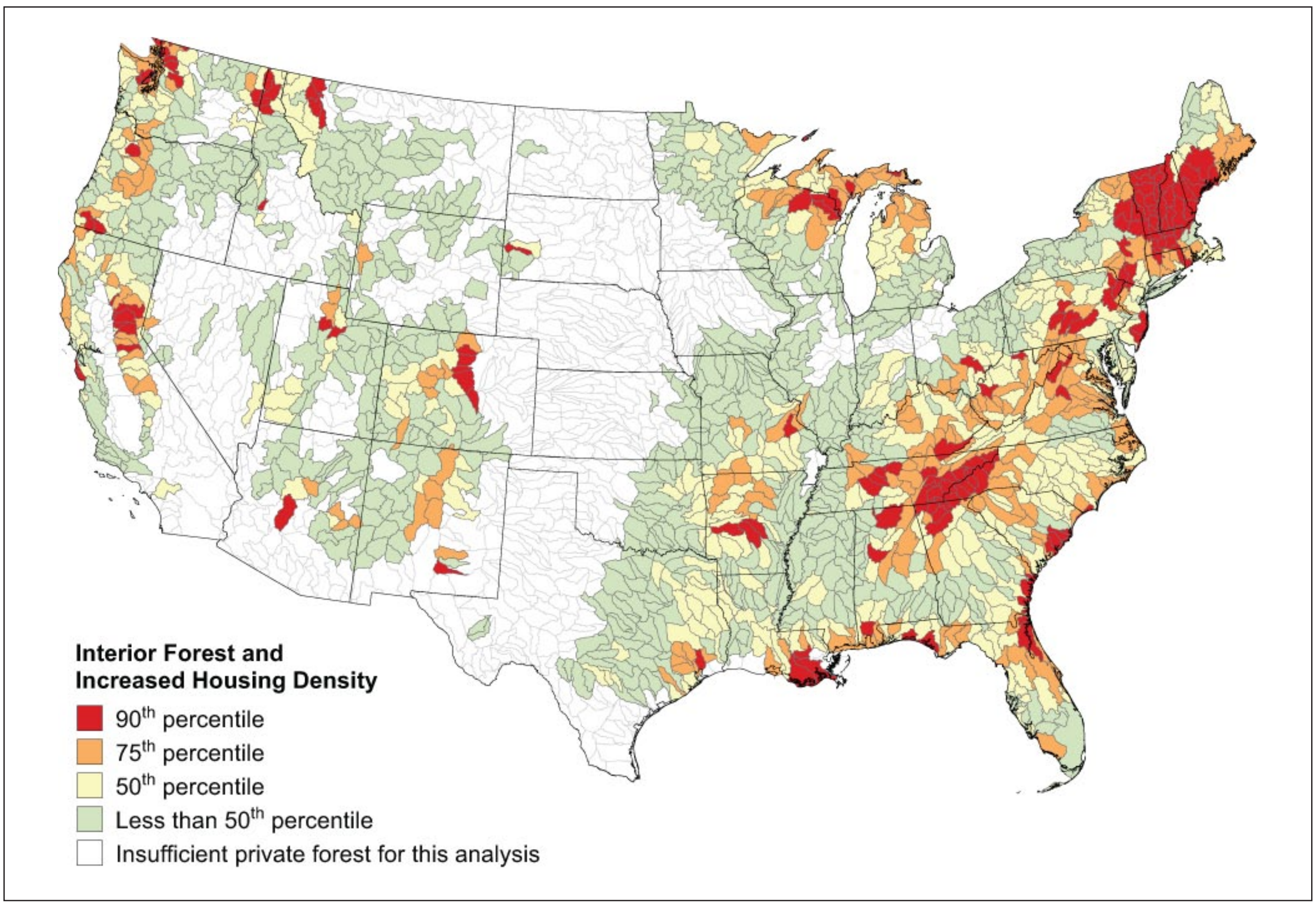


Figure 13—Watersheds by potential for changes in interior forest as a result of projected increases in housing density on private forest lands.

Table 4 presents the 15 watersheds projected to experience the largest reduction in interior forest as a result of increases in housing density on private forests. Eight high-ranking watersheds are located in the Northeast, primarily in New York, Vermont, New Hampshire, and Maine. The list also includes four Western watersheds, in Colorado, Idaho, Washington, and California.

Table 4—The 15 watersheds projected to experience the most change in interior forest as a result of increases in housing density on private forest lands

Numerical rank	Watershed	State(s)	Private forest that is interior	Private forest to experience increased housing density
			Percent	
1	Contoocook	New Hampshire	53	55
2	Sacandaga	New York	70	34
3	Winooski	New York, Vermont	52	38
4	Saco	Maine, New Hampshire	43	45
5	Honcut headwaters	California	46	40
6	Middle Delaware-Mongaup-Brodhead	New Jersey, New York, Pennsylvania	58	32
7	Upper Little Tennessee	Georgia, North Carolina, Tennessee	47	37
8	Coosawattee	Georgia	42	45
9	Lamoille	New York, Vermont	48	36
10	Pemigewasset	New Hampshire	69	29
11	St. Vrain	Colorado	40	46
12	Tuckasegee	North Carolina, Tennessee	57	30
13	Upper Spokane	Idaho, Washington	38	49
14	Priest	Idaho, Washington	43	38
15	West	Vermont	63	27

Implications

Forest fragmentation influences the ecology of most U.S. forests and is associated with numerous conservation problems. Impacts can include changes in microclimate, pollution deposition, and tree growth; the spread of invasive species; altered habitat suitability; and reductions of wildlife movement (Riitters et al. 2002). Impacts of forest fragmentation are species specific (Debinski and Holt 2000) and can adversely affect many species of amphibians, reptiles, birds, mammals, and plants (Riitters et al. 2002). Specific documented impacts on wildlife include changes in the number (richness) of breeding bird species (Jones et al. 2000), decline in numbers of interior forest birds (McWilliam and Brown 2001), altered species interactions (Taylor and Merriam 1995), and changes in species behavior and foraging success (Keyser 2002, Mahan and Yahner 1999, USGS 2006, Whelan and Maina 2005).

Housing density increases in interior forest will be high along an axis from southern Maine to northern Georgia.

Faces of Private Forest Owners

Rick Dunning

Using the Land Well

Rick Dunning and his wife Karen purchased land in southwestern Washington in 1988 as a financial investment. After selling 35 acres, the Dunnings now have about 150 acres to plant, manage, and harvest timber; promote fish and wildlife conservation; and use for recreation.

When the Dunnings bought their land they knew they couldn't live on the income but recognized other returns they would reap from the forest—among them the ability to raise their family with the work ethic and lifestyle that comes from owning and working on the land.

The area around the Dunning property is beginning to break into smaller parcels as a consequence of accelerating local growth. Developers have shown up on the doorstep, and solicitations by mail are frequent. The Dunnings have been offered "phenomenal" amounts for their land, and the pressure to develop is intense for local landowners.

Rick Dunning—who also wears the hat of executive director of the Washington Farm Forestry Association—prefers to look at development as an "opportunity" rather than an inherent "threat." He suggests that regulation and taxation issues may overshadow housing development as the most serious challenge to private forest owners.

He is convinced that people don't have to choose between forests and development. "You **can** have human population and working forests together," he said. "If we have population and green areas mesh, we can absorb the population and still use the land well."

Go to Part 3

Return to Part 2

Additional Pressures

Ted Wood/Aurora Photos

MANY ECOLOGICAL and socioeconomic forces—including wildfires, native and exotic (nonnative) insects and other pests, extreme weather events, and timber harvest—help keep forests dynamic and constantly changing. The frequency, severity, and magnitude of these forces and their impacts on forest conditions can be heavily influenced by housing density increases and associated development. For example, as described in this section, increased housing development has been associated with an increase in wildfire ignitions (Syphard et al. 2007), roads have been linked to the spread of invasive plants (Meekins and McCarthy 2001), and urbanization can lead to the spread of forest insect pests (Poland and McCullough 2006).

This section displays and describes maps that indicate where U.S. private forests are affected by the pressures of wildfire, insect pests and diseases, or air pollution. It also provides a ranking of watersheds according to the prospects that increased housing density and one of these factors will occur in the same watershed.

Presented here are only a few of the many possible maps that identify areas across the country where pressures in addition to increased housing density may affect private forest benefits and contributions, and where housing density increases in turn may exacerbate the effects of insect pests, diseases, wildfire, and air pollution. For additional maps and to create individualized maps, please visit the Forests on the Edge Web site, http://www.fs.fed.us/openspace/fote.

Insect Pests and Diseases

Assessment of Current Situation

Forest insects and diseases play critical roles in forest ecosystems but can also have adverse impacts on forest health (Tkacz et al. 2007). An estimated 117 species of exotic insect species have been introduced to U.S. forests since the 1800s (Stolte and Darr 2006); the spread and impacts of some of these—such as the hemlock woolley adelgid (*Adelges tsugae*) and the emerald ash borer (*Agrilus planipennis*)—are well-documented (Frelich 2003, Liebhold et al. 1995, Tkacz et al. 2007). Another exotic pest, the gypsy moth (*Lymantria dispar*), has spread to 17 states and the District of Columbia (Tkacz et al. 2007). In addition to exotic pests, U.S. forests have also been affected by native pests. For example, outbreaks of mountain pine beetle (*Dendroctonus ponderosae*), native to North America, have been increasing throughout the Western United States since 2003.

Ray Roper, ©iStockphoto.com

Bark beetle damage.

Among the dozens of diseases that affect U.S. forests each year, chestnut blight (*Cryphonectria parasitica* (Murrill) Barr), Dutch elm disease (*Ophiostoma ulmi* (Buisman) Nannf.), and beech bark disease (*Neonectria faginata* (Lohman et al.) Castl.) alone have led to the near elimination of important tree species in many areas (Frelich 2003, Liebhold et al. 1995). A recently introduced disease called sudden oak death (*Phytophthora ramorum*) is responsible for the deaths of thousands of native oak trees (*Quercus* spp.) in coastal California (Tkacz et al. 2007). Native and exotic insects and diseases can cause substantial damage to roots, stems, and leaves of plants (Nair and Sumardi 2000), which overall can affect forest condition and productivity (USDA FS 2005). In 2006 alone, more than 5 million acres of tree mortality in the United States was due to insects and diseases (USDA FS 2007a).

Insect pests and diseases have caused up to 41 percent basal area loss in watersheds across the United States.

Figure 14 displays watersheds according to the average percentages of basal area[2] expected to be lost owing to insects and diseases. The map is based on data compiled by the Forest Service's Forest Health Monitoring Program (Krist et al. 2007). Watersheds in the 90th percentile are scattered across the country and include many watersheds in the interior West. Large concentrations of watersheds in the 90th percentile are also found in and around West Virginia, eastern Washington and Oregon, and northern California.

Eric G. Vallery

Western pine beetle (*Dendroctonus brevicomis*)

[2] Basal area is the cross-section area of a tree stem in square feet, commonly measured at breast height (4.5 feet in the United States). Basal area is often used as an indicator of plot or stand attributes because it combines the number of trees and the sizes of those trees.

What Is Forest Health?

WHAT DO we mean by "forest health?" The U.S. Forest Service forest health definition is: "A condition wherein a forest has the capacity across the landscape for **renewal**, for **recovery** from a wide range of disturbances, and for retention of its **ecological resiliency** while meeting current and future needs of people for desired levels of values, uses, products, and services" (USDA FS 2003).

Determining the health or condition of a forest is not an easy task. Forest ecosystems are complex and forest health can be influenced by the interaction of many natural and human-caused factors over time—including climate change, timber harvesting and other types of forest management, fire, windstorms, diseases, and insects. The determination as to whether a forest is healthy or not can also differ considerably depending on the interests and needs of the person or organization making the determination.

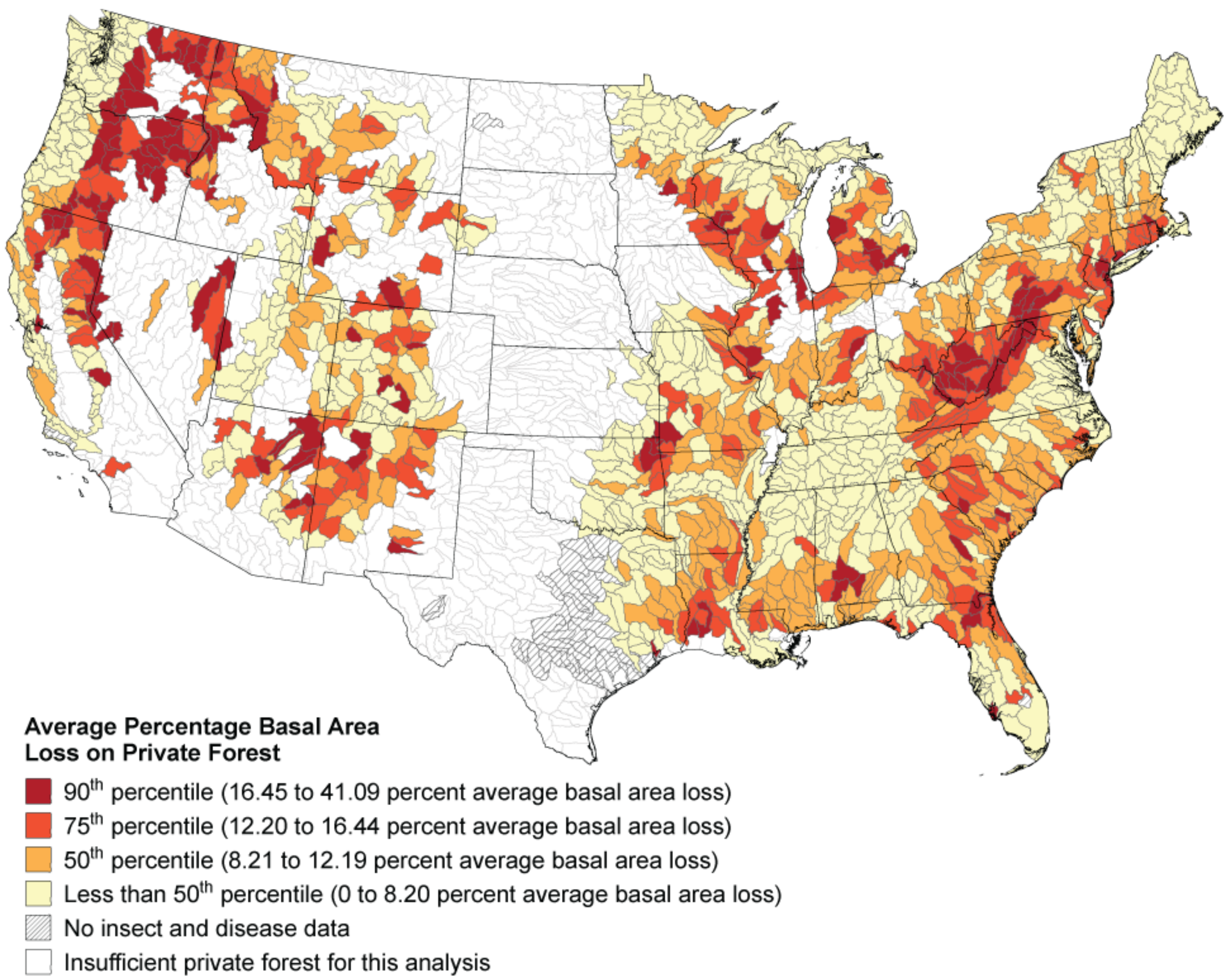


Figure 14—Watersheds by susceptibility and vulnerability of private forests to insect pests and diseases.

Whitney Cranshaw, Colorado State University

Identifying Areas Where Insect Pests and Diseases Could Compound the Impacts of Future Housing Density Increases

Figure 15 indicates where nationwide the greatest percentages of private forests might be most affected by insects and diseases as well as by increased housing density. Eastern watersheds ranking in the 90th percentile are concentrated in Connecticut, Rhode Island, New Jersey, Pennsylvania, western regions of North Carolina, South Carolina, and Michigan. In the West, watersheds in the 90th percentile are found in western Montana, Washington, California, Colorado, New Mexico, and Arizona.

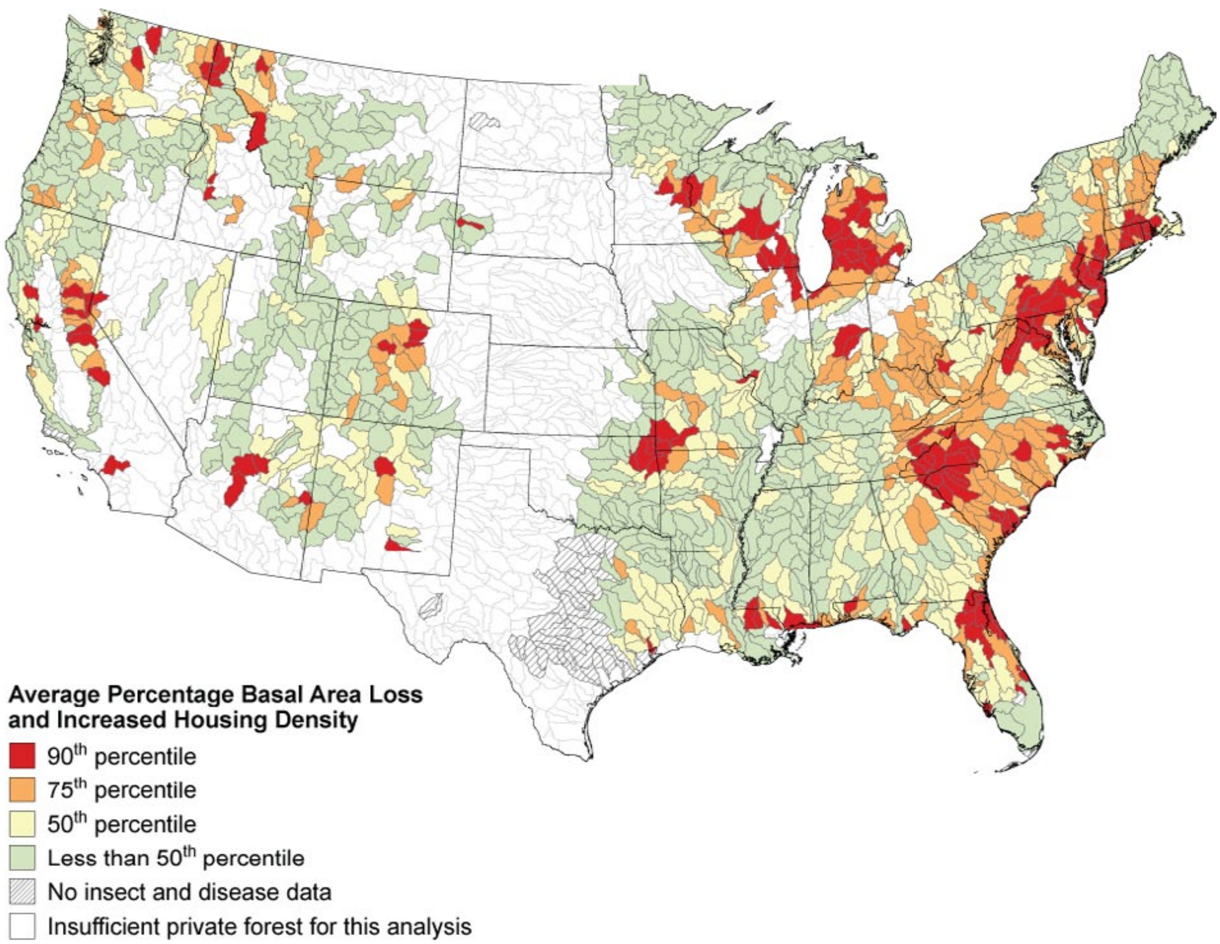


Figure 15—Watersheds by overlap of projected housing density increases on private forest lands and susceptibility to insect pests and diseases.

Table 5 presents the 15 highest ranking watersheds projected to experience exacerbated impacts from increased housing density because of additional pressures from insects and diseases; 6 are located in the Midwest and 4 in the West; 3 of the 4 located in the South are in Florida.

Table 5—The 15 highest ranking watersheds projected to experience exacerbated impacts from increased housing density on private forest lands because of additional pressures from insects and diseases

Numerical rank	Watershed	State(s)	Average basal area[a] loss	Private forest to experience increased housing density
			Percent	
1	Middle Fork Payette	Idaho	29	41
2	Des Plaines	Illinois, Wisconsin	20	47
3	Charlotte Harbor	Florida	18	60
4	Upper Spokane	Idaho, Washington	19	49
5	Clearwater-Elk	Minnesota	25	39
6	Clinton	Michigan	18	52
7	North Galveston Bay	Texas	21	40
8	Shenandoah	Virginia, West Virginia	23	37
9	Huron	Michigan	17	47
10	Driftwood	Indiana	39	34
11	Blackstone	Massachusetts, Rhode Island	24	34
12	Clear	Colorado	20	37
13	Daytona–St. Augustine	Florida	15	65
14	Upper Fox	Illinois, Wisconsin	17	43
15	Lower St. Johns	Florida	16	44

[a] The cross-section area of a tree stem in square feet, commonly measured at breast height (4.5 feet in the United States).

Implications

Outbreaks from insects and diseases can lead to damaging levels of defoliation or mortality, and forests weakened from insects and diseases are likely to be more susceptible to further stress from development (Tkacz et al. 2007).

Urbanized areas are more likely than rural areas to be points of entry for many exotic insect pests. One reason for this phenomenon is that urbanized areas receive a greater volume of international shipments, many of which contain wood packing materials harboring exotic insects. Furthermore, some tree species most popular for urban plantings, such as maple (*Acer* spp.) or ash (*Fraxinus* spp.), have also been frequent hosts for exotic insect species such as emerald ash borer and Asian longhorned beetle (*Anoplophora glabripennis*). In addition, urban trees are often planted in settings such as parking lots and roadsides that do not promote healthy tree growth, and weaker trees are more susceptible to insect attack (Poland and McCullough 2006). Urbanized areas also contain greater numbers of ornamental

Watersheds ranking highest for increased housing density and insect/pest damage are scattered from Idaho to Florida.

David Cappaert, Michigan State University

Emerald ash borer.


Joseph O'Brien, USDA Forest Service, Bugwood.org

plantings, which are another source of insect and pest invasion. For example, rhododendrons (*Rhododendron* spp.) and camellias (*Camellia* spp.)—popular nursery plants widely used in home landscaping—can be hosts to the pathogen that causes sudden oak death (Stokstad 2004, Tooley et al. 2004).

Although this section focuses on insect pests and diseases, the condition of private forests can also be affected by invasive plants; roads often serve as a primary entry point for invasive plants (Meekins and McCarthy 2001, Parendes and Jones 2000).

Insects and diseases cause varying degrees of damage to host tree species and forests through defoliation, death, or other injuries and stresses. Sudden oak death causes lethal trunk infestations in oaks and other species (Stokstad 2004).

Faces of Private Forest Owners

Clifty View Nursery

Courtesy of Merrifield family

Lon Merrifield and his family proudly hold a copy of an article in the local newspaper on the new conservation easement that is helping to conserve 1,642 acres of their forest land.

Three decades ago, **Lon Merrifield** returned from overseas and purchased the 320-acre property that had been his childhood home. The property is nestled at an elevation of 2,350 feet, at the base of Clifty Mountain in Boundary County, Idaho, between the Cabinet and Selkirk mountain ranges. Bordering the Panhandle National Forest and Bureau of Land Management lands, the area is under heavy development pressures. With a strong desire to keep the property and surrounding land in its current undeveloped state, Lon and his wife Donna purchased an additional 1,300 acres of adjacent land, piece by piece, over the past 30 years—an achievement that required considerable effort, patience, and strategic planning. In some cases, they purchased land a considerable distance away and then traded it with timber companies for land adjacent to their property. The Merrifields financed their efforts by operating the Clifty View Nursery, by living frugally, by getting help from "… some very understanding bankers…," and by selling a conservation easement through the Forest Legacy program operated by the U.S. Forest Service. About 200 acres of the property are managed as part of the nursery; many of the remaining acres are managed for timber and wildlife. The property provides many public services, including habitat for lynx and grizzly bear, two at-risk species that rely on a mosaic of private and public lands.

Wildfire

Tom Iraci

Assessment of Current Situation

Wildfire is an important component of some forest ecosystems and can provide beneficial effects under particular circumstances; however, wildfire can also be a threat to forest land and landowners because of diverse and complex impacts on aquatic and terrestrial ecosystems depending on the specific situation (Rieman et al. 2005). Immediate or long-term effects can include increased soil erosion (Kocher et al. 2001); reduced carbon sequestration (Hurteau et al. 2009); and a host of other impacts including death or displacement of fish and wildlife, changes to stream temperature and chemistry, altered sediment levels, modification of vegetation, and increased access by off-highway vehicles (Rieman et al. 2005). Activities to suppress wildfires can also lead to soil damage (Rieman et al. 2005), water quality degradation, and damage to aquatic life in environmentally sensitive areas (Kalabokidis 2000).

Over 90 percent of private forests in many southwestern watersheds have high wildfire potential.

Wildfire suppression is costly; in 2000, for the first time ever, federal wildfire suppression expenditures exceeded $1 billion (Donovan and Brown 2007). Other economic implications include a potential decrease in timber supply over the long term and a consequent stimulus to salvage more timber from damaged areas (Prestemon et al. 2005). Increased wildfire events can also lead to decreases in tourism; in 2002, for example, visitor numbers in Colorado dropped by 40 percent in some areas owing to wildfire and drought (Scott 2003).

Figure 16 depicts watersheds according to the potential for wildfire on private forests. The rankings are derived from the Wildland Fire Potential Model produced by the Forest Service's Fire Modeling Institute (http://www.fs.fed.us/fmi/). For watersheds in the 90th percentile, more than 90 percent of the private forests have a high wildfire potential. Large concentrations of these watersheds are found throughout the interior West and, in fact, most Western U.S. watersheds are in the upper 50th percentile or higher. Clusters of high-ranking watersheds (upper 75th percentile or higher) are also found in California, Georgia, North Carolina, South Carolina, and Florida.

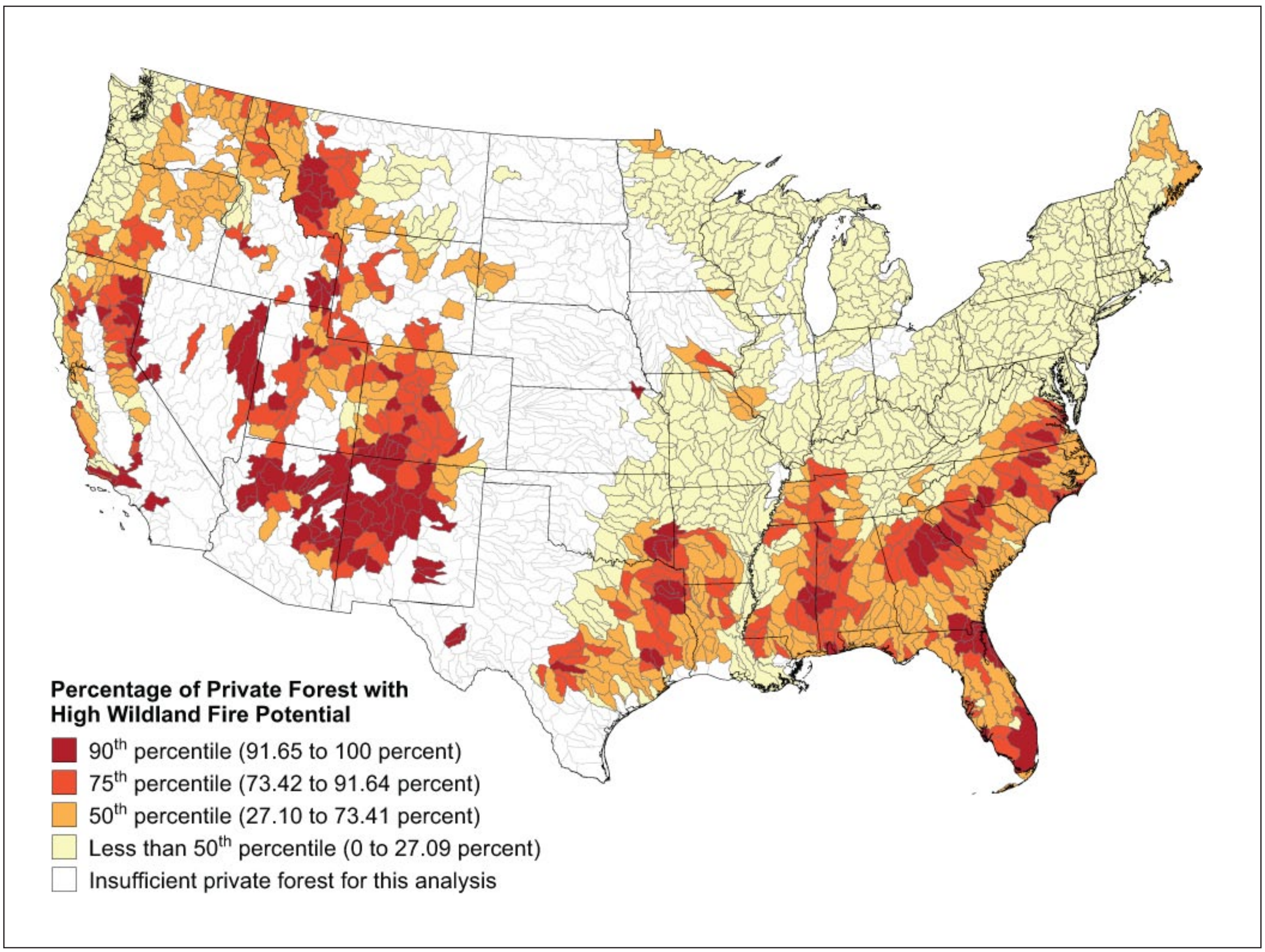


Figure 16—Watersheds by susceptibility and vulnerability of private forests to wildfire.

Identifying Areas Where Wildfire Could Compound the Impacts of Future Increases in Housing Density

Figure 17 displays watersheds where projected increases in housing density and susceptibility to wildfire may overlap. Watersheds where wildfire threat and future housing density increases are highest (in the 90th percentile) are scattered throughout the West and parts of the South. Western areas include central Colorado, New Mexico, and Arizona, as well as parts of Idaho, Washington, Oregon, and California. Southern areas include Florida, a cluster of watersheds in north Georgia, North Carolina, and South Carolina, as well as parts of eastern Texas.

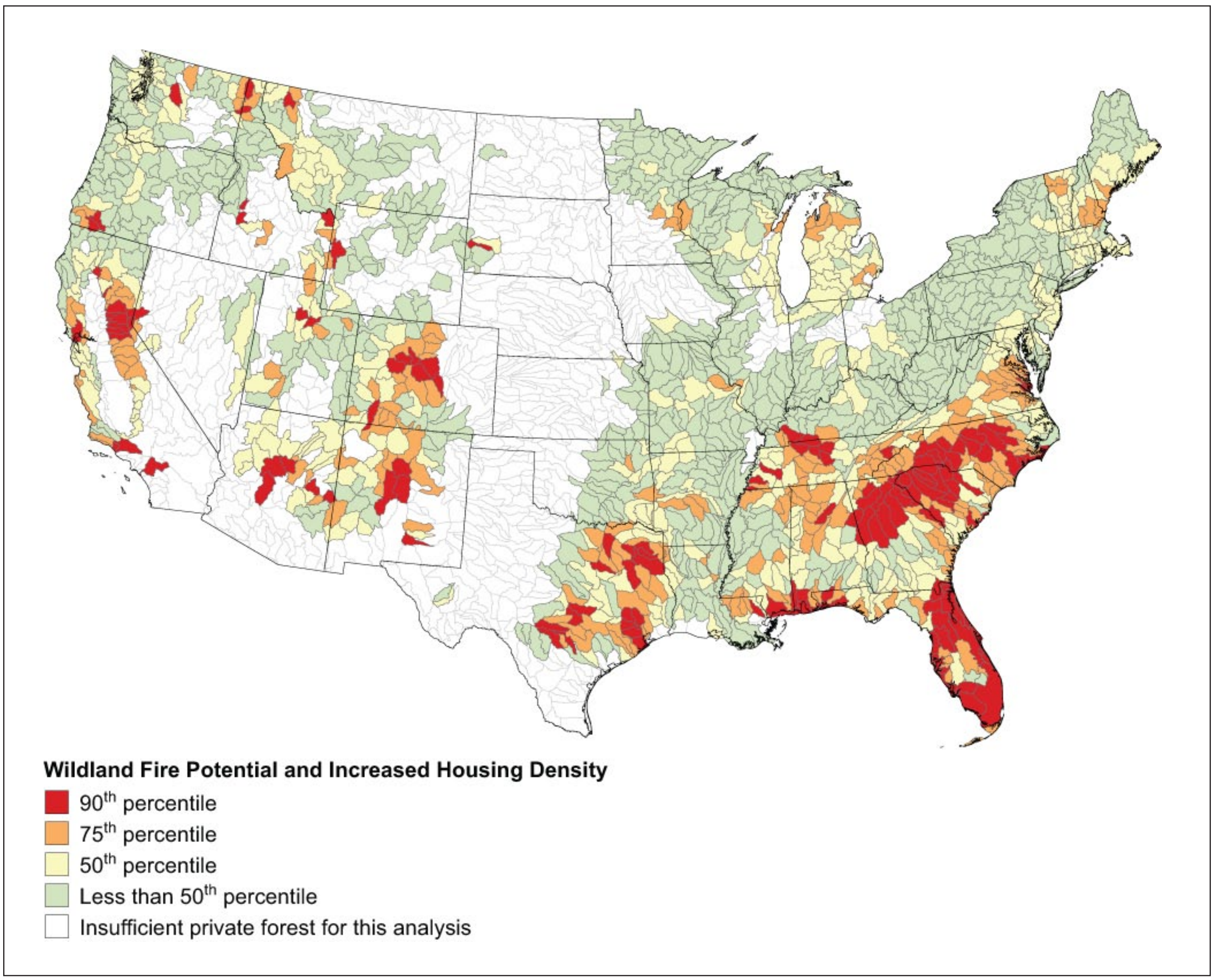


Figure 17—Watersheds by projected overlap of increased housing density on private forest lands and susceptibility to wildfire.

Many watersheds with highest fire susceptibility and projected housing density increases are in the South.

Table 6 presents the 15 highest ranking watersheds projected to experience exacerbated impacts from increased housing density because of additional pressures from wildfire; 11 are located in the South, including 3 in Florida and 4 in North Carolina and South Carolina; the 4 Western watersheds are located in Utah, Wyoming, Colorado, and California.

Table 6—The 15 highest ranking watersheds projected to experience exacerbated impacts from increased housing density on private forest lands because of additional pressures from wildfire

Numerical rank	Watershed	State(s)	Private forest with high fire susceptibility	Private forest to experience increased housing density
			Percent	
1	Charlotte Harbor	Florida	99	60
2	Daytona–St. Augustine	Florida	97	65
3	Rocky	North Carolina, South Carolina	99	48
4	Mobile Bay	Alabama	97	48
5	Jordan	Utah	99	40
6	Lower St. Johns	Florida	98	44
7	New	North Carolina	94	52
8	Upper Cape Fear	North Carolina	94	51
9	East Fork San Jacinto	Texas	95	46
10	West Fork San Jacinto	Texas	95	46
11	Greys–Hobock	Wyoming	90	56
12	Perdido Bay	Alabama, Florida	89	52
13	South Platte headwaters	Colorado	92	46
14	Lower Catawba	North Carolina, South Carolina	100	33
15	Ventura	California	98	36

Implications

A proliferation of houses in areas at risk for wildfire increases the risk to human property and life and at the same time makes wildfire management and suppression more complicated, controversial, and expensive (Stein et al. 2007, Syphard et al. 2007, US GAO 2007). Increased numbers of houses and people are associated with more frequent wildfire ignitions (Hammer et al. 2007, Stein et al. 2007, Syphard et al. 2007), and wildfire size and spread are influenced by the presence and flammability of houses (Spyratos et al. 2007).

Nationwide, current patterns of housing growth in the wildland-urban interface—where homes, businesses, and other structures abut or are intermingled with wildland vegetation—are exacerbating wildfire problems and costs (Grulke et al., in press; Hammer et al. 2007; Syphard et al. 2007). In areas where fire risk is already high, increased housing is exacerbating the problem. The number of people and structures located in the wildland-urban interface has increased by 11 percent (20,458 square miles) in west coast states in the 1990s (Hammer et al. 2007) and by more than 50 percent nationwide from 1970 to 2000, to a total of 179,727 square miles (Theobald and Romme 2007). Nearly 90 percent (30,293 square miles) of the wildland-urban interface in the West occurs in high-severity wildfire regimes (Theobald and Romme 2007). Wildfire associated with housing density increases in the wildland-urban interface is also a critical concern in the South, where more than 5 million acres of land are at high risk of wildfire (Andreu and Hermansen-Baez 2008).

Faces of Private Forest Owners

Andrew Kornylak/Aurora Photos

"You've got to really love your land to stay on it,"

said 63-year-old North Carolina land-owner **Albert Beatty**. The original farm was purchased by Mr. Beatty's ancestors at the beginning of the 20th century; he has lived on his land his entire life and plans to keep it in his family for many years to come. But the 360-acre Beatty farm—located midway between Fayetteville and Wilmington—is in high demand for development. Many properties nearby have already been sold for this purpose.

Efforts by Albert Beatty and his wife Ada have contributed to the conservation of working farm and forest land in their area. Over the years, they have increased their property to its current size by purchasing adjoining land. The diverse farm includes more than 200 acres of managed loblolly (*Pinus taeda* L.) and longleaf pine (*Pinus palustris* Mill.), a confined swine operation, grain production, and 55 head of cattle. The land is bisected by state highway 210 and is bordered by the South River.

The Beattys are approached several times each month by real estate brokers, who are primarily interested in developing riverfront properties for beach houses—ranging in size from small cottages to 3,000-square-foot homes. Many are willing to buy the entire property just for the waterfront land.

Although finances have always been an issue in holding on to the property, the Beatty family has managed well and is now on solid financial footing. But management challenges continue, such as last summer's severe drought, when they lost two wells, the crops were dry, and they had to reroute water for the cattle. In part to ensure the farm's longevity, Mr. Beatty involves his daughter in its operations. Although she lives and works a distance away, she does the farm's taxes and "…knows about the lands…." This year, the Beattys incorporated the farm and named their daughter vice president.

Air Pollution

iStockphoto.com/rusm

Assessment of Current Situation

Air pollution—especially ozone and nitrogen compounds from vehicle exhausts and other fossil fuel combustion—has increased substantially since World War II (Grulke et al., in press). This section focuses on ozone because it is known to be transported long distances from source metropolitan areas to rural forested areas. Ozone concentrations have risen substantially since pre-industrial times, especially in the South (Tkacz et al. 2007), and models predict that concentrations will continue to increase over the next 50 years (Chappelka and Samuelson 1998). Ozone can reduce tree seedling growth and photosynthesis by 20 percent or more and can also affect the growth of mature trees (Pye 1988). Oak-hickory forests in the southern Midwest have the highest risk of changes to the structure and function of the ecosystem from ozone damage (USDA FS 2004).

Other air pollutants such as nitrates and sulfates are major components of acid rain (National Acid Precipitation Assessment Program 1990). Rapid increases in urbanization, population, and distances driven in the West have contributed to a steady increase in nitrogen deposition (Fenn et al. 2003). Atmospheric sulfate deposition to the Northeastern United States has increased more than fivefold in the past 150 years, and most acid-sensitive ecosystems have been exposed to high inputs of strong acids for many decades (Driscoll et al. 2001). Although acid rain deposition has decreased in recent years, emissions still need to be reduced to maintain ecological recovery (US EPA 2009a).

Figure 18 shows watersheds with private forests that are susceptible or vulnerable to ozone damage, based on observations by FIA field crews. Watersheds containing the highest percentages (67 to 100 percent) of private forests vulnerable to ozone damage are displayed in dark red. These watersheds are concentrated in specific areas across the country, including a large area covering much of South Carolina and Georgia; an area extending along the Atlantic Coast from Massachusetts through Maryland and along the southern border of Pennsylvania; an area overlapping northern Kentucky and southern Indiana; most watersheds in the vicinity of central California; and several watersheds in Michigan.

Forests with highest ozone vulnerability are found in central California and the East.

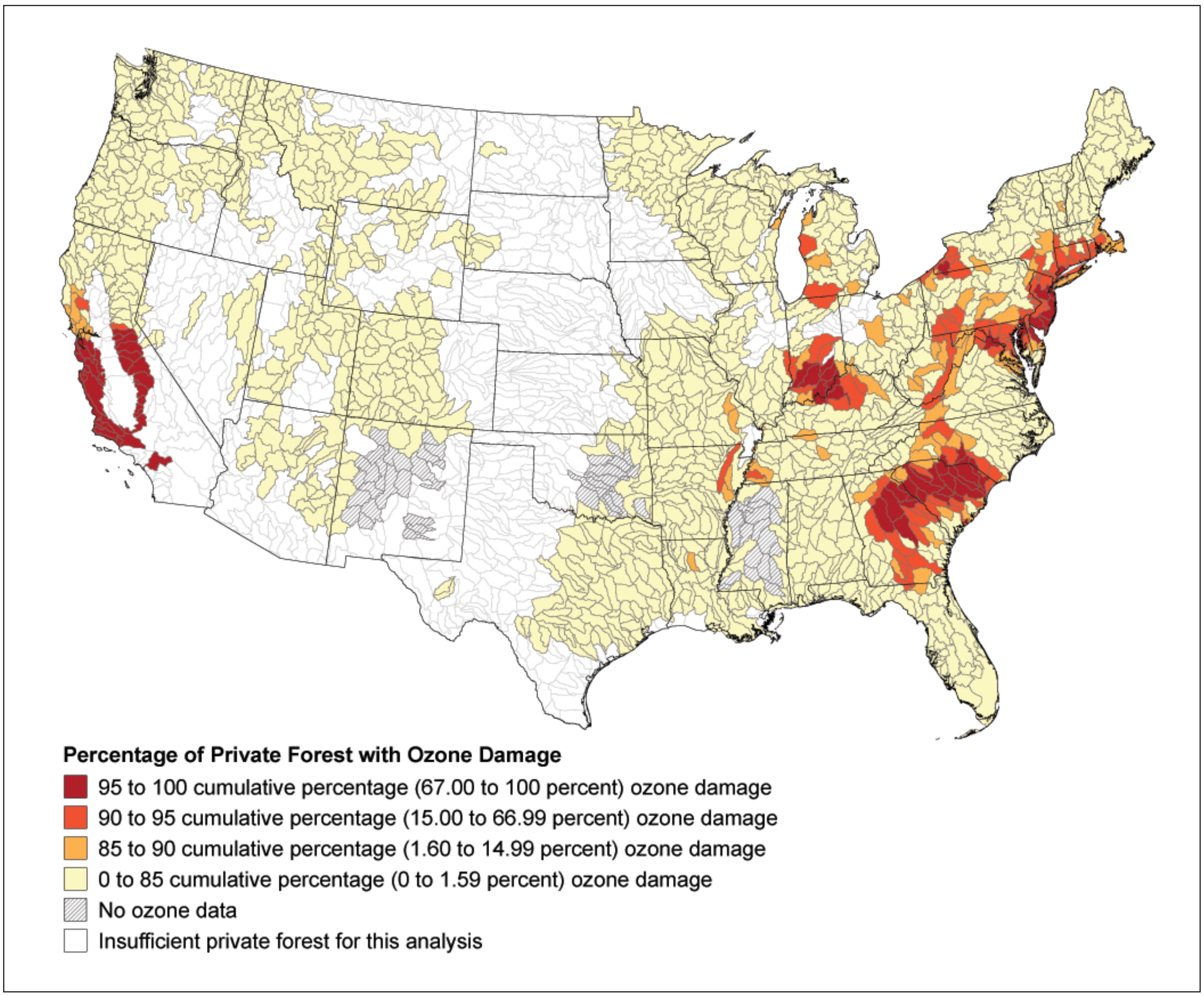


Figure 18—Watersheds by susceptibility and vulnerability of private forests to ozone pollution.

For maps showing watersheds with private forests with elevated levels of nitrates and sulfates, see the FOTE Web site, http://www.us.fed.us/openspace/fote.

Identifying Areas Where Ozone Pollution Could Compound the Impacts of Future Increases in Housing Density

Figure 19 displays watersheds where projected increases in housing density and high or moderate levels of ozone damage are expected to overlap. Although increased housing density may not directly result in an increase in ground-level ozone, it can place additional stresses on forests that are already susceptible to ozone damage. Watersheds colored red on the map contain the highest percentages of private forest susceptible to both ozone damage and increased housing density. These watersheds follow a pattern similar to that depicted in figure 17, but they are grouped in smaller clusters scattered across the country.

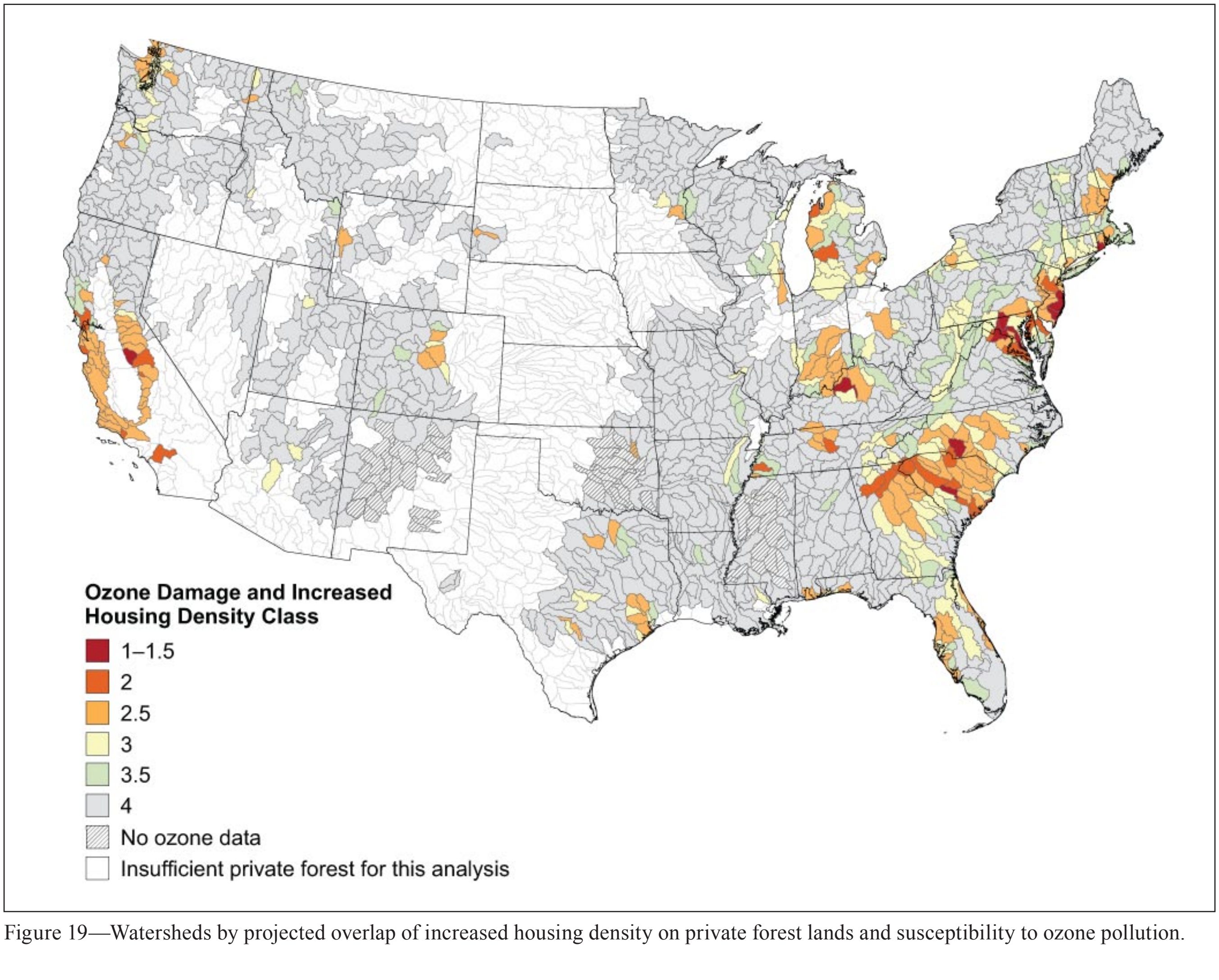


Figure 19—Watersheds by projected overlap of increased housing density on private forest lands and susceptibility to ozone pollution.

Table 7 presents the 10 highest ranking watersheds[3] projected to experience exacerbated impacts from increased housing density because of additional pressures from ozone damage. Nine of the 10 are located in the East, including the highest ranking watershed, the Middle Potomac-Catoctin, which stretches across the District of Columbia, Maryland, Virginia, and West Virginia. The only Western watershed in this category is in California.

Table 7—The 10[a] highest ranking watersheds projected to experience exacerbated impacts from increased housing density on private forest lands because of additional pressures from ozone pollution

Numerical rank	Watershed	State(s)	Private forest vulnerable to ozone damage	Private forest to experience increased housing density
			Percent	
1	Middle Potomac-Catoctin	DC, Maryland, Virginia, West Virginia	90	63
2	Upper Chowchilla–Upper Fresno	California	100	38
3	Salt	Kentucky	96	45
4	Mullica-Toms	New Jersey	94	43
5	North Fork Edisto	South Carolina	79	39
6	Great Egg Harbor	New Jersey	78	44
7	Pawcatuck-Wood	Connecticut, Rhode Island	63	46
8	Rocky	North Carolina, South Carolina	62	48
9	Monocacy	Maryland, Pennsylvania	58	53
10	Patuxent	Maryland	33	47

[a] This table displays only 10 highest ranking watersheds, rather than 15 as in other sections of this report. Because of the way in which we combined the two layers, the scores for the next 25 watersheds all have the same value.

Implications

The relationship between increased housing density and ozone production is complex. Higher levels of housing density and associated development can result in increased fossil fuel combustion, electricity generation, and use of lawn and garden equipment, each of which can contribute to ozone production (Driscoll et al. 2003). Although the level of ozone production may be negligible in areas of low housing density, in more urbanized areas the addition of more housing and related infrastructure could have a more substantial effect.

Ozone specifically causes foliar lesions and rapid leaf aging, alters species composition, weakens pest resistance, and reduces root biomass

Paul A. Mistretta, USDA Forest Service, Bugwood.org

Ozone damage.

[3] It was not possible to distinguish 15 highest ranking watersheds for the ozone analysis, as was done for other sections in this report, because the scores for the next 25 watersheds after the 10th are identical.

O.J. Byrne

(Chappelka and Samuelson 1998, Grulke et al. 1998, Karnosky et al. 2005). Several recent studies have shown that ozone affects forest growth and that the level of impact varies by tree species and forest type (Chappelka and Samuelson 1998, Karnosky et al. 2005). Ozone and elevated nitrogen deposition cause changes in forest tree carbon, nitrogen, and water balance that increase tree susceptibility to drought and insect attack, and these changes make the whole ecosystem more susceptible to wildfire (Grulke et al., in press; Karnosky et al. 2005). Ozone and acid precipitation are known to have damaging effects on vegetation, soil chemistry, aquatic and terrestrial species, and human health (National Acid Precipitation Assessment Program 1990, Unger 2006). Decreases in tree growth and excessive tree mortality from ozone and nitrogen pollution also can potentially lead to decreases in timber and agricultural yields (US EPA 1997, Wallenstein 2004). The growing body of research on ozone effects indicates that the degree of change in plant growth varies substantially with each species and according to the duration and level of exposure to ozone (Pye 1988).

Summary and Conclusions

HOUSING DENSITY is expected to continue to increase on rural private forests across the country, and the resulting changes will continue to affect numerous public goods and services. In many areas, the impacts of increased housing density are likely to be exacerbated by other threats.

Watersheds with the greatest percentages of forest land under private ownership are concentrated in the East—not a surprising finding because much of the forest land in the West is in public ownership. Watersheds where private forests make the greatest contributions to the goods and services analyzed—water quality, timber volume, at-risk species habitat, and interior forest—follow a similar pattern.

As the U.S. population increases by 80 million people, increases in housing density will continue to affect many public benefits of private forests.

This pattern is particularly true for **water quality** but less so for other contributions. Most of the California watersheds included in this analysis, as well as most watersheds in western Oregon and Washington, also contain private forests making substantial contributions to U.S. **timber volume**. Although private forest contributions to **at-risk species** habitat and interior forest are high in the East, they are quite high in many Western U.S. watersheds as well; in fact, most watersheds in the Southwest, California, and western Oregon that were included in this analysis contain substantial numbers of at-risk species. Many Western U.S. watersheds also rank fairly high in terms of contributions to **interior forest**.

Interestingly, some watersheds in Florida, the Southwest, Washington state, and coastal California contain low percentages of private forest but harbor high numbers of at-risk species associated with private forest. These areas also contain several watersheds with low percentages of private forest that contain high percentages of interior forest.

Watersheds with the greatest percentages of private forests under pressure from **insect pests and diseases** are distributed across the West and East. With the exception of watersheds in western Oregon and western Washington, a high percentage of private forests in most western watersheds are classified as having high **wildfire** potential. This is also true of a swath of watersheds across the Southeast. Watersheds with private forests exposed to **ozone** pollution are found primarily in the East but also in California.

What happens when any of the threat layers (insect pests and diseases, wildfire, or ozone) are combined with the housing density layer? In each case, more watersheds in the 90^{th} percentile are found in the East. Nevertheless, in **every** region of the United States, private forests are experiencing increases in housing density, and these increases are associated with numerous economic and ecological changes. Private forest lands across the country are also at risk from other threats—including insect pests and diseases, wildfire, and air pollution—that compound the effects of increased housing density.

The projections in this report assume a continuation of economic conditions in the country as they exist in the early part of this century. Although the future of housing markets is uncertain at this time, residential development in rural landscapes in the United States has been occurring for a long time. With the U.S. population projected to increase by at least another 80 million people between 2000 and 2030, forest resource managers should expect and plan for continued development pressure on many of the Nation's private forests. Monitoring land-use changes and relationships to economic conditions—as well as monitoring changes in population and personal income levels—will therefore be important. Forests on the Edge will periodically update data and projection methods as appropriate.

Future research should also address the need to anticipate and understand the implications of housing density increases within the rural I category (fewer than 16 housing units per square mile). Additionally, analysis of woody vegetation types that do not qualify as forest in the NLCD but that are critically important and under development pressures, should also be a focus of future research. This would include woodlands and narrow riparian forests common in the interior West and the Plains States.

The results of this analysis are based on national-level data and are best suited for use at national levels, but the information can provide context and inspiration for local discussions about forest land development. It is at the local level where scientists, resource managers, landowners, and communities contend with the challenges of planning for growth while conserving the potential for private forests to provide valuable goods, services, and economic opportunities far into the future.

Forest Service Tools for Open Space Conservation

THE FOREST SERVICE has a number of resources and tools designed to address open space conservation needs. Visit **http://www.fs.fed.us/openspace/index.html** for a list of tools and resources and for additional information on open space conservation.

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Metric Equivalents

When you know:	Multiply by:	To find:
Feet	0.3048	Meters
Cubic feet	0.0283	Cubic meters
Yards	0.914	Meters
Acres	0.405	Hectares
Miles	1.609	Kilometers
Square feet	0.0929	Square meters
Square miles	2.59	Square kilometers

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Appendix

Methodology

The objectives of this Forests on the Edge analysis are to (1) obtain or construct nationally consistent data layers depicting the spatial location of private forest lands and their contributions, (2) construct similar layers depicting future increases in housing density and other threats to private forest land, and (3) identify watersheds where private forest contributions coincide with increased housing density and other threats.

All data layers were obtained as or constructed to be nationally consistent and were summarized at the spatial scale of 4^{th}-level hydrologic units (referred to as watersheds or 8-digit watersheds in this report) (Steeves and Nebert 1994). The conterminous United States contains 2,108 fourth-level watersheds averaging 1 million acres and ranging from 22,000 to 13 million acres. Watersheds were selected as the analytical units because they highlight the important connections between private forests and ecological processes. Only watersheds with at least 10 percent overall forest cover and containing at least 10,000 acres of private forest were considered for the study.

For each contribution and threat layer, the distribution of watershed values was determined and a percentile ranking was assigned to each watershed. Each layer was then combined with the layer for projected housing density. This was accomplished by re-ranking each watershed according to the average of two percentile categories (for example, the percentile categories for at-risk species and future housing density).

Several data layers lacked data for some watersheds. These watersheds were not ranked but were assigned to a separate "no data" category. However, if any of them satisfied the initial filtering criteria of 10 percent overall forest cover and 10,000 acres of private forest, their number was included in the total number of watersheds for purposes of calculating percentiles. Three results follow: (1) the relative order of the watersheds in the ranking does not change, regardless of the total number used to calculate percentiles; (2) the number of watersheds corresponding to a given percentile is always the same, regardless of the particular attributes assessed; and (3) the particular watersheds assigned to percentile categories is approximate because the watersheds for which data were not available were not included in the rankings.

Private Forest Contributions

Area of Private Forest Land

A 100- by 100-meter (328.1- by 328.1-foot) resolution forest ownership layer was constructed by aggregating the classes of the National Land Cover Dataset (NLCD) (Homer et al. 2007) into forest and nonforest classes and using the Protected Areas Database (PAD v4.6) (CBI 2007, DellaSalla et al. 2001, Theobald 2007) to distinguish ownership and protection categories. The emphasis for this study was private forest land—defined as all land not coded as federal, state, or city in the protected areas database. Stein et al. (2006) provided detailed information on this layer.

Water Quality

The water quality layer depicts the contribution of private forest land to the production of clean water and is based on three underlying assumptions:

- Water bodies near the heads of hydrologic networks are more sensitive to the loss of forest buffers than are water bodies near the bases of the networks.
- The presence or absence of upstream forest buffers influences water quality downstream in the networks.
- The total amount of private forest land in each watershed is considered a better indicator of the contributions of private forest land to water quality than the location of that private forest land in the watershed (for example, location of forested buffers) (FitzHugh 2001).

The water quality layer was constructed from two underlying layers—the forest ownership layer and the National Hydrography Dataset (USGS 2000), which depicts water bodies in the 48 contiguous states. The layer was constructed in four steps: (1) a 30-meter (98.4-foot) buffer was constructed around all water bodies, (2) the buffers were intersected with the private forest land class of the forest ownership layer to quantify the amount of private forest land close to water bodies, (3) each buffer segment was assigned to one of four categories based on the relative position of the segment to the head of its hydrologic network, and (4) for each watershed, the percentage in each of the four categories was determined. Water quality index (WQI) was then calculated for each watershed as

$$WQI = 0.6[A_1 + (A_1 A_2)] + 0.4(0.48B_1 + 0.24B_2 + 0.16B_3 + 0.12B_4) \qquad (1)$$

where A_1 = percentage of watershed in private forest land, A_2 = percentage of total forest land in watershed that is privately owned, B_1 = percentage of private forest land buffer in the first category (nearer head of hydrologic network headwater),

B_2 = percentage of buffer in the second category, B_3 = percentage of buffer in the third category, and B_4 = percentage of buffer in the fourth category (farthest downstream from the head of hydrologic network). Variables A_1 and A_2 represent private forest coverage throughout the watershed, and variables B_1 through B_4 represent private forest coverage in the buffers. In *WQI*, A_1 and A_2 are collectively weighted 0.6, and variables B_1 through B_4 are collectively weighted 0.4 to reflect the third assumption above. Watershed boundaries for this and all other layers were determined through Steeves and Nebert (1994).

Stacy Allen

Forest Inventory and Analysis (FIA): The Nation's Forest Census

The Forest Service's FIA Program has been collecting field data for more than 70 years and offers the largest source of forest data in the United States. The FIA conducts annual surveys of all forest land in the country and remeasures plots on 5- to 10-year cycles. The FIA reports on status and trends in forest area and location; on the species, size, and health of trees; on total tree growth, mortality, and removals by harvest; on wood production and utilization rates by various products; and on forest land ownership (FIA 2007).

Timber Volume

The timber volume layer depicts the ranking of watersheds relative to the amount of growing-stock volume (cubic feet) found on privately owned timberland within the watershed, based on Forest Inventory and Analysis (FIA) plot data (http://fia.fs.fed.us/tools-data/default.asp). Timberland is defined by the FIA Program as forest land that is a minimum of 1 acre, a minimum width of 120 feet, has a minimum stocking of 10 percent, has not been withdrawn from timber production, and is capable of producing 20 cubic feet per year of industrial wood per acre. Growing stock volume is defined as the volume of trees of commercial species with diameters of at least five inches d.b.h. (diameter at breast height) growing on forest land.

At-Risk Species

NatureServe and its member Natural Heritage Programs and Conservation Data Centres prepared a geographic data set depicting the number of at-risk species occurring on private forest lands within 8-digit watersheds in the contiguous 48 states. At-risk species are defined as species with element occurrences (EO) that have been observed by an authoritative source within at least the past 50 years and are either (1) federally designated under the Endangered Species Act (endangered, threatened, candidate, proposed) or (2) designated as critically imperiled, imperiled, or vulnerable according to the NatureServe Conservation Status Ranking system (G1/T1 to G3/T3) (http://www.natureserve.org/explorer/ranking.htm). An EO is an area of land or water in which a species or natural community is, or was, present.

NatureServe selected only those populations that occur on private forested lands by conducting a geographic analysis comparing the location of at-risk populations with private forest locations (both protected and nonprotected). These species are labeled as forest-associated rather than forest-obligated because a separate analysis to refine this species list using knowledge of species habitat requirements and preferences was not conducted. Known data gaps include (1) no at-risk species data available in Arizona, Massachusetts, and the District of Columbia; (2) no at-risk fish data available for Idaho; and (3) incomplete at-risk animal data in Washington. Private forest lands were determined using the data layer described above under Area of Private Forest Land.

Interior Forest

Habitat contiguity can be measured in terms of the amount of interior forest cover that is functionally distinct from forest edge. The interior forest layer was constructed through a fragmentation analysis in which the 30- by 30-meter (98.4- by 98.4-foot) NLCD forest pixels were labeled as interior forest if they were forested and at least 90 percent of the area in a surrounding 65-hectare (160.6-acre) window was also forest. The forest cover layer described above under Area of Private Forest Land was used to identify forest/nonforest pixels.

Each watershed was divided into pixels of 30- by 30-meter (98.4- by 98.4-foot) resolution. The results were used to determine the fragmentation values for all the NLCD pixels in each watershed. The pixel-level fragmentation values were then masked by private forest land and summarized by watershed. This method was used to determine the proportions of private forest pixels identified as interior forest in each watershed. Note that the proportion is not the same as area; a watershed could have very little forest overall but a high proportion that met the threshold.

Threats to Private Forest Lands

Future Housing Density

The housing density layer depicts projected pressures on private forest lands resulting from housing density increases from 2000 to 2030. Three categories of housing density are used: rural I (fewer than 16 housing units per square mile), rural II (16 to 64 housing units per square mile), and exurban/urban (more than 64 housing units per square mile). The future housing density layer identifies forest lands projected to convert from rural I to exurban/urban or rural II categories, as well as from rural II to exurban/urban categories (Stein et al. 2007). The housing density layer is based on estimates of current population and housing density data obtained from the 2000 U.S. Census (U.S. Census Bureau 2001) and projections of housing density increases. A spatially explicit model was used to predict the full urban-to-rural spectrum of housing densities (Theobald 2005). The model uses an allocation approach where population requirements are met and is based on the assumption that future growth patterns will be similar to those in the past decade.

Current housing density patterns are estimated using housing unit counts from census blocks and a dasymetric modeling approach, which eliminates public lands and water bodies and is weighted toward NLCD 2001 urban land cover classes and higher road densities. For rural II areas in the 11 Western States, residential groundwater well densities were also used to better allocate housing units.

Future patterns are projected on a decadal basis in four steps: (1) the number of new housing units in the next decade is forced to meet the quantity demanded of the projected county-level populations; (2) a location-specific average population growth rate from the previous to current time step is computed for each of three density classes: exurban/urban (less than 0.6 acre per unit to 10 acres per unit), rural II (10 to 40 acres per unit), and rural I (more than 40 acres per unit); (3) the spatial distribution of projected new housing units is adjusted with respect to accessibility as computed by travel time along the road infrastructure to the nearest urban core area; and (4) projected new housing density is added to the current housing density under the assumption that housing densities do not decline over time.

For these analyses, projected housing density increases were not permitted to occur on protected private land as indicated by the PAD v4.6 (DellaSalla et al. 2001). The spatially explicit housing density projections were combined with the forest ownership layer to identify watersheds with the greatest projected conversion of private forest land to rural II and exurban/urban uses between the years 2000 and 2030. Stein et al. (2006) provided detailed information on this layer. Note that analyses using census urban and developed data would not necessarily have the same result as the analyses conducted for this study.

Insect Pests and Disease

A measure of the impact of forest insect pests and diseases on forest health is the reduction of tree basal area, which is defined as the cross-section area of a tree stem in square feet at breast height (4.5 feet in the United States). The Forest Health Monitoring Program of the U.S. Forest Service formed a risk map integration team (RMIT) to coordinate the development of a nationally consistent database for mapping insect pest and disease risk. The RMIT developed a GIS-based multicriteria risk modeling framework based on Eastman's risk assessment process (Eastman et al. 1997).

A five-step multicriteria process was used to construct a 1- by 1-kilometer (0.62- by 0.62-mile)-resolution map depicting risk (Krist et al. 2007):

(1) Identify a list of forest pests (risk agents) and their target host species; this is conducted at the regional level with models constrained to selected geographic areas.
(2) Identify, rank, and weight criteria (factors and constraints) that determine the susceptibility and vulnerability to each risk agent.
(3) Standardize risk agent criteria values, and combine the resultant criteria maps in a final risk assessment using a series of weighted overlays.
(4) Convert predicted values of potential risk of mortality for each pest to predicted basal area loss over a 15-year period; this is accomplished for each risk agent/forest host species pair included in the national risk assessment.
(5) Compile the resultant values from step 4 and identify areas (1- by 1-kilometer [0.62- by 0.62-mile] raster grid cells) on a national base map that are at risk of encountering a 25 percent or greater loss of total basal area in the next 15 years.

Wildfire

Projecting wildfire risk is extremely complex and relies on a variety of regional models using regional variables. The wildfire layer depicts the amount of private forest land with wildfire potential deemed high or very high based on the Wildland Fire Potential Model produced by the U.S. Forest Service Fire Modeling Institute (http://www.fs.fed.us/fmi/). The model is based on the following three components:

1. Fuels Potential: surface fuel potential (rate of spread and surface flame length from the national Fuel Characterization Classification Systems) and crown fire potential (by assigning relative classes of fire intensity to a current vegetation cover type map).
2. Weather Potential: weather zones; average number of days with high relative energy release component (above the 95^{th} percentile from 1980 to 2005); and number of days of extreme fire weather (based on thresholds of temperature, wind, and humidity from 1982 to 1997).
3. Fire Occurrence Potential: average number of fires greater than 0.25 acres per 1 million acres, average number of fires greater than 500 acres per 1 million acres, and average number of fires by weather zone; all inputs from 1986 to 1996.

Note that the period selected is somewhat different for each of the factors described above. Time and resource constraints precluded the use of data with exactly the same period for each. More detail on this model is provided on the following Web site: http://svinetfc4.fs.fed.us/RS2008/j_menakis/index.htm.

The Wildland Fire Potential Model ranks the Nation's wildlands for fire potential on the following scale: very low, low, moderate, high, and very high. This analysis focused on the amount of private forest land rated as high or very high fire potential.

Air Pollution: Ozone

The ozone layer depicts private forest land threatened by ground-level ozone and was based on late-summer observations by FIA field crews of ozone damage to bioindicator species known to be sensitive to ground-level ozone. Bioindicator species are used to monitor the health of the environment; changes in the health of bioindicator species may indicate a problem for the ecosystem they inhabit. Each FIA plot was assigned a biosite value based on a subjective assessment by trained observers of the quantity and severity of damages (Coulston et al. 2003, Smith et al. 2003). Inverse distance-weighted interpolation was used to create a map of ozone damage for each data set from FIA plots for the years 2000 through 2005. These maps were then combined by averaging ozone damage with all available data years for this study. The resulting map was then combined with the forest ownership layer to identify private forest land with elevated levels of ozone damage. For each watershed, the percentage of private forest land with bioindicator evidence of ozone damage was calculated.

For the ozone classification, four classes were constructed by selecting percentiles of affected area as class boundaries as follows: 1 (95^{th} to 100^{th} percentile), 2 (90^{th} to 94^{th} percentile), 3 (85^{th} to 89^{th} percentile), and 4 (0 to 84^{th} percentile). The same percentiles were used as class boundaries for the housing density layer before combining this with the ozone layer to identify areas with high projected housing density increase as well as high percentage of ozone damage.

Sensitivity Analyses

These analyses involved decisions regarding the selection of screening criteria and specific housing density categories. The screening criteria used for this study were that a watershed had to have at least 10 percent forest cover and that at least 10,000 acres of forest had to be under private ownership (screening criteria were used in order to avoid highlighting entire watersheds with very low amounts of private forest as being at great risk of change from increased housing density). We conducted two sets of sensitivity analyses to objectively assess the effects of these decisions on the results of our analyses.

First, we assessed the impact of our screening criteria on the analysis of watersheds containing substantial expanses of private forest that are projected to be affected by increases in housing density between 2000 and 2030. The analyses indicated that eliminating the screening criteria altogether had little effect on watersheds in higher percentile categories for increased housing density or interior forest; most of the additional watersheds that were included after eliminating screening criteria were in the lower percentile categories. Although elimination of the criteria did identify new watersheds west of the Rocky Mountains in higher percentile categories for insects and disease and for wildfire, most of these watersheds had less than 5 percent and very frequently less than 1 percent private forest land.

The second set of analyses focused on the effects of using 16 housing units per square mile as the upper threshold for the least dense housing density category. In particular, the issue was whether the rural I category should be subdivided into two categories: rural Ia with 8 or fewer houses per square mile, and rural Ib with 9 to 16 houses per square mile.

To address this issue, we split the rural I category into rural Ia and rural Ib categories and evaluated watersheds with respect to amounts of their private forest lands that changed among any of the now four housing density categories. We then ranked the watersheds in the same manner as was done when using only three housing density categories and determined that the use of our original three categories was appropriate for this study. The analyses indicated a slight increase in the overall number of watersheds in the East with high percentile rankings but no such increase for the watersheds in the West. We attribute this result to subdivision of a greater number of small parcels in the East than in the West. These results are consistent with those of a sensitivity analysis conducted in conjunction with the 2005 Forests on the Edge report (White et al. 2009).

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Forests on the Edge

Forests on the Edge is a project of the U.S. Department of Agriculture, Forest Service, State and Private Forestry, Cooperative Forestry staff, in conjunction with Forest Service Research and Development. The project has produced a series of reports to increase public understanding of the contributions of and pressures on America's forests. The first report, *Forests on the Edge: Housing Development on America's Private Forests* (Stein et al. 2005), identified development pressures on private forested watersheds in the conterminous United States. Subsequent reports have identified national forests and grasslands most likely to be affected by increased housing density along their borders (Stein et al. 2007); studied future development on private forests in Georgia, Washington, and Maine (White and Mazza 2008); and reported on sensitivity analyses conducted for the first *Forests on the Edge* report. (White et al. 2009).

This report focuses on watersheds where pressure from development may affect private forest contributions to water quality, timber volume, at-risk species habitat, and interior forest nationwide, and where development impacts may be exacerbated by additional pressures of wildfire, insect pests and diseases, and air pollution.

Future Forests on the Edge work will include assessments of additional contributions and risks and construction of an Internet-based system that permits users to select particular contribution and threat layers, options for combining them, and options for depicting the results.

Specific studies currently underway examine:

- Housing development on private forests providing habitat for at-risk species.
- Pressures on urban forests across the Nation.
- Development projections for private forest lands in Alaska, Hawaii, Puerto Rico, the Virgin Islands, and the Pacific Islands.
- Implications of development on ecosystem goods and services.

For further information on Forests on the Edge, contact Susan Stein, U.S. Department of Agriculture, Forest Service, Cooperative Forestry staff, 1400 Independence Avenue, SW, Mailstop 1123, Washington, DC 20250-1123. (202) 205-0837. sstein@fs.fed.us. http://www.fs.fed.us/openspace/fote/.