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Forests on the Edge: The Influence of Increased Housing Density on Forest Systems and Services

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Abstract

The forests of the United States are changing, along with the rich services and resources they provide. In rural forests across the country, housing density is increasing, with associated changes to forest structure and function that affect such ecological and economic benefits as water quality, timber volume, and habitats for at-risk species of plants and animals. Additional pressures such as insect pests, diseases, and wildfire compound—and are influenced by—the impacts of housing density. Future efforts to conserve America's forest lands will require a continued emphasis on partnerships, and new approaches to plan for and provide sustainable housing for America's growing population in ways that minimize the negative impacts of increased housing density on rural areas.

America's Changing Forests

From coast to coast and beyond to "the islands," from old-growth Douglas-fir and ponderosa pine forests in the U.S. West to pine barrens and oak hickory forests in the East, from arid pinyon-juniper woodlands to lush temperate and tropical rainforests—America's 304 million hectares (751 million acres) of diverse public and private forest lands provide a wealth of goods and services. As described in detail elsewhere in this volume, forests help ensure clean water and diverse forest products, furnish abundant fish and wildlife habitats, provide incomparable recreational and spiritual settings, supply energy, sequester carbon, and support numerous other invaluable ecological, social, and economic public benefits.

The forests of the United States are changing, along with the rich services and resources they provide. Constant change and flux are natural and inevitable for any forest system—as plant and animal communities evolve, as weather patterns shift, as disturbances such as fire or insect populations come and go, and as people alter the ways in which they use and live on forest lands. But many of the transformations seen in recent years and projected to increase in coming decades have to do with dramatic increases in housing density and

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associated development of roads, parking lots, and other housing-related infrastructure in rural and exurban areas. In many places nationwide, what had been large tracts of private forests are becoming fragmented, reduced in size, and subdivided for an increasing number and density of housing (Stein et al., 2009). Typically, along with the breakup into smaller disconnected pieces comes parcelization, or diversification of land ownership, as well.

Parcelization of forests can in some cases bring enhanced appreciation for and stewardship of forest lands (Butler, 2008). However, fragmentation and parcelization can also provoke a host of adverse changes in water quality and aquatic species diversity, timber volume and management, native terrestrial wildlife populations, forest structure and function, wildfire risk, scenic quality, and recreational opportunities (Sampson and Decoster, 2000; Smail and Lewis, 2009; Stein et al., 2005; as cited in Stein et al., 2009). Such changes may be exacerbated by—or may increase the risks from—other pressures, such as wildfire, insect and disease infestations, and air pollution (Stein et al., 2009). And as Butler (2008) noted, the decreasing size of forest holdings is also highly correlated with behaviors and attitudes of forest owners, with implications for how the land is managed and how long it is held before being divided yet again.

According to the U.S. Forest Service's Forests on the Edge (FOTE) project (Stein et al., 2009) (Box 4–1), development pressures on private forests and their services in the conterminous United States are concentrated in the East but are also found in the north-central region, parts of the West and Southwest, and the Pacific Northwest. Nationwide, more than 23 million hectares (57 million acres) of rural private forest land are projected to experience a substantial increase in housing density from 2000 to 2030, during which time the U.S. population is projected to increase by at least another 80 million people (U.S. Census Bureau, 2005). Some 8.5 million hectares (21 million acres) of rural private lands located today within 16 km of a national forest or grassland boundary—again, mostly in the East but also in several Western states—are projected to undergo substantial increases in housing density by 2030; some 13 national forests or grasslands will each experience increased housing density on more than a 200,000 ha of adjacent private rural lands (Stein et al., 2007).

This chapter provides an overview of how development at the rural–urban interface and projected increases in rural housing density affect forest systems, services, and health. Our discussion is drawn largely from data and national-level mapping on private forest lands in the conterminous (lower 48) United States produced by the FOTE project since 2005.

The FOTE analyses focus on housing density increases in rural private forest lands. We focus on rural lands because these lands provide critical ecosystem services, which are being altered by increasing housing density. We focus on private forests because public forests are largely protected from direct impacts of increased housing density. We try to answer such questions as: where in the United States do private forests make substantial contributions to clean water, timber volume, habitats for at-risk plant and animal species, air quality, and carbon sequestration? Where are these contributions likely to change because of increased housing density in rural private forests? How does increased housing density interact with other factors (e.g., fire,

Box 4–1. About Forests on the Edge

Forests on the Edge is a project of the USDA Forest Service, State and Private Forestry, Cooperative Forestry staff, in conjunction with Forest Service Research and Development, National Forest System staff, universities, and other partners. The project aims to increase public understanding of the contributions of and pressures on America's forests, and to create new tools for strategic planning. The first report (Stein et. al., 2005) identified private forested watersheds in the conterminous United States most likely to experience housing development. Subsequent reports have included more in-depth discussion and updated data on: the impacts of increased housing density and other pressures on private forest benefits (Stein et. al., 2009), impacts on national forests and grasslands from development on nearby private forests (Stein et. al., 2007), threats to at-risk species in private forests (Stein et. al., 2010), and sustaining America's urban trees and forests (Nowak et. al., 2010). Additional reports in progress include the extent and impacts of development on forests in Alaska, Hawaii, and U.S. affiliated islands in the Pacific and Caribbean; the relationship between housing in the wildland–urban interface and wildfire; and pressures and changes affecting America's family forest landowners. Future plans include construction of an online system that enables users to view, combine, and depict results for selected contribution and threat layers.

insects, diseases, and air pollution) that pose risks to forests? (Stein et al., 2009).

Although our perspective is at the U.S. national level and may not precisely describe conditions or projections for specific locations or watersheds, it is hoped that forest resource managers will find context and inspiration for local discussions about forest land development. Other authors in this volume explore many of these issues in more detail and with specific localized case studies from throughout the world. It is at the local level that land managers, owners, and communities will need most to address the challenges of planning for growth while conserving the potential for forests to provide invaluable goods, services, and economic opportunities far into the future.

The Geography and Diversity of America's Forests

Some 33% (~304 million ha) of the total land base of the United States is forest land today (Oswalt et al., 2009; Smith et al., 2009), accounting for about 16% of global forest area (FAO, 2011a). In the United States the area of forest is down from about 46% in the mid 1600s (Smith et al., 2009), but this country has experienced a steady net increase in forest cover in the past 100 years, including a net annual increase of about 0.13% since 2000 (FAO, 2011a), a trend that is not expected to continue into the future, however. Today some 14% of U.S. forests are currently protected under wilderness or similar status (USDA Forest Service, 2011a).

In contrast, net overall forest area worldwide has decreased by about the same percentage annually (0.13% since 2000; FAO, 2011a), largely because of drought, fire, and conversion to other uses, primarily agriculture (FAO, 2010). The amount of forest per person in the United States today is about 1 ha (2.5 acres), compared to about 0.6 ha (1.5 acres) per person worldwide (FAO, 2011a).

Although forest area in the United States has been relatively stable during the 20th and early 21st centuries, the nature of American forests has changed substantially during that time. Some land has been converted to agriculture and back to forest again, some forests have aged or been affected by fire or other natural processes, and others have been managed and manipulated in ways that have altered their composition, structure, and wild inhabitants (Oswalt et al., 2009, Smith et al., 2009; USDA Forest Service, 2011a). As the most recent report on sustainability of U.S. forests notes, "fragmentation and loss of forest land are occurring in many regions and localities, owing mostly to human development" (USDA Forest Service, 2011a) (Box 4–2).

Box 4–2. America's Urban Forests: A Bonus

America's urban areas—some 3% of the land area of the conterminous 48 U.S. states—also support significant amounts of publicly and privately owned trees collectively called the "urban forest." Such forests are not included in the calculations for total forest area in the United States mentioned above, but they provide more than 220 million people a set of essential ecosystem services not unlike those provided by forests in rural and exurban areas. Similarly, urban forests also face a myriad of management challenges related to increasing human populations and related development. (Nowak et al., 2010)

The forests of the United States are extraordinarily diverse (Box 4–3). Distributed almost evenly east and west of the continent's central plains, U.S. forests contain more than 800 tree species, of which about 90% are native (Smith et al., 2004). According to the Forest Service's Forest Inventory and Analysis (FIA) program, western U.S. forest types include Douglas-fir, hemlock–Sitka spruce; ponderosa, western white, and lodgepole pines; fir–spruce; redwood; chaparral; pinyon–juniper; and western hardwoods

Box 4–3. What Is a Forest?

Exactly what constitutes a "forest" or a forest type depends somewhat on whose data and definitions are being used. The Forest Service's Forest Inventory and Analysis (FIA) program defines forest land as "land that is at least 1 acre [0.4 ha] and at least 10% stocked by trees of any size" (Smith et. al., 2004), and its forest cover type map (Fig. 1) displays some 27 major forest types including those found in Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands (USDA Forest Service 2011a).

The U.S. Geological Survey (USGS) used a different definition of forest—land "with at least 25% tree crown cover from trees that are greater than about 18 feet tall [~5.5 m]" (Homer et. al., 2007)—to create detailed forest cover data for the conterminous 48 states. NLCD organizes U.S. forests into 21 land cover classes with varying specific definitions. For example:

- Deciduous forest—Areas dominated by trees where 75% or more of the trees shed foliage in response to seasonal change.
- Evergreen forest—Areas dominated by trees where 75% 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% of the cover present.

The 2001 National Land Cover Database (NLCD) database was the basis for forest cover data presented later in this chapter.

(including scrub oak, alder, and aspen) (see Fig. 4–1). Eastern forests include several pine types (white–red–jack, longleaf–slash, and loblolly–shortleaf); several oak types (oak–pine, oak–hickory, oak–gum–cypress); and other hardwoods (elm–ash–cottonwood, maple-–beech–birch, aspen–birch). Alaska forests are characterized as spruce–birch, fir–spruce, and hemlock–Sitka spruce; in Puerto Rico we find evergreen broadleaf forests; and Hawaii includes both native and mixed forests (USDA Forest Service, 2011a).

U.S. Forest Ownership

Worldwide, only about 16% of forest land is privately owned (FAO, 2010). In the United States, slightly more than one-half (56% of the forest land is privately owned (~171 million hectares, 423 million acres; see Fig. 4–2) (Smith et. al., 2009); two-thirds of this area is owned by about 11 million individuals, estates, trusts, non-governmental organizations, and other "non-corporate" owners (Butler, 2008; Smith et al., 2009). Most U.S. private forests are found in the eastern portion of the country, 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 (Stein et al., 2009).

The remaining 44% of America's forests are publicly managed, including about 60 million hectares (147 million acres) managed by the U.S. Forest Service as national forests (Oswalt et al., 2009; Smith et al., 2009). These lands, too, are affected by population growth nationwide, because, as discussed elsewhere in this chapter, much development on rural private lands occurs within 10 miles of National Forest System boundaries (Stein et al., 2007).

Forest Development Trends across the United States

Many of America's forests are disappearing, and much of our remaining forest land is being heavily altered by development and other human actions. Even as total forest cover nationwide has remained stable, forests in some areas have been permanently converted to urban use (Alig et al., 2010), and the acreage occupied by various forest species groups has shifted (Smith et al., 2009). In the future, America's total forest cover is expected to decrease, primarily because of urbanization (Wear, 2011). Recent analyses have documented a number of trends, all of which point to increased human influence in and around our forested landscapes, as described below.

Large Areas of Forest are Being Permanently Lost Each Year

Although from 1910 to 2007, the total amount of U.S. forest cover increased, a decline in forest cover is projected for the future. According to one estimate, the United States will have experienced a net loss of ~15 million hectares (37.472 million acres) of forest between 1997 and 2060 (Wear, 2011). Even during the period 1982–1997, when America experienced a net gain of 202,000 hectares (500,000 acres) in forest cover, close to 4 million hectares (10 million acres) of forest were lost to urban development, and forest land was converted to urban use at an increasing rate (Alig et al., 2010). This conversion of rural land (both forested and agricultural) to urban uses is happening around the world, but according to one analysis, the greatest absolute loss of rural land area to cities from 1970 to 2000 was in North America, even though the highest *rates* of urban growth during that period were found in the developing regions of China, India, and Africa (Seto et al., 2011).

Developed Land Area Has Increased at a Higher Rate than Population Growth

From 1982 to 2000, the U.S. population increased by 19%, while developed land area increased by 42% (Wear, 2002, cited in Faulkner, 2004). This finding is consistent with that reported by Seto et al. (2011), whose analysis of 326 studies worldwide concluded that "across all regions and for all three decades (1970–2000), urban land expansion rates are higher than or equal to urban population growth rates, suggesting that urban growth is becoming more expansive than compact."

Some Forest Types are Decreasing While Others are Increasing

According to an assessment by the Forest Service, from 1987 to 2007 (a period of net increase in forest cover), 16 forest type groups decreased, while 8 increased (Smith et al., 2009). Examples include:

- A 2.8 million–ha (7 million–acre) loss of land under the oak–gum–cypress species group.
- About 1.2 million –ha (3 million–acre) losses in each of several eastern species groups including spruce–fir, long-leaf slash pine, and oak–pine, as well as two western groups: ponderosa–Jeffrey pine, and fir-spruce.
- Increases in acreage under loblolly–shortleaf pine, oak–hickory, elm–ash–cottonwood, and various western timber species groups.

Fig. 4–1. Forest types of the United States. As a part of the 1997 Resource Planning Act Assessment, the U.S. Forest Service's Forest Inventory and Analysis (FIA) program collaborated with the U.S. Geological Survey to update the Forest Types of the United States map, found at http://www.fia.fs.fed.us/library/maps/ (accessed 13 Mar. 2012). Source: USDA Forest Service (2011b).

Much of America's Forest Cover is Fragmented

"Core forests" are landscapes that are completely forested (Oswalt et al., 2009). According to one analysis, more than 99% of all core forest in the United States is located within 1.6 km (1 mile) of a boundary with nonforested land (Oswalt et al., 2009). Although the results of core forest analyses vary, depending on scale, "The larger the landscape being examined, the less likely it is that it will be core forest. For 10-acre [4-ha] landscapes, 46% of all forest land is classified as core forest. Less than 1% of forest land is classified as core forest in landscapes that are 1500 acres [607 ha] or larger" Oswalt et al. (2009).

The term *interior forest* generally describes forest land that is surrounded by other forest. Interior forest is inversely related to the degree that

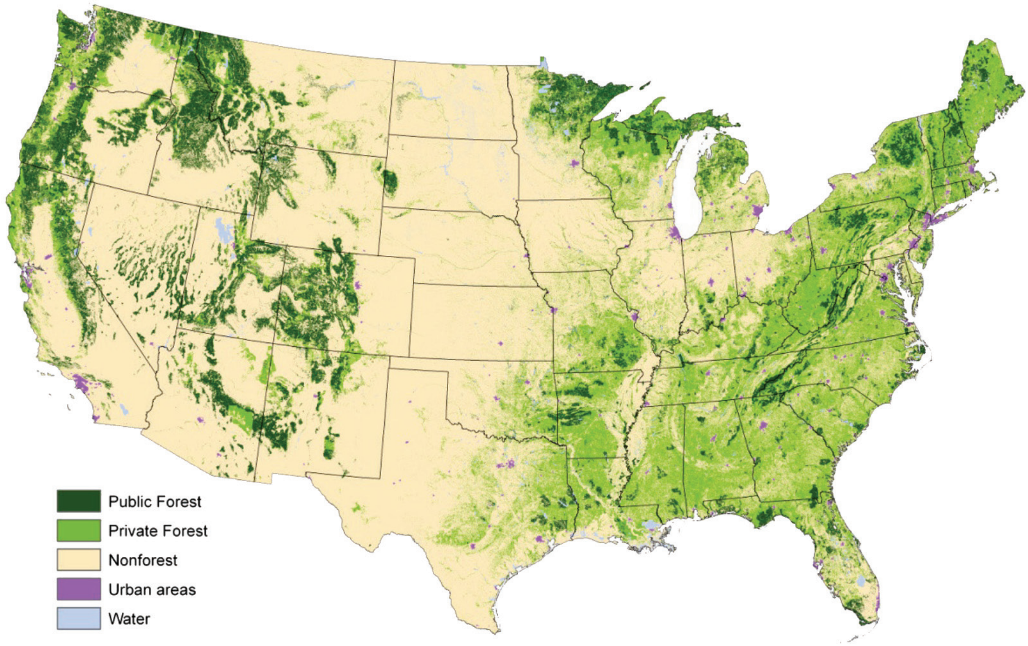

Fig. 4–2. Location of private and public forest, nonforest, and urban areas in the conterminous United States. About three-quarters of U.S. private forests are in the East. This Forests on the Edge mapping effort did not include Alaska, Hawaii, or U.S. affiliated islands because of lack of available data at the time of publication (Stein et. al., 2009).

a forested landscape is fragmented, or separated, into disconnected patches (Stein et al., 2009). Interior forests provide numerous public services including habitat for wildlife species; as forests are fragmented, the relative amount of forest edge increases, to the benefit of some species and the detriment of others (Oswalt et al., 2009; Stein et al., 2009). Figure 4–3 ranks counties across the United States according to the percentage of forest in each county that is identified as "interior."

Housing Density Will Continue to Increase in Private Rural Forest Land and Will Affect Public Forests As Well

Many forest lands not lost entirely to development are expected nevertheless to experience increased housing density and consequent fragmentation to some degree in the years ahead. According to an estimate by the Forests on the Edge project, from 2000 to 2030, some 57 million acres of private rural forest (15% of all private forest) are projected to experience a substantial increase in housing density.

Even the 134 million hectares (330 million acres) of public forest land in America may be affected by housing density, despite the fact that actual development is precluded on most public lands, because many of these lands are adjacent to cities, suburbs, or rural areas where housing is on the rise. In fact, counties with national forests and grasslands are already experiencing some of the highest population growth rates in the country (Garber-Yonts, 2004, cited in Stein et al., 2007). Some 9 million hectares (22 million acres) of private lands within 16 km (10 miles) of national forests and grasslands are projected to experience a substantial increase in housing density from 2000 to 2030 (Stein et al., 2007).

Influence of Increased Housing Density on Private Forest Systems and Services[1]

All forests experience change over time, regardless of the degree of human influence. Forest land cleared by an intense fire, for example, will go through a series of stages referred to as "succession," where one plant community replaces another, and each stage of succession creates conditions suitable for the next stage. A typical sequence begins with a

[1] The majority of this section has been excerpted or adapted from Stein et al. (2009), Private forests, public benefits: Increased housing density and other pressures on private forest contributions. Gen. Tech. Rep. PNW-GTR-795. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

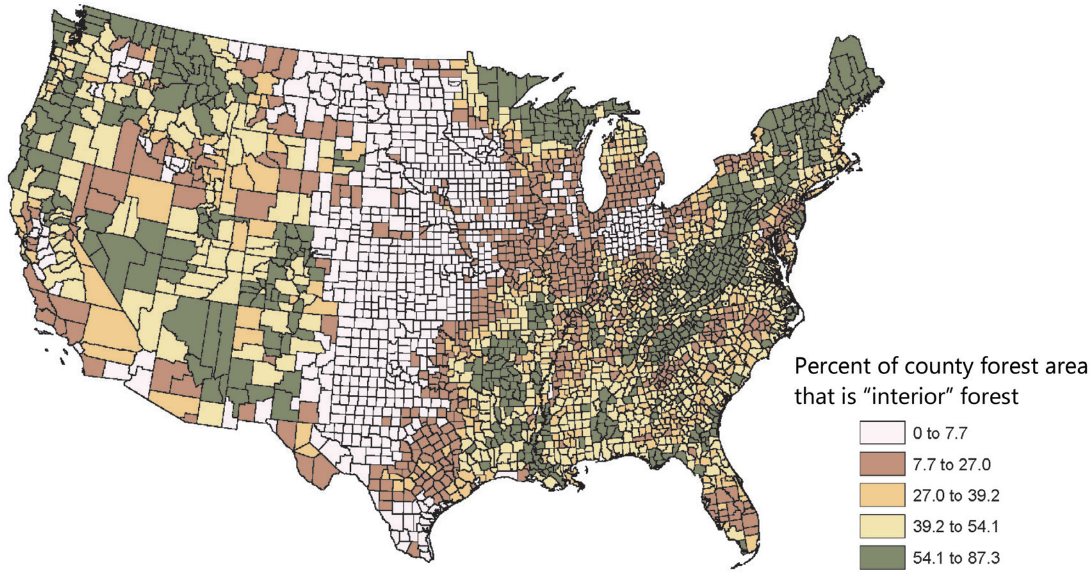

Fig. 4–3. Interior forest percentage of total forest. Watersheds in the 90th percentile are concentrated in the East, but some high-ranking watersheds are also found in the West and Southwest. The map shows the percentage of forest pixels in each county identified as interior. The map was created by dividing all land into 30- by 30-m pixels; each pixel was tested to see if the land in the surrounding pixels (15.2 ha) was identified as forest. Note that some counties that are mostly unforested but contain at least some forest show up as "green" (the 50th percentile); this is because much of the small amount of forest contained in these counties is identified as "interior." Source: Riitters (2011).

grass–forb community, followed by shrubs–seedlings, saplings–poles, young trees, mature trees, and lastly, a climax community, a relatively stable plant community, dominated by shade-tolerant tree species that can reproduce under their own shade (Martin and Grower, 1996). Disturbances—in the form of fire, pests, windstorms, or management activities, for example—can cause a forest area to revert back to an earlier successional stage (Martin and Grower, 1996) or can delay or redirect succession (McCullough and Werner, 1998).

Housing development can affect the process of forest succession and the structure and function of forests. In addition to causing the permanent removal of forest, the isolation and continued disturbance of forest patches remaining in urban areas, for example, can result in the replacement of native forest vegetation by urbanized plant communities (Guntenspergen and Levenson, 1997). Decreases in tree species diversity have been directly correlated with increasing levels of urbanization (Polyakov et al., 2005). Human disturbances such as trampling, mowing, and air pollution can all have an effect on "the dominance, structure, species richness, and successional processes of plant communities" (Guntenspergen and Levenson, 1997).

In addition to direct effects on forest structure and dynamics, changes in air and water quality associated with development can cause additional impacts, such as decreased water quality and increased surface water flows, which can have additional impacts on forest plant communities. Urbanization in upland areas adjacent to the New Jersey Pinelands, for example, has affected the quantity and quality of water flowing into nearby cedar wetlands, resulting in changes to species compositions of understory plants (Ehrenfeld and Schneider, 1991). Air pollution can affect forest ecosystems in many ways, including changes in species compositions; forest growth; carbon, nitrogen, and water balance; and increased tree mortality. Many of these factors in turn can increase susceptibility to drought, insect attack, and wildfire (Stein et al., 2009), the potential for which also are expected to accelerate even further with climate change (Dale et al., 2001, cited in Aubry et al., 2011).

The impacts of increased housing density on forest structure and dynamics, on water quality and quantity, and on other key forest elements such as open space, thereby affect such invaluable forest services and products as: clean drinking water, aquatic species habitats, fish and wildlife habitats, flood and erosion control, carbon storage, timber and other non-timber forest products, clean air, recreational opportunities, and cultural and spiritual sustenance (Table 4–1).

The remainder of this chapter focuses on three such elements and benefits, as analyzed and reported in Stein et al. (2009): water quality and quantity, timber volume, and at-risk species habitats.

To understand where increases in housing density in rural forest areas might be more likely to affect private forest lands and their public benefits and services, Stein et al. (2009) constructed nationally consistent data layers and summarized the data across fourth-level watersheds. Only watersheds with 10% forest cover and at least ~4050 ha (10,000 acres) of private forest were included in the analysis. Rural lands were identified as likely to undergo a substantial increase in housing density if one of the following criteria were met:

- Housing density on lands with fewer than 16 housing units per 259 ha (1 square mile) in 2000 was projected to increase to a density of more than 16 units per 259 ha by 2030.
- Housing density on lands with 16 to 64 housing units per 259 ha (1 square mile) was projected to increase to a density of more than 64 units per 259 ha by 2030.

Housing density projections were based on census data on housing and population, past growth patterns, road densities, and locations of urban areas (Theobald, 2005) (Fig. 4–4).[2]

Water Quality

Approximately 53% of the water supply in the conterminous 48 states originates on forests (Brown et al., 2005)—and more than one-half of that flows from private forests. Water flowing from forests is widely recognized as clean compared to water flow from other sources. Watersheds with more forest cover have been shown to have higher groundwater recharge, lower storm water runoff, and lower levels of nutrients and sediment in streams than areas dominated by urban or agricultural uses (Brett et al., 2005; Crosbie and Chow-Fraser, 1999; Matteo et al., 2006).

Private—and public—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.

Impacts of Housing Development on Water Quality

Water quality and quantity can be altered when forest and riparian vegetation is replaced by housing developments and associated roads, parking lots, driveways, and rooftops. A 2005 review of urbanization impacts on watershed functions (Wheeler et al., 2005) described a plethora of research on the physical, chemical, and biological impacts of development on water resources. The increase in impervious surface associated with urbanization can increase the amount, speed, and location of water flow into local streams, producing increased stream flow and flooding (Im et al., 2003; Wheeler et al., 2005). This, in turn changes the physical and chemical nature of streams as increased bank erosion leads to streams that are wider, deeper, and contain more sediment, which in turn affects stream biota. Increased surface water flows mean that subsurface flow and groundwater are delivered inconsistently, often causing stream flow to be lower or nonexistent between storm events. One study of a coastal watershed in the Southeast found that annual stream flow volume and sediment loads were 72 and 66% higher for an urbanized stream than for a comparable forested stream (Wahl et al., 1997). Furthermore, depending on the land use, urban runoff can carry pesticides, fertilizers, oils, and metals (Stein and Butler, 2004). About 85% of urban runoff, which contains a host of chemical pollutants, ends up in rivers and streams.

Urban runoff also can be high in nutrients that cause algal blooms and decreased oxygen levels. The risk of reaching harmful nutrient levels is said to increase when a forested watershed loses 10% of its forest cover (Wheeler et al., 2005). Other biological impacts from the physical and chemical impacts of development include the reduction or loss of macroinvertebrate communities, decreased fish species richness and abundance, and an increase of lead in the tissues of some fish species (Wheeler et al., 2005). The size of the forested area is important—wetlands adjacent to large forested tracts, for example, have lower levels of harmful nutrients and pollutants than do wetlands adjacent to smaller forested tracts (Houlahan and Findlay, 2004).

[2] More detailed descriptions of this or any other Forests on the Edge analyses presented here can be found in Stein et al. (2009).

Table 4–1. Forests as providers of public benefits and services.

Forest element	Benefit/service	Some statistics
Water quality and quantity	Clean drinking water	More than half of the fresh water in the United States comes from forests (Brown et. al., 2005).
		Water flowing through forests is generally acknowledged to be cleaner and of higher quality than water derived from other sources.
		U.S. Forest Service estimates some 180 million people depend on forests for their drinking water (Sedell, 2005, personal communication, cited in Stein et. al., 2005).
	Aquatic species habitats	Riparian forests are key for shade and keeping streams cool; they are critical sources of woody debris and other materials that create complex habitats for all kinds of fishes.
		Forest soils and vegetation absorb and moderate the flow of water in streams, important for fish spawning and for migration of anadromous fish.
	Flood and erosion prevention	Forests slow storm water runoff, stabilize soils, prevent erosion and floods, and filter pollution (Stein et. al., 2005, 2009).
Forest structure/dynamics	Wildlife habitats in interior forests†	Some large mammals such as bears, birds such as the red-bellied woodpecker, and small mammals such as the eastern chipmunk prefer or require interior forest for their survival (Whelan and Maina, 2005; Mahan and Yahner, 1999; Phelps and Hoppe, 2002; all cited in Stein et. al., 2009).
	At-risk species‡ habitats	60% of at-risk species of plants and animals in the conterminous United States are associated with private forests (Robles et. al., 2008; Stein et. al., 2009).
	Timber volume	Private forest land accounts for some 92% of all timber harvested in the United States (Smith et. al., 2009). In coming years most U.S. timber harvest is expected to occur in the Southeast (Alig and Butler, 2004; Haynes et. al., 2001; Stein et. al., 2009).
	Carbon sequestration	In 2006, forests in the lower 48 states removed from the air and stored in their tissues or forest products enough carbon to offset about 11% of gross U.S. CO_2 emissions (Oswalt et. al., 2009).
	Clean air	Urban trees alone in the lower 48 states remove some 711,233 metric tons of air pollution annually, with a value of $3.8 billion (Nowak et. al., 2006, cited in Nowak et. al., 2010).
Open space	Recreation opportunities	Nearly half (45% of all recreation in the United States occurs in forests (Heinz Center, 2008).
		Forest-based recreation and tourism are important sources of employment and income; engaging in outdoor recreation in forests also helps build support for sustainable forests (Cordell et. al., 2008).
		In 2007–2008, American public and urban forests alone provided between 1.2 and 7.5 billion “forest recreation visitor days” (roughly, forest visits) for people hiking; viewing or photographing birds, flowers, wildlife, and scenery; and walking for pleasure (Cordell et. al., 2008).
	Cultural, social, and spiritual values	Forests serve as settings for cultural and social events, repositories of cultural heritage, and sources of products for rituals and ceremonies (FAO, 2011b). Cultural values also include “aesthetic and passive uses” (such as scenery, and the value people attach to the knowledge that forests exist) (Krieger, 2001).
		Of 202 individuals surveyed in 2008, nearly 80% said they value trees and forests for their “beauty and splendor;” more than half found spiritual aspects of “happiness, growth, intrinsic, stewardship” to be forest values important to them (USDA Forest Service, 2011a).
		Economic impacts of forest scenery along the Blue Ridge Parkway in North Carolina and Virginia have been estimated at $1.3 billion in tourism expenditures, $98 million in annual tax revenues, and 26,500 jobs (Krieger, 2001).

† Interior forest generally refers to an area of forest land that is surrounded by other forest; inversely related to the degree that a forested landscape is fragmented, or separated, into disconnected patches (Stein et. al., 2009); defined by Forest Inventory and Analysis (2009, p. 14) as “landscapes that are more than 90% forested.”

‡ Includes plants and animals listed under the U.S. Endangered Species Act (ESA) or designated as critically imperiled, imperiled, or vulnerable according to the NatureServe Conservation Status ranking system (Stein et. al., 2009).

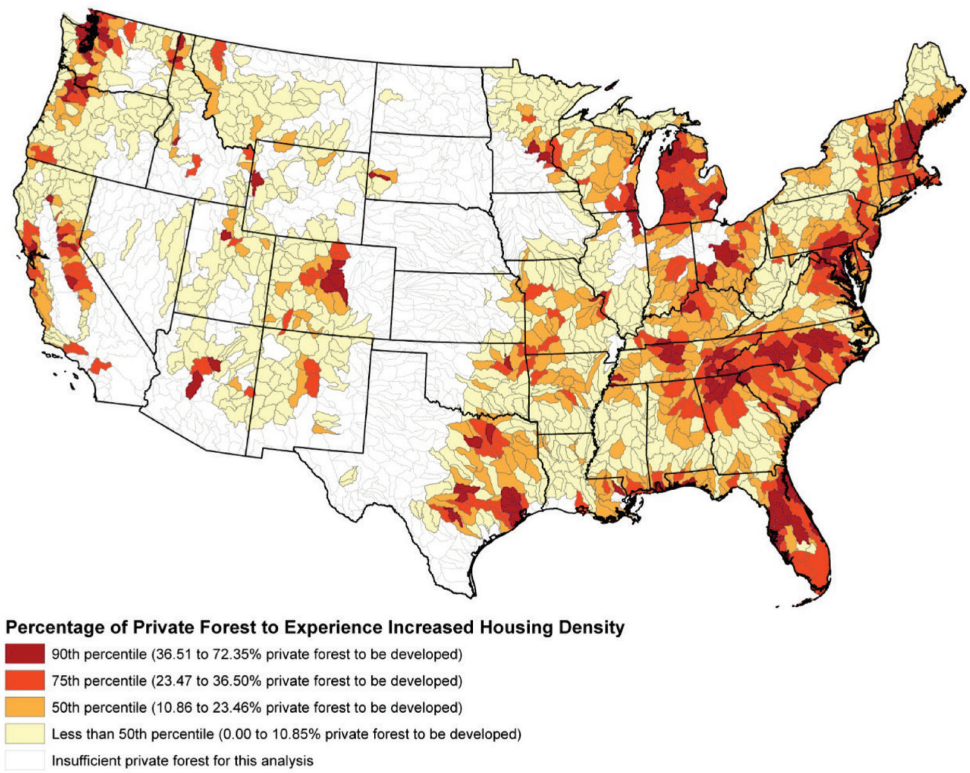

Fig. 4–4. Percentage of private forest to experience increased housing density. More than 23 million hectares (57 million acres) of rural forest land could experience a substantial increase in housing density from 2000 to 2030. As displayed here, watersheds with the highest percentages of private forest to be developed are concentrated in the East—in particular in Michigan, in the southern Appalachians, 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. Source: Stein et. al. (2009).

Identifying Watersheds Where Increased Housing Density Could Affect Future Water Quality

Figure 4–5 displays watersheds according to the contributions of private forests to water quality combined with the potential for increased housing density. Watersheds in the East, where there is a higher proportion of private forests compared to the West, have the highest potential for future change in water quality as a result of future housing density increases. 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. The highest ranking watersheds in the West are in the Pacific Northwest, central California, and northern Idaho.

Timber Volume

Private forest land makes a substantial contribution to U.S. timber resources, accounting for 92% 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 U.S. timber harvest is expected to occur in the Southeast in coming decades; forecasts indicate that by 2050 roughly two-thirds of the softwood timber harvest will come from plantations on less than 20% of the timberland base (Alig and Butler, 2004; Haynes et al., 2001).

Impacts of Urbanization on Timber Volume

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

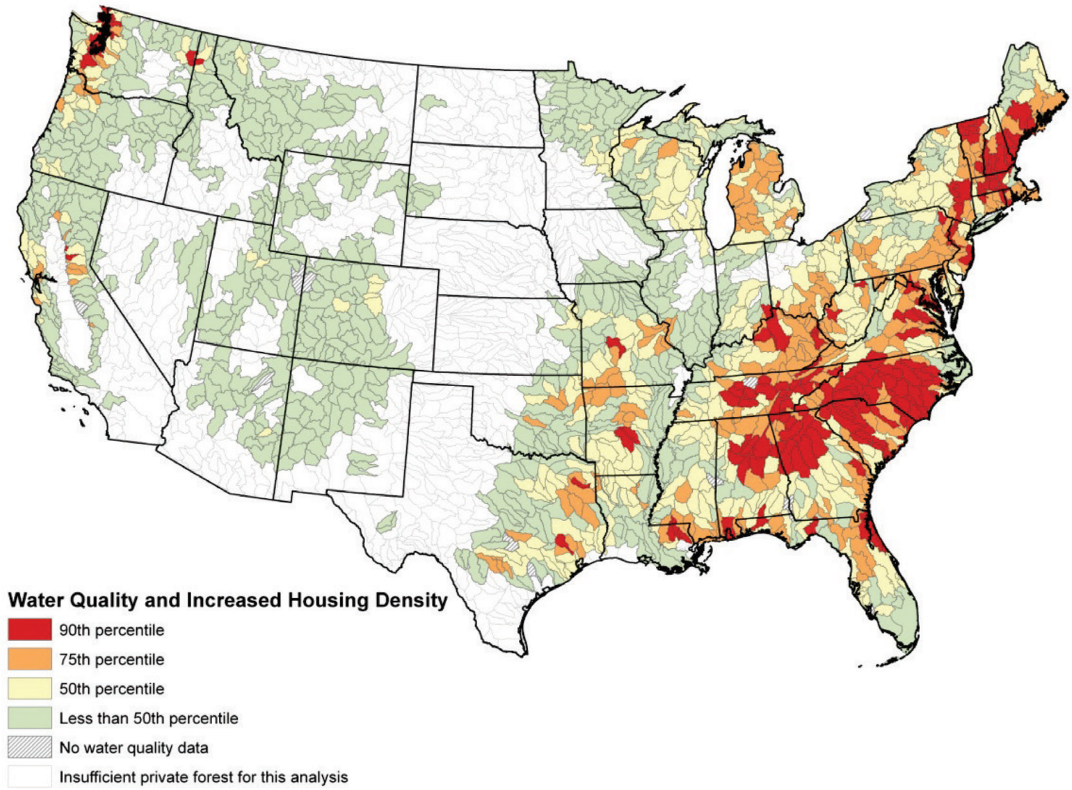

Fig. 4–5. Water quality and increased housing development. Watersheds in the Eastern United States have high potential for changes in water quality as a result of projected increases in housing density on private forest lands, along with a few watersheds in the Pacific Northwest, central California, and northern Idaho. Source: Stein et. al. (2009). Methods used for the creation of these maps can be found in Stein et al. (2009).

a consequence of increased development, generating a concern about wood supply (Egan et al., 2007) and price (LeVan, 1995). A growing body of literature on urbanization impacts on commercial forest management contains the following findings:

- A study of the south-central United States concluded that urbanization led to lower rates of timber harvesting and to an overall decrease in regional short-term timber supply (Munn et al., 2002).
- As population increased in forested areas of Virginia, commercial forestry decreased (Wear et al., 1999).
- Declining parcel size of New Hampshire forests made forest management less profitable, to the point where it was generally not profitable to harvest timber on parcels smaller than 4 to 8 ha (10–20 acres) (Thorne and Sundquist, 2001).
- In central New York State, the likelihood of sustained yield management declined substantially with increased road density and increased population (Vickery et al., 2009).
- The mean percentage of basal area in acceptable growing stock was lower on New York forestland properties that had been subdivided between 1984 and 2001, than in those that had not been subdivided (Germain et al., 2007).

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).

[3] Growing stock volume is defined as the volume of trees of commercial species with diameters of at least 12.7-cm (5-inch) diameter at breast height (dbh) growing on forest land.

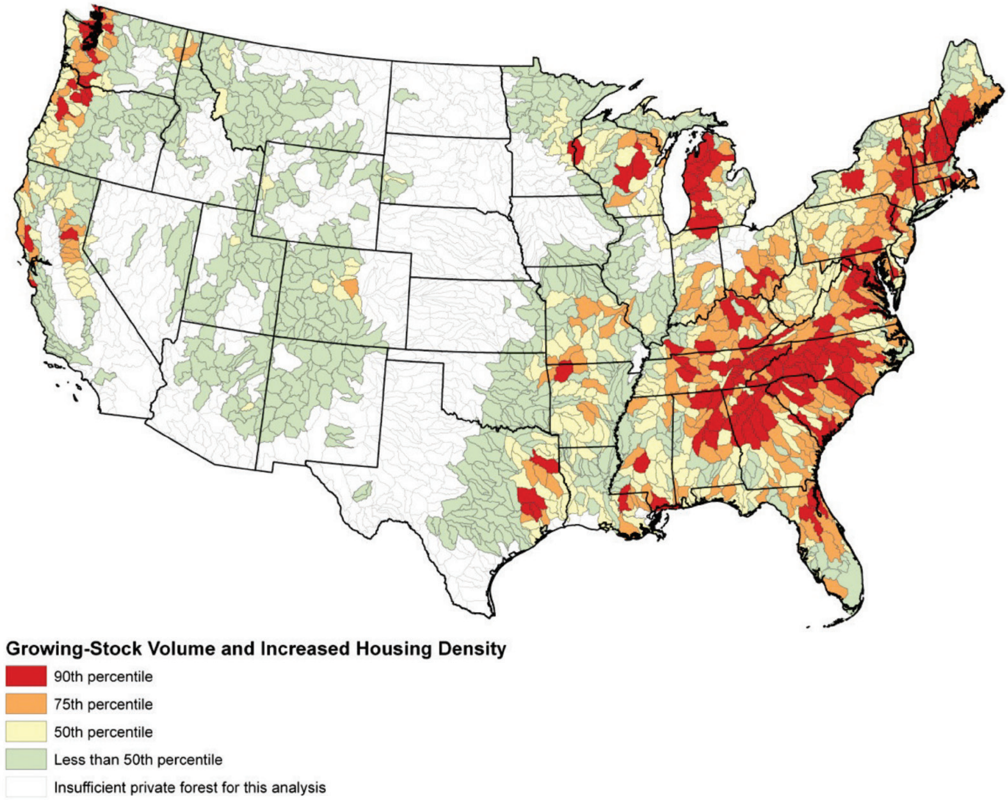

Fig. 4–6. Timber volume and increased housing density. High-ranking watersheds are found throughout the East, especially in New England and the southern Appalachians. High-ranking watersheds in the West are scattered across western Washington, Oregon, and northern California. Source: Stein et. al. (2009).

Identifying Watersheds Where Increased Housing Density Could Affect Future Timber Volume

Figure 4–6 displays watersheds according to the potential for changes in the amount of private timber growing stock volume, hereafter referred to as timber volume, as a result of future housing density increases.[3] Timber volume estimates are based on the most recent estimates by the Forest Service's FIA program, which conducts the U.S. national forest inventory (see Stein et al., 2009, for more details). This map was produced by combining the growing stock volume and projected housing density increase layers using the method described in Stein et al. (2009).

Habitats for At-Risk Species

Approximately 60% of "at-risk" (Box 4–4) vertebrate and invertebrate animals and plants in the conterminous United States are associated with private forests (Robles et al., 2008), 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 or the grizzly bear (Robles et al., 2008). Land use conversion due to development has contributed to the decline of approximately 35% of all imperiled species nationwide (Wilcove et al., 2000).

Impacts of Housing Development on At-Risk Species and Other Wildlife

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).

Box 4–4. 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 five 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. (Stein et al., 2009)

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. A study of spring Chinook salmon, for example, concluded that continued habitat degradation could result in extinction within a century if historical trends continue (Ratner et al., 1997). The presence of roads alone can have impacts even tens to hundreds of meters away, including interruption of wildlife movement and modification of habitat, microclimate, and the chemical environment (Riitters and Wickham, 2003) (Box 4–5).

Wide-ranging impacts of housing development on aquatic organisms found in streams and rivers relate to impacts on water quality and quantity, as summarized earlier. Urbanization is also predicted to compound the effects of climate change on aquatic species, as outlined by Nelson et al. (2009): "The interaction of climate change and urban growth may entail significant reconfiguring of headwater streams, including loss of ecosystem structure and services, which will be more costly than climate change alone."

Identifying Watersheds Where Increased Housing Density Could Affect At-Risk Species Habitats

Figure 4–7 depicts watersheds according to the number of at-risk species associated with private forests and the percentage of private forest projected to be developed. Data on at-risk species were provided by NatureServe and its member Natural Heritage Programs and Conservation Data Centers in mid 2007. 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 watershed 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, CA and contains 35 at-risk species associated with private forests. 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.

Additional Pressures[4]

Many ecological and socioeconomic forces—including wildfires, native and exotic (nonnative) insects and other pests, extreme weather events, and timber harvest—help keep forests

[4] The majority of the text in this section has been excerpted from Stein et al. 2009.

Box 4–5. Wildlife Species Changes along an Urban–Rural Gradient

The level and nature of impact of housing development on wildlife species can vary with distance from urban areas. An increasing number of studies investigate changes in wildlife communities along an urban-to-rural gradient. Highlights of findings from two reviews (McKinney 2008; Chace and Walsh 2006) and a 2011 investigation (Suarez-Rubio et. al., 2011) include:

- While bird density (the number of birds per unit area) tends to be higher in urban areas than in rural areas of similar ecology, species richness (the number and variety of bird species) is usually lower, often dominated by a few introduced species that thrive in urban environments. Larger forested patches tend to have higher numbers of migratory bird species (Chace and Walsh 2006). Bird communities in upland forests, on the other hand, tend to see declines in both bird density and species richness with increased development nearby (Marzluff 2001).
- Even low densities of housing development have been detrimental for natural bird communities, and exurban development has been known to significantly reduce the abundance of forest-specialist species (Suarez-Rubio et al., 2011).
- Extreme urbanization almost always results in a reduction of species richness of non-avian vertebrates and invertebrates (McKinney 2008).
- Plant species richness tends to be higher under moderate levels of urbanization than in more urbanized or more rural areas, possibly because of (i) the availability of a wider range of habitat types, allowing a wide range of native species, including early successional species to thrive, and (ii) the importation and spread of nonnative plants that also thrive in urbanizing environments (McKinney 2008).

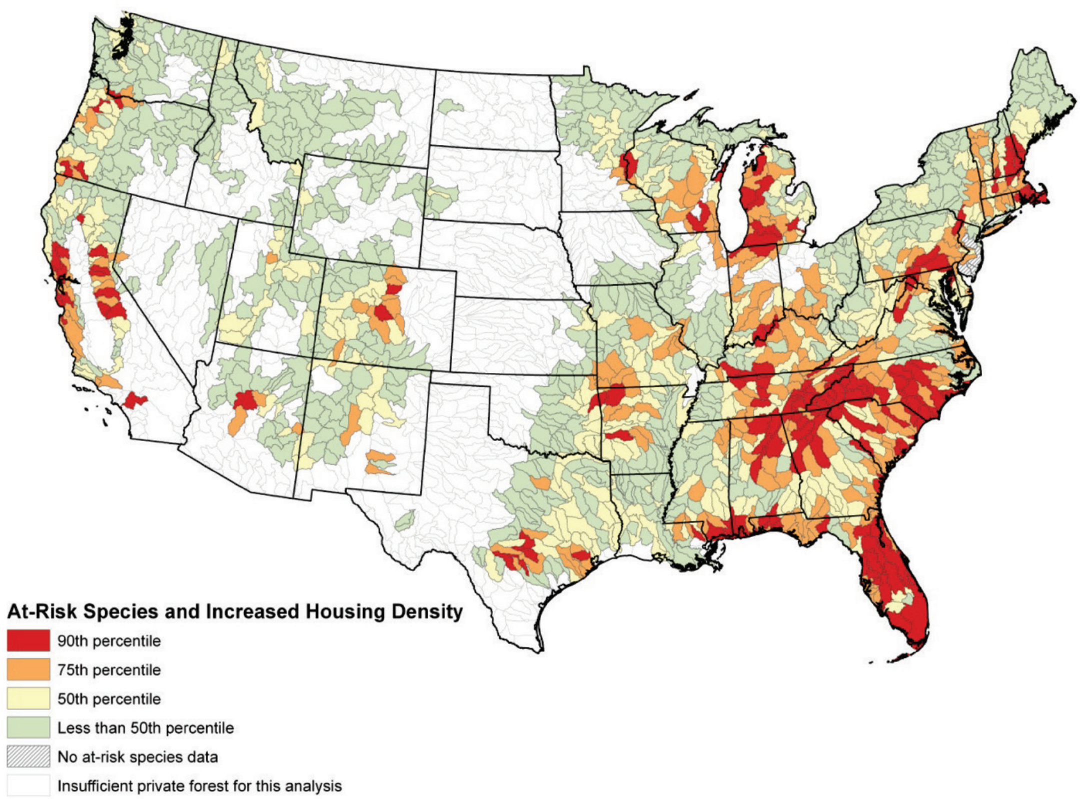

Fig. 4–7. At-risk species and increased housing density. Watersheds with the highest at-risk species counts and potential for increased housing density are in the East and in California. Source: Stein et. al. (2009).

dynamic and constantly changing. The frequency, severity, and magnitude of these forces and their impacts on forest conditions can be heavily influenced by housing development and associated infrastructure. 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 contribute to the spread of forest insect pests (Poland and McCullough, 2006).

Many of these additional pressures are expected to increase with climate change in at least some areas of the United States, further complicating the impacts of housing development. One study of forest biodiversity in the Pacific Northwest notes that range expansion and population outbreaks of mountain pine beetle [*Dendroctonus ponderosae* (Hopkins)], a native bark beetle, resulting from recent warming has led to widespread mortality in high-elevation pines, in turn leading to increase fire risk in the affected areas (Aubry et al., 2011). While such high-elevation locations are far from the threat of increased housing density, the study illustrates the already complicated relationship between insects and disease, fire, and climate change that can be exacerbated by the additional factor of housing development.

This section displays and describes maps that indicate where U.S. private forests may be affected by future increases in housing density as well as by the pressures of wildfire and by insect pests and diseases, primarily excerpted or adapted from Stein et al. (2009).

Insect Pests and Diseases

Forest insects and diseases play vital 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* (Annand)] and the emerald ash borer [*Agrilus planipennis* (Fairmaire)]—are well documented (Frelich, 2003; Liebhold et al., 1995; Tkacz et al., 2007). Another exotic pest, the gypsy moth [*Lymantria dispar* (L.)], has spread to 17 states and the District of Columbia (Tkacz et al., 2007). In addition to exotics, U.S. forests have also been affected by native pests. For example, outbreaks of mountain pine beetle, native to North America, have been increasing throughout the western United States since 2003.

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 Forest Service, 2005). In 2006 alone, mortality of more than 2 million hectares (5 million acres) of trees in the United States was caused by insects and diseases (USDA Forest Service, 2007).

Interaction Between Increased Housing and Insect Pests and Diseases

Urbanized areas are more likely than rural areas to be points of entry for many exotic insect pests and diseases.[5] 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 popular for neighborhood 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* (Motschulsky)]. 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). Developed areas also contain greater numbers of ornamental 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).

[5] Although this section focuses on insect and disease pests, the condition of private forests can also be affected by invasive plants associated with development and roads, which often serve as primary entry points for invasive plants (Meekins and McCarthy, 2001; Parendes and Jones, 2000).

Identifying Watersheds Where Increased Housing Density Could Compound the Effects of Insect Pests and Diseases

Figure 4–8 indicates where the greatest percentages of private forests might be most affected by both insects/diseases and development in the United States. Estimates of the impacts of insect pests and diseases are based on the average percentages of basal area expected to be lost to insects and diseases, compiled by the Forest Service's Forest Health Monitoring Program (Krist et al., 2007).[6]

Wildfire

Wildfire is an important component of many forest ecosystems and provides a myriad of vital beneficial effects. However, in some circumstances, wildfire can 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, Stein et al., 2009). As more and more people choose to live in and around the rural–urban interface, fire-related management challenges are also increasing (Hammer et al., 2009; National Association of State Foresters, 2009). The number and size of large wildfires (exceeding 20,000 ha) has increased over the past 30 yr, especially in the past decade (National Association of State Foresters, 2009). Many of these wildfires are more frequent and more intense than they were in the past (Schmidt et al., 2002) and are occurring in or near areas where people live and work, making large fires more difficult to control. The economic costs to reduce fire risk, fight fires, and protect homes and human lives have also risen sharply in recent decades (Hesseln and Berry, 2008; National Association of State Foresters, 2009).

[8] Basal area is the cross-section area of a tree stem in square feet, commonly measured at breast height (1.37 m (4.5 ft) 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.

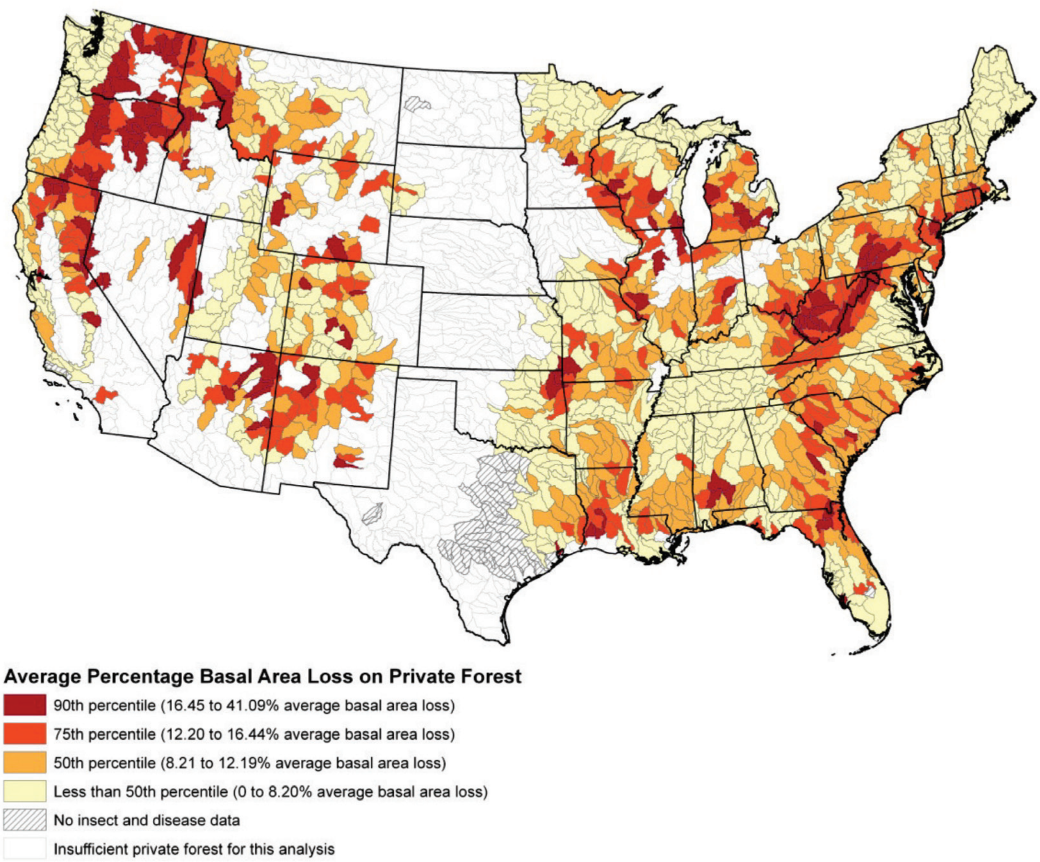

Fig. 4–8. Average percentage basal area loss and increased housing density. Watersheds where projected housing density increases on private forest lands overlap with susceptibility to insects and diseases are scattered from Idaho and California to Florida and New England. Source: Stein et. al. (2009).

Interaction Between Increased Housing and Wildfire

While the risk of wildfire can occur almost anywhere where wildland vegetation is found, the risk to people and their homes is especially acute in the wildland–urban interface, where homes and other structures abut or are intermingled with wildland vegetation (Grulke et al., 2010; Hammer et al., 2007; Stein et al., 2007; Syphard et al., 2007; U.S. Government Accountability Office, 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), especially in areas where fire risk is already high.

The number of people and structures located in the wildland–urban interface has increased by 11% (20,458 square miles) in west coast states in the 1990s (Hammer et al,. 2007), and increased by more than 50% nationwide from 1970 to 2000, to a total of 179,727 square miles (Theobald and Romme, 2007). Nearly 90% (~5,300,000 ha, ~20,000 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 2 million hectares of land are at high risk of wildfire (Andreu and Hermansen-Baez, 2008).

Identifying Areas Where High Wildfire Potential Overlaps with Future Increases in Housing Density

Figure 4–9 displays watersheds where projected housing density increases and susceptibility to wildfire may overlap. Data on wildfire are derived from the Wildland Fire Potential Model produced by the Forest Service's Fire Modeling Institute (http://www.firelab.org/fmi, accessed 13 Mar. 2012). Watersheds where combined 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, South Carolina, as well as parts of eastern Texas.

Summary and Conclusions

In rural forests across the United States, housing density is increasing today and is expected to continue escalating into the future, given that our population will have increased by 80 million people during 2000–2030. Population growth and the trends of larger parcel sizes per house, increased migration to rural areas, and the movement of people to West and Southeast are predicted to lead to wildfire danger in the wildland–urban interface (Hammer et al., 2009). The resulting changes to the structure and function of America's forests will vary and will likely include declines in many of the services that forests provide—to people as well as to wildlife.

As noted in Stein et al. (2009), watersheds with the greatest percentages of forest land under private ownership are concentrated in the East (whereas most forested land in the West is under public management). Watersheds where private forests make the greatest contributions to the goods and services analyzed also are concentrated in the East, especially with respect to water quality (a tremendous number of watersheds that rank in the 75th and 90th percentiles for relative contributions to the production of clean water are located in the East). However, substantial contributions of other public benefits, such as timber volume and habitat for at-risk species, also are found in watersheds located in Western private forests.

What happens when additional pressure layers (e.g., insect pests, diseases, and wildfire) are combined with the housing density layer? In each case, more watersheds in the 90th percentile again are found in the East. However, watersheds with high percentages of private forests under pressure from insect pests and diseases are distributed across both the West and East; further, 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 (also true of a swath of watersheds across the Southeast).

Nevertheless, in every region of the United States, forests are experiencing increases in housing density, and these increases are associated with numerous economic and ecological changes, compounded by (and compounding) the effects of additional pressures under further influence from climate change.

The good news is that, across the country, at many geographic levels, new approaches are being crafted to plan for and provide sustainable housing for America's growing population in a way that minimizes negative impacts on our rural areas. These include a renewed emphasis on "urban infill" (consciously directing new

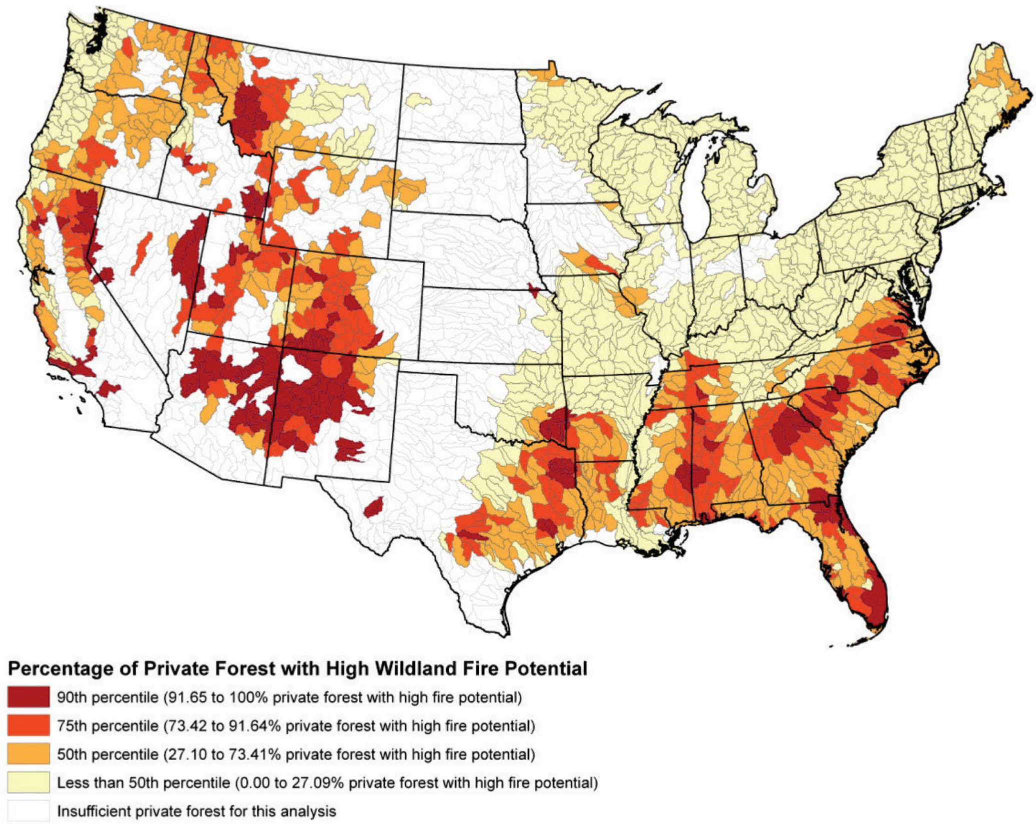

Fig. 4–9. Wildland fire potential and increased housing density. Many watersheds with highest fire susceptibility and projected housing density increases are in the South. Source: Stein et. al. (2009).

development into areas that are already urbanized), the revamping of urban areas to create more livable communities, the creation of Green-Infrastructure plans by the Conservation Fund and others in partnership with local communities to ensure the connection of natural areas across broad landscapes, the creation of a plethora of networks such as the Smart Growth Network and the Partnership for Sustainable Communities to facilitate the exchange of materials and ideas on sustainable development, the creation of conservation planning tools by planners and conservation biologists, and support by private organizations and governments at all levels for the creation of conservation easements to conserve natural areas.

Each of these approaches has been driven by creative and dedicated individuals and/or organizations that have reached out to others across a wide spectrum of disciplines and approaches. Future efforts to conserve America's forest lands will require a continued emphasis on partnerships, and new approaches, as well as training and education for forest managers, planners, and communities. Specific needs include better understanding and addressing the needs of rural communities wishing to take a conservation-oriented approach to planning, more detailed analyses of impacts of various housing densities and development configurations on forests, and a better understanding of the economic implications of forest fragmentation and loss.

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