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.

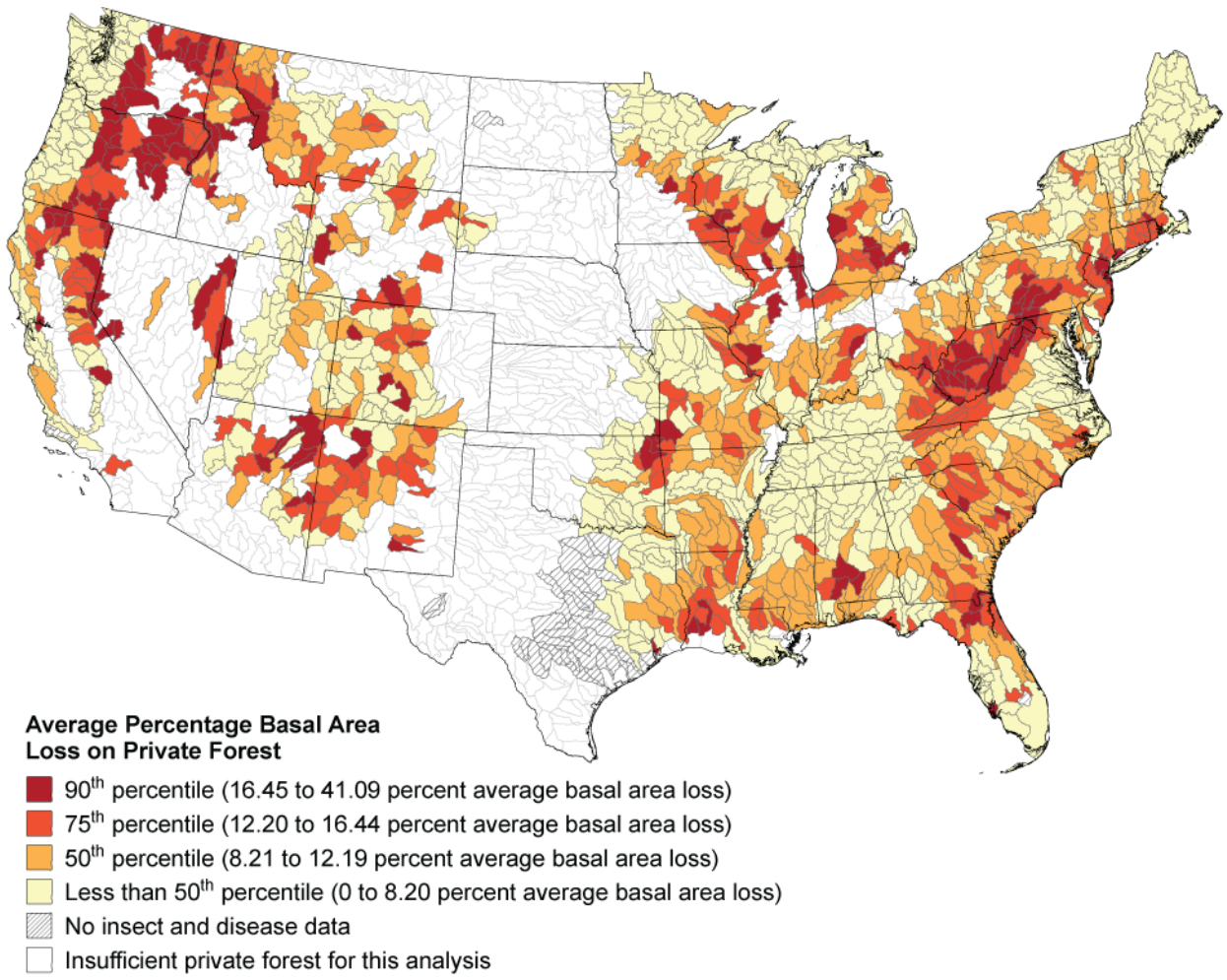

Figure 14—Watersheds by susceptibility and vulnerability of private forests to insect pests and diseases.

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.

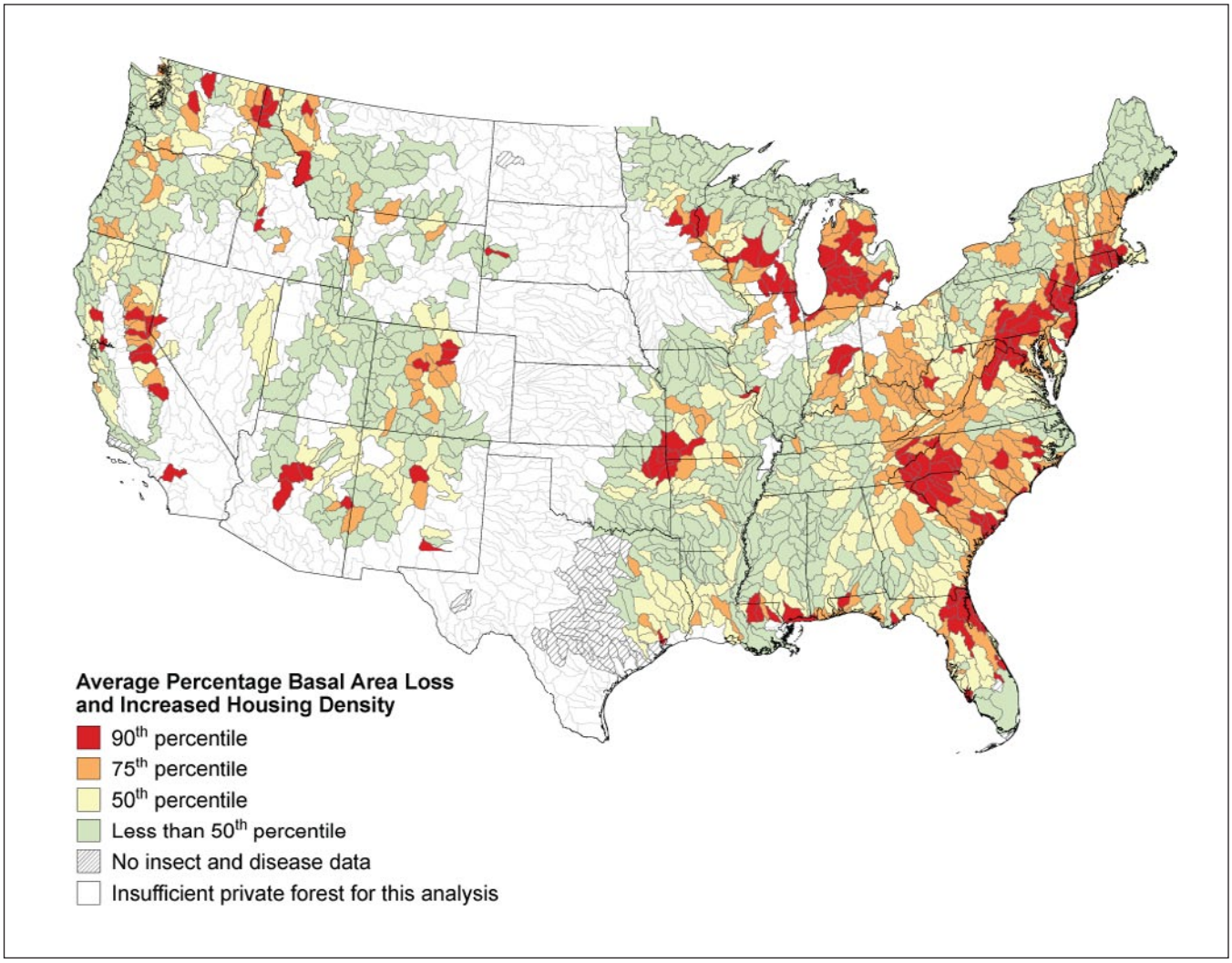

Figure 15—Watersheds by overlap of projected housing density increases on private forest lands and susceptibility to insect pests and diseases.

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

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

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).

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.

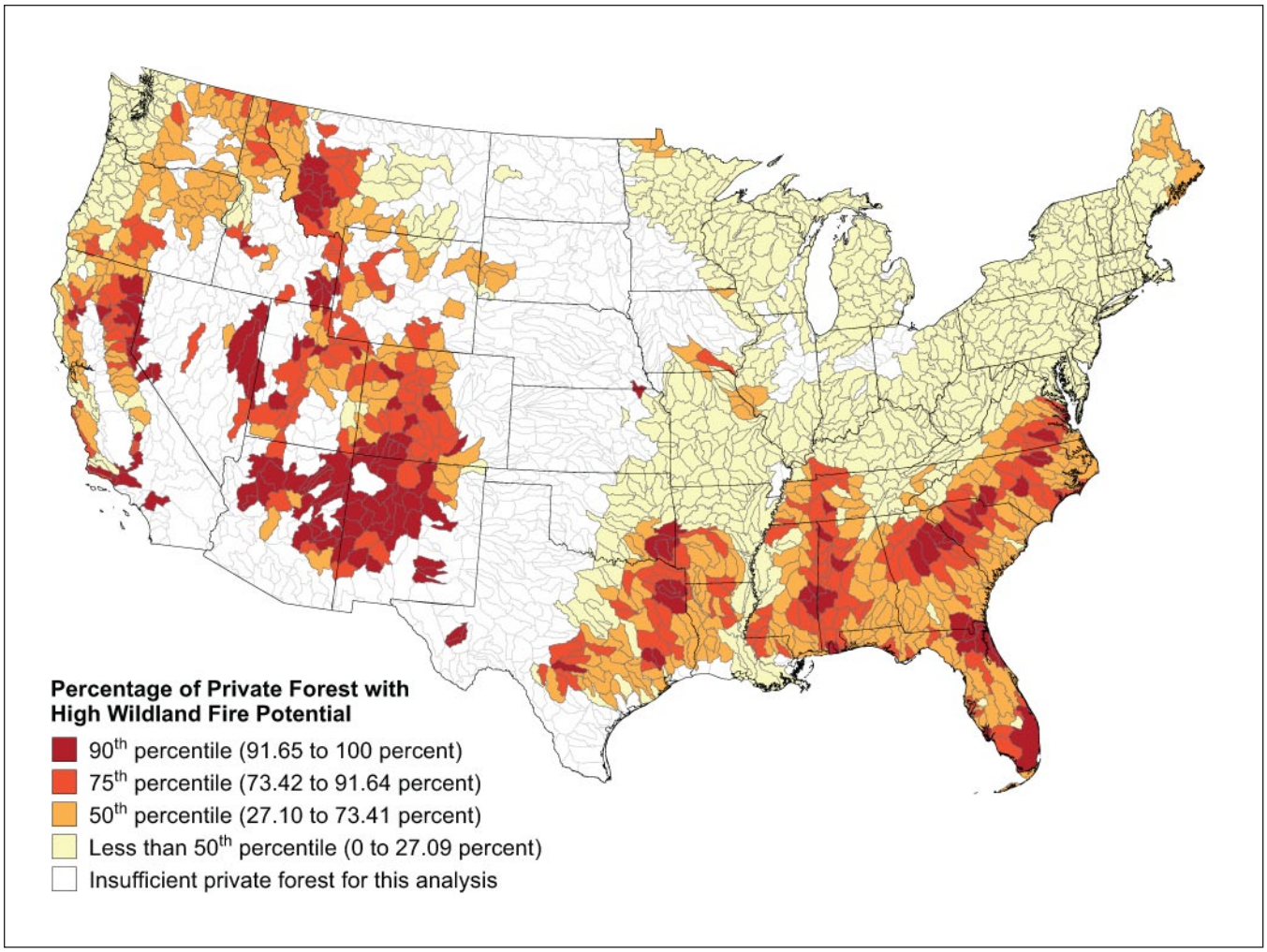

Figure 16—Watersheds by susceptibility and vulnerability of private forests to wildfire.

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.

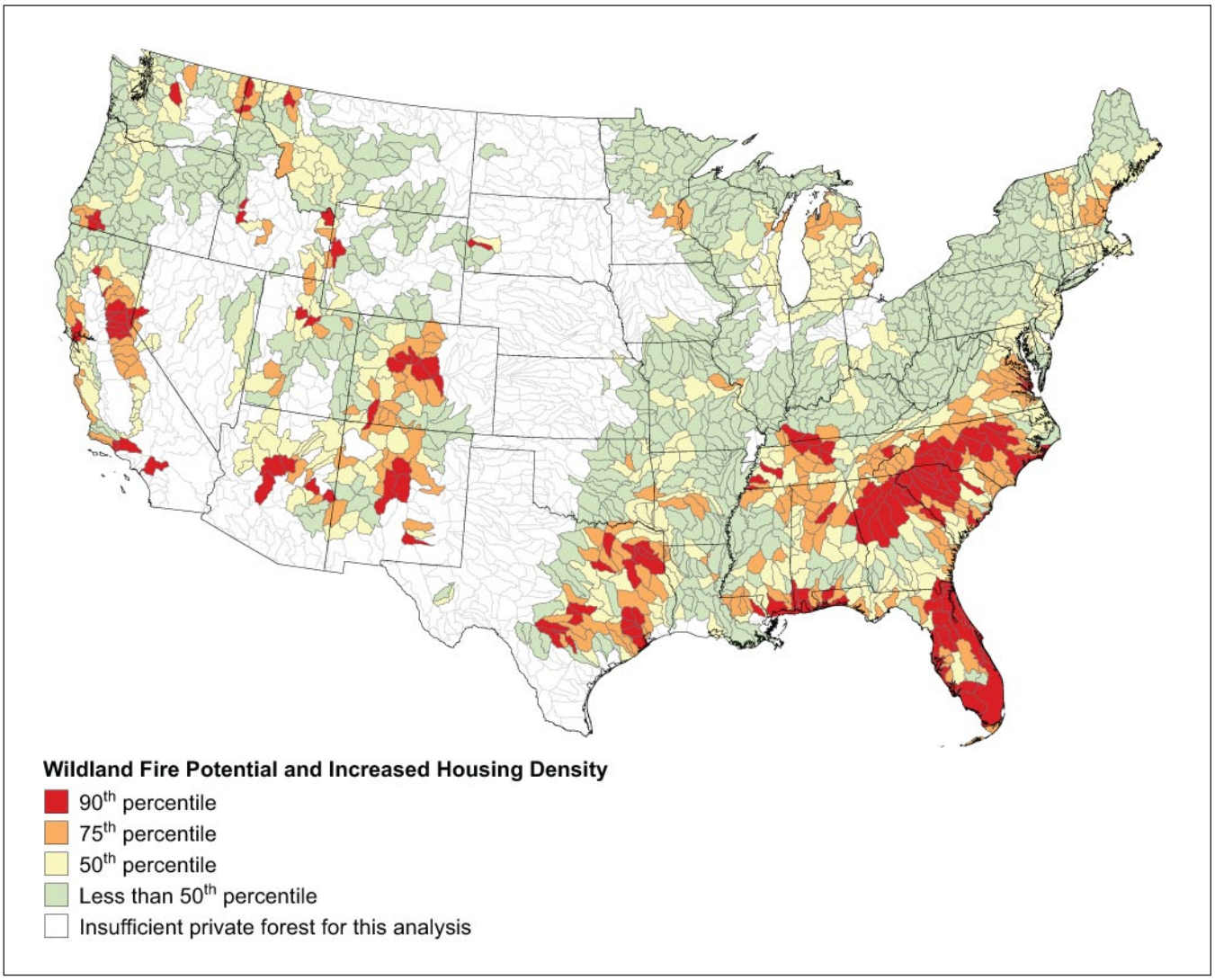

Figure 17—Watersheds by projected overlap of increased housing density on private forest lands and susceptibility to wildfire.

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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 landowner **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.

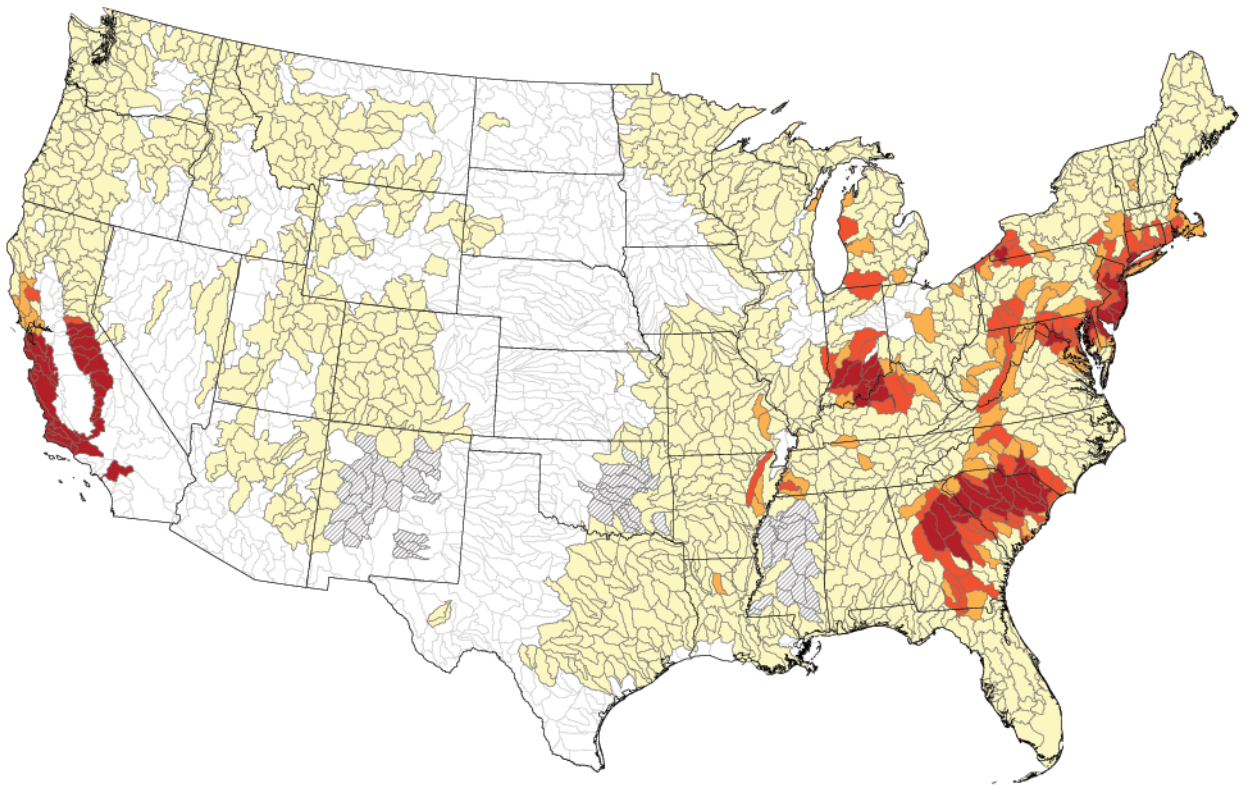

Figure 18—Watersheds by susceptibility and vulnerability of private forests to ozone pollution.

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.

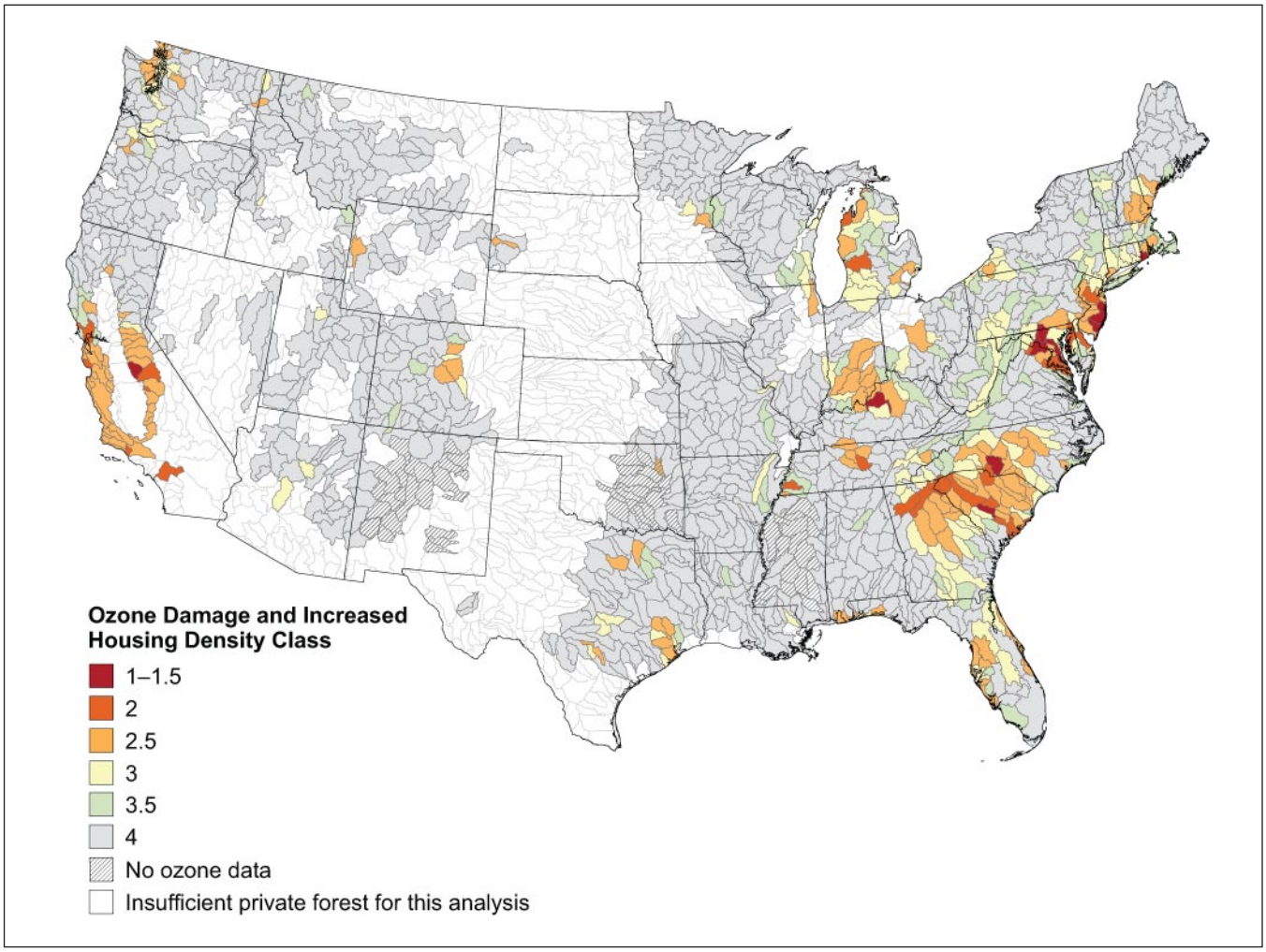

Figure 19—Watersheds by projected overlap of increased housing density on private forest lands and susceptibility to ozone pollution.

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 90th 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.

Acknowledgments

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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

References

Alig, R. 2007. A United States view on changes in land use and land values affecting sustainable forest management. Journal of Sustainable Forestry. 24(2/3): 209–227.

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

Andreu, A.; Hermansen-Baez, A. 2008. Fire in the South 2: the southern wildfire risk assessment. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 30 p. www.southernwildfirerisk.com/reports/FireInTheSouth2.pdf. (17 February 2009).

Brett, M.T.; Arhonditsis, G.B.; Mueller, S.E.; Hartley, D.M.; Frodge, J.D.; Funke, D.E. 2005. Non-point-source impacts on stream nutrient concentrations along a forest to urban gradient. Environmental Management. 35(3): 330–342.

Brown, T.C.; Hobbins, M.T.; Ramirez, J.A. 2005. The source of water supply in the United States. RMRS-RWU-4851 Discussion Paper. 57 p. Unpublished report. On file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO 80526.

Butler, B. 2008. Private forest owners of the United States, 2006. Gen. Tech. Rep. NRS-27. Newtown, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 37 p.

Chappelka, A.H.; Sameulson, L.J. 1998. Ambient ozone effects on forest trees of the Eastern United States: a review. New Phytologist. 139: 91–108.

Clutter, M.; Mendell, B.; Newman, D.; Wear, D.; Greis, J. 2005. Strategic factors driving timberland ownership changes in the U.S. South. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 15 p.

Coleman, J.S.; Temple, S.A. 1993. Rural residents' free-ranging domestic cats: a survey. Wildlife Society Bulletin. 21(4): 381–390.

Conservation Biology Institute [CBI]. 2007. Protected areas database v4.6. [Unpublished data set]. http://www.consbio.org/what-we-do/protected-areas-database-pad-version-4. (15 September 2009).

Coulston, J.W.; Smith, G.C.; Smith, W.D. 2003. Regional assessment of ozone sensitive tree species using bioindicator plants. Environmental Monitoring and Assessment. 83: 113–127.

Crosbie, B.; Chow-Fraser, P. 1999. Percentage land use in the watershed determines the water and sediment quality of 22 marshes in the Great Lakes basin. Canadian Journal of Fisheries and Aquatic Sciences. 56(10): 1781–1791.

Daniels, T. 1999. When city and country collide: managing growth in the metropolitan fringe. Washington, DC: Island Press. 361 p.

Debinski, D.M.; Holt, R.D. 2000. A survey and overview of habitat fragmentation experiments. Conservation Biology. 14: 342–355.

DellaSala, D.A.; Staus, N.L.; Strittholt, J.R.; Hackman, A.; Iacobelli, A. 2001. An updated protected areas database for the United States and Canada. Natural Areas Journal. 21: 124–135.

Donavan, G.H.; Brown, T.C. 2007. Be careful what you wish for: the legacy of Smokey Bear. Frontiers in Ecology. 5(2): 73–79.

Donovan, T.M.; Flather, C.H. 2002. Relationships among North American songbird trends, habitat fragmentation, and landscape occupancy. Ecological Applications. 12: 364–374.

Driscoll, C.T.; Lawrence, G.B.; Bulger, A.J.; Butler, T.J.; Cronan, C.S.; Eager, C.; Lambert, K.F.; Likens, G.E.; Stoddard, J.L.; Weathers, K.C. 2001. Acidic deposition in the Northeastern United States: sources and inputs, ecosystem effects, and management strategies. BioScience. 51: 180–198.

Driscoll, C.T.; Whitall, D.; Aber, J.; Boyer, E.; Castro, M.; Cronan, C.; Goodale, C.L.; Groffman, P.; Hopkinson, C.; Lambert, K.; Lawerence, G.; Ollinger, S. 2003. Nitrogen pollution in the Northeastern United States: sources, effects, and management options. BioScience. 53(4): 357–374.

Eastman, J.R.; Emani, S.; Hulina, S.; Johnson, A.; Jiang, H.; Ramachandran, M. 1997. Applications of geographic information systems (GIS) technology in environmental risk assessment and management. In: United Nations Environment Programme (UNEP), ed. The Idrisi project—Clark labs for cartographic technology. Worcester, MA: Clark Labs/Clark University, in cooperation with UNEP: 1–10.

Egan, A.; Taggart, D.; Annis, I. 2007. Effects of population pressures on wood procurement and logging opportunities in northern New England. Northern Journal of Applied Forestry. 24(2): 85–90.

Engels, T.; Sexton, C. 1994. Negative correlation of blue jays and golden-cheeked warblers near an urbanizing area. Conservation Biology. 8: 286–290.

Fenn, M.E.; Haeuber, R.; Tonnesen, G.S.; Baron, J.S.; Grossman-Clarke, S.; Hope, D.; Jaffe, D.A.; Copeland, S.; Geiser, L.; Rueth, H.M.; Sickman, J.O. 2003. Nitrogen emissions, deposition, and monitoring in the Western United States. BioScience. 53: 1–13.

Findlay, C.S.; Houlahan, J.E. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. Conservation Biology. 11: 1000–1009.

FitzHugh, T. 2001. Watershed characteristics and aquatic ecological integrity: a literature review. The Nature Conservancy Freshwater Initiative. http://conserveonline.org/docs/2001/06/watershed.pdf. (10 January 2006).

Forest Inventory and Analysis [FIA]. 2007. Forest Inventory and Analysis national program: we are the Nation's forest census. U.S. Department of Agriculture, Forest Service. http://fia.fs.fed.us/. (24 April 2007).

Frelich, L.E. 2003. Global warming and forest impacts in MN—a background paper to guide discussion. 1 p. Unpublished report. On file at: University of Minnesota, St. Paul, MN 55108.

Graham, K.L. 2007. Human influences on forest wildlife habitat. In: Southern forest resource assessment. Chapter 3 (terra-3), final online report. Asheville, NC: U.S. Department of Agriculture, Southern Region and Southern Research Station; U.S. Environmental Protection Agency; U.S. Fish and Wildlife Service; Tennessee Valley Authority; and state forestry agencies of the Southern United States: 63–90. http://www.srs.fs.usda.gov/sustain/report/terra3/terra3.htm. (17 February 2009).

Grulke, N.E.; Andersen, C.P.; Fenn, M.E.; Miller, P.R. 1998. Ozone exposure and nitrogen deposition lowers root biomass of ponderosa pine in the San Bernardino Mountains, California. Environmental Pollution. 103(1): 63–73.

Grulke, N.E.; Paine, T.; Riggan, P. [In press]. Air pollution increases forest susceptibility to wildfires: a case study for the San Bernadino Mountains in southern California. In: Pye, J.M.; Rauscher, H.M.; Sands, Y.; Lee, D.C.; Beatty, J.S., eds. Advances in threat assessment and their application to forest and rangeland management. Gen. Tech. Rep. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Hammer, R.B.; Radeloff, V.C.; Fried, J.S.; Stewart, S.I. 2007. Wildland-urban interface housing growth during the 1990s in California, Oregon, and Washington. International Journal of Wildland Fire. 16: 255–265.

Hartley, M.J.; Hunter, M.L. 1998. A meta-analysis of forest cover, edge effects, and artificial nest predation rates. Conservation Biology. 12: 465–469.

Haynes, R.; Adams, D.; Alig, R.; Brooks, D.; Durbak, I.; Howard, J.; Ince, P.; McKeever, D.; Mills, J.; Skog, K.; Zhou, X. 2001. Projections of the U.S. timber supply and demand situation to 2050—draft findings from the USDA Forest Service 2000 RPA timber assessment. In: Proceedings, Society of American Foresters 2000 national convention. http://www.fpl.fs.fed.us/documnts/pdf2000/hayne00a.pdf. (17 July 2007).

Homer, C.; Dewitz, J.; Fry, J.; Coan, M.; Hossain, N.; Larson, C.; Herold, N.; McKerrow, A.; VanDriel, J.N.; Wickham, J. 2007. Completion of the 2001 national land cover database for the conterminous United States. Photogrammetric Engineering & Remote Sensing. 73(4): 337–341.

Homer, C.; Huang, C.; Yang, L.; Wylie, B.; Coan, M. 2004. Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing. 70(7): 829–840.

Houlahan, J.E.; Findlay, C.S. 2003. The effects of adjacent land use on wetland amphibian species richness and community composition. Canadian Journal of Fisheries and Aquatic Sciences. 60: 1078–1094.

Houlahan, J.E.; Findlay, C.S. 2004. Estimating the "critical" distance at which adjacent land-use degrades wetland water and sediment quality. Landscape Ecology. 19: 677–690.

Houlahan, J.E.; Keddy, P.A.; Makkay, K.; Findlay, C.S. 2006. The effects of adjacent land use on wetland species richness and community composition. Wetlands: the Journal of the Society of the Wetland Scientists. 26(1): 79–96.

Hurteau, M.D.; Hungate, B.A.; Koch, G.W. 2009. Accounting for risk in valuing forest carbon offsets. Carbon Balance and Management. 4: 1. http://www.cbmjournal.com/content/4/1/1. (4 February 2009).

Im, S.; Brannan, K.M.; Mostaghimi, S. 2003. Simulating hydrologic and water quality impacts in an urbanizing watershed. Journal of the American Water Resources Association. 39(6): 1465–1479.

Jacobson, S. 2006. The increasing threat of highway-caused wildlife mortality and barrier impacts on U.S. public lands. [Poster/abstract.] Presented at Advances in threat assessment and their application to forest and rangeland management, Boulder, CO, July 2006. http://www.forestryencyclopedia.net/p/p26/p52. (29 April 2008).

Johnson, M.; Stone, B. 2008. Minnesota forests for the future: strategic report of the DNR commissioner's advisory team on the Minnesota Forests for the Future program. St. Paul, MN: Minnesota Department of Natural Resources. 53 p. www.mndnr.gov/forestlegacy. (25 February 2009).

Jones, K.B.; Neale, A.C.; Nash, M.S.; Riitters, K.H.; Wickham, J.D.; O'Neill, R.V.; van Remortel, R.D. 2000. Landscape correlates of breeding bird richness across the United States Mid-Atlantic region. Environmental Monitoring and Assessment. 63(1): 159–174.

Kalabokidis, K.D. 2000. Effects of wildfire suppression chemicals on people and the environment: a review. Global Nest. 2(2): 129–137.

Karnosky, D.F.; Pregitzer, K.S.; Zak, D.R.; Kubiske, M.E.; Hendrey, G.R.; Weinstein, D.; Nosal, M.; Percy, K.E. 2005. Scaling ozone responses of forest trees to the ecosystem level in a changing climate. Plant, Cell and Environment. 28: 965–981.

Kerr, J.T.; Deguise, I. 2004. Habitat loss and the limits to endangered species recovery. Ecology Letters. 7: 1163–1169.

Keyser, A.J. 2002. Nest predation in fragmented forests: landscape matrix by distance from edge interactions. Wilson Bulletin. 114(2): 186–191.

Kline, J.D.; Alig, R.J. 2005. Forestland development and private forestry with examples from Oregon (USA). Forest Policy and Economics. 7: 709–720.

Kline, J.D.; Azuma, D.L.; Alig, R.J. 2004. Population growth, urban expansion, and private forestry in western Oregon. Forest Science. 50(1): 33–43.

Kocher, S.; Harris, R.; Nakamura, G. 2001. Recovering from wildfire: a guide for California's forest landowners. Agricultural and Natural Resources Publication 21603. Oakland: University of California. 16 p.

Krist, F.J.; Sapio, F.; Tkacz, B. 2007. Mapping risk from forest insects and diseases. FHTET-2007 06. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team. 115 p.

Kurki, S.; Nikula, A.; Helle, P.; Linde, H. 2000. Landscape fragmentation and forest composition effects on grouse breeding success in boreal forests. Ecology. 81(7): 1985–1997.

Lampila, P.; Monkkonen, M.; Desrochers, A. **2005.** Demographic responses by birds to forest fragmentation. Conservation Biology. 19(5): 1537–1546.

LeVan, S. 1995. Life cycle assessment: measuring environmental impact. Proceedings, 49th annual meeting of the Forest Products Society. Madison, WI: Forest Products Society: 7–11. http://www.fpl.fs.fed.us/documnts/pdf1998/levan98b.pdf. (17 February 2009).

LeVert, M.; Colgan, C.; Lawton, C. 2008. Are the economics of a sustainable Maine forest sustainable? Maine Policy Review. 16(2): 26–36.

Liebhold, A.M.; MacDonal, W.L.; Bergdahl, D.; Mastro, V.C. 1995. Invasion by exotic pests: a threat to forest ecosystems. Forest Science Monographs 30. Bethesda, MD: Society of American Foresters. 49 p.

Mahan, C.G.; Yahner R.H. 1999. Effects of forest fragmentation on behaviour patterns in the eastern chipmunk (*Tamias striatus*). Canadian Journal of Zoology. 77: 1991–1997.

Matteo, M.; Randhir, T.; Bloniarz, D. 2006. Watershed-scale impacts of forest buffers on water quality and runoff in urbanizing environment. Journal of Water Resources Planning and Management. 132 (3): 144–152.

McWilliam, W.J.; Brown, R.D. 2001. Effects of housing development on bird species diversity in a forest fragment in Ontario, Canada. Landscape Research. 26(4): 407–419.

Meekins, J.F.; McCarthy, B.C. 2001. Effect of environmental variation on the invasive success of a nonindigenous forest herb. Ecological Applications. 11(5): 1336–1348.

Mendell, B.; Clutter, M.; Newman, D.; Wear, D.; Greis, J. 2005. Under new management: a case study of southern timberland ownership changes. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 13 p.

Munn, I.A.; Barlow, S.A.; Evans, D.L.; Cleaves, D. 2002. Urbanization's impact on timber harvesting in the South-Central United States. Journal of Environmental Management. 64: 65–66.

Nair, K.S.S.; Sumardi. 2000. Insect pests and diseases of major plantation species. In: Insect pests and diseases in Indonesian forests: an assessment of the major threats, research efforts and literature. Bogor, Indonesia: Center for International Forestry Research: 15–38. http://www.cifor.cgiar.org/publications/pdf_files/Insect-pests.pdf. (17 February 2009).

National Acid Precipitation Assessment Program. 1990. Acidic deposition: episodic acidification of surface waters due to acidic deposition. State of Science and Technology Report 12. Washington, DC. 100 p.

Parendes, L.A.; Jones, J.A. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the H.J. Andrews Experimental Forest, Oregon. Conservation Biology. 14: 64–75.

Phelps, M.G.; Hoppe, M.C. 2002. New York–New Jersey Highlands regional study: 2002 update. NA-TP-02-03. Newtown, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 209 p.

Poland, T.M.; McCullough, D.G. 2006. Emerald ash borer: invasion of the urban forest and the threat to North America's ash resource. Journal of Forestry. 104(3): 118–124.

Prestemon, J.P.; Wear, D.N.; Stewart, F.J.; Holmes, T.P. 2005. Wildfire, timber salvage, and the economics of expediency. Forest Policy and Economics. 8(3): 312–322.

Pye, J.M. 1988. Impact of ozone on the growth and yield of trees: a review. Journal of Environmental Quality. 17: 347–360.

Ratner, S.; Lande, R.; Roper, B.B. 1997. Population viability analysis of spring Chinook salmon in the South Umpqua River, Oregon. Conservation Biology. 11(4): 879–889.

Rieman, B.; Luce, C.; McIver, J.D.; Kershner, J.; Webster, M.; Robichaud, P.; Cook, R.; Swanson, R., contributors. 2005. Earth…water…fire: the role and management of fire in aquatic ecosystems. FS-828. Wildland Waters. Washington, DC: U.S. Department of Agriculture, Forest Service. 24 p. http://www.fs.fed.us/wildlandwaters/newsletters/wildlandwaters_summer05.pdf. (18 March 2009).

Riitters, K.H.; Wickham, J.D. 2003. How far to the nearest road? Frontiers in Ecology and Environment. 1(3): 125–132.

Riitters, K.H.; Wickham, J.D.; Coulston, J.W. 2004. A preliminary assessment of Montréal Process indicators of forest fragmentation for the United States. Environmental Monitoring and Assessment. 91(1–3): 257–276.

Riitters, K.H.; Wickham, J.D.; O'Neill, R.V.; Jones, K.B.; Smith, E.R.; Coulston, J.W.; Wade, T.G.; Smith, J.H. 2002. Fragmentation of continental United States forests. Ecosystems. 5(8): 815–822.

Robles, M.D.; Flather, C.H.; Stein, S.M.; Nelson, M.D.; Cutko, A. 2008. The geography of private forests that support at-risk species in the conterminous United States. Frontiers in Ecology and the Environment. 6(6): 301–307. http://www.esajournals.org/doi/pdf/10.1890/070106. (17 February 2009).

Sampson, N.; DeCoster, L. 2000. Forest fragmentation; implications for sustainable private forests. Journal of Forestry. 98(3): 4–8.

Scott, D. 2003. Climate change and tourism in the mountain regions of North America. Presentation to first international conference on climate change and tourism, Djerba, Tunisia, 9–11 April 2003. 9 p. http://www.linkbc.ca/torc/downs1/danielscott.pdf?PHPSESSID=e936ec3c4637a5da5a8523f12ed665ae. (17 February 2009).

Sieving, K.E.; Willson, M.F. 1999. A temporal shift in Steller's jay predation on bird eggs. Canadian Journal of Zoology. 77: 1829–1834.

Smail, R.A.; Lewis, D.J. 2009. Forest land conversion, ecosystem services, and economic issues for policy: a review. Gen. Tech. Rep. PNW-GTR-797. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 40 p.

Smith, G.C.; Coulston, J.W.; Jepsen, E.; Prichard, T. 2003. A national ozone biomonitoring program—results from field surveys of ozone sensitive plants in Northeastern forests (1994–2000). Environmental Monitoring and Assessment. 87: 271–291.

Smith, W.B.; Miles, P.D.; Vissage, J.S.; Pugh, S.A. 2004. Forest resources of the United States, 2002. Gen. Tech. Rep. NC-241. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 137 p. http://www.ncrs.fs.fed.us/pubs/gtr/gtr_nc241.pdf. (17 February 2009).

Spyratos, V.; Bourgeron, P.S.; Ghil, M. 2007. Development at the wildland-urban interface and the mitigation of forest-fire risk. Proceedings of the National Academy of Sciences. 104(36): 14272–14276.

Steeves, P.A.; Nebert, D.D. 1994. Hydrological unit maps of the conterminous United States [database]. U.S. Geological Survey [USGS], open-file dataset "huc250," ed. 1. Reston, VA: U.S. Geological Survey. http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml. (10 January 2006).

Stein, S.; Alig, R.J.; White, E.M.; Comas, S.J.; Carr, M.; Eley, M.; Elverum, K.; O'Donnell, M.; Theobald, D.M.; Cordell, K.; Haber, J.; Beauvais, T.W. 2007. National forests on the edge: development pressures on America's national forests and grasslands. Gen. Tech. Rep. PNW-GTR-728. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 26 p.

Stein, S.; Butler, B. 2004. On the frontline: private forests and water resources. FS-790. Wildland Waters. Washington, DC: U.S. Department of Agriculture, Forest Service. 24 p.

Stein, S.; McRoberts, R.E.; Alig, R.J.; Nelson, M.D.; Theobald, D.; Eley, M.; Dechter, M.; Carr, M. 2005. Forests on the edge: housing development on America's private forests. Gen. Tech. Rep. PNW-GTR-636. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 16 p.

Stein, S.M.; Hatfield, M.H.; McRoberts, R.E.; Meneguzzo, D.M.; Comas, S.J. [In press]. Threats to private forest lands in the USA. In: Pye, J.M.; Rauscher, H.M.; Sands, Y.; Lee, D.C.; Beatty, J.S., eds. Advances in threat assessment and their application to forest and rangeland management. Gen. Tech. Rep. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Stein, S.M.; McRoberts, R.E.; Nelson, M.D.; Theobald, D.; Eley, M.; Dechter, M. 2006. Forests on the edge: a GIS-based approach to projecting housing development on private forests. In: Aguirre-Bravo, C.; Pellicane, P.J.; Burns, D.P.; Draggan, S., eds. Monitoring science and technology symposium in the western hemisphere. RMRS-P-42CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 736–743. http://www.fs.fed.us/rm/pubs/rmrs_p042/rmrs_p042_736_743.pdf. (17 February 2009).

Stokstad, E. 2004. Nurseries may have shipped sudden oak death pathogen nationwide. Science. 303(26): 1959.

Stolte, K.; Darr, D. 2006. Major stressors, effects, and risks to forest ecosystems throughout the United States. [Abstract.] Presented at Advances in threat assessment and their application to forest and rangeland management, Boulder, CO, July 2006. http://www.forestryencyclopedia.net/p/p124. (29 April 2008).

Syphard, A.D.; Radeloff, V.C.; Keeley, J.E.; Hawbaker, T.J.; Clayton, M.K.; Stewart, S.I.; Hammer, R.B. 2007. Human influence on California fire regimes. Ecological Applications. 17(5): 1388–1402.

Taylor, P.D.; Merriam, G. 1995. Habitat fragmentation and parasitism of a forest damselfly. Landscape Ecology. 11: 181–189.

Theobald, D. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society. 10(1): 32. http://www.ecologyandsociety.org/vol10/iss1/. (13 September 2006).

Theobald, D. 2007. Unprotected private, protected private, public, tribal lands in the U.S. [Unpublished data set]. On file with: David M. Theobald, Colorado State University, Natural Resource Ecology Laboratory, Fort Collins, CO 80523-1499.

Theobald, D.; Romme, W.H. 2007. Expansion of the U.S. wildland-urban interface. Landscape Urban Planning. 83(4): 340–354.

Thorne, S.; Sundquist, D. 2001. New Hampshire's vanishing forests: conversion, fragmentation and parcelization of forests in the granite state. Report of the New Hampshire Forest Land Base Study. Concord, NH: Society for the Protection of New Hampshire Forests. 164 p.

Tkacz, B.; Moody, B.; Castillo, J.V. 2007. Forest health status in North America. Proceedings: Impacts of air pollution and climate change on forest ecosystems. The Scientific World Journal. 7(S1): 28–36.

Tooley, P.W.; Kyde, K.L.; Englander, L. 2004. Susceptibility of selected ericaceous ornamental host species. Plant Disease. 88(9): 993–999.

Unger, N. 2006. Interaction of ozone and sulfate in air pollution and climate change. Goddard Institute for Space Studies Science Brief. http://www.giss.nasa.gov/research/briefs/unger_01/. (18 July 2007).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2003. America's forests: 2003 health update. AIB-776. Washington, DC. 15 p. http://www.fs.fed.us/foresthealth/publications/foresthealthupdate2003.pdf. (5 February 2009).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2004. U.S. forest resource facts and historical trends. FS-801-M. Washington, DC. 37 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2005. Forest insect and disease conditions in the United States, 2004. Washington, DC: Forest Health Protection. http://www.fs.fed.us/foresthealth/current_conditions.shtml. (22 April 2008).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2007a. Forest insect and disease conditions in the United States, 2006. Washington, DC: Forest Health Protection. 176 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2007b. Interim update of the 2000 Renewable Resource Planning Act (RPA) assessment. FS-874. Washington, DC. 114 p. http://www.fs.fed.us/research/rpa/2005rpa/RPA_Interim_Update_April2007_low_resolution.pdf. (17 February 2009).

U.S. Department of Agriculture, Forest Service [USDA FS]. [N.d.]. Welcome to the Eastern Forest Threat Center! http://www.forestthreats.org/. (07 June 2007).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2007. Effects of exurban development on wildlife and plant communities. Tech. Note 75. Washington, DC: Agricultural Wildlife Conservation Center. 4 p.

U.S. Department of Commerce, Census Bureau [U.S. Census Bureau]. 2001. Census 2000 Summary file 1. Washington, DC.

U.S. Environmental Protection Agency [US EPA]. 1997. EPA's revised ozone standard. Research Triangle Park, NC: Office of Air Quality Planning and Standards. 4 p. http://www.epa.gov/ttn/oarpg/naaqsfin/o3fact.html. (17 February 2009).

U.S. Environmental Protection Agency [US EPA]. 2009a. Acid rain and related programs: 2007 progress report. EPA-430-K-08-010. 52 p. http://www.epa.gov/airmarkets/progress/docs/2007ARPReport.pdf. (12 January 2009).

U.S. Environmental Protection Agency [US EPA]. 2009b.Climate change. http://www.epa.gov/climatechange/. (02 February 2009).

U.S. Environmental Protection Agency [US EPA]. [N.d.]. Multi-resolution land characteristics consortium (MRLC): 1992 national land cover data (NLCD). http://www.epa.gov/mrlc/nlcd.html. (09 April 2008).

U.S. Geological Survey [USGS]. 2000. The national hydrology dataset. http://nhd.usgs.gov/. (16 December 2005).

U.S. Geological Survey [USGS]. 2006. Habitat establishment, enhancement and management for forest and grassland birds in Illinois: area requirements of forest and grassland birds. http://www.npwrc.usgs.gov/resource/birds/manbook/areareq.htm. (17 July 2007).

U.S. Geological Survey [USGS]. [N.d.]. The USGS land cover institute: USGS land cover. http://landcover.usgs.gov/usgslandcover.php. (09 April 2008).

U.S. Government Accountability Office [US GAO]. 2007. Wildland fire management: lack of clear goals or a strategy hinders federal agencies' efforts to contain the costs of fighting fires. GAO-07-655. Washington, DC. 47 p.

Wallenstein, M.D. 2004. Effects of increased nitrogen deposition on forest soil nitrogen cycling and microbial community structure. Durham, NC: Duke University, University Program in Ecology. 111 p. Ph.D. dissertation.

Wear, D.N.; Liu, R.; Foreman, J.M.; Sheffield, R.M. 1999. The effects of population growth on timber management and inventories in Virginia. Forest Ecology and Management. 118: 107–115.

Whelan, C.J.; Maina, G.G. 2005. Effects of season, understorey vegetation density, habitat edge and tree diameter on patch-use by bark foraging birds. Functional Ecology. 19: 529–536.

White, E.M.; Alig, R.J.; Stein, S.M.; Mahal, L.G.; Theobald, D.M. 2009. A sensitivity analysis of "Forests on the edge: housing development on America's private forests." Gen. Tech. Rep. PNW-GTR-792. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 35 p.

White, E.M.; Mazza, R. 2008. A closer look at forests on the edge: future development on private forests in three states. Gen. Tech. Rep. PNW-GTR-758. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 20 p.

Wilcove, D.S.; Rothstein, D.; Dubow, J.; Phillips, A.; Losos, E. 2000. Leading threats to biodiversity: what's imperiling U.S. species. In: Stein, B.A.; Kutner, L.S.; Adams, J.S., eds. Precious heritage. Oxford, United Kingdom: Oxford University Press: 239-254.

Woodbury, P.B.; Smith, J.E.; Heath, L.S. 2007. Carbon sequestration in the U.S. forest sector from 1990 to 2010. Forest Ecology and Management. 241: 14–27.

Woods, M.; McDonald, R.A.; Harris, S. 2003. Predation of wildlife by domestic cats *Felis catus* in Great Britain. Mammal Review. 33(2): 174–188.

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 4th-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

$$WQI = 0.6[A_1 + (A_1A_2)] + 0.4(0.48B_1 + 0.24B_2 + 0.16B_3 + 0.12B_4) \qquad (1)$$

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 95th 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 (95th to 100th percentile), 2 (90th to 94th percentile), 3 (85th to 89th percentile), and 4 (0 to 84th 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.

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