Threats to Private Forest Lands in the U.S.A.: A Forests on the Edge Study

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Abstract

The Forests on the Edge project, sponsored by the USDA Forest Service, uses geographic information systems to construct and analyze maps depicting threats to the contributions of America's private forest lands. For this study, watersheds across the conterminous United States are evaluated with respect to the amount of their private forest land. Watersheds with at least 10 percent forest land, of which 50 percent is privately owned, are then ranked relative to the contributions of their private forest lands to water quality, timber supply, at-risk species habitat, and interior forest. In addition, threats from housing development, fire, air pollution, and insect pests and disease to private forest land contributions are assessed. Results indicate that private forest lands contributions and threats are concentrated in the Eastern and Southeastern United States but are also distributed throughout the north-central, central hardwoods, and Pacific Northwest regions.

Keywords: Ecological services, forest contributions, geographic information systems, fourth-level watershed, land use change, private forest, sustainable forest management.

Introduction

America's forest lands contribute in a myriad of ways to the economic, ecological, and social well-being of the Nation. Increasingly, however, forest lands are threatened from a variety of sources including urbanization, low-density housing development, climate change, invasive flora and fauna, wildfire, pollution, fragmentation, and parcelization. The increasing emphasis on sustainable forest management and loss of open space requires quantitative and spatial assessments of the impacts of threats to forest lands and their contributions. The Forests on the Edge (FOTE) project, sponsored by the Cooperative Forestry Staff, State and Private Forestry, USDA Forest Service, conducts map-based assessments of threats to the private forest lands of the United States using spatial data layers and geographic information systems. The objectives of the study described here are threefold: (1) to construct nationally consistent data layers depicting the spatial location of private forest lands and their contributions; (2) to construct similar layers depicting threats to the contributions of private forest land from sources such as conversion to urban and exurban uses, wildfire, and pollution; and (3) to identify watersheds whose private forest lands simultaneously make the most important contributions and face the greatest threats.

The Montreal process criteria and indicators provide an appropriate context for framing and conducting these assessments (McRoberts and others 2004). For example, criterion 2, maintenance of the productive capacity of forest ecosystems, includes indicators related to forest area and timber production; criterion 3, maintenance of forest ecosystem health and vitality, includes indicators related to fire, wind, disease, and insects; and criterion 4, conservation and maintenance of soil and water resources, includes indicators related to the contributions of forests to water quality.

Data Layers

All data layers were obtained as or constructed to be nationally consistent and were summarized at the spatial scale of fourth-level watersheds (Steeves and Nebert 1994). Watersheds were selected as the analytical units because they highlight the important connections between private forests and ecological processes.

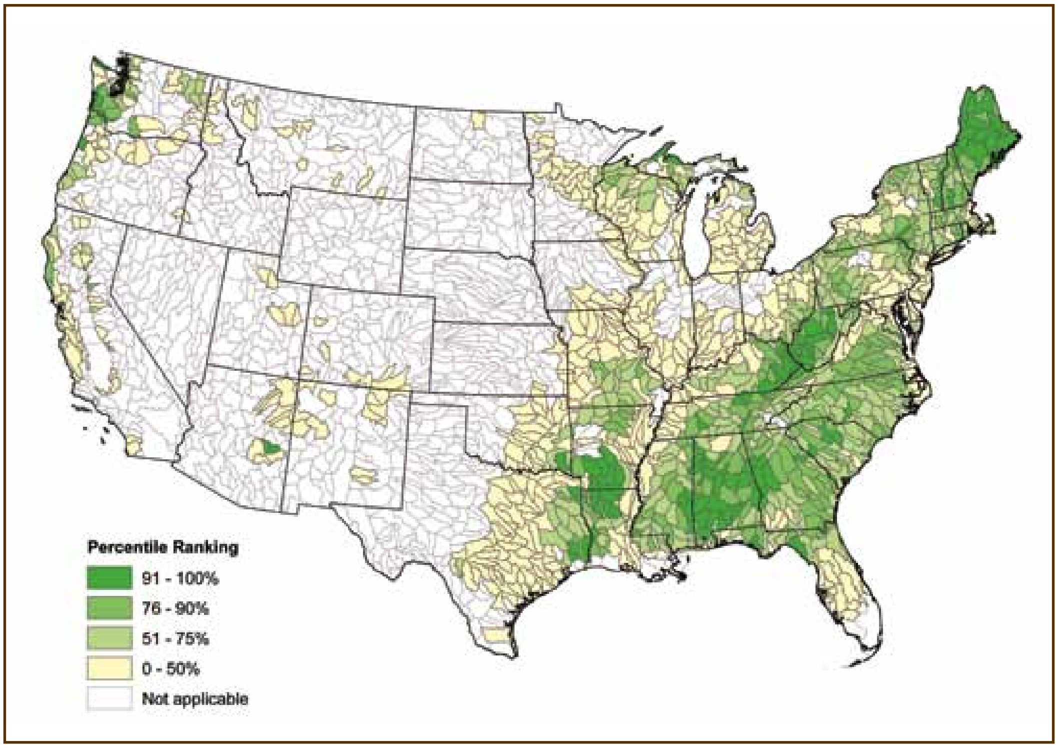

Figure 1—Percentile rankings of watersheds with respect to percentage of private forest land.

Private Forest Contributions

Area of Private Forest Land—

A 100-m-resolution forest ownership layer was constructed by aggregating the classes of the National Land Cover Dataset (NLCD) (Vogelmann and others 2001) into forest and nonforest classes and using the Protected Areas Database (PAD) (DellaSalla and others 2001) to distinguish ownership and protection categories. The emphasis for this study was private forest land, which includes tribal, forest industry, and nonindustrial ownerships. Stein and others 2005a, 2005b) provide detailed information on this layer. Only watersheds with at least 10 percent forest land, of which 50 percent is privately owned, qualified for subsequent analyses. Figure 1 depicts the percentile rankings of qualifying watersheds relative to the percentage of privately owned forest land; for example, a watershed in a 91 to 100-percentile category has a higher percentage of private forest land than at least 90 percent of the qualifying watersheds.

Water Quality—

Private forest lands provide nearly 60 percent of all water flow from U.S. forests and nearly 30 percent of the water flow originating on land in the Lower 48 States (Personal communication. Thomas C. Brown. 2004. Hydrologist, Rocky Mountain Research Station, 2150 Centre Ave. Bldg. A, Suite 376, Fort Collins, CO 80526). Water flow from private forests is generally considered clean relative to water flow from other land uses and, therefore, makes a positive contribution to 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: (1) water bodies near the heads of hydrologic networks are more sensitive to the loss of forest buffers than water bodies near the bases of the networks, (2) the presence or absence of upstream forest buffers influences water quality downstream in the networks, and (3) forest lands throughout watersheds, not just those in immediate proximity to water bodies, are important when considering the contributions of private forest land to water quality (FitzHugh 2001).

The water quality layer was constructed from two underlying layers, the forest ownership layer and the National Hydrography Dataset (NHD) (USGS 2000), which depicts water bodies in the 48 contiguous States. The layer was constructed in four steps: (1) 30-m 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 in proximity 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,

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

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 third category, and B_4 = percentage of buffer in 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, whereas 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 using Steeves and Nebert (1994).

Timber Supply—
Private forest lands make a substantial contribution to America's timber resources, accounting for 92 percent of all timber harvested in the United States in 2001 (Smith and others 2004). The timber supply layer depicts the ranking of watersheds relative to an index of the importance of private timberland and is based on Forest Inventory and Analysis (FIA) plot data (http://www.fia.fs.fed.us/tools-data/default.asp.). The private timberland importance index (TI) is based on three subindices of contributions of the timberland subset of private forest land. Timberland is defined by the FIA program as forest land that has not been withdrawn from production and that is capable of producing 20 cubic feet per year of industrial wood. For each watershed, the three subindices are calculated as follows: (1) growth index (GI) is the average growing stock volume growth rate on private timberland in a watershed relative to the average across all private timberland, (2) volume index (VI) is the average net growing stock volume per acre on private timberland in a watershed relative to the average on all private timberland, and (3) area index (AI) is the ratio of private timberland area to total private land area in a watershed relative to the same ratio across all watersheds. TI was calculated for each watershed as, TI = AI(GI + VI).

At-Risk Species—
Private forests provide the key to conservation for many species. In the Pacific Northwest, they provide significant habitat for the spotted owl (Holthausen and others 1995). 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 forested lands within fourth-level watersheds in the Lower 48 States of the United States. At-risk species are defined as species with element occurrences (EO) that have been observed by an authoritative source within at least the last 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- G3/T3) (http://www.natureserve.org/explorer/ranking.htm). An EO is an area of land or water, or both, in which a species or natural community is, or was, present.

NatureServe selected populations that only 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 as opposed to 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) at-risk animal data in Washington are incomplete. Private forested lands were determined using the data layer described in the "Area of Private Forest Land" section.

Interior Forest and Habitat Contiguity—
Habitat contiguity is an index of the structural integrity of forests, an important conservation concern (Wear and others 2004). 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 created using three steps. First, the forest cover layer described in the section "Area of Private Land" was used to identify forested pixels in each watershed. Second, forested pixels were labeled interior forest if 90 percent of the pixels in a surrounding 65-ha window were also forested. Third, the proportion of interior forest pixels in each watershed was determined, and all watersheds were assigned a percentile ranking based on this proportion. Note that a watershed could have very little forest land but a high proportion that satisfied the interior forest criteria.

Threats to Private Forest Lands

Development—
The development layer depicts predicted threats to private forest lands resulting from conversion to urban or exurban uses. The layer is based on estimates of current population and housing density data obtained from the 2000 U.S. Census, and predictions 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 a supply-demand-allocation approach and is based on the assumption that future growth patterns will be similar to those in the past decade. Future patterns are forecast on a decadal basis in four steps:

1. The number of new housing units in the next decade is forced to meet the demands of the predicted populations.
2. A location-specific average population growth rate from the previous to current time step was computed for each of four density classes: urban, suburban, exurban, and rural.
3. The spatial distribution of predicted new housing units was adjusted with respect to accessibility to the nearest urban core area.
4. Predicted new housing density was added to the current housing density under the assumption that housing densities do not decline over time.

For these analyses, predicted new housing was not permitted to occur on protected private land as indicated by PAD (DellaSalla and others 2001). The spatially explicit housing density predictions were combined with the forest ownership layer to identify watersheds with the greatest predicted conversion of private forest land to urban and exurban uses. Stein and others (2005b) provided detailed information on this layer.

Wildfire—
Although wildfire is one of the most compelling threats to forest land, particularly in the Western United States, predicting the threat of wildfire incidence is extremely complex and relies on a variety of regional models and regional variables. Further, even if the models could be readily implemented to construct a national layer, the geographic consistency of the layer would be questionable. Therefore, as a surrogate for wildfire risk, FOTE used the 1-km by 1-km-resolution current fire condition class (CFCC) data, which depict deviations of fire incidence from historical natural fire regimes and estimated efforts necessary to restore stands to historical regimes (Schmidt and others 2002). These data reflect the assignment of forest lands to one of three CFCC classes:

1. $CFCC_1$—forest lands with fire regimes that are within or near historical ranges and that can be maintained by treatments such as prescribed fire or fire use.
2. $CFCC_2$—forest lands with fire regimes that have been moderately altered from historical ranges and that may require moderate levels of prescribed fire, fire use, hand or mechanical treatment, or a combination to restore to historical fire regime.
3. $CFCC_3$—forest lands with fire regimes that have been substantially altered from historical ranges and that may need high levels of hand or mechanical treatment before fire is used to restore historical fire regimes.

The appeal of the CFCC classes is that they are objective, nationally consistent, and are assumed to correlate well with the threat of wildfire incidence. Although these classes reflect the widely varying State-level commitments to wildfire mitigation efforts, they do not reflect ease of access to forest lands experiencing wildfire or the availability of resources to combat wildfires.

For each watershed, all private forest lands were assigned to one of the three CFCC classes, and a watershed-level index was calculated as,

$$CC = CC_1 + 2CC_2 + 4CC_3,$$

where CC_i is the area of private forest land in class $CFCC_i$. The wildfire layer used for this study depicts the percentile ranking of each watershed with respect to its CC index value.

Ozone

Ozone affects forest ecosystems by causing foliar lesions and rapid leaf aging, altering species compositions, and weakening pest resistance (Chappelka and others 1997, Miller and others 1996). It is the only gaseous air pollutant that has been measured at known phytotoxic levels at both remote and urbanized forest locations (US EPA 1996). 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. Data for more than 2,500 FIA plots were available for the study. Each plot was assigned a biosite value based on a subjective assessment by trained observers of the quantity and severity of damages (Coulston and others 2003, Smith and others 2003). Inverse distance weighted interpolation was used to create a map of ozone damage. This 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 in moderate or high-damage categories was calculated.

Nitrate and Sulfate Deposition—
Acidic deposition, the transfer of strong acids and acid-forming substances from the atmosphere to the Earth, has become a critical stress affecting forested landscapes across the United States. Effects can include increased sulfate and nitrate levels in soils and waters, which, in turn, can alter soil and water chemistry and affect trees and other living organisms that depend upon affected soils and waters (Driscoll and others 2001). The nitrate and sulfate layers were created from National Atmospheric Deposition Program data. The data were used to interpolate yearly wet sulfate and wet nitrate deposition maps using gradient plus inverse distance interpolation (Nalder and Wein 1998). This technique adjusts for elevational, longitudinal, and latitudinal gradients when present in the data based on local regression of the 20 nearest neighbors. The wet sulfate deposition maps (2000-2004) were then averaged to produce a map of average annual deposition 2000-2004 (kg/ha per year). The same was done for wet nitrate deposition. Cross-validation (Issaks and Srivastava 1989) was performed to estimate the bias and precision of the yearly map.

Insect Pests and Disease—
Forest insect pests and diseases can affect forest health, including the reduction of tree basal area. The Forest Health Monitoring Program of the USDA 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 and others 1997).

A five-step multicriteria process was used to construct a 1-km by 1-km-resolution map depicting risk (Krist and others 2006): (1) Identify a list of forest pests (risk agents) and their target host species; this is conducted at the regional level with certain models constrained to select 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. Users assign a level of potential to values within GIS layers that represent criteria. (4) Convert modeled values of potential risk of mortality for each pest to predicted basal area (BA) 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-km raster grid cells) on a national base

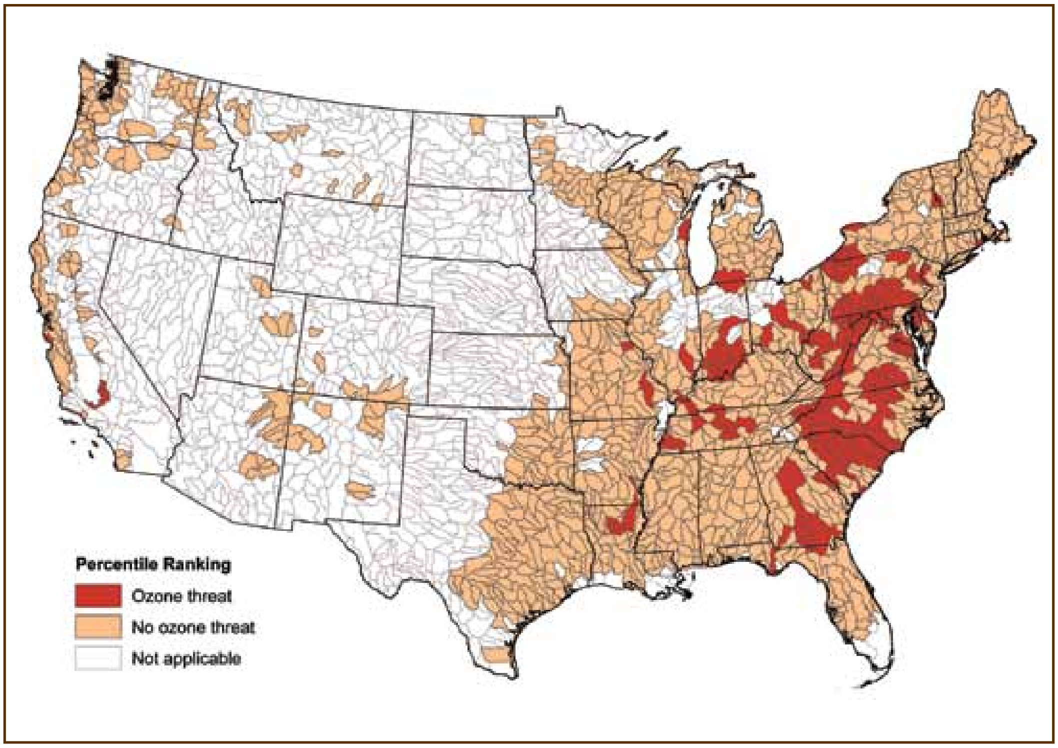

Figure 2—Percentile ranking of watersheds with respect to ozone threat.

map that are at risk of encountering a 25-percent or greater loss of total basal area in the next 15 years.

Methods

For each contribution and threat layer, the distribution of watershed index values was determined, and a percentile ranking was assigned to each watershed. Threats to particular contributions were evaluated in two steps. First, the averages of the contribution and threat percentile rankings were calculated on a watershed-by-watershed basis. Second, the distribution of the averages was determined and used to assign a new percentile ranking to each watershed. The results are depicted using percentile-based categories similar to those used for individual contributions and threats.

Results

The results are briefly discussed. Because of space limitations, only a few maps presenting data on individual layers of contributions or threats are displayed here. Instead, this paper focuses on some of the more interesting intersections of contributions and threats in the "Threats" section.

Contributions

Watersheds with the greatest percentages of private forest land are generally in New England, the Southeast, and the Pacific Northwest (Figure 1). The concentration in the East is not surprising because much of the forest land in the West is in public ownership. Watersheds whose private forests make the greatest contributions to water quality, timber supply, at-risk species habitat, and interior forest closely align with the watersheds with greatest amounts of private forest land.

Threats

Development threats to private forest land area are concentrated in southern New England and the Southeast, although some are also found in the Pacific Northwest; wildfire threats to private forest land (as indicated by the surrogate CC layer), are primarily in the Northeastern quadrant of the country. Data for these two layers are shown in conjunction with the "contributions" data in the next paragraphs. Threats to private forests from ozone are found scattered throughout the Eastern United States (Figure 2). Loss of basal area on

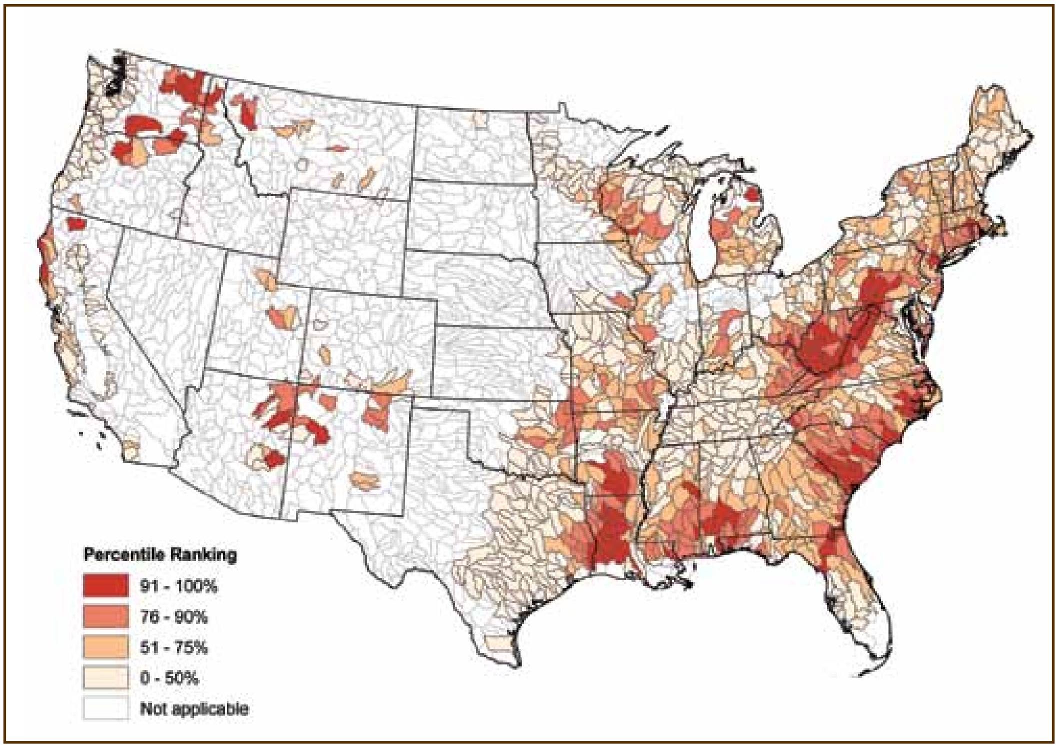

Figure 3—Percentile rankings of watersheds with respect to loss of basal area of private forests associated with insect pests and diseases.

private forest land from insect pests and diseases is most likely to occur in the East, but also in the lake States, the Southwest, California, and the Northwest (Figure 3).

Development threat to at-risk species associated with private forest is highest in the East, including Tennessee, North Carolina, and States immediately north and south of these States, as well as coastal California and the Pacific Northwest (Figure 4). Development threats to private interior forests are found throughout the Eastern United States and the Great Lakes area and are concentrated in the Southeast and Maine (Figure 5). Development threats to the contributions of private forest land to both water quality and timber supply are concentrated in southern New England and the Southeast (due to space limitations, these maps are not shown here).

Wildfire threats to both water quality and timber supply contributions are distributed throughout the East, the lake States, the central hardwoods region, and the Pacific Northwest (Figures 6 and 7).

Conclusions

Four primary conclusions may be drawn from this study:

1. The FOTE spatial approach to assessing threats to the contributions of private forest lands produces useful, visual information that is relatively easy to obtain. The only serious impediment is the difficulty in obtaining or constructing nationally consistent data layers that depict the contributions and threats of interest.
2. The watersheds making the greatest private forest contributions to water quality, timber supply, at-risk species, and interior forest are generally the watersheds with the greatest percentages of private forest land (i.e., those in the Eastern United States, particularly New England and the Southeast, and some watersheds in the Pacific Northwest). Two exceptions are noted. Some watersheds in western California and Florida do not have large amounts of private forest but do have large numbers of at-risk forest-associated species. In addition, some

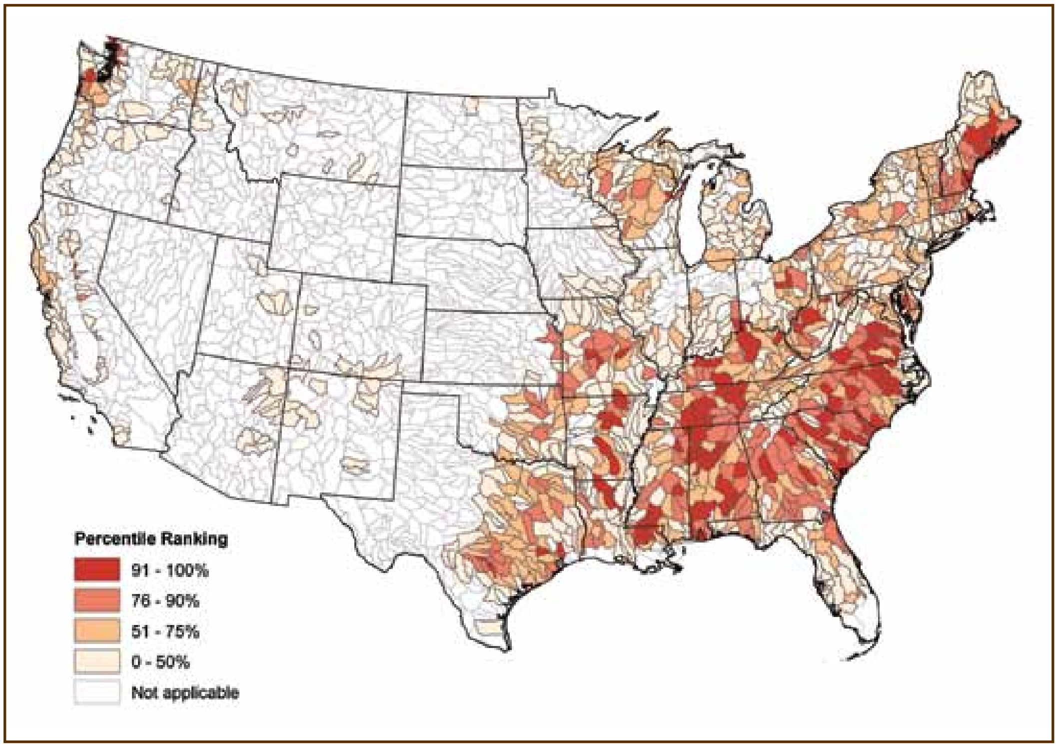

Figure 4—Percentile rankings of watersheds with respect to housing development threat to contribution of private forest land to at-risk species habitat.

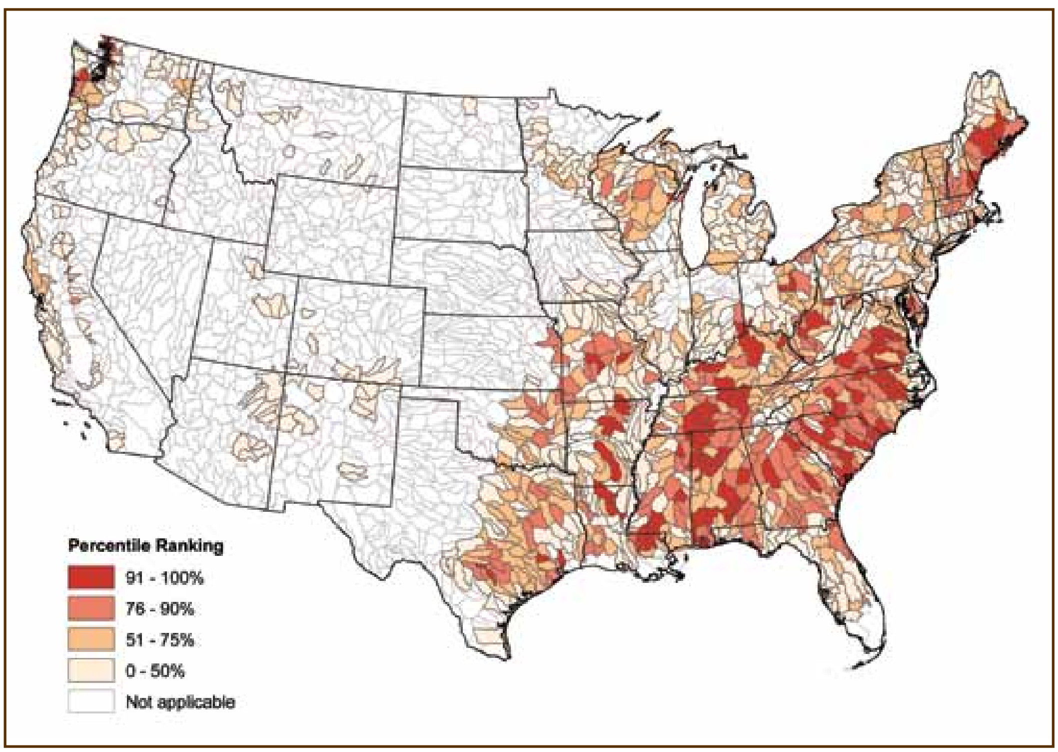

Figure 5—Percentile rankings of watersheds with respect to housing development threat to interior forest on private lands.

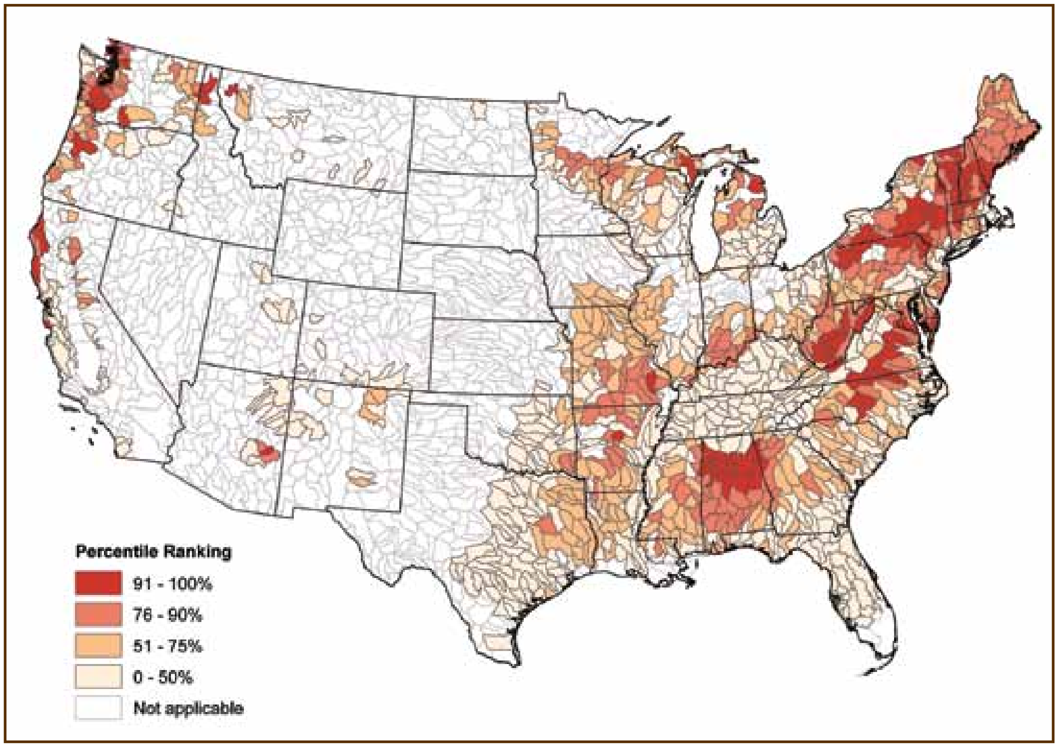

Figure 6—Percentile rankings of watersheds with respect to wildfire threat to contribution of private forest land to water quality.

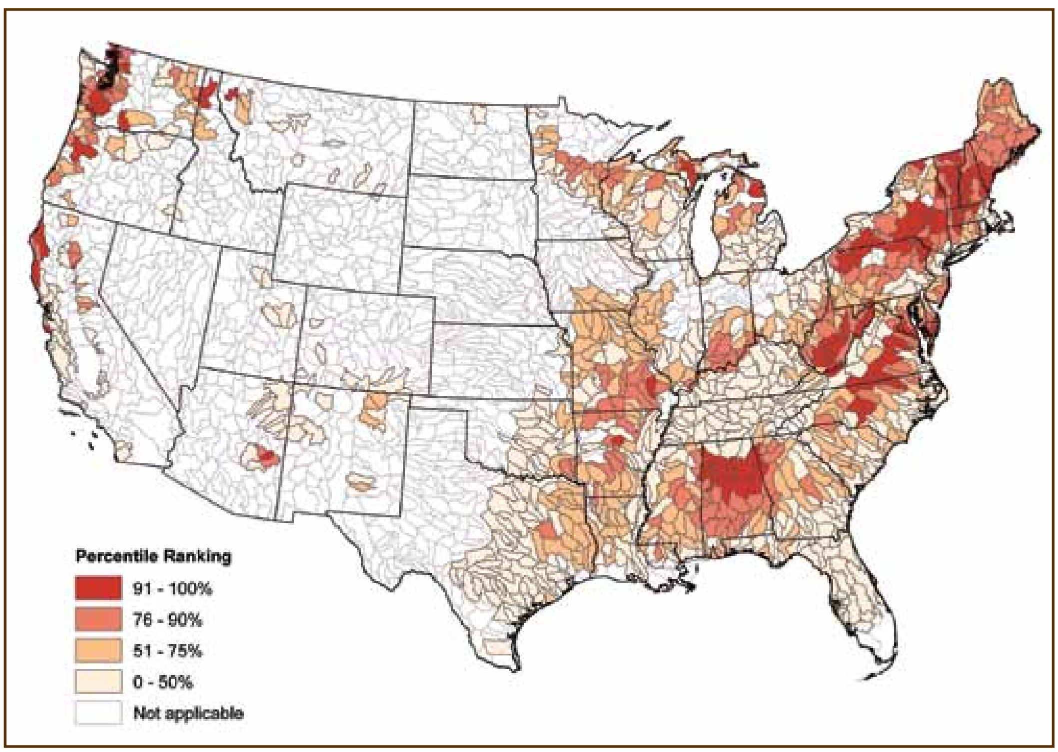

Figure 7—Percentile rankings of watersheds with respect to wildfire threat to contribution of private forest land to timber supply.

watersheds in eastern Texas, the Southwest, and Washington State also do not have large amounts of private forest but do have high proportions of private forest classified as interior forest.

3. Watersheds with the greatest development threat to the contributions to water quality, timber supply, at-risk species, and interior forest are also generally the watersheds with the greatest percentages of private forest land. The exceptions for at-risk species and interior forest noted in the previous paragraph apply here as well.
4. The CC surrogate for wildfire depicts the greatest threats to watersheds in the central part of the Eastern United States and the Pacific Northwest (although watersheds in the central part of the United States have relatively small percentages of private forest land). Percentile rankings of watersheds based on wildfire threat to private forest contribution to water quality and timber supply follow this pattern as well.

Future Forests on the Edge work will include assessment of additional contribution and risk intersections and the 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. In addition, an assessment of national forests and grasslands most likely to experience increased pressures from housing development on adjacent lands is nearing completion. For more information on Forest on the Edge, go to our Web site at http://www.fs.fed.us/openspace/fote.

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