The geography of private forests that support at-risk species in the conterminous United States

Marcos D Robles[1*], Curtis H Flather[2], Susan M Stein[3], Mark D Nelson[4], and Andrew Cutko[1]

In this study, we present a coarse-scale, first approximation of the geographic areas where privately owned forests support at-risk species in the conterminous United States. At-risk species are defined as those species listed under the US Endangered Species Act or with a global conservation status rank of critically imperiled, imperiled, or vulnerable. Our results indicate that two-thirds of the watersheds in the conterminous US contain at-risk species associated with private forests, with counts ranging from one to 101 species. Those watersheds with the greatest number and density of such species are found in the Southeast, Midwest, and west coast states. Many private forests are threatened by land-use conversion. Those forests projected to experience the greatest increase in housing density within the next 25 years, and with relatively high densities of at-risk species, are found in over 100 watersheds, most of them in the Southeastern states.

Front Ecol Environ 2008; 6(6): 301–307, doi:10.1890/070106

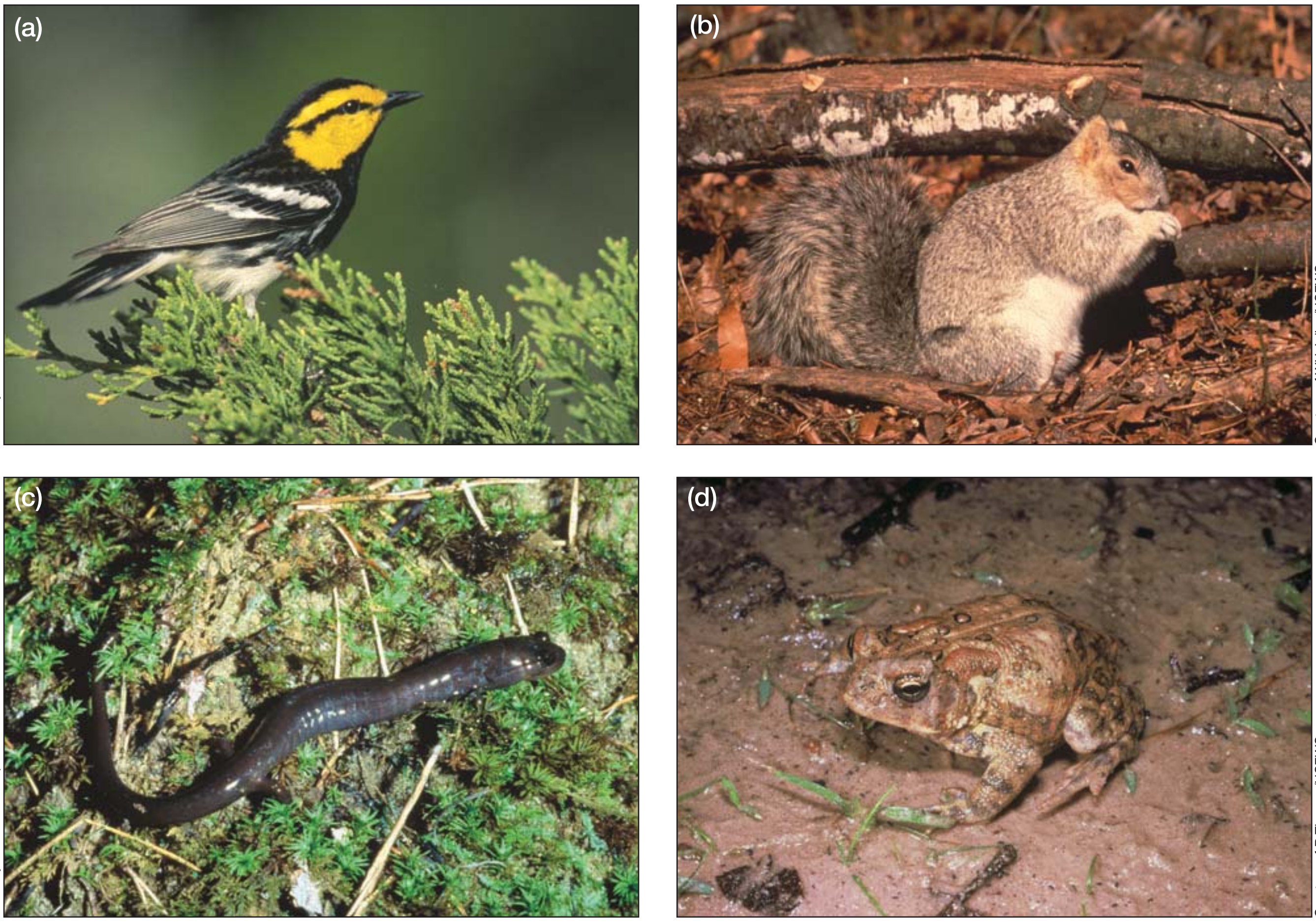
While investigators have examined the location of biodiversity hotspots in the US (Flather *et al.* 1998; Chaplin *et al.* 2000), and the extent to which these areas are protected by the current network of publicly managed lands (Crumpacker *et al.* 1988; Groves *et al.* 2000; Scott *et al.* 2001), far less detailed information has been collected on the geographic distribution and conservation significance of private lands (Knight 1999). Studies of at-risk and endangered species, for example, suggest that important conservation areas in the conterminous US are located in California, Florida, and the southern Appalachians (Chaplin *et al.* 2000). A conservative estimate is that private lands, which cover roughly 70% of the continental US, harbor more than half of these at-risk species (Groves *et al.* 2000; Figure 1). This finding complements other studies demonstrating that many habitats are found disproportionately on privately owned lands (Crumpacker *et al.* 1988; Scott *et al.* 2001; Figure 2).

More detailed studies conducted at state and regional scales also support the notion that privately owned lands are integral to species conservation. Extensive studies in Florida, for example, have quantified the extent to which species are dependent upon private lands. An estimated 30% of the state's rare plants and animals are not adequately protected within the current network of protected areas, requiring conservation of an additional 1.65 million hectares of private lands (12% of the state) to ensure their long-term survival (Kautz and Cox 2001). Private lands are especially important for wide-ranging animals, whose home ranges necessarily encompass a patchwork of public and private lands; for example, private lands in Florida account for 50% of the habitat occupied by the endangered Florida panther (*Felis concolor coryi*; Maehr 1990) and 87% for the crested caracara (*Caracara cheriway*; Morrison and Humphrey 2001).

Conservation and protection strategies in private forests are urgently needed, given that many of these areas are under threat of development, which has been associated with increased mortality of large mammals, declines in fish populations, and reductions in wetland species richness (Findley and Houlahan 1997; Ratner *et al.* 1997; Riley *et al.* 2003). A companion study estimates that 10% of the nation's private forests, or more than 44 million acres, will probably experience increases in housing densities over the next several decades (Stein *et al.* 2005). In fact, forest product companies are selling their US land holdings at an unprecedented rate, leading to large-scale changes in land ownership of the nation's private timberlands. In the southeastern US, for example, over 18.4 million acres of timberlands changed ownership from 1996 to 2005 (Mendell *et al.* 2005). Similar changes have been noted in the northeast (Hagan *et al.* 2005).

While the majority of these former timber industry lands remain in forest use, there is growing concern that this fragmentation in ownership may result in a diminishment of sustainable practices and, ultimately, increased habitat fragmentation. Many of the new owners are institutional investment entities, including timber investment management organizations (TIMOs), real estate investment trusts (REITs), and limited liability corporations (LLCs), whose management and investment strategies are not limited to forestry. Whereas most lands purchased by TIMOs are likely to remain under forestry management, at least in the short term, lands under LLC ownership are more likely to be sold for other uses,

[1]*NatureServe, Arlington, VA* [*]*(mrobles@tnc.org);* [2]*USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO;* [3]*USDA Forest Service, State and Private Forestry, Washington, DC;* [4]*USDA Forest Service, North Central Research Station, St Paul, MN*



Courtesy of USFWS
Courtesy of WH Julian/USFWS
Courtesy of E Blankenship/USFWS
Courtesy of R Thomas/USFWS

Figure 1. *Private forest lands support many at-risk species across the US, including (a) golden-cheek warbler (*Dendroica chrysoparia*), (b) Delmarva fox squirrel (*Sciurus niger cinereus*), (c) Red Hills salamander (*Phaeognathus hubrichti*), and (d) Houston toad (*Bufo houstonensis*).*

including real estate development (Mendell *et al.* 2005). In the northeastern US, these land ownership changes are associated with declines in sustainable forestry practices (Hagan *et al.* 2005). Furthermore, state agencies and conservation organizations often cannot conserve these lands at the speed or monetary scale needed to compete with private investors (Mendell *et al.* 2005). Recently, for example, The Nature Conservancy and other conservation organizations were able to acquire approximately 280 000 acres of lands sold by International Paper in the Southeast and Wisconsin. While this accomplishment is notable, it represents only a fraction – 5% – of the more than five million acres sold (Reuters 2006; Woodard 2006). These trends only add urgency to conservation strategies that specifically address private forests.

Here, we identify geographic areas where private forest lands support populations of at-risk species across the conterminous US. We present maps of watersheds ranked according to several species indices that account for species presence in private forests and forest acreage found within watersheds. We also compare patterns of species imperilment with the geography of development threats (specifically, estimates of increased housing densities) on private forest lands. Watersheds are an appropriate unit for a national-level analysis because they integrate hydrologic function across large areas, are correlated with the distribution of many species, and serve as planning units for many public and private land management organizations. Our study was designed to specifically address the following questions:

(1) In which watersheds do privately owned forests support the greatest number of at-risk species?
(2) Accounting for variation in private forest acreage, in which watersheds do private forests make a disproportionate contribution to at-risk species conservation?
(3) Accounting for variation in the occurrence of forest-associated species in both private and public forests, in which watersheds do private forests make a disproportionate contribution to at-risk species conservation?
(4) In which watersheds is there a convergence of species imperilment and threat of private forest conversion?

Methods

We used three national datasets to characterize the occurrence of at-risk species on private forest lands. The first

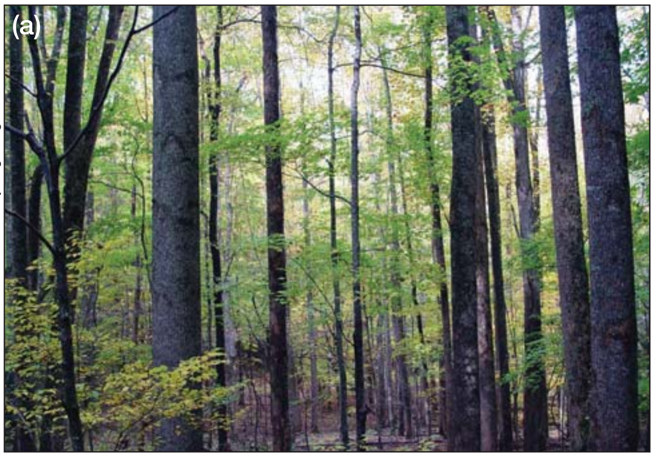


Figure 2. *Two examples of forests that support the at-risk species shown in Figure 1: (a) Appalachian mixed hardwood forest and (b) longleaf pine forest.*

dataset represents fourth-level watershed boundaries (ie surface drainage basins or distinct hydrologic features; USGS 2001). The second identifies the location of at-risk species populations (NatureServe 2004; Figure 3). We defined at-risk species as those species, subspecies, or varieties that meet at least one of two criteria: (1) federally designated under the US Endangered Species Act (endangered, threatened, candidate, proposed, special concern, similarity of appearance), or (2) designated as globally critically imperiled (< 5 viable populations), globally imperiled (6–20 viable populations), or globally vulnerable (21–80 populations), according to NatureServe conservation status ranks. We selected all extant populations of species that had been observed by an authoritative source within the past 50 years. Although the NatureServe dataset is recognized as containing one of the most comprehensive and accurate national census datasets on rare and endangered species (Stein and Davis 2000), there were several data gaps relevant to this study: (1) incomplete species data for Arizona, (2) no species data for Massachusetts and the District of Columbia, (3) no fish data for Idaho, and (4) incomplete animal data for Washington. In Arizona, species data were available only for the portion of the state coincident with the Navajo Nation. Watersheds that border Arizona, Massachusetts, and the District of Columbia are displayed in results based on species populations found within these watersheds in neighboring jurisdictions.

The third dataset classifies lands using one of four land-use categories: private forests, public forests, private non-forests, and public non-forests (Figure 3). This dataset was derived from two sources: the National Land Cover Dataset of 1992 (NLCD; Vogelmann *et al.* 2001) and a national land stewardship layer of public and privately managed lands, the Protected Areas Database (PAD; DellaSala *et al.* 2001). Forest lands were identified from five NLCD land-cover types: 33 (transitional), 41 (deciduous forest), 42 (evergreen forest), 43 (mixed forest), and 91 (woody wetlands). Estimates of forest land cover derived from NLCD correlated well with area estimates derived from the Forest Inventory and Analysis program of the US Forest Service (Nelson *et al.* 2005). PAD-based estimates of federal land area were similar to estimates from US Census Bureau statistics (Nelson *et al.* 2005). PAD delineations for non-federal ownerships were not formally assessed, but were observed to be somewhat less complete than those for federal lands.

In order to evaluate the relative contribution of private forests to forest biodiversity conservation, we evaluated populations that occur in both public and private forests. We were not able to independently verify that all species selected were obligate forest inhabitants. Many of the rarest species in the Southeast, for example, were aquatic or riparian species, dependent on habitats embedded within forested landscapes. For this reason, we describe these species as "forest associated" or "forest occurring" throughout the study. Given the national scope of this assessment, we believe that this coarse-scale comparison of land cover, land ownership, and populations provides an adequate first approximation of the places where at-risk species are supported by private forests.

We used a Geographic Information System (GIS) to identify populations of at-risk species associated with forest lands. We excluded all watersheds with < 1% acreage in private forests. We selected populations associated with forested lands using a rule-based algorithm that considered the degree of overlap between a population and a forest tract in conjunction with the amount of spatial uncertainty associated with the population. Selected populations met one of the following rules: (1) populations with 0–100 m uncertainty and at least 1% overlap with a forest tract; (2) populations with 100–2400 m uncertainty and at least 24% overlap with a private forest tract; and (3) populations with 2400–8000 m uncertainty and at least 80% overlap with a private forest tract. Thresholds of forest overlap used in these rules were based on the ratio 1:24:80, derived from quality-controlled, spatial error classes in the NatureServe dataset: 100 m, 2400 m, and 8000 m, respectively. Populations were labeled as occurring in private and public forests.

Where a population overlapped with both private and public forested lands, populations with the majority of their area overlapping private forests were labeled private-occurring, and vice versa.

In a second step, we used GIS to generate at-risk species counts by watershed. Forest-associated populations were labeled with the watershed in which they occurred; populations overlapping more than one watershed were labeled with the watershed with which there was the greatest area of overlap. We then summarized populations to the species level, resulting in three counts of at-risk species per watershed: $S_{i,priv}$ (number of species found in private forests in watershed i); $S_{i,pub}$ (number of species found in public forests in watershed i); and $S_{i,priv} \cap S_{i,pub}$ (number of species found in both public and private forests in watershed i). We used these sets to discriminate between species found in private and public forests, as described below.

We calculated three at-risk species–watershed indices. The first index is an absolute count of species found in private forests for watershed i, or $S_{i,priv}$. Because species counts are known to be influenced by the area of habitat, the second index adjusts this count by private forest acreage. Given that species vary with habitat area in a non-linear way, our density index accounts for the power-law species–area relationship as follows:

$$D_{i,priv} = S_{i,priv} / A^{z}_{i,priv} \qquad (1)$$

where $D_{i,priv}$ is the density of at-risk species occurring in private forest for watershed i, $A_{i,priv}$ is the area of private forest in the watershed, and z is a fitted exponent that indicates the rate at which species are added with increasing area (NRC 2000). We estimated z by fitting the following linear regression (SAS Institute 2003):

$$\log (S_{i,priv}) = c + z (\log [A_{i,priv}]) \qquad (2)$$

to our log-transformed watershed data to linearize the relationship (c is a constant). Our estimate of z was 0.481. The third index highlights those places where private forests (relative to public forests) have the potential to play an important role in species conservation. It represents the proportion of forest-associated species found exclusively on private forests, and was calculated as follows:

$$P_{i,priv} = (S_{i,priv} - [S_{i,priv} \cap S_{i,pub}])/(S_{i,priv} + S_{i,pub} - [S_{i,priv} \cap S_{i,pub}]) \qquad (3)$$

To further elucidate the geography of species imperilment, we evaluated the degree to which private forests harboring at-risk species are also predicted to experience development pressures over the next several decades. We used data from a companion study (Stein *et al.* 2005) that estimated the number of private forest acres in watershed i predicted to shift from rural or ex-urban housing densities (16 and 16 to 64 housing units per mi^2, respectively) to urban densities (>64 housing units per mi^2) by 2030 (private forest acres converted or PFCi). Predictions of future housing densities were derived by evaluating trends in historic and current housing densities and assuming that future growth patterns will be similar to those found in the past decade. PFCi is calculated using 2000 US Census block group datasets (US Census Bureau 2001) and a spatially explicit growth model (for more detailed information, see Stein *et al.* 2006). To test the strength of the spatial relationship between estimated private forest conversion and at-risk species occurrence, we ranked watersheds according to PFCi and at-risk species density, $D_{i,priv}$, and calculated a Spearman's rank correlation coefficient, r_s, between these two indices (Conover 1971; SAS Institute 2003).

We present five national watershed maps, one for each species-at-risk index (three in total), one for the estimated private forest conversion index, and one showing watersheds with the highest measurements of at-risk species density and estimated private forest conversion. To allow for comparison across maps, we display data according to the following percentiles: 0–50‰, 50–75‰, 75–85‰,

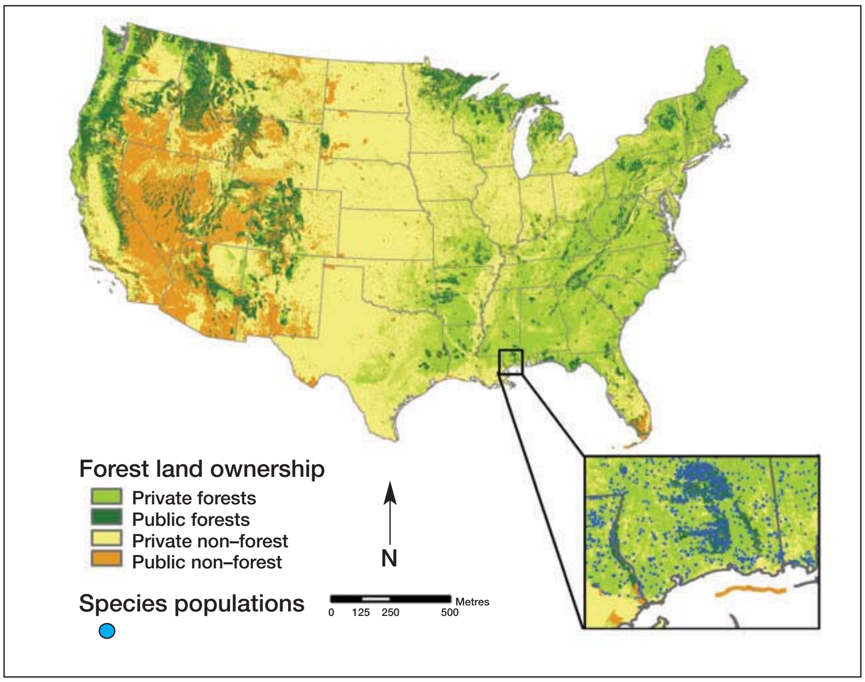
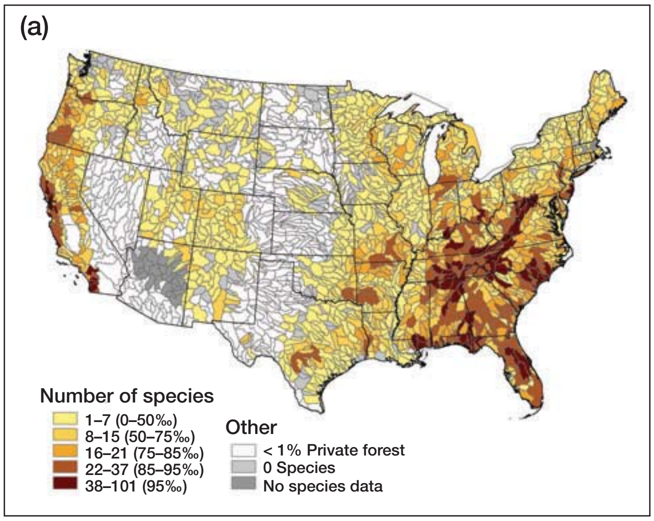
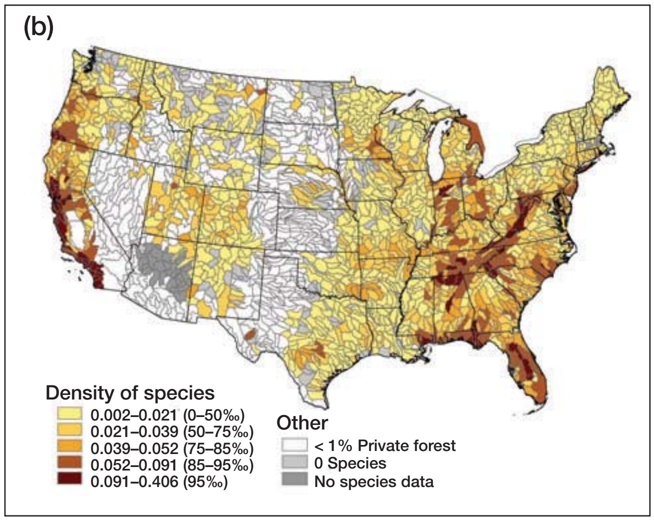


Figure 3. *Map showing location of private and public forests in the conterminous US. (inset) Coastal Mississippi, showing location of populations of at-risk species in relation to private and public forest lands. Forest land-cover data from Vogelmann* et al. *(2001) and DellaSala* et al. *(2001). Species data from NatureServe (2004).*





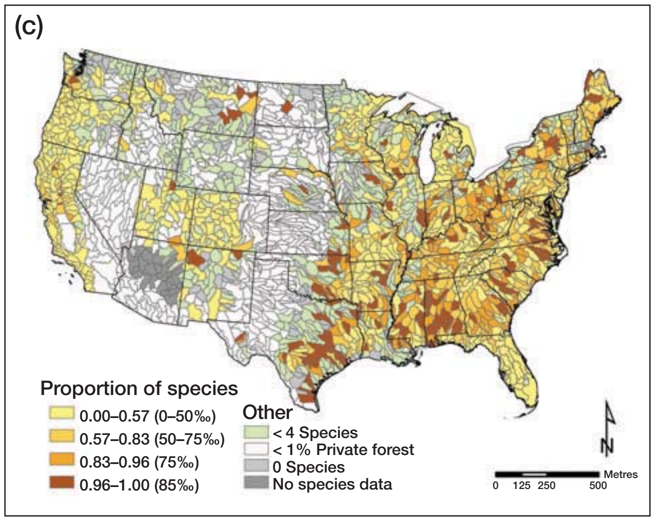


Figure 4. *Patterns of at-risk species supported by private forests. (a) Number of at-risk species found in private forests. (b) Log-transformed density of at-risk species found in private forests. (c) Proportion of at-risk species found only in private forests. All data are reported by watershed, according to percentile classes. Data from Vogelmann* et al. *(2001); USGS (2001); DellaSala* et al. *(2001); NatureServe (2004).*

85–95‰, and > 95‰. We also display watersheds that did not qualify for one of these categories as follows: "< 1% private forest" for watersheds eliminated from the analysis; "no species data" where species data were not available; and "0 species" when no at-risk species were found in private forests.

Data for the third species index, $P_{i,priv}$, were distributed in such a way that we could only initially display three of the five percentile classes. This occurred because there were many watersheds where forest-associated species were found only in private forests, giving $P_{i,priv}$ a value of 1. This was particularly the case for watersheds with few species. In order to place a greater focus on watersheds with multiple species, we eliminated watersheds within the first quartile (< 4 species) for the $P_{i,priv}$ map, allowing display of four percentile classes. In a similar attempt to display only the most nationally important watersheds, we display only watersheds that rank within the last three percentile classes for the species density-estimated private forest conversion map.

Results

At-risk species associated with private forests included 588 vertebrate animals, 1133 invertebrate animals, 1899 vascular plants, and 84 non-vascular plants. This accounts for 60% (3704 of 6187) of all such species found in the conterminous US (NatureServe 2004). Given the difficulties associated with gaining access to private lands (Hilty and Merenlender 2003) and the likelihood that populations on private lands are under-sampled relative to public lands (Groves *et al.* 2000), these approximations are conservative, and are probably underestimated.

Geographically, over two-thirds of watersheds in the continental US (1460 of 2108 watersheds) include private forests that support at least one at-risk species (Figure 4a). Watersheds with the greatest number of at-risk species are found in the Southeast, Midwest, and west coast states. In the Southeast, high-count watersheds are embedded within mountain landscapes (central and southern Appalachians, Ouachitas, Ozarks), interior plateaus and valleys, and coastal plains. When the number of at-risk species associated with private forests is adjusted for private forest acreage (Figure 4b), private forests in the Southeast and the Midwest, but also on the west coast, especially in California, emerge as important areas. This distinction is notable, given that, in western coastal states, private forests are not the dominant land-use type.

When the relative proportion of at-risk species associated with private forests is taken into account, a wider distribution of notable watersheds emerges. Figure 4c displays watersheds according to the proportion of forest-associated species at risk that are found exclusively associated with private forests. The highest category in this map, for example, shows watersheds where approximately 95% of forest-associated species occur only in

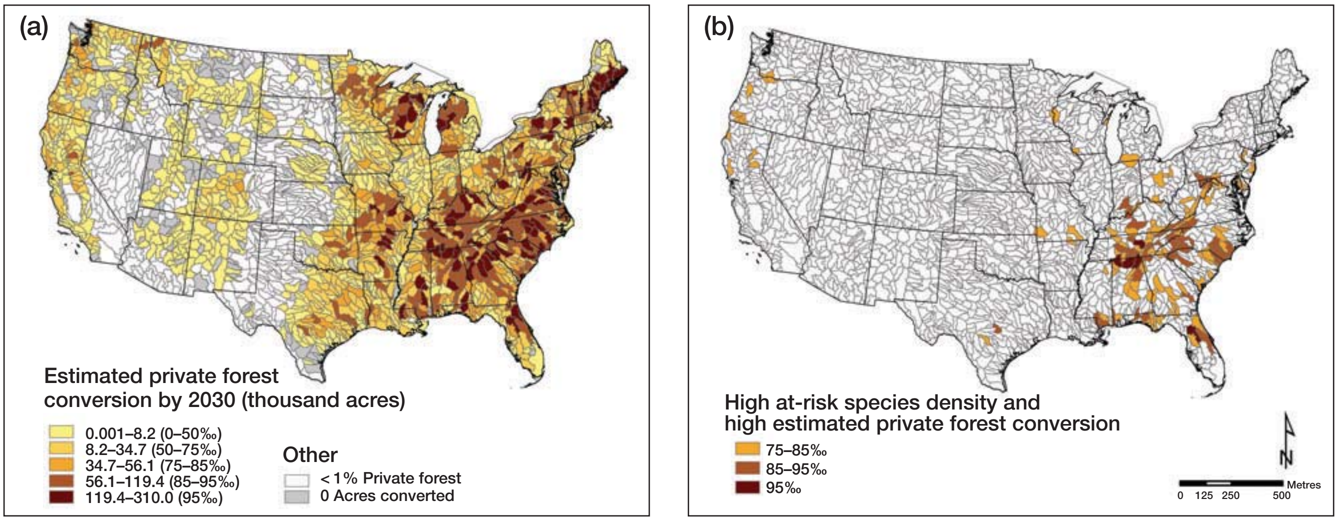


Figure 5. *Comparison of predicted private forest conversion and at-risk species density. (a) Acreage of private forests predicted to experience increased housing densities by 2030. (b) Coincidence of high estimated housing density increases in private forests and high at-risk species densities. In (b), only those watersheds that rank in the 75th percentile for both indices are displayed in color. All data are reported by watershed according to percentile classes. Data from Vogelmann* et al. *(2001); USGS (2001); DellaSala* et al. *(2001); NatureServe (2004); Stein* et al. *(2005).*

private forests. These forests are common and widespread, and include those in the private-forest matrix of the eastern US, but also along the prairie–forest border of Texas and Oklahoma and within riparian areas or isolated forests in the Midwest, Northeast, and the interior basins of the West.

The geography of projected private-forest development initially appears similar to patterns of species imperilment (Figure 5a). In many midwestern and eastern watersheds, tens to hundreds of thousands of private forest acres are predicted to change from rural/exurban to urban housing densities. However, the rank correlation (Conover 1971) between at-risk species density ($D_{i,priv}$; Figure 4b) and estimated private forest conversion (PFC_i; Figure 5a) was low (Spearman's $r = 0.18$, $P < 0.0001$). This minimal degree of association is due to the fact that many watersheds on the west coast have high at-risk species densities, but a relatively low acreage of predicted housing development on private forest lands. The opposite pattern occurs in many eastern watersheds. Despite the low correlation on a national level, there are clearly watersheds where both indices ranked high. Figure 5b shows those watersheds (n = 126) that rank within the 75th percentile for both indices, most of them in the Southeast.

Conclusions

This assessment provides a geographic snapshot of watersheds to which national and regional conservation strategies could direct resources. Many eastern watersheds, especially in the Southeast, and several western coastal watersheds, consistently ranked high for at-risk species indices. These findings are similar to those of other studies (Flather *et al.* 1998; Chaplin *et al.* 2000), suggesting that these areas are important in terms of protecting species diversity and endemism. In particular, the watersheds shown in Figure 5b may warrant national conservation attention, because they contain private forests that support high densities of at-risk species and these forests are predicted to experience increasing housing densities in the next several decades. Many other watersheds that do not harbor the highest number of at-risk species from a national standpoint might still be of importance from a regional or statewide perspective. For example, private forests that exclusively support at-risk species are widespread and often isolated (Figure 4c). Some of these forests are embedded within a more dominant habitat type such as grasslands or shrublands; some occur in riparian areas or river floodplains; and some are adjacent to public forest lands.

Conservation strategies should include, but not be limited to: (1) acquisition of highest priority areas through private/public partnerships; (2) application of conservation easements for working forest lands using funding from the US Department of Agriculture's (USDA) Forest Legacy and private sources; (3) expansion of state-based "current use" taxation programs; (4) use of incentive programs that reduce costs of long-term forest management on private lands, including the USDA Forest Stewardship and Forest Land Enhancement Program and the US Fish and Wildlife Service's Landowner Incentive Program; and (5) expansion of forest certification systems, such as the Sustainable Forestry Initiative and Forest Stewardship Council certifications. Regardless of the strategy, it is clear that effective management and conservation of private forest lands will be critical to safeguarding the nation's biological diversity.

References

Chaplin SL, Gerrard RA, Watson HM, *et al.* 2000. The geography of imperilment: targeting conservation toward critical biodiversity areas. In: Stein BA, Kutner LS, and Adams JS (Eds).

Precious heritage: the status of biodiversity in the United States. Oxford, UK: Oxford University Press.

Conover WJ. 1971. Practical nonparametric statistics. New York, NY: John Wiley & Sons.

Crumpacker DW, Hodge SW, Friedley D, *et al.* 1988. A preliminary assessment of the status of major terrestrial and wetland ecosystems on federal and Indian lands in the United States. *Conserv Biol* **2**: 103–15.

DellaSala DA, Staus NL, Strittholt JR, *et al.* 2001. An updated protected areas database for the United States and Canada. *Nat Area J* **21**: 124–35.

Findley CS and Houlahan J. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. *Conserv Biol* **11**: 1000–09.

Flather CH, Knowles MS, and Kendall IA. 1998. Threatened and endangered species geography. *BioScience* **48**: 365–76.

Groves CR, Kutner LS, Stoms DM, *et al.* 2000. Owning up to our responsibilities: who owns lands important to biodiversity? In: Stein BA, Kutner LS, and Adams JS (Eds). Precious heritage: the status of biodiversity in the United States. Oxford, UK: Oxford University Press.

Hagan JM, Irland LC, and Whitman AA. 2005. Changing timberland ownership in the Northern Forest and implications for biodiversity. Brunswick, ME: Manomet Center for Conservation Sciences. Report # MCCS-FCP-2005-1.

Hilty J and Merenlender AM. 2003. Studying biodiversity on private lands. *Conserv Biol* **17**: 132–37.

Kautz RS and Cox JA. 2001. Strategic habitats for biodiversity conservation in Florida. *Conserv Biol* **15**: 55–77.

Knight RL. 1999. Private lands: the neglected geography. *Conserv Biol* **13**: 223–24.

Maehr DS. 1990. The Florida panther and private lands. *Conserv Biol* **4**: 167–70.

Mendell, B, Newman D, Wear D, *et al.* 2005. Under new management: a case study of southern timberland ownership changes. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station. Final Report.

Morrison JL and Humphrey SR. 2001. Conservation value of private lands for crested caracaras in Florida. *Conserv Biol* **15**: 675–85.

NRC (National Research Council). 2000. Ecological indicators for the nation. Washington, DC: National Academy Press.

NatureServe. 2004. Biotics database, version 4. NatureServe Central Databases. Arlington, VA: NatureServe.

Nelson MD, McRoberts RE, and Lessard VC. 2005. Comparison of US forest land area estimates from Forest Inventory and Analysis, National Resources Inventory, and four satellite image-derived land cover datasets. In: McRoberts RE, Reams GA, Van Deusen PC, *et al.* (Eds). Proceedings of the 5th Annual Forest Inventory and Analysis Symposium; 18–20 Nov 2003; New Orleans, LA. Washington, DC: US Department of Agriculture, Forest Service. Gen Tech Rep WO-69.

Reuters. 2006. International Paper to sell most of its forestland. *New York Times*. **April 5**: Sect C: 5.

Ratner S, Lande R, and Roper B. 1997. Population viability analysis of spring chinook salmon in the South Umpqua River, Oregon. *Conserv Biol* **11**: 879–89.

Riley SPD, Sauvajot RM, Fuller TK, *et al.* 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. *Conserv Biol* **12**: 566–76.

SAS Institute. 2003. The SAS system for windows, version 9.1. Cary, NC: SAS Institute Inc.

Scott JM, Davis FW, McGhie RG, *et al.* 2001. Nature reserves: do they capture the full range of America's biological diversity? *Ecol Appl* **11**: 999–1007.

Stein SM, McRoberts RE, Alig RJ, *et al.* 2005. Forests on the edge: housing development on America's private forests. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. Gen Tech Rep PNW-GTR-636.

Stein SM, McRoberts RE, Nelson MD, *et al.* 2006. Forests on the edge: a GIS-based approach to projecting housing development on private forests. In: Aguirre-Bravo C, Pellicane PJ, Burns DP, *et al.* (Eds). Proceedings of the monitoring science and technology symposium: unifying knowledge for sustainability in the western hemisphere. 20–24 Sep 2004; Denver, CO. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. Gen Tech Rep RMRS-P-42CD.

Stein BA and FW Davis. 2000. Discovering life in America: tools and techniques of biodiversity inventory. In: Stein BA, Kutner LS, and Adams JS (Eds). Precious heritage: the status of biodiversity in the United States. Oxford, UK: Oxford University Press.

US Census Bureau. 2001. Census 2000 summary file 1 technical documentation. Washington, DC: US Census Bureau.

USGS (US Geological Survey). 2001. Hydrologic units boundaries of the United States. Washington, DC: USGS.

Vogelmann JE, Howard SM, Yang L, *et al.* 2001. Completion of the 1990s National Land Cover Dataset for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. *Photogramm Eng Rens S* **67**: 650–62.

Woodard C. 2006. The sale of the century. *Nature Conserv* **56**: 20–25.