Mapping Forest Inventory and Analysis Forest Land Use: Timberland, Reserved Forest Land, and Other Forest Land

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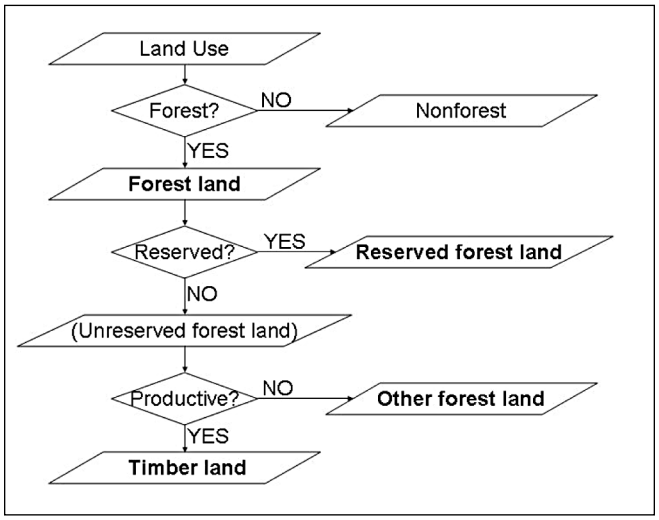
Abstract.—The Forest Inventory and Analysis (FIA) program produces area estimates of forest land use within three subcategories: timberland, reserved forest land, and other forest land. Mapping these subcategories of forest land requires the ability to spatially distinguish productive from unproductive land, and reserved from nonreserved land. FIA field data were spatially interpolated to produce a geospatial data set of forest site productivity. A geospatial data set of lands reserved from wood products utilization was delineated from the Protected Areas Database. The combination of these two geospatial data sets, along with a geospatial data set of forest land cover, provided an initial approach for mapping three subcategories of forest land use. Compared with inventory estimates, the mapping approach led to similar estimates of forest land area, overestimates of timberland and reserved forest land, and an underestimate of other forest land. Additional work is needed to improve geospatial data sets of forest site productivity.

Introduction

Detailed surveys of the Nation's forest land are conducted through the Forest Inventory and Analysis (FIA) program of the U.S. Department of Agriculture (USDA) Forest Service. Through the FIA program, design-based estimates of forest land area by estimation units (e.g., counties, States, regions) and the Nation are produced. Bechtold and Patterson (2005) provided FIA definitions of forest and nonforest land (appendix A), which include land use constraints and measures of minimum tree stocking, forest land area, and forest land width. Furthermore, using FIA definitions, forest land use can be differentiated into three subcategories: timberland, reserved forest land, and other forest land (appendix A). FIA subcategories of forest land are defined by site productivity and reserved status, (i.e., availability or unavailability of forest land for wood product utilization) (fig. 1).

FIA estimates represent forest land use (e.g., forest land not currently developed for a nonforest use) (appendix A), while satellite-image-based data sets and their derived estimates represent forest land cover. A mapping approach for differentiating land use versus cover would provide a more consistent basis for comparing classified satellite imagery with FIA estimates of forest land area. Nelson *et al*. (2005) explored the efficacy of satellite-image-derived forest land cover maps for portraying forest land use in the United States by comparing estimates obtained from FIA data, the USDA Natural Resources Conservation Service's National Resources Inventory), and

Figure 1.—*Decision rules for classifying forest land into timber land, reserved forest land, and other forest land.*



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four satellite-image-derived data sets: 1991 Forest Cover Types (Zhu and Evans 1994), 1992–93 Land Cover Characteristics (Loveland *et al.* 2000), 2001 Vegetation Continuous Fields (Hansen *et al.* 2002), and the 1992 National Land Cover Data set (NLCD) (Vogelmann *et al.* 2001)). The four satellite-image-derived land cover maps differ in date of image acquisition, classification scheme, and spatial resolution, and show varying degrees of similarity with inventory estimates of forest land use across the conterminous United States (CONUS).

Differentiation of forest land use maps into FIA's three subcategories of forest land would allow for validation and integration of satellite image products with inventory estimates of forest land use. In this paper we address approaches to mapping timberland, reserved forest land, and other forest land.

Data and Methods

Forest Land Cover

The circa 1992 NLCD is a 30-m spatial resolution national land cover data set produced and distributed by the U.S. Geological Survey Center for Earth Resources Observation and Science. Landsat Thematic Mapper imagery from the early 1990s and other sources of geospatial data were used in the classification system, and provided the basis for a consistent hierarchical approach to defining 21 classes of land cover across CONUS (Vogelmann *et al.* 2001). We produced a forest/nonforest cover map by grouping five NLCD classes into a "forest" class: transitional (33)[3], deciduous forest (41), evergreen forest (42), mixed forest (43), and woody wetland (91). The remaining 16 NLCD classes were aggregated into a "nonforest" class. For ease of processing and for integration with other geospatial data sets of coarser spatial resolution, the 30-m forest/nonforest data set was rescaled to a 250-m spatial resolution forest/nonforest data set.

Forest Land Use

Area estimates of forest land use per State were obtained from Forest Resource Assessment 2002 tables on U.S. forest resources, as part of the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93-378, 99 Stat. 4765 (USDA 2003). RPA data primarily were derived from FIA data, except for portions of some Western States where National Forest System lands were inventoried independently (Smith *et al.* 2001, USDA Forest Service 2003). RPA 2002 source dates ranged from 1983 to 2000 with an average acquisition year of 1994 (Smith *et al.* 2004). Inventory estimates of forest land area were obtained by multiplying total land area by the mean proportion of forest land from forest inventory plot observations (Scott *et al.* 2005). Although sufficient RPA data exist for Southeast and South Central Alaska, portions of the State's interior have few field plot data. Likewise, Hawaii has few or no field plot data. Therefore, analyses in this study were constrained to CONUS.

Forest Land Productivity

Observations from forest inventory plots were used for spatially modeling forest site productivity. Publicly available geographic location coordinates, land use codes, and productivity attributes were queried from the RPA 2002 database. The resulting records totaled 167,920 forested condition observations on 155,149 RPA plots, and some plots had multiple forested conditions. Nonforest conditions were excluded from the query. Site Class Code (SITECLCD) is the inventory attribute that describes site productivity of each condition observation (Miles *et al.* 2001) (table 1). Area-weighted site productivity (SITEPLT) was calculated for each plot as

$$SITEPLT = \frac{\sum_{i=1}^{N} \left(c_i s_i \right)}{C} \qquad (1)$$

where c_i is the condition proportion (CONDPROP) of the i[th] of N forested conditions on a plot, s_i is the approximate midpoint of the range of site productivity values associated with each SITECLCD for the i[th] condition (table 1), and C is the sum of condition proportions (sum of c_i s) across all N forested conditions on a plot. For some plots, condition proportions summed to < 1.0 when plots contained both

[3] The correct numerical designation for the transitional class is 33; its designation as 31 in Vogelmann et al. (2001) is attributed to a manuscript error (Vogelmann, EROS Data Center, U.S. Geological Survey, personal communication, 10 October 2001).

Table 1.—*Site Productivity Class (SITECLCD), approximate midpoint productivity value (SITECLMID), and resulting forest land use category for nonreserved forest land.*

SITECLCD	Cubic feet/ acre/year	SITECLMID	Forest land use
1	225+	225.0	Timber land
2	165–224	195.0	Timber land
3	120–164	142.5	Timber land
4	85–119	102.5	Timber land
5	50–84	67.5	Timber land
6	20–49	35.0	Timber land
7	0–19	10.0	Other forest land

forested and nonforested conditions, or when forested conditions did not contain trees of suitable size from which to determine site productivity, and this resulted in a no data value for SITECLCD. Excluded from analyses were condition records having SITECLCD values of -1 or 0 (not recorded or no data, respectively), or CONDPROP values of 0. Plot location accuracy was determined by spatially joining plot locations to a geospatial data set of county boundaries (ESRI Data & Maps 2002) and comparing county Federal Information Processing Standards codes between plots and county boundaries, and a subset of plots with erroneous location coordinates were excluded from analyses.

Spatial interpolation of site productivity was performed using the ArcGIS Geostatistical Analyst software package and the Inverse Distance Weighted (IDW) interpolator, with 75 percent of plot observations used for training data and 25 percent for test data. Analyses using IDW interpolations with power levels 1 (IDW), 2 (IDW^2), and 3 (IDW^3) resulted in mean prediction error and root mean square error values, respectively, of 0.3422 and 31.07 for IDW; 0.2665 and 32.15 for IDW^2; and 0.2198 and 33.76 for IDW^3. Subsequent analyses included only the IDW interpolation, which was converted to an ArcInfo GRID with 250-m spatial resolution and was masked to exclude areas outside of CONUS. Pixels with interpolated site productivity values greater than 20 ft^3/ac were considered to meet the criteria for the definition of timberland, given that such land is forested and is not reserved.

Forest Land Reserved Status

A suite of land ownership and protection categories is included in Gap Analysis Program (GAP) State maps. The Conservation Biology Institute aggregated the State GAP map products and other sources of geospatial data into a comprehensive North American data set known as the Protected Areas Database (PAD) (DellaSala *et al.* 2001). Version 3 of the PAD (PAD 2005) was used in this study for differentiating reserved from nonreserved lands. The PAD includes two designations of land protection status: (1) GAP codes and (2) Categories for Conservation Management as defined by the International Union for the Conservation of Nature (IUCN) (appendix B). Based on local knowledge and preliminary assessments, IUCN categories I–V (appendix B) were defined as representing reserved lands, and selecting them resulted in a subset of 37,844 reserved land polygons from the 345,861 PAD polygons within CONUS. Areas within CONUS not designated as reserved according to the PAD data were defined as nonreserved lands. Polygons representing reserved and nonreserved lands were rasterized to a 250-m resolution data set for ease of integration with other data layers.

Geospatial Analysis

ArcGIS software was used to combine the geospatial data sets of NLCD forest/nonforest classes, interpolated site productivity values, and PAD reserved land into a single raster layer. Using these three geospatial data sets and the criteria defined in figure 1, a new data set was attributed with categories of timberland, reserved forest land, other forest land, and nonforest land. Per-State pixel counts and resulting area estimates of each land use category were summarized by intersecting a geospatial data set of detailed State boundaries.

Statewide RPA estimates of forest land, timber land, reserved forest land, and other forest land were compared with modeled geospatial estimates to produce area weighted root mean square deviations (RMSD) using methods derived by Häme *et al.* (2001):

$$RMSD_{rs} = \sqrt{\sum_i \frac{a_i}{A}\left(\hat{p}_{ir} - \hat{p}_{is}\right)^2} \qquad (2)$$

where a_i is the area of the i[th] state, A is the total area across CONUS (sum of a_i s for all states), and $\hat{p}_{ir}$ and $\hat{p}_{is}$ denote the estimated proportion of forest land, timber land, reserved forest land, or other forest land area in the i[th] state obtained from the RPA (*r*) and modeled (*s*) estimates.

Results

The map of CONUS timber land, reserved forest land, other forest land, and nonforest land (fig. 2) revealed local spatial distributions of forest land subcategories. Although areas of reserved forest land are evident across CONUS, the largest blocks are most prevalent in the Western United States, where national parks and wilderness areas are more abundant. In nonreserved areas, most forest land is portrayed as timberland, except for arid portions of Southwestern United States, where site productivity values are lower. Compared with RPA estimates of CONUS forest land use, map based area estimates were 1 percent lower for forest land, 8 percent higher for timberland, 12 percent higher for reserved forest land, and 58 percent lower for other forest land (fig. 3). The comparison between map and RPA statewide estimates resulted in largest area-weighted RMSDs for forest land and other forest land; reserved forest land had the smallest RMSD (fig. 4).

Figure 2.—*Conterminous United States map of nonforest (white) and forest land subcategories: timber land (light gray), reserved forest land (medium gray), and other forest land (black).*

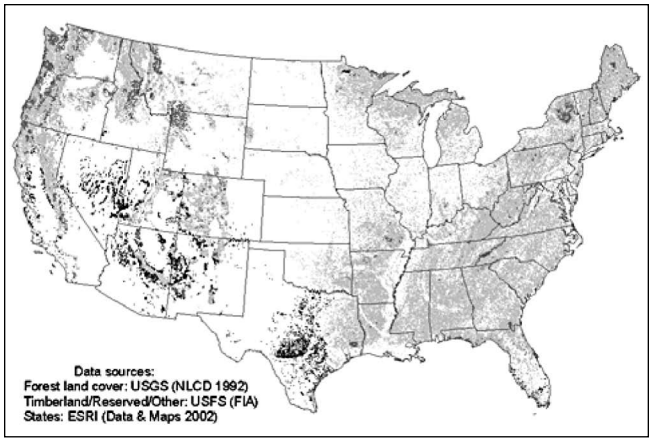
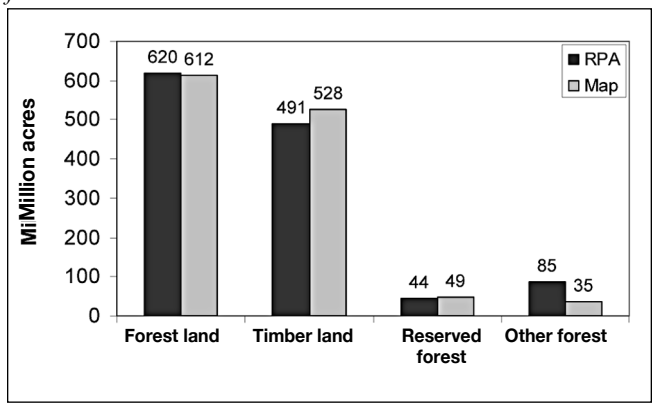
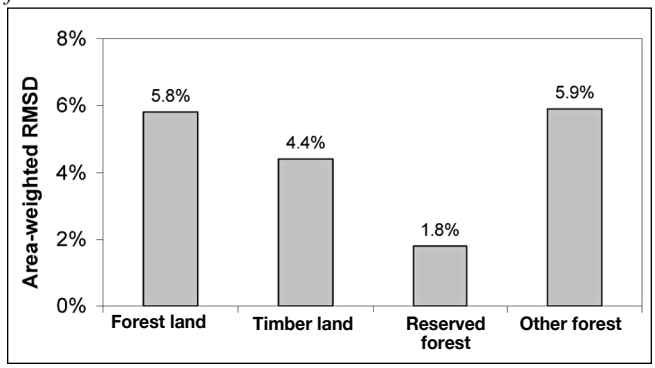


Figure 3.—*Comparison of RPA-based and map-based area estimates of conterminous United States forest land and three subcategories: timber land, reserved forest land, and other forest land.*



RPA = Forest and Rangeland Renewable Resources Planning Act of 1974.

Figure 4.—*Area-weighted root mean square deviations between RPA-based and map-based statewide area estimates of conterminous United States forest land and three subcategories: timber land, reserved forest land, and other forest land.*



RPA = Forest and Rangeland Renewable Resources Planning Act of 1974; RSMD = root mean square deviations.

Discussion

The NLCD-based estimate of CONUS forest land area was about 1 percent less than the RPA inventory estimate, but per-State estimates differed by wider margins, and had an RMSD of 5.8 percent. Inclusion of the NLCD "transitional" class may have offset some of the expected differences between forest land use (e.g., RPA) and forest land cover (e.g., NLCD), because the "transitional" class includes forest clearcuts and

other areas of forest regeneration not typically recognized by satellite imagery as forest cover. Differences between modeled estimates and RPA estimates of CONUS timberland and reserved forest land were moderately larger than for forest land, but RMSDs were smaller (fig. 3, fig. 4). The modeled estimate of other forest land was 59 percent smaller than the RPA estimate, and the RMSD for other forest land was the largest of any forest category at 5.9 percent. Reserved forest land, however, appears to be represented adequately using PAD 2001 IUCN Categories I–V when combined with the NLCD forest/nonforest data set.

Interpolation of forest site productivity, using RPA plot data with public coordinates and IDW, lead to overestimation of productive forest land (site productivity classes 1–6) and underestimation of unproductive forest land (class 7). At least two factors could have contributed to this bias. First, the NLCD data set used for representing forest land appears to under-represent RPA estimates of forest land on unproductive sites. In six arid Southwestern States, more than 10 percent of all forest land is considered other forest land. The RPA estimates of other forest land were Arizona (20 percent), California (16 percent), Colorado (11 percent), Nevada (13 percent), New Mexico (14 percent), and Utah (19 percent). NLCD-based estimates of total forest land in these six States were 12–38 percent lower than RPA estimates (Nelson *et al*. 2005). In contrast, NLCD-based estimates of total forest land were 10–61 percent greater than RPA estimates in States where other forest land comprised less than 5 percent (often less than 1 percent) of all forest land. Second, the use of RPA productivity class midpoints may not be representative of the distribution of productivity within each class range. One or both of the midpoints from the two least productive classes may be too large. For example, a hypothetical interpolation of plots equally distributed among only these two classes—midpoint 10 for the 10 to19 class, and midpoint 35 for the 20 to 49 class—would produce mean a site productivity value of about 22.5 ft^3/ac, which is greater than the timberland threshold of minimum productivity (20 ft^3/ac).

Conclusions

Currently available land cover and land use data provide a basis for mapping FIA attributes, but additional assessment of forest cover mapping is recommended, especially in areas of lower site productivity. Specifically, work is needed to improve geospatial data sets of forest site productivity. Future approaches may include optimizing class midpoints and incorporating other geospatial data sets, such as ecological units or topographic information. Work is ongoing to improve mapping of land use versus land cover and forest cover versus tree cover.

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Appendixes

Appendix A.—*Forest Inventory and Analysis definitions of forest land use; from glossary of Bechtold and Patterson (2005).*

forest (forest land). Land that is at least 10 percent stocked by forest trees of any size, or land formerly having such tree cover, and not currently developed for a nonforest use. The minimum area for classification as forest land is 1 ac. Roadside, streamside, and shelterbelt strips of timber must be at least 120-ft wide to qualify as forest land. Unimproved roads and trails, streams and other bodies of water, or natural clearings in forested areas are classified as forest, if less than 120 ft in width or 1 ac in size. Grazed woodlands, reverting fields, and pastures that are not actively maintained are included if the above qualifications are satisfied. Forest land includes three subcategories: timberland, reserved forest land, and other forest land.

nonforest. Areas defined as nonforest land, census water, or noncensus water.

other forest land. Forest land other than timberland and reserved forest land. It includes available and reserved low-productivity forest land, which is incapable of producing 20 cubic ft of growing stock per acre annually under natural conditions because of adverse site conditions such as sterile soil, dry climate, poor drainage, high elevation, steepness, or rockiness.

reserved forest land. Land permanently reserved from wood products utilization through statute or administrative designation.

timber land. Forest land that is producing or capable of producing in excess of 20 cubic ft per acre per year of wood at culmination of mean annual increment. Timber land excludes reserved forest lands.

Appendix B.—*Categories for Conservation Management, International Union for the Conservation of Nature.*

I. Strict nature reserve/Wilderness area.
II. National Park.
III. Natural Monument.
IV. Habitat/Species Management Area.
V. Protected Landscape/Seascape.
VI. Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems.