A 30-METER SPATIAL DATABASE FOR THE NATION'S FORESTS

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ABSTRACT.—The FIA vision for remote sensing originated in 1992 with the Blue Ribbon Panel on FIA, and it has since evolved into an ambitious performance target for 2003. FIA is joining a consortium of Federal agencies to map the Nation's land cover. FIA field data will help produce a seamless, standardized, national geospatial database for forests at the scale of 30-m Landsat pixels. This database includes classifications of forest types, estimates of percent tree cover, and other land attributes that can be used in geospatial models for large-area assessments. Mapping of more detailed forest conditions is feasible.

EVOLUTION OF A VISION

Today's vision for operational remote sensing in the Forest Inventory and Analysis[2] (FIA) Program began 10 years ago with the First Blue Ribbon Panel[3] on FIA (AFPA 1992). The panel included national leaders from all sectors of the forestry community. In its report, the panel recommended that FIA implement satellite remote sensing to improve cost-effectiveness and that FIA should have a "preeminent position in all federal efforts to inventory and monitor forest resource conditions at the regional and national levels."

In 1997, the Office of Science and Technology Policy[4] developed a framework for the Nation's environmental inventory and monitoring programs, including FIA (CENR 1997). In its report, the office noted that existing programs are based on conflicting definitions and methods that constrain the availability and affordability of geospatial data for the Nation. Rather, these programs need to "be conducted in a coordinated fashion and provide the types of integration that have so far been unachieved."

The following year, the FIA Blue Ribbon Panel[5] issued its second report (AFPA 1998). The panel recommended that FIA produce more timely and consistent information by converting to an annual forest inventory system, which would require development of new and expanded remote sensing technologies. In its report, the panel recommended that FIA should prepare a vision for operational remote sensing, create an extensive Web site containing forest maps produced by FIA, use remote sensing to improve areal estimates of forest cover for small geographic areas, and collaborate with other agencies in remote sensing endeavors. The report includes an unusually strong criticism: "FIA has been unable, for a variety of reasons, to demonstrate the leadership that was called for by the first Blue Ribbon Panel: 'FIA should also have a preeminent position in all federal efforts to inventory and monitor forest resource conditions at the regional and national levels.'" The panel asked FIA to develop a set of performance-based measures[5] with timetables and periodic assessments to evaluate achievement.

Later that same year, the 1998 Farm Bill[6] directed the Secretary of Agriculture to transform the FIA program into an annual forest inventory and monitoring system. Congress also required development of a detailed strategic plan that describes the process for employing remote sensing in FIA.

After issuing its national framework[4] for environmental monitoring (CENR 1997), the Office of Science and Technology Policy commissioned the RAND Corporation to analyze operational capabilities in the U.S. for remote sensing in forestry[7]. The resulting report by Peterson and others (1999) acknowledges the importance of FIA as the Nation's premier program for forest inventory and

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[2] http://fia.fs.fed.us/

[3] http://fia.fs.fed.us/library/bluerib.pdf

[4] http://www.epa.gov/cludygxb/Pubs/framewrk.wp5

[5] http://fia.fs.fed.us/library/brp2.htm

[6] Agriculture Research, Extension, and Education Reform Act of 1998, Public Law 105-185, http://www.reeusda.gov/1700/legis/areera.htm#s253

[7] http://www.rand.org/publications/MR/MR1111.0/

monitoring with ground measurements. However, RAND found a "widespread perception that existing efforts and capabilities for monitoring...America's forest resources are failing to meet increasingly complex and broad-scale forest management needs." RAND went on to note that national assessments for the Government Performance and Results Act[8], the Montreal Criteria and Indicators, and other international initiatives require a "more ambitious and qualitatively different measurement system than currently exists." According to RAND, institutional barriers slow the development of this system, and significant institutional changes are needed. RAND specifically identified improvements through better management and integration of existing programs, such as FIA, the Gap Analysis Program[9] (GAP), the National Resources Inventory[10], and the Multi-Resolution Land Characteristics[11] (MRLC) program. RAND suggested that use of remote sensing by FIA for stratification is likely to stimulate operational applications of remote sensing to other forest monitoring efforts, and basic classification of forest conditions with remotely sensed data would offer significant opportunities for coordination, integration, and cost-sharing among Federal programs. RAND concluded that Federal authorities must make a long-term commitment to ensure that forest conditions be periodically mapped by FIA and MRLC using consistent methods.

Later that year, Van Deusen and others (1999) gave a users' perspective on the role of remote sensing in the annual FIA system. They reaffirmed the importance of FIA field plots as ground truth for remote sensing and precise measurements of tree and stand attributes. However, they predicted "today's system of placing one plot every...6,000 acres and making little use of satellite remote sensing will seem extravagant in the future." They suggested that progress is hindered by the lack of an FIA vision for operational remote sensing. Such a vision might lead to "radical changes in the FIA system and yield significant improvements in information quality and cost-effectiveness."

In 2000, the national FIA program articulated this vision for operational use of satellite remote sensing (Guldin 2000)[12].

The FIA vision is deeply rooted in recommendations from the Second Blue Ribbon Panel[5] (AFPA 1998) and the national technology assessment conducted by RAND[7] (Peterson and others 1999). Guldin emphasized the emerging importance of geospatial data: "the key analytical outputs today are maps, map layers, or other spatial representations of information and complex (spatial) models." This is a paradigm shift for FIA, in which new geospatial products join with traditional FIA statistical products for the comprehensive inventory and analysis of the Nation's forests and rangelands. FIA will use remote sensing technologies not only to improve statistical efficiency through stratification, but also to map the Nation's forest conditions in support of broad-scale geospatial analyses.

Guldin also offered an ambitious performance target for implementation of this vision: FIA will complete the transition to satellite imagery by the end of 2003. Specifically, FIA will rely on satellite imagery to produce area estimates, including estimates for small geographic areas; produce accurate, high resolution, remotely sensed maps of forest attributes; and enable a wide variety of spatial analyses by linking satellite imagery to the spatial data in the FIA database. FIA will map 15 to 20 major forest cover types at the national to regional levels. Further refinements may be important below the regional level. The image processing process will be highly automated to reduce cost. High-resolution geospatial data from other sources will improve geospatial modeling and accuracy assessments. Small-area models will interpolate FIA ground data for each 30-m pixel using techniques such as the "k-Nearest Neighbor" method (e.g., McRoberts and others, this volume). This vision includes the capability to combine data from various programs to more effectively answer a much broader range of analyses than any agency could achieve alone. The outcome will be consistent, multi-scale geospatial data for all parts of the U.S.

EVOLUTION OF A PARTNERSHIP

In 1992, the USGS EROS Data Center (EDC) helped form a national consortium of Federal programs to build a library of Landsat-5 imagery that covers the U.S. This Multi-Resolution Land Characteristics[13] (MRLC) consortium includes the EPA Environmental Monitoring and Assessment Program[14] and

[8] http://www.fs.fed.us/plan/

[9] http://www.gap.uidaho.edu/

[10] http://www.nhq.nrcs.usda.gov/NRI/

[11] http://landcover.usgs.gov/natllandcover.html

[12] http://fia.fs.fed.us/library/RS2000.rtf

[13] http://edcwww.cr.usgs.gov/glis/hyper/guide/old_mrlc

[14] http://www.epa.gov/emap/index.html

the North American Landscape Characteristics[15] Project; the USGS National Water-Quality Assessment Program[16] and GAP Program[9]; the NOAA Coastal Change Analysis Program[17] (C-CAP); and the USDA Forest Service. The consortium purchased 680 Landsat scenes for the conterminous U.S.[13].

In 1995, EDC facilitated a second cost-sharing partnership to produce the National Land Cover Dataset[13] (NLCD-1992). NLCD-1992 is a set of consistent land cover maps at 30-m spatial resolution for the entire Nation (Vogelmann and others 2001). NLCD-1992 is derived from Landsat-5 scenes for approximately 1992 that were purchased by the MRLC consortium[13]. The NLCD partnership serves business needs for three consortium members: EDC, EPA[14], and NOAA[17]. NLCD-1992 replaces the land use and land cover maps developed by USGS in the 1970s and 1980s from high-altitude aerial photography.

At 30-m spatial resolution, NLCD supports geospatial analyses that require more spatial detail than coarse-scale global datasets (e.g., 1-km spatial resolution of the AVHRR satellite) but that extend across broad geographic areas that are too large to practically process with very fine-scale datasets (e.g., 4-m or less spatial resolution). Suitable uses for NLCD can include broad-area assessments and national analyses of wildlife habitat, wildfire hazards, priorities for forest fuel treatments, risks from insects and disease impacts to forests, landscape patterns, and ecosystem health (Vogelmann and others 2001). Analyses for a small area (e.g., a county) are not recommended with NLCD because it is nearly impossible to ensure sufficient accuracy of a national product for each local area. Errors in NLCD at the local level can “average out” when analyzing larger areas, without major distortions to broad-scale spatial patterns.

NLCD uses 21 classes of land cover based on the Anderson Level II[18] and C-CAP systems[17]. Upland forest is separated into deciduous, evergreen, and mixed forest. There are categories for woody wetlands, shrublands, and grasslands; two water classes; three barren classes; three urban classes; six agricultural classes; and an emergent wetland class. At this level of detail, classification accuracy is around 60 percent but increases to 80 percent for aggregations of land types to Anderson Level I[19] (Yang and others 2001). Modifying the spatial resolution from a 30-m pixel to a larger element (e.g., a 3 X 3 pixel cluster) also improves accuracy.

Soon after completion of NLCD-1992, FIA scientists began comparing NLCD products to other remote sensing alternatives for stratification of FIA plots. In the Northeast, Hoppus and others (this volume) and Hoppus and Lister (this volume) report that NLCD-1992 produces statistical efficiencies nearly identical to the alternatives. Wayman and others (2001) find there are no significant differences in accuracy between NLCD data and alternative Landsat products, although traditional FIA photointerpretation is more accurate and produces more precise statistics. Dunham and others (2003) report that NLCD is very efficient because development costs are divided among many agencies. In the Pacific Northwest, Dunham and others (this volume) find that stratification based on NLCD sacrifices little precision in inventory estimates, although no alternative, including traditional FIA photointerpretation, completely satisfies FIA targets for statistical precision. At the same time, FIA began to work with other agencies to use NLCD-1992 to build a national geospatial database containing indicators of landscape conditions, including spatial patterns of forest cover (Riitters and others 2000)[20]. These are useful in large-area ecological assessments and national-scale modeling of biogeographic and socio-economic phenomena.

In 1999, NASA launched Landsat-7. Its new Enhanced Thematic Mapper (ETM+) is a substantial technological advancement (Goward and others 2001) over Landsat-5, which was the basis for NLCD-1992. Almost immediately, the MRLC-2000[21] consortium formed to share costs for a new collection of Landsat-7 imagery. Based on experiences with NLCD-1992, EDC made significant improvements to MRLC-2000 procurement specifications. Three seasons of imagery are being selected for every path/row: early season (green up), peak greenness (summer), and late season

[15] http://www.epa.gov/nerlesd1/land-sci/north-am.htm

[16] http://water.usgs.gov/nawqa/

[17] http://www.csc.noaa.gov/crs/ccap_index.html

[18] http://landcover.usgs.gov/classes.html

[19] Forest, water, urban, barren land, agricultural land, wetland, and rangeland

[20] http://www.srs.fs.fed.us/4803/landscapes/index.html and http://www.esapubs.org/archive/ecol/E081/004/metadata.htm

[21] http://edcw2ks15.cr.usgs.gov/lccp/mrlc2k/mrlc2k.asp

(brown up). Target dates for each image are optimized based on analyses[22] of AVHRR bi-weekly data and NLCD-1992. MRLC-2000 data are terrain-corrected and re-sampled for an average registration accuracy of 1-pixel, which expedites overlays of MLRC and NLCD products for 1992 and 2000. Data are available to any partner agency for $45 per CD without restrictions for non-commercial applications[21]. FIA joined the consortium in 2001.

At that same time, land cover maps from NLCD-1992 were quickly becoming outdated; technologies for land cover classification had improved; and the transition by FIA to annual surveys improved the value of FIA ground plots as training sites and accuracy assessment data for remote sensing. EDC approached potential Federal partners to build NLCD-2000 based on new Landsat-7 data. NLCD-2000 includes radiometric calibrations[22] that provide seamless data across scenes. NLCD-2000 uses regression models that predict tree canopy density from Landsat data; 1-m resolution satellite data are used to develop these regression models. NLCD produces an index of spatial texture that uses spectral variability among contiguous pixels, and NLCD uses image segmentation to produce additional indices that describe land cover patterns (McGarigal and Marks 1995, Gustafson 1998). A 30-m Digital Elevation Model provides information on elevation, aspect, slope, and position of the pixel on the slope. National STATSGO soil maps supply coarse-scale indices of available water capacity, soil organic carbon, texture, and depth. All of these ancillary data help separate different land cover types that have similar spectral signatures. While NLCD-1992 produced only a national map of land cover, NLCD-2000 will provide a nationwide geospatial database for land cover and forest type classifications plus the ancillary geospatial data used to build those classifications.

Early in 2001, a team of FIA and EDC scientists began testing the value of FIA plots as training data for NLCD-2000. Chengquan and others (this volume) report results for study areas in the east coast and the Rocky Mountain regions. They found that FIA plot data are useful for training data and accuracy assessments. They separated forest from nonforest cover with 80-90 percent accuracy; deciduous, evergreen, and mixed forest with 79-83 percent accuracy; and achieved 66 percent overall accuracy for more detailed forest types[23]. They conclude that FIA plot data can substantially improve efficiency, accuracy, and consistency. FIA field plots also statistically describe the composition of each forested map class in a broad region (e.g., distribution of stem densities by tree species and size class; median crown bulk density; range of stand ages; average wood volume per acre; average tree mortality rates; average fuel loading; and so on).

In 2002, FIA recognized that joining the NLCD-2000 consortium could help FIA reach its performance target for operational remote sensing. The extensive mapping infrastructure already developed at EDC could become the Nation's "assembly line" for remotely sensed maps of forest conditions, and FIA could share the $10 million cost of NLCD-2000 with other consortium members. This would allow FIA to serve a much broader range of spatial analyses in forestry than it could accomplish alone.

BENEFITS TO FIA CUSTOMERS

The Forest Service and other agencies conduct broad-area assessments using geospatial models that require data with fine spatial resolution. Current assessments are constrained by lack of consistent fine-resolution geospatial data that cover entire provinces, multiple states, and the Nation. NLCD-2000 will improve this situation because it will contain nationally consistent data on land cover and forest conditions, terrain, soils, climate, and potential natural vegetation. These data themes are at the core of many geospatial models for forest lands. For example, when the Western Governors' Association (2001) released its national strategy[24] to address catastrophic wildfires, new geospatial models were needed to assess communities at risk; current vegetative conditions with respect to likelihood of severe wildland fire; and threats to local economies, key habitats, air quality, and water quality (e.g., post-fire erosion). Such broad-scale analyses identify high-priority geographic areas

[22] http://landcover.usgs.gov/publications.html

[23] This level of classification detail meets the FIA vision for remote sensing (Guldin 2000); detailed forest types for mapping included spruce/fir, loblolly & shortleaf pine, oak/pine, oak/hickory, oak/gum/cypress, elm/ash/red maple (i.e., six types) in the mid-Atlantic region; and pinyon/juniper, Douglas-fir, ponderosa pine, fir/spruce/mountain hemlock, lodgepole pine, other western softwoods, aspen/birch, western oak, other western hardwoods (i.e., nine types) the Rocky Mountains.

[24] http://www.westgov.org/wga/initiatives/fire/

for more intensive analysis and management. As inputs to those models, the geospatial database must have detailed maps for vegetation type, forest structural-stage, stand density, and other physiographic and ecological attributes. FIA participation in NLCD-2000 could increase quality of such data, and thus indirectly improve the cost-effectiveness of reducing wildland fire risks to communities and the environment.

FIA plot data could increase the value of NLCD-2000 to other Federal efforts that use geospatial data on forest conditions to predict risks from insects and diseases, habitat suitability, and other forestry applications. FIA could use its ground data with remotely sensed data to map more detailed attributes of forest stands, such as 30 to 50 different forest types, stand density, stand structure, and potential fuel loading. This could be accomplished with statistical techniques such as the "k-Nearest Neighbor" procedure discussed by Guldin (2000) and illustrated by McRoberts and others (this volume). Other programs would not have access to FIA plot coordinates, but they would have access to high-quality, detailed maps of forest conditions that were produced with FIA ground plots. The responsibility of FIA would end at the production of forest condition maps, and other programs would assume responsibility for application of those maps in their own analyses and management decisions. As the value of NLCD-2000 products increases, so does the motivation for more partners to share costs. This improves program efficiency, product delivery, and data consistency for each partner. Potential partners include State agencies, the USDA National Resources Inventory[10], EPA[14,15], NOAA[17], and other USGS programs[9,16].

NLCD is optimized for broad-area assessments, ranging from provincial to national levels. This does not reduce the importance of specialized geospatial products for "local" areas (e.g., a national forest). Local products are optimized to satisfy local analysis requirements; they benefit from local knowledge and acceptance; and they are less prone to confounding variability across space and Landsat scene dates. Since management decisions occur at all spatial scales, an integrated system should be developed that allows for multi-scale analysis. Local decisions need to be analyzed within a broader geographic context. The database philosophy adopted in NLCD-2000 allows local users to derive land cover products tailored to their specific applications[25], and local users can identify cases in which a national product needs improvements in certain locations. However, further integration is possible.

RISKS TO THE FIA PROGRAM

While a partnership with the NLCD-2000 consortium directly serves FIA objectives, there are also risks. The primary value of FIA plots for remote sensing operations is automated "training" of digital statistical algorithms. These algorithms are the basis for statistical prediction of forest conditions in each pixel. Exact coordinates of each FIA ground plot are used to accurately register that plot to its corresponding cluster of Landsat pixels. Those coordinates must be stored at EDC because FIA does not have sufficient infrastructure to process such massive geospatial datasets. However, disclosure[26] of exact FIA plot coordinates is controlled under the Food Security Act of 1985 (as amended) to protect landowner privacy, guard the long-term integrity of the FIA ground sample, and maintain the FIA reputation for providing unbiased information. FIA has never shared with any external partner the exact coordinates for all 120,000 forested FIA ground plots in the USA. If EDC were to disclose those coordinates, then the very foundation of the national FIA program could crumble. This dire consequence, even if very unlikely, poses great risks to FIA. However, there are techniques to manage those risks. An FIA scientist stationed at EDC could monitor security of FIA coordinates. The amount of FIA data residing in EDC at any one time could be minimized. FIA coordinates could be immediately purged from the EDC database when no longer needed in the production process. A culture and code of ethics could be fostered at EDC that recognizes their obligations as "duly authorized agents" of the FIA program under its privacy and confidentiality policy[26]. A formal agreement between FIA and EDC could precisely specify roles, responsibilities, authorities, and expectations of each partner.

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[25] http://landcover.usgs.gov/natlandcover_2000.html

[26] By law, any person who publicly discloses exact coordinates of FIA plots will be fined not more than $10,000 or imprisoned for not more than 1 year, or both. http://fia.fs.fed.us/library/privacy.htm

THE DECISION

In January 2002, FIA decided, in principle, to join the NLCD-2000 consortium and use FIA ground plots to improve mapping of 15 to 20 forest types across the Nation. This begins the operational remote sensing component of FIA, thus accomplishing its 2003 performance target. As the benefits of this strategy materialize, FIA may expand its suite of remotely sensed products to include forest structure, volume, and other important forest attributes. Now, FIA has a preeminent role in the comprehensive mapping and analysis of the America's forests. Preeminence does not connote dominance, but it does mean an essential role within a multi-agency team that shares resources and creates a superior product for the Nation.

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