CHAPTER 7

APPLICATIONS OF NATIONAL LAND COVER MAPS IN UNITED STATES FORESTRY

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ABSTRACT

Land cover maps derived from satellite imagery have a long and varied history of uses in United States forestry science and management. This article reviews recent developments concerning the use of national- to continental-scale land cover maps for inventory, monitoring, and resource assessment in the U.S. Forest Service. The use of mid-scale digital resolution information (from 10 to 30 meters) is ideal for many forest applications from stand exams to watershed assessments of numerous forest related attributes. Forest and landscape patterns can be meaningfully assessed at those spatial scales as well, and consistent national land cover maps are required for conducting consistent national assessments of forest patterns. National and continental strategies for land cover mapping should recognize that almost all forest inventory, monitoring, and assessment applications require map comparisons over time, and an ideal temporal frequency for most applications is no more than five years.

Key words: *forest, inventory, monitoring, pattern*

INTRODUCTION

Land cover maps derived from satellite imagery have a long and varied history of uses in United States forestry science and management. Here we review some recent developments and applications in landscape pattern assessment, and forest inventory and monitoring. While land cover maps of various heritage and scale are used from local to regional to national scales, we focus on national applications because that scale is most relevant to the conference discussion of continental-scale issues and opportunities.

LAND COVER PATTERN

Land cover pattern refers broadly to the spatial arrangement of different types of land cover. While some spatial relationships may be visually apparent, human perception of land cover pattern is subjective. Pattern analysis is needed not only to quantify those perceptions unambiguously, but also to discover patterns that are not apparent to the human eye. This section discusses why land cover pattern is important and highlights some recent applications of national land cover maps.

People care about land cover pattern for a variety of reasons. Society is informed in the popular press about land cover patterns through headline issues such as urban sprawl and forest fragmentation. Spatial ecologists care about pattern because the spatial arrangement of the environment affects the flows of matter, energy, and information across the landscape, thus impacting ecological processes. Resource managers consider land cover pattern because it affects the production of ecological goods and services; the same amount of a land cover can be arranged in different ways with consequences for biodiversity, water quality, recreation experience, and other amenities. Land use planners describe landscape context partly in terms of the land cover patterns that contribute to a "sense of place" for human occupation. Assessment scientists consider land cover pattern as a leading indicator in risk assessment; when landscape patterns change, the ecological and social processes embedded within landscapes change, putting goods and services at risk. In summary, there is a widespread appreciation that land cover pattern is an important environmental attribute.

Consistent national-scale assessments of land cover patterns require consistent land cover maps as input data, and these have become available only recently with the advent of satellite-based imaging systems. An early application of global maps for assessing patterns (Riitters et al. 2000a) utilized the relatively coarse-scale Global Land Cover Characteristics (GLCC) database derived from the advanced very high resolution radiometer (AVHRR) platform (Loveland et al. 2000) and later applications (Heilman et al. 2002; Riitters et al. 2002) have taken advantage of higher-resolution maps produced by the Multi-Resolution Land Characteristics Consortium (MRLC) and National Land Cover Dataset

(NLCD) programs from Thematic Mapper (TM) imagery (Vogelmann et al. 2001; Homer et al. 2004). The underlying TM imagery has also fueled more detailed sub-national land cover mapping efforts, for example by the GAP Analysis Program (GAP; Scott et al. 1996) and those efforts, in turn, can potentially be used to improve the interpretation of national-scale analyses (Riitters et al. 2003).

Extensive analyses of spatial patterns on the 1990s MRLC/NLCD national land cover map were prompted to report forest fragmentation statistics in national assessments including the 2000 RPA Assessment and Interim Update (USDA Forest Service 2001, 2007), the 2002 State of the Nation's Ecosystems (Heinz Center 2002), and the 2003 National Report on Sustainable Forests (USDA Forest Service 2004). The supporting studies concluded that while forest was typically well-connected and the dominant land cover where it occurred, fragmentation, perforation, and roads were so pervasive that most forest land was at risk from potential 'edge effects' extending only a hundred meters from forest edge (Heilman et al. 2002; Riitters et al. 2002, 2004a, 2004b).

Figure 1 illustrates how a relatively simple 'pattern primitive' (a fundamental aspect of pattern) can be interpreted with respect to forest fragmentation at national scale. The pattern primitive is defined as the percentage of forest in a fixed-area neighborhood surrounding a pixel of forest on the land cover map. The measurement of the primitive was repeated for each forest pixel and for different neighborhood sizes surrounding each forest pixel. The results were summarized according to the percentage of all forest pixels that were surrounded by neighborhoods containing 100% forest (solid line in Figure 1) and >60% forest (dashed line). Note that if forests were not fragmented, then the solid and dashed lines would be superimposed horizontally at the 100% level in Figure 1. Fragmentation is represented by the departure from that condition, and the Figure shows that as expected, apparent fragmentation is both scale- and threshold-dependent. From the circled point on the dashed line, we can infer that forest is dominant where it occurs – 70% of all forest occurs in landscapes that are >60% forested within 50 km^2. From the circled point on the solid line, we can infer that fragmentation is pervasive – 50% of all forest is within 90 meters of forest edge (to see this, note there is a correspondence between the largest window that contains 100% forest and the minimum distance to forest edge).

A classical analysis of land cover pattern starts with the definition of analysis units such as counties

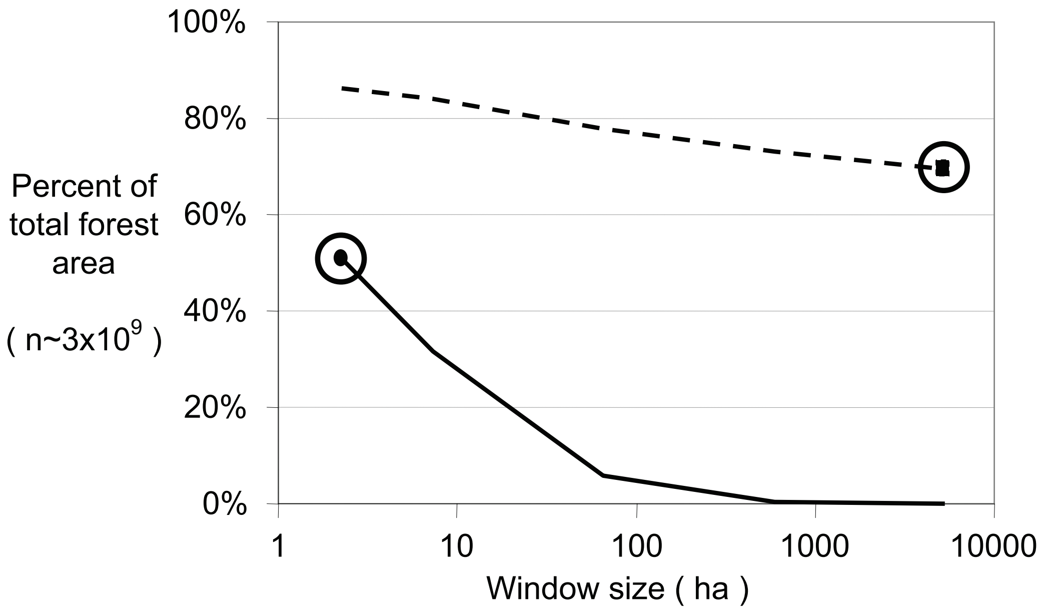

Figure 1. An example of interpreting the pattern primitive of percentage forest in moving windows of different sizes. See text for explanation. The sample size is approximately 3 x 10^9 pixels per plotted point.

or ecoregions, and patterns are then measured within each of those units. In that approach, a different analysis must be carried out for each different way of defining analysis units, for example as watersheds or as counties. In contrast, our applications have mapped pattern primitives at the pixel level, which preserves options for aggregating results to different analysis units such as watersheds or counties without having to repeat the analysis of pattern. In addition, it facilitates overlay with other maps to address more detailed questions. For example, the map of the pattern primitive described above can be aggregated over sub-national geographic extents to evaluate local forest spatial patterns (Riitters 2005), combined with forest type maps to evaluate the fragmentation context of different forest types (Riitters et al. 2003), or combined with road maps to evaluate the fragmenting effects of roads on forests (Riitters et al. 2004b). The use of pixel-level pattern primitives alleviates some of the problems associated with classical patch-based approaches to spatial pattern measurement on land cover maps (Riitters et al. 2004a, b).

Several pixel-level pattern primitives can be combined to better define land cover patterns and to address more complicated assessment questions. For example, if a second pattern primitive is defined as forest connectivity (roughly, the probability that a pixel next to a forest pixel is also forest), and evaluated in the same neighborhoods, the two primitives together differentiate among types of fragmentation (Riitters et al. 2000a) which exhibit substantial geographic variance and clustering (Riitters and Coulston 2005). Similarly-defined pattern primitives for other land cover types can be used to highlight the proximate causes (e.g., agriculture, urbanization) of forest fragmentation (Wade et al. 2003).

Riitters et al. (2000b) suggested that a database of land cover pattern primitives could facilitate integration of pattern information among ecological research and assessment projects. While common usage of a pattern database cannot guarantee integration among studies, the alternative of having each study conduct a separate pattern analysis is unlikely to achieve any meaningful integration because analyses rarely use identical protocols. The “National Land Cover Pattern Database” has been distributed on the internet since 2002 as a test of the concept.

One question posed by conference organizers was whether there are opportunities to leverage resources and avoid duplication. Experience shows that pattern analyses on land cover maps from remote sensing are usually duplicative and divergent – duplicative in the sense that analyses are repeated by different groups addressing a similar question, and divergent in the sense that such analyses are rarely similar enough to be strictly comparable across groups. Thus, there is an opportunity to leverage resources and avoid duplication by integrating some level of pattern analysis within the land cover database (Figure 2). Maps of land cover pattern primitives could be distributed with the land cover maps, obviating the need for duplicating some basic analyses and reducing divergence in some of the more advanced types of analyses.

INVENTORY AND MONITORING

There has always been a strong demand for timely, consistent, and reliable forest inventory and monitoring information of the type provided by the USDA Forest Service Forest Inventory and Analysis (FIA) and Forest Health Monitoring (FHM) programs. Recently the demand has been growing. Customers want more recent information, covering a broader scope of forest attributes, with more analysis and reporting and easier access to program databases. Many of these demands

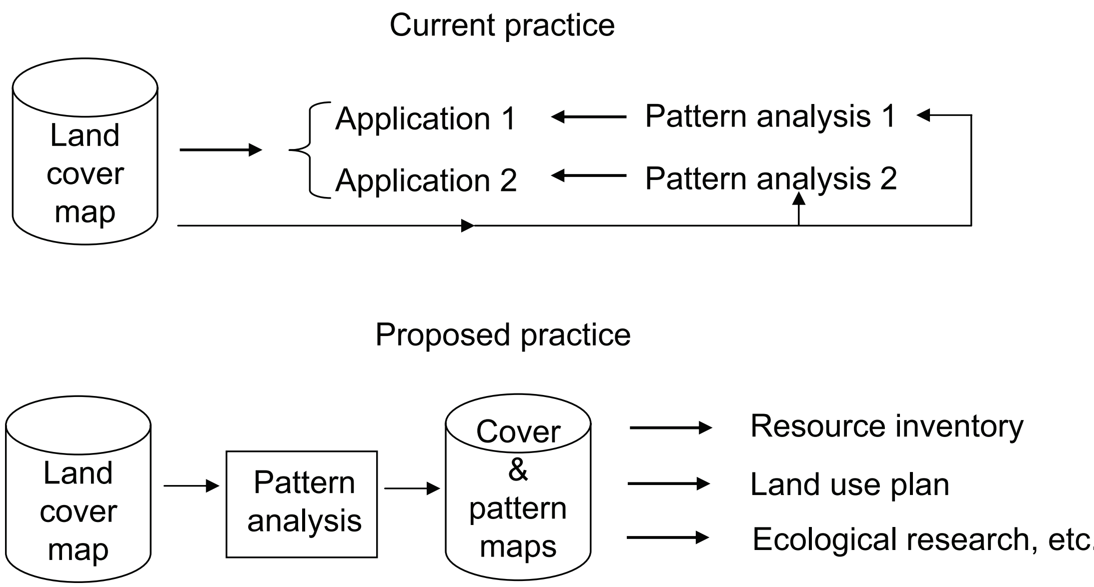

Figure 2. To avoid duplication or divergence of land cover pattern analysis (top: current practice), maps of land cover pattern could be integrated with the land cover map (bottom: proposed practice).

were expressed in the Agriculture Research, Extension, and Education Reform Act of 1998 (16 USC 1642(e)).

Collectively, the forest monitoring component of FIA provides a nationwide systematic sample of a wide array of measurements on forested ecosystems, which are used by a diverse set of customers for many purposes. For example, FIA data have been used to map habitat for endangered animal species, to identify areas of forest decline, and to track the effect of global change reflected in changing species distributions. In addition to producing a variety of reports and analyses at the state and regional level, information from the FIA forest monitoring program are publicly available through our online database (http://fia.fs.fed.us).

In response to needs for increased spatial and temporal resolution of forests, the USDA Forest Service has significantly enhanced the FIA program by changing from a periodic survey to an annual survey, by increasing the capacity to analyze and publish data, and by merging the FIA and FHM plots into a single three-tiered (or three-phase) FIA system. Phase 1 is the remote sensing activity used to characterize the spatial arrangement and ultimately the area of forest and non-forest land in the US. Phase 2 is the traditional FIA ground plots that focus on forest and tree information as it relates to timber and non-timber attributes. There is a Phase 2 field sample site for every 6,000 acres of forest, where field crews collect data on forest type, site attributes, tree species, tree size, and overall tree condition. FIA currently samples approximately 200 tree- and forest-related attributes at each Phase 2 sample point. Phase 3 consists of a subset of Phase 2 sample plots which are measured for a broader suite of forest health attributes including tree crown conditions, lichen community composition, understory vegetation, woody debris on the forest floor, and soil attributes including a laboratory chemical analysis. Finally, an associated sample scheme exists to detect cases of ozone damage.

In 1999, FIA integrated forest health monitoring (FHM) indicators into the Phase 3 (P3) subsample of the P2 plots. There are approximately 8,000 forested P3 sample plots in the United States where detailed health data are collected, roughly one for every 96,000 acres of forest. P3 plots are co-located with P2 (Phase 2) plots at approximately every 16th P2 plot. The spatial pattern of the FIA sampling hexagons is illustrated in Figure 3 (Brand et al. 2000).

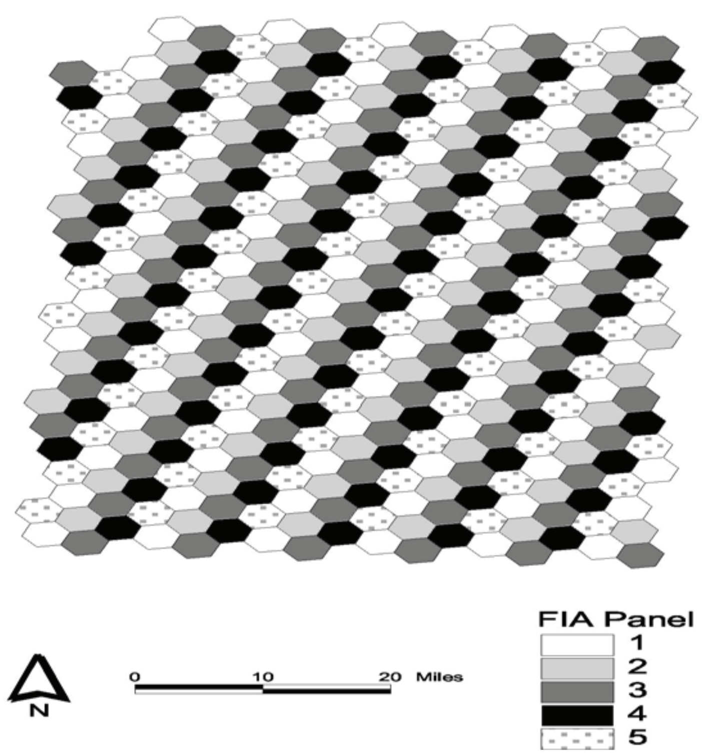

Figure 3. The assignment of FIA sampling hexagons to one of five annual panels.

Of special interest to this conference is that in 1999, FIA entered into a partnership with USGS and the EROS Data Center to provide the FIA ground plots as *in situ* ground samples for cover type model development, verification and accuracy assessment for NLCD 2001. The 1992 NLCD is a successful example of a national-scale digital land-cover database and map and is of value to FIA as an initial stratification layer of forest cover. The statistical efficiency gains from NLCD are profound. For example, using NLCD 1992 as an initial stratification of forest cover and subsequently using FIA databases on land use, FIA is able to show increases in relative efficiency of between 2 and 4 for the estimates of state forest inventories (Hansen 2001). This means that without the NLCD land cover information, that FIA would need to double or quadruple the number of FIA ground plots to meet the same precision standards.

The use of mid-scale digital resolution information of between 10 to 30 meters is ideal for many forest applications from stand exams to watershed assessments of numerous forest related attributes. For example, 30 meter resolution digital information like NLCD has been ideal for assessing the effects of urban sprawl, fire risk at the urban interface, watersheds and private forest lands at risk due to urbanization, pests such as southern pine beetle and emerald ash borer, habitat characterization for at-risk species, and the combined effects of all of these risks on timber and biomass supply. To assess the increasing fragmented landscape there is a need for frequently updated mid-scale resolution digital maps. Given the eventual research and development applications, it is not a stretch to say, that land cover map products are made most useful by integration of *in situ* sample data to increase both attribute and temporal resolution.

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