Development of Issue-relevant State Level Analyses of Fragmentation and Urbanization

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Abstract: There has been considerable research concerning the extent and effect of urbanization and fragmentation and the importance of monitoring current and potential magnitudes of change is recognized. However, there are limited guidelines for interpreting fragmentation data or for their application for analysis and statewide planning efforts. In this study we take a first step toward developing a state-level analysis of urbanization and fragmentation that addresses three categories of information. Example maps, tables, and analyses are drawn from New York, Maryland, and Delaware. Landscape metrics calculated from various regional or national datasets were chosen for their relevance to issues of interest and other traits such as accuracy and consistency. Examples of results include maps accompanied by graphic and tabular analyses addressing several landscape factors that are increasingly impacting forest resources and the ecosystem services and products they provide. Where published guidelines are available, results include management-relevant maps in which the metrics have been translated into impacts on stream water quality, interior bird species composition, and other processes. From these elements a prototype structure can be developed for reporting on the status of fragmentation and urbanization in a state and across the region so that we can better understand our forest resource in the context of its surrounding landscape and the status of changes in its natural, social, or economic ecology.

Keywords: Urbanization, forest fragmentation, landscape metrics, state forest assessments, FIA reports.

Introduction

Forest land is a significant factor in the protection of surface and groundwater quality and is a major component of many increasingly threatened wildlife habitats. Forest land is also a resource heavily relied upon by people for recreation, timber, and nontimber products, and for more intangibles, such as aesthetics and intrinsic value.

As human population growth continues, many areas of the country are seeing developed land uses expand, often at the expense of forest land (Hammer et al.

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In: McWilliams, Will; Moisen, Gretchen: Czaplewski, Ray, comps. 2009. 2008 Forest Inventory and Analysis (FIA) Symposium; October 21-23, 2008; Park City, UT. Proc. RMRS-P-56CD.Fort Collins, CO; U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 1 CD.

2007, Nowak and Walton 2005, Robles et al. 2008, Stein et al. 2006). In addition to losing forest land to development, remaining areas of forest land are currently under pressure in many regions in terms of both fragmentation — being divided up into smaller and more disconnected pieces; and urbanization —an increasing proximity to urban development, population, and other anthropogenic pressures. Fragmentation causes changes in light, wind, and moisture microclimates, all of which provide an avenue for the introduction and spread of invasive plant and animal species. Fragmentation also introduces barriers to the movement of native species and degradation of native habitats (e.g., Belisle et al. 2001, Burke and Nol 2000, Cam et al. 2000, Herrmann et al. 2005, Rosenberg et al. 2003).

Urban development in or near forests can change local hydrology, increase recreation pressures, alter native species diversity, provide vehicles for the introduction of invasive species either by design or by accident, and often bring significant disturbance to the area (e.g., Airola and Buchholz 1984, Bastin and Thomas 1999, Heckscher et al. 2000, Iida and Nakashizuka 1995, McDonnell and Pickett 1990, Rudnicky and McDonnell 1989). Together, fragmentation and urbanization cause a disruption of the flow of material through the forest ecosystem, affecting both forest health and sustainability (e.g., Macie and Hermansen 2002). Researchers have documented varied impacts of forest fragmentation and urbanization on the probability of commercial forest management and timber harvesting (Wear et al. 1999, Munn et al. 2002, Kline et al. 2004), and on water quantity and water quality (e.g. Hunsaker et al. 1992, McMahon and Cuffney, 2000, Riva-Murray et al. in prep).

Forest fragmentation and urbanization are also inextricably linked to the effects of climate change. Since the dispersal and movement of forest plants and animals are disrupted by forest fragmentation, impacts of climate change on species and diversity losses can be magnified (McDonnell and Pickett 1990, Rodenhouse et al. 2008). Similarly, systems already under pressure from urbanization and fragmentation will be less resistant to the additional stresses imposed by climate change.

With the increasing fragmentation and urbanization of our landscape (Hobbs and Stoops 2002), interest has grown in the location, type, and magnitude of its potential impacts. The U.S. Forest Service's Forest Inventory and Analysis program (FIA) has begun to address landscape context and change in its reports containing state-level forest inventory results. Information on forest distribution and context is crucial for monitoring and assessment efforts like the U.S. Forest Service State and Private Forestry's statewide assessments, U.S. Geological Survey's national water quality assessments, the U.S. Environmental Protection Agency's wadeable streams assessments, and regional forest assessments like those done in Oregon and Washington.

Metrics and Data Sources

Thus, FIA is being asked to monitor the distribution, urbanization, and fragmentation characteristics of the forest over time, just as we monitor the change in total forest land over time. To do this we must choose both metrics and the landscape data source(s) carefully.

Of all the fragmentation and urbanization metrics that could be calculated from the available data, it is important to identify a concise set of relevant, useful landscape metrics for fragmentation analyses. Avoiding redundant metrics (Riitters et al. 1995) and metric inconsistency over space and time (De Clercq et al. 2006) have been identified as useful ways to create a subset of potential landscape descriptors. When identifying useful metrics, insensitivity to both the spatial resolution and number of classes in the remotely sensed classification is desirable where monitoring over time is a goal (De Clercq et al. 2006). However, as De Clercq et al. (2006) and McAlpine and Eyre (2002) point out that in order to be truly useful for forest monitoring, individual metrics also need to be carefully chosen based on the particular questions being asked. In this study, we are interested in those landscape metrics that add value to the interpretation of forest inventory data because of their direct relationship to changes in the forest resource, our utilization of it, or its ability to provide ecosystem services and products. We have identified from the current literature accurate, consistent landscape descriptors and classification schemes (thresholds) that are most consistently related to forest ecological, social, or economic impacts of concern and can be more accurately and consistently calculated from available data sources.

The landscape data source used must also be carefully chosen because of its impact on both resulting values and interpretation of results (e.g., Riva-Murray et al. unpublished, and Riemann et al. in prep). Several studies have noted the impact of data source and have addressed this by applying different ‘corrections’ to the landscape dataset to more closely reflect conditions on the ground as they are typically seen by land managers or planners, or used by wildlife. For example, Heilman et al. (2002) included roads in their calculation of a forest intactness metric. Lister et al. (2005) removed patches smaller than a certain area and width to more closely match FIA definitions of forest land, and used local road density to relabel those forest or agriculture pixels in the 1992 National Land Cover Dataset (NLCD) dataset that were likely to be developed based on road density. In this study we have chosen to keep land cover and land use clearly separate, utilizing the 2001 NCLD for land cover, and U.S. Census-based datasets for factors relating to urban land uses, with a clear understanding of the development and limitations of each of these landscape datasets and any impacts on interpretation.

The goals of this paper are to:

- Provide a suite of reliable, interpretable, standardized fragmentation measures to authors and consumers of FIA state inventory reports
- Provide examples of how these measures can be added to state reports to enhance the interpretation of FIA forest inventory data and the understanding of the forest resource
- Describe briefly how these were derived from the best available landscape data sources, and provide links to complete metadata

The potential additions to state reports include maps, tables, and graphs that A) describe the current status of fragmentation and urbanization on forest land in general; B) begin to address its probable or potential impact; and C) combine landscape context information with data on FIA plots to characterize the forest affected.

Methods

Identifying Metrics to Use

We were specifically interested in interpretability of results with respect to impacts on the forest resource or on the forest's ability to provide ecosystem services and products. To be able to monitor over time and utilize any known relationships established in the literature, we have focused on choosing metrics based on their performance with respect to several criteria: A) consistency over time – e.g, robust to changes in dataset resolution; B) accuracy in comparison to what is observed on the ground or interpret as 'fragmentation'; and (C) representative of those characteristics of forest fragmentation and/or urbanization that have been shown in the literature to be relevant to the ecological, social, and economic impacts of concern.

Data Sources Used

We required the landscape data sources to be spatially continuous, available over broad areas, and of sufficient spatial resolution to meaningfully describe landscape processes of interest. The most widely available dataset meeting these criteria was the 2001 NLCD, a set of satellite image-based products produced by a consortium of federal agencies, led by the U.S. Geological Survey (Homer et al. 2007). These products are comprised of 30-m pixels, each labeled with a land cover category, percent impervious surface, and percent canopy cover estimates. In past studies, we used the U.S. Geological Survey's GAP datasets, which are similar to NLCD datasets, but are created with varying methods and slightly different goals. We chose NLCD over GAP data because they are produced with reasonably consistent methods and their accuracy and other properties over large areas are better understood.

With some caveats, particularly regarding impervious surface, NLCD captures land cover information reasonably well (Riemann et al. in prep). NLCD forest land was used for calculating forest pattern metrics even though it does not match the FIA definition of forest land (Ruefenacht et al. 2008). Thus the forest pattern metrics in this paper reflect the distribution of forest cover, not FIA forest land. Figure 1 illustrates the unit-level differences in forest area calculated by the two metrics in New York. It is evident that FIA forest percent is less than that reported by NLCD across most survey units, with a maximum difference between the two data sources of ~0.3 million acres (about 10 percent) in the Catskills-

Lower Hudson survey unit, an area with a substantial amount of residential development and forest/urban intermix (Radeloff et al. 2005). In the northeastern United States, NLCD's forest classification includes trees in residential areas, which would not fall under the FIA forest definition.

Derivation of urban and land-use data required integration of information from the U.S. Census Bureau. Road data were derived from the TIGER/Dynamap 2000 dataset (U.S. Census Bureau 2002). Metrics related to the levels and types of urbanization were drawn from the Wildland Urban Interface (WUI) database (Univ. of Wisconsin n.d., Radeloff et al. 2005), and from the U.S. Census Bureau block-level data (2002) on population, housing, and second home density compiled for the WUI project (Univ. of Wisconsin n.d.). Change in house density over time also was obtained from WUI database (Univ. of Wisconsin n.d., Hammer et al. 2004).

Hydrologic Unit Code (HUC) polygons were developed as part of the national hydrologic dataset and downloaded from the USDA Geospatial Data Gateway (USDA Nat. Resour. Conserv. Serv. n.d.). We used the HUC12 scale, which approximated that scale used in studies identifying the percent impervious thresholds chosen.

Forest Inventory and Analysis data were accessed from the internal FIA database (U.S. Forest Service n.d.).

Landcover Mosaic (LCM), Morphological Spatial Pattern Analysis (MSPA), and Forest Area Density (FDEN) datasets describe A) the mixture of agricultural/urban/natural land-cover type (Riitters et al. 2009); B) the structural element of which a forest patch is part (as described at European Commission, DG-Joint Research Centre, Institute for Environment and Sustainability, http://forest.jrc.it/biodiversity/Product); and C) the percent forest area, respectively, in the 15 ha (37 acre) local area surrounding each grid cell. Graphics showing this information for the continental United States are currently available at www.forestthreats.org/tools/landcover-maps. Geospatial datasets containing this information will be available shortly.

In this study we did not apply 'corrections' to the landscape data source. Instead we relied on careful qualification of 'forest cover' vs. 'forest land use' and the use of multiple metrics including specifically land use-based metrics. This approach provides more potential for application, as well as increasing ease of both calculation and interpretation.

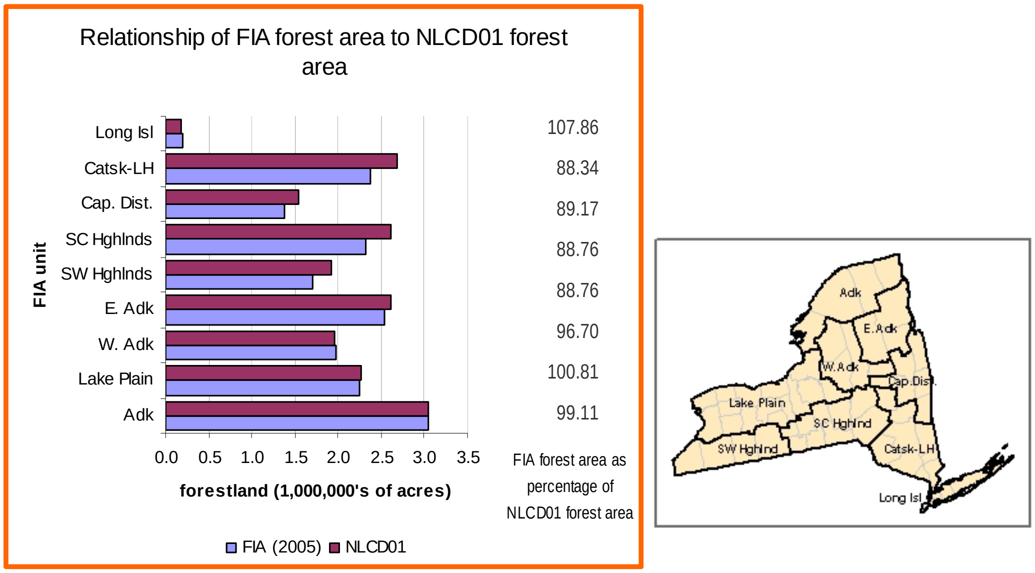

Figure 1: Relationship of FIA forest area to NLCD2001 forest area in New York, by FIA unit.

Processing

ArcMap software was used to prepare and analyze the input datasets. We automated most of the processing with ArcMap models to facilitate application of these processes to other datasets. Most of the spatial datasets shown in this paper have already been produced for the northeastern quadrant of the United States (the 20 states comprising the U.S. Forest Service's Northern Research Station).

Complete processing details for each spatial dataset are available at: http://www.fia.fs.fed.us/symposium/metadata/fragurban_metrics_metadata.doc. In general, data preparation included clipping input datasets to state or region boundaries and reclassifying the NLCD land cover data into appropriate land-cover groups (e.g., forest/nonforest, or forest/natural vegetation/water) for further geospatial analyses. A series of geoprocessing operations were then applied to the datasets to derive the landscape metrics, including vector-to-raster conversion and distance calculations (e.g. for distance to nearest road), calculation of patch areas, shrinking patch edges (for edge/interior calculations), area tabulations and/or continuous data summaries of the metrics by analysis unit (e.g., county, 10 km x 10 km grid, and watershed), and extraction of pixel values to FIA plots (e.g. patch size, distance to road, WUI class). For example, one ArcMap model used the Euclidean distance tool, the census roads, and the NLCD forest dataset for New York to assign each valid output pixel the distance to the nearest road. Subsequent steps in the model summarized the output of this step and created a table showing the frequency distribution of forest cover by distance to road category.

Thresholds to Facilitate Interpretation

Interpretation of the likely impacts of certain configurations of fragmentation and urbanization requires an understanding of their relationship to the ecological, social, or economic response of interest. In addition, ecosystem response to fragmentation and urbanization does not always occur gradually across all levels of landscape change intensity. In some cases the observed response indicates a particular threshold of interest beyond which the rate or level of response is sharply different. In other cases, crossing artificial thresholds cause an impact, like in the case of passing legally allowable limits of forest cutting. Some studies have developed general management guidelines from these observed relationships between fragmentation measures and an ecosystem response. Where guidelines were available, we utilized this information to categorize our map and tabular outputs. In particular, in this paper the following guidelines were utilized in the interpretation or development of the maps and tables presented in the results:

- **Patch size and forest proportion:** Habitat requirements for wildlife vary by species. However, for reporting purposes it is often helpful to summarize forest-patch data using general guidelines. Many wildlife species prefer contiguous forest patches that are at least 100 acres. This patch area is often used as a minimum size still containing enough interior forest to be a source rather than a sink for populations of some wildlife species. Depending on your geographic region of interest or species of concern, this threshold could be customized. Some studies have found that in addition to patch size, the proportion of forest land in an area that extends beyond the patch can be used to develop habitat thresholds. Rosenberg et al. (1999) found that forest-patch size information can be used in relation to the amount of forest land in a surrounding 2500-acre area to develop habitat suitability models for certain species of interior forest dwelling birds. Their resulting matrix of ecosystem responses provides detailed information that can be applied, with some understanding of the quality of the landscape data source being used.

- **Forest edge**: While edge effects vary somewhat with distance, depending on the type of effect and species of vegetation or wildlife, (e.g., Chen et al. 2002, Rosenberg et al. 1999, Flaspohler et al. 2001), 100 to 300 ft (~30 to 90 m) is frequently used as a general range for the 'vanishing distance' or the distance into a patch where the edge effect disappears and interior forest conditions begin.

- **Impervious surface**: The amount of land area within a watershed that is impervious to water (pavement, buildings, parking lots, etc.) affects water quality. When water is able to pass through the ground, soil and vegetation act as a filter and improve water quality. As the proportion of impervious surface increases, however, many pollutants flow directly into the waterway. Impervious surface areas of 10 and 25 percent are generally recognized to be the thresholds above which small watersheds are impaired and impacted, respectively (Arnold 1996).

- **Human population density:** Population densities are generally recognized as having a negative effect on the viability and practice of commercial forestry (Barlow et al. 1998, Kline et al. 2004, Munn et al. 2002, Wear et al. 1999). In this study we used thresholds identified by Wear et al. (1999), which showed that the probability of commercial forestry dropped from 75 to 25 percent as population density increased from 20 to 70 people per square mile. These thresholds were estimated based on data from the 2000 U.S. Census and other data from Virginia. As research results become available that are more timely and region-specific, these data will be used to create improved commercial forest probability maps.

- **House density:** Thresholds of house density used in the wildland-urban interface (WUI) and intermix definitions come from the Forest and Wildlife Ecology SILVIS laboratory at the University of Wisconsin-Madison. The WUI interface is defined as the area where human development meets rural or wildland areas. These thresholds were originally established to describe wildland firefighting guidelines (Radeloff et al. 2005).

The thresholds and guidelines presented are not an exhaustive list of what is available. Rather they represent examples in several important areas. More guidelines, including those of regional development and relevance, may be available now and more will be available in the future.

Results and Discussion

Forest fragmentation and urbanization data analyzed for inclusion in FIA state reports can be organized into three broad categories of information. The first are statistics, maps, and/or graphs that describe the landscape character and spatial pattern of forest land distribution in a state. Wherever possible, legend class breaks in these maps should be chosen with respect to known or suspected impact thresholds. The second category identifies the impact of forest fragmentation or urbanization on a particular ecological, social, or economic issue. These statistics, maps, and/or graphs frame the data with respect to the specific threshold(s) and scale(s) identified (and ideally established) in the literature and can thus be more directly interpreted for their probable impact on these issues. The third type of information that could be useful is the result of an overlay of the spatial context and urbanization information with data collected on FIA plots to assess the impact on different populations of the forest resource.

Table 1 provides a summary of the figures presented, in terms of the category of information, question addressed, input datasets used, and methods used in its creation. This is not an exhaustive list of the fragmentation or urbanization analyses desirable. Rather, the maps and graphs chosen represent some of the carefully chosen metrics that should be used as a starting point.

Table 1: Summary of figures presented in this paper.

Category of information (1, 2 or 3)	Question answered	Input Datasets Used	Summary of methods	Example figure in text
1	Where is forest land affected by underlying house densities greater than 6 per sq. km (15.54 per sq. mile)	1) U.S. Census 2000 house density data at the block level 2) NLCD2001 for the nonforest land cover mask	Block-level choropleth with 30m raster mask	2a
1	How much fores tland is affected by underlying house densities greater than 6 per sq. km	--same as above, plus: 3) FIA unit boundaries	Extraction of census block values to 30 m forest pixels Data summarization	2b
1	Where is the forest land affected by roads and to what extent	1) U.S. Census Bureau TIGER/Dynamap 2000 dataset [all roads] 2) NLCD2001 for nonforest land cover	Per-pixel distance calculation	3a
1	To what extent is forest land affected by proximity to roads	--same as above	Data summarization	3b
1	Where is a substantial proportion of the forest land occurring in patches less than 100 acres in size	1) NLCD2001 for forest pixels 2) 10 km x 10 km grid poly coverage	Patch area calculation Extraction of patch size values to 30 m pixels Data summarization to 100 sq. km grid cells	4a
1	How much forest land occurs in patches less than 100 acres	1) NLCD2001 for forest pixels	Patch area calculation Extraction of patch size values to 30 m pixels Data summarization	4b
2	What is the probable stream water quality as predicted by percent impervious surface alone?	1) NLCD2001 impervious surface layer 2) U.S. Census 2000 house density data at the block level 3) U.S. Census Bureau TIGER/Dynamap 2000 dataset 4) Hydrologic Unit level 12 polygons (HUC12) from the National Hydrologic dataset	Modeled percent impervious values for HUC12 basins Choropleth mapping of results	5
2	Where is forest land still suitable for an interior forest bird species such as scarlet tanager?	1) Land Management table from Rosenberg et al. 1999. 2) NLCD2001 for forest pixels	Patch area calculation Moving window analysis for percent forest in surrounding 2500 acre area Application of Rosenberg et al. (1999)'s table	6
2	What is the probability of commercial forestry occurring, and where?	1) NLCD2001 for forest pixels 2) U.S. Census 2000 population density data at the block level 3) Thresholds of	Extraction of population density values to 30 m pixel Application of Wear et al.'s (1999) thresholds as the legend	7

		commercial forestry probability by population density from Wear et al. 1999		
2	What is the probability of commercial forestry occurring within each county	--same as above, plus 4) County boundaries	Area tabulation to counties	8
3	How are species distributed with respect to the Wildland Urban Interface or Intermix Areas?	1) Wildland Urban Interface dataset 2) FIA plot-level data	Extraction of WUI code to FIA plots Data summarization	9

Characterizing forest distribution and context

In these examples, the metrics chosen relate to some aspect of urbanization or fragmentation that is suspected of, or has been documented to have an effect on the forest, its management, or on its ability to provide ecosystem services and products. Figures 2a through 4b provide examples of such maps and related graphs for New York. For example, figures 2a and 2b illustrate how much forest land is affected by underlying house densities greater than six houses per sq. km (15.54 per sq. mile), and where it occurs. Figures 3a and 3b show where and to what extent forest land is affected by roads. As Riitters and Wickham (2003) reported, this can be quite extensive. The distribution of forest land occurring in patches less than 100 acres is portrayed in figures 4a and 4b. One hundred acres is a threshold identified in the literature as an approximate minimum size for patches that contain enough interior forest area to be sources rather than sinks for wildlife populations. Other metrics and data sources providing valuable information with respect to understanding where fragmentation and urbanization impacts on forest land are occurring include: forest occurring within the WUI (Radeloff et al. 2005), changes in housing density over time (Hammer et al. 2004, Univ. of Wisconsin n.d.), forest land affected by edge conditions, forest connectivity for species requiring large ranges, and areas of forest where there is a substantial amount of second home development. The latter two maps can be depicted at the scale of 30 m pixels (e.g. depicting actual distance class to the nearest road), or at a summarized scale (e.g. 100 sq. km grid) depicting the proportion of the forest land in that pixel that is above or below a certain important threshold. In addition, the land-cover mosaic and spatial pattern metrics developed by Riitters et al. (2009), while not specific to a particular issue, do provide easily understandable, complementary, consistent and robust metrics of land-cover pattern that could also be analyzed with FIA plot data to describe some of the characteristics of those segments of forest land most under pressure from urbanization and fragmentation influences. All of the above information can also be tabulated, describing the proportion of forest land in each county that's affected by any one (or more) particular criteria (Table 2).

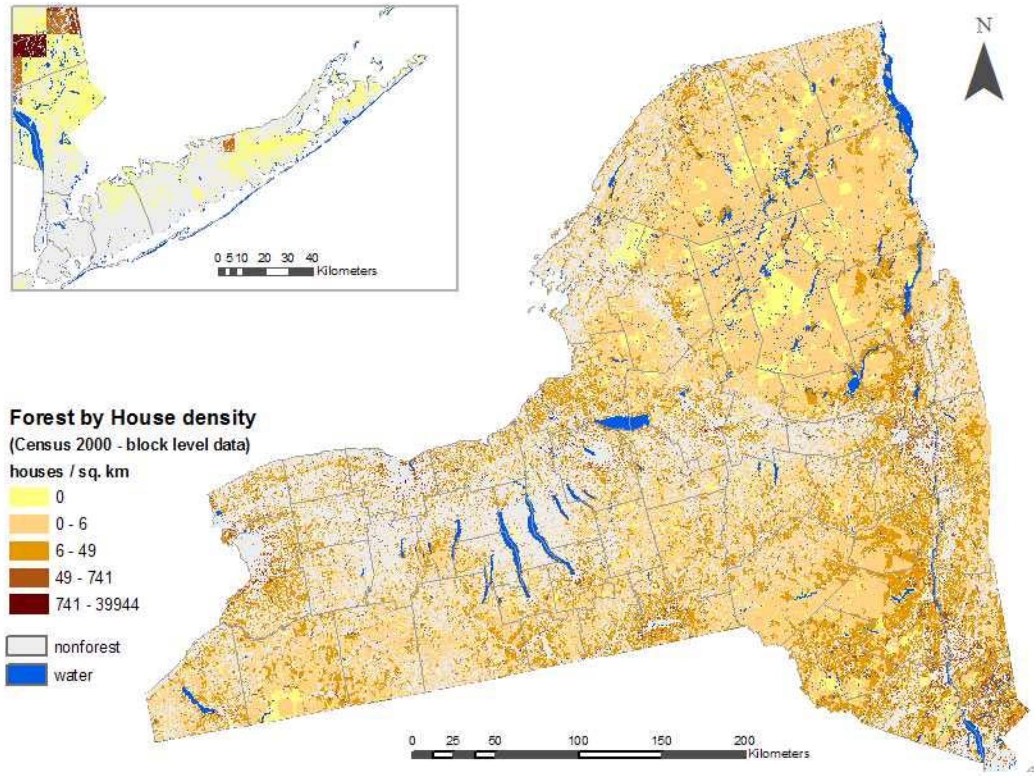

Figure 2a: Distribution of forest cover by house density, New York, 2001 (forest), 2000 (house density).

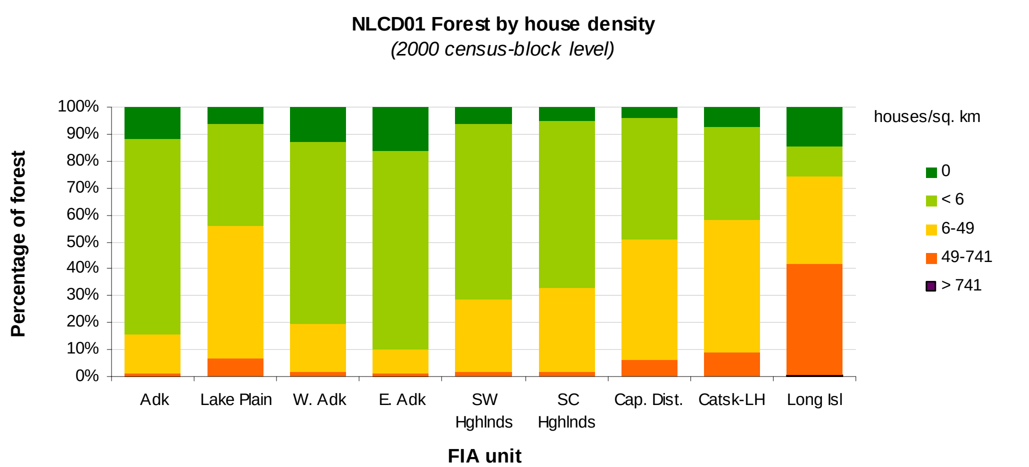

Figure 2b: Distribution of forest cover by house density, by FIA unit, New York, 2001 (forest), 2000 (house density).

Within FIA units in New York, between 10 and 73 percent of the forest occurs intermixed with house densities of $\geq$6 per sq. km. This represents the approximate density at which firefighting switches from 'wildland' to 'structure' firefighting techniques and costs (Radeloff et al. 2005). Forest intermixed with houses also represents areas of forest cover more likely to be in nonforest land use, and/or more likely to be experiencing pressures from recreation, invasives, and other local human effects.

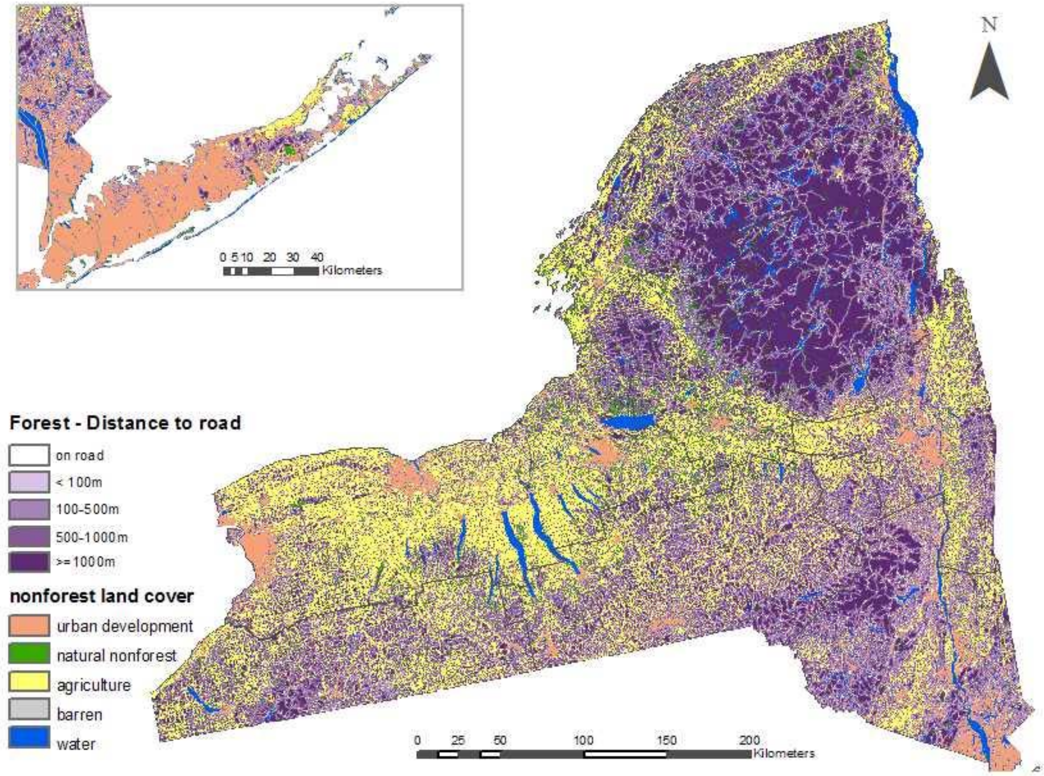

Figure 3a: Spatial distribution of forest cover by distance to road, New York, 2001 (forest), 2000 (roads).

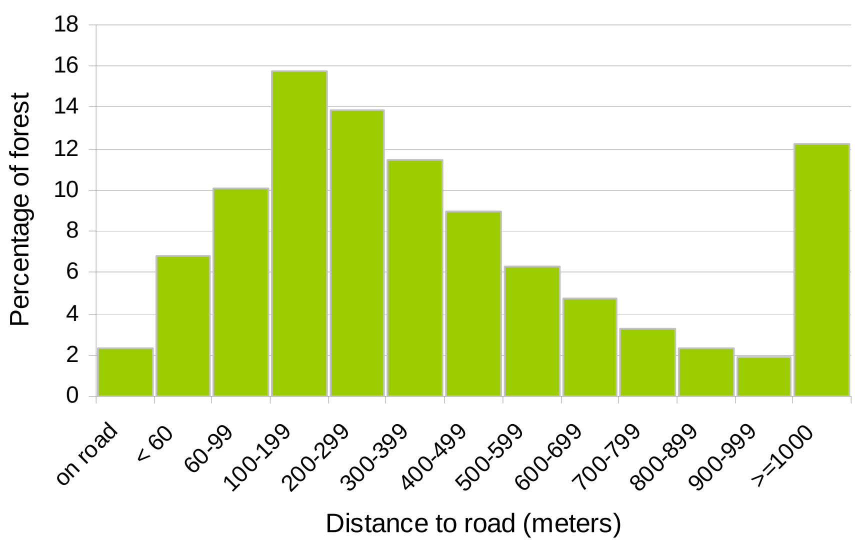

Figure 3b: Frequency distribution of forest cover by distance to road, New York, 2000.

In New York, nearly 60 percent of the forest is within 400 m of a road. According to Riitters and Wickham (2003), regions with more than 60 percent of their total land area within 382 m of a road may be at greatest risk of cumulative ecological impacts from roads.

Road effects distances range from 100 m for secondary roads (a rough estimate of a highly variable zone), 305 m for primary roads in forest (assuming 10,000 vehicles per day), and 810 m from roads in urban areas (50,000 vehicles per day) (Forman 2000). Using currently available road data, these thresholds could easily be applied state or regionwide to identify more specifically the location and magnitude of forest area affected by roads.

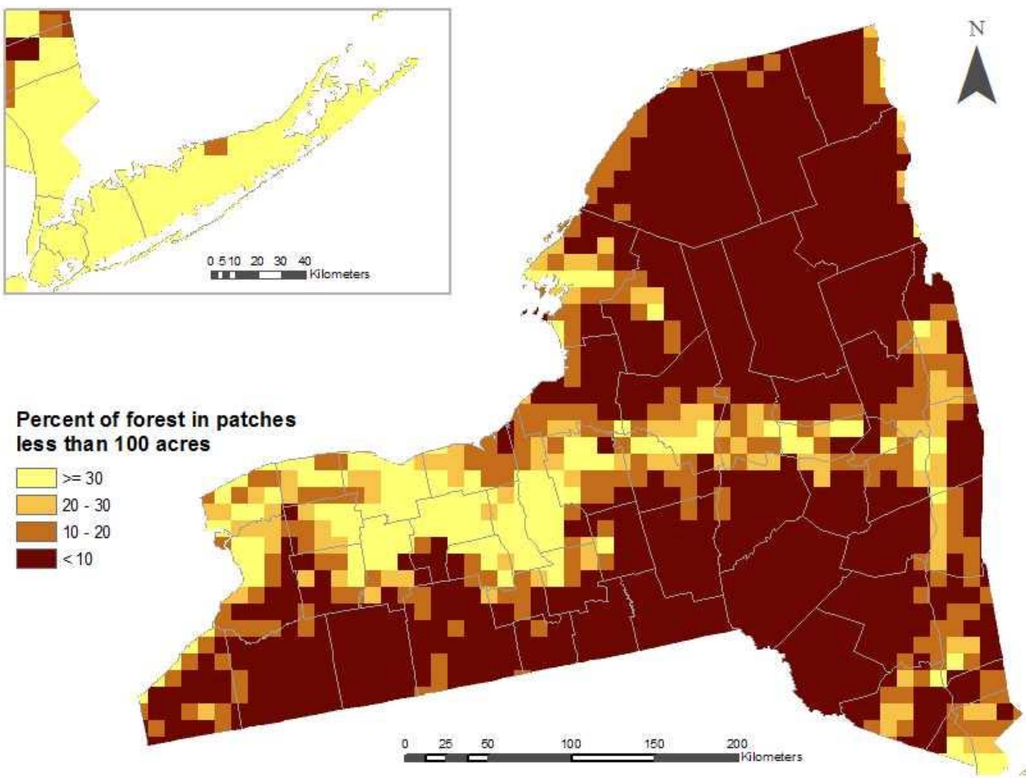

Figure 4a: Percent of forest cover in patches less than 100 acres, by 100 sq. km grid cell, New York, 2001.

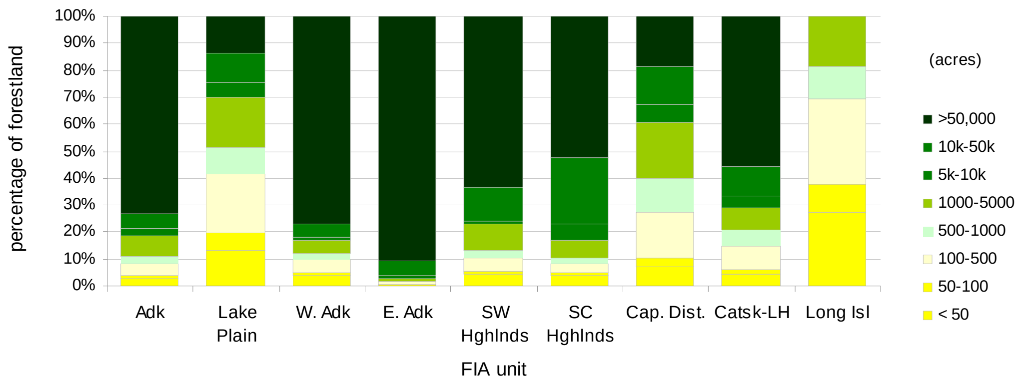

Figure 4b: Distribution of forest cover by patch size, by FIA unit, New York, 2001.

Areas with high proportions of forest area in small patches (patches <100 acres) occur along the river valleys in eastern and central New York, along the shores of Lake Erie and Lake Ontario, and over most of northwestern New York.

Table 2: The distribution of forest land with respect to several urbanization and fragmentation factors, expressed as a percent of the total land area in each unit.

FIA unit	% Forest land in unit	Forest land with house density > 6 per sq. km[a]	Forest land >90 m from an ag or developed edge[b]	Forest land located in patches >100 acres in size[c]	Forest land >300 meters from a road[d]	Forest land located in a block with population densities > 150/sqmi (390/sqkm)[e]
Adirondack	72	23	43	71	43	0
Capital District	59	54	28	59	24	1
Catskill-Lower Hudson	68	56	43	68	31	1
Eastern Adirondack	81	19	60	81	59	0
Lake Plain	41	60	14	41	18	1
South-Central Highlands	65	32	34	61	27	0
Southwest Highlands	64	35	30	64	29	0
Western Adirondack	68	25	36	68	42	0

[a] Approximating the forest land potentially affected by underlying development.
[b] Approximating the forest land undisturbed by edge conditions.
[c] Approximating the forest land with potentially enough core area for sustainable interior species populations.
[d] Approximating the forest land outside the effects of roads.
[e] Approximating the forest land not available for commercial forestry.

Table 2 shows that in the Adirondack unit, which is 72 percent forested, 23 percent of the land area (and 23/72 = 32 percent of the forest) is forest potentially affected by house densities greater than 6 per sq. km, 43 percent of the land area is in forest land that is far enough from an edge to be considered interior forest conditions. Most of that forest is in large patches (>100 acres), but only 60 percent of that forest (43/72) is greater than 300 m from a road (Table 2).

Identifying impact on a particular issue

A second type of analysis that would substantially enhance state reports is the use of published models or thresholds to depict the impact of forest fragmentation and/or urbanization on an ecological, social, or economic issue of particular concern in the state. This can only be done where such management-relevant information exists and data sources are available at the appropriate scale. Although few guidelines are definitive, useful information does exist in several areas so far, including three we have chosen to illustrate in this study: water quality (e.g. Arnold 1996), probability of occurrence of interior bird species (Rosenberg et al. 1999 and 2003), and commercial forestry (Wear et al. 1999). Application of these guidelines provides the user with not just a map of one aspect of fragmentation or urbanization but one that is already interpreted for probable or potential impact on a particular issue. Application of the thresholds established in these guidelines do not represent the final answer, rather they represent the best available knowledge of the impacts to date. To be most useful, such maps can and should be qualified for what they are presenting, as in the examples provided here.

Water Quality: As summarized in Arnold (1996), several thresholds have been identified for the amount of impervious surface that is correlated to a stream's water quality being *impacted* or *nonsupporting*. Applying these thresholds at the same scale as that identified in the literature (approximately HUC 12 basins), and with an understanding of the accuracy of the data source used, reveals a map of probable water quality (Fig. 5). In this map, percent impervious surface values are not calculated directly from the NLCD2001 data source because of known inaccuracies with percent impervious estimates at this scale when compared to photo-interpreted data (Riemann et al. in prep). Instead, basin-level percent impervious values are first modeled for HUC12 basins using the procedure identified in Riemann et al. (in prep).

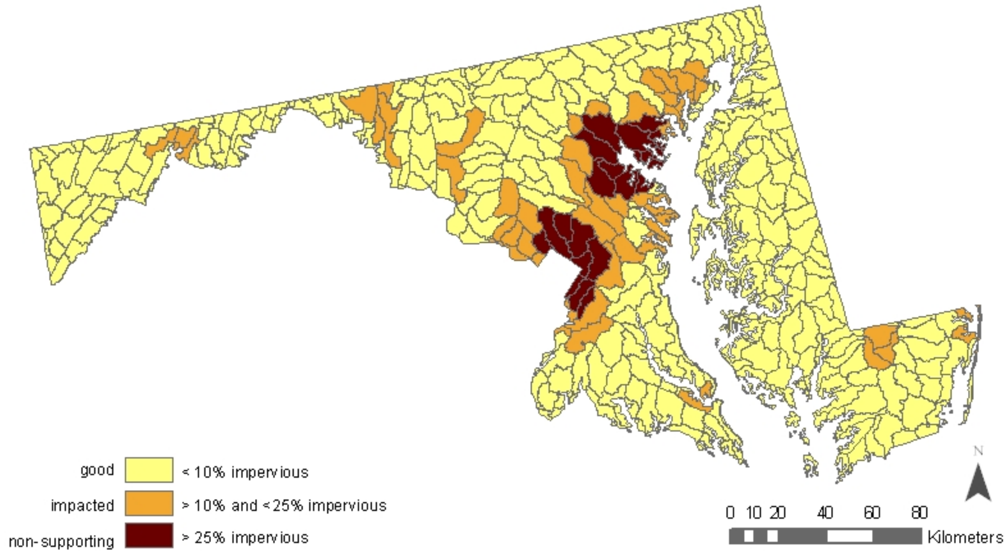

Figure 5: Probable stream water quality as predicted by percent impervious surface alone.

Impervious surface is highly correlated with stream water quality. This is due both to impacts of increased runoff from surfaces that add rather than filter pollutants, and due to its close relationship to increased levels of urbanization that are associated with multiple chemical, physical, and hydrologic changes (Arnold and Gibbons 1996). This example of using impervious surface information illustrates those watersheds in Maryland that are likely to be suffering from impaired stream water quality using thresholds fairly well established in the literature (e.g., Arnold 1996). The map is created by matching as closely as possible both the scale (watersheds no larger than HUC12) and data source (photo-intepreted or ground survey) that were used in the studies identifying the thresholds. Thus, Figure 5 is created using HUC12 watersheds and the NLCD2001 percent impervious layer modified by the observed relationship between the percent impervious in NLCD2001 and percent impervious values from photo-interpreted datasets (Riemann et al. in prep). Though it is an excellent and quantifiable land-use indicator, impervious surface is only one factor, and thus this map does not *predict* stream water quality in each watershed, but rather depicts the probable water quality absent of other mitigating or exacerbating factors. For more accurate information and suggestions for water quality improvement, watersheds in impacted and nonsupporting areas should be examined for mitigating factors that could be improved (e.g., additional forest land, additional tree cover in developed areas, additional forested stream buffer, restoring wetlands). Similarly, watersheds depicted as having very good or impacted water quality should be examined for any exacerbating factors (point sources, more grass than trees in developed areas, highly fragmented forests) that may reflect lower than depicted water quality, or identify landscape factors that could be addressed (Riva-Murray et al. in prep). Local management, regional assessment, and strategic planning efforts would all benefit from such information.

Probability of interior bird species: Rosenberg et al. (1999 and 2003) developed region-specific and species-specific guidelines that describe the probability of finding breeding individuals in a particular forest patch based upon patch size and the proportion of forest land in the surrounding 2500-acre landscape. Figure 6 depicts the results of applying the Atlantic Coast guidelines for scarlet tanager in Maryland and Delaware (Rosenberg et al. 1999). Patches with high habitat suitability have the same probability of supporting tanagers as a suitable unfragmented forest. Patches that are predicted to have a 25 percent lower probability of supporting tanagers are labeled as having moderate suitability, and patches which are 50 percent less likely to support tanagers relative to unfragmented forest are labeled as having low habitat suitability.

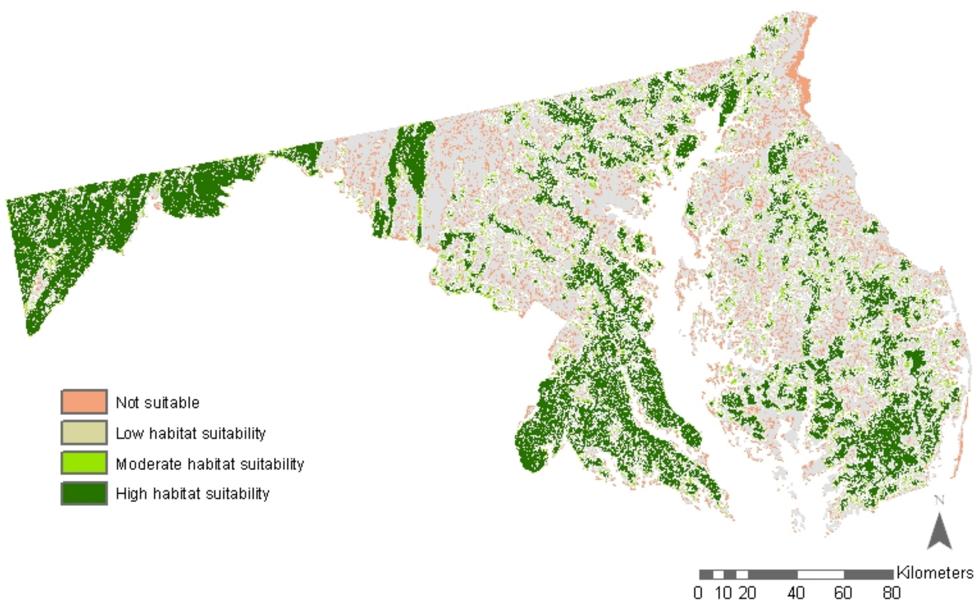

Figure 6: Forest land in Maryland/Delaware shaded by degree of habitat suitability for breeding scarlet tanagers (an interior forest species).

In addition to requirements of forest type, forest habitat suitability depends upon the configuration of forest land. For an interior bird species such as scarlet tanager, this suitability can be described as a function of patch size and the proportion of forest in the surrounding 2500-acre block. Forest type and other forest characteristics are not considered in Figure 6, but future versions of this analysis could easily include FIA modeled forest type and structure data. Future work is needed to study the accuracy of the percent forest and patch size data derived from NLCD2001.

Probability of Commercial Forestry: From a survey of experts in Virginia, Wear et al. (1999) developed a relationship between human population density and the probability that a patch of forest land is used for commercial forestry. More recent studies have reported this general relationship for other areas

(Barlow et al. 1998, Kline et al. 2004), however none have identified thresholds as clearly as Wear et al. (1999).

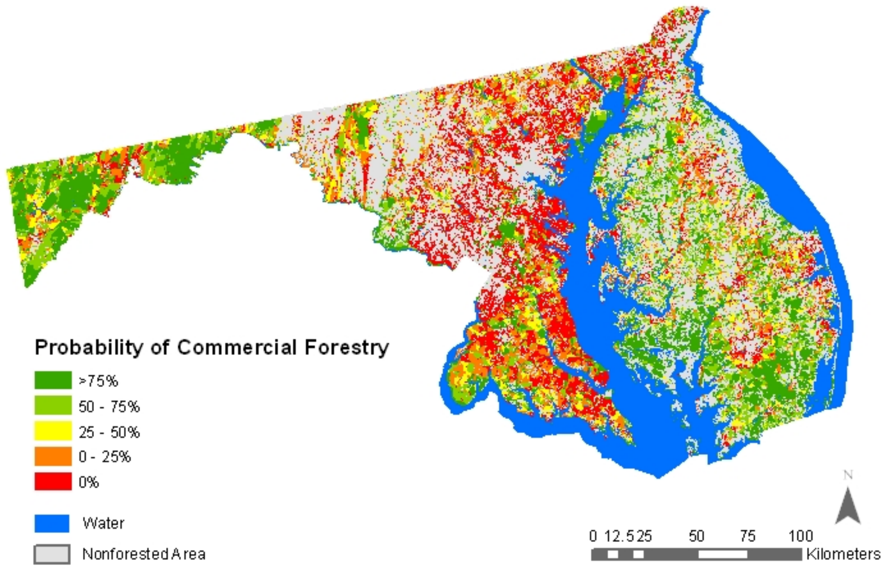

Figure 7: Forest cover by Probability of commercial forestry occurring (based on local population density effects and thresholds identified by Wear et al. (1999) in Virginia and applied in Maryland/Delaware).

Figures 7 and 8 show the relationship between local (block-level) population density and the probability that the forest land in that block will be used for commercial forestry, as developed by Wear et al. (1999).

Generally, harvesting and commercial forest management decline as forest landscapes become more populated and more urbanized. Other factors affecting timber management decisions include proximity to roads, distance to markets, ownership category, parcel size, and nontimber amenity value (see summary in Barlow et al. 1998). The base probability that the forest is under commercial use is 82 percent. Wear et al.'s (1999) study used data from Virginia circa 1991, so probability levels represent conditions in that state at that time. Actual probabilities may be different in Maryland/Delaware and will change as both forest treatments and people's perspectives evolve over time.

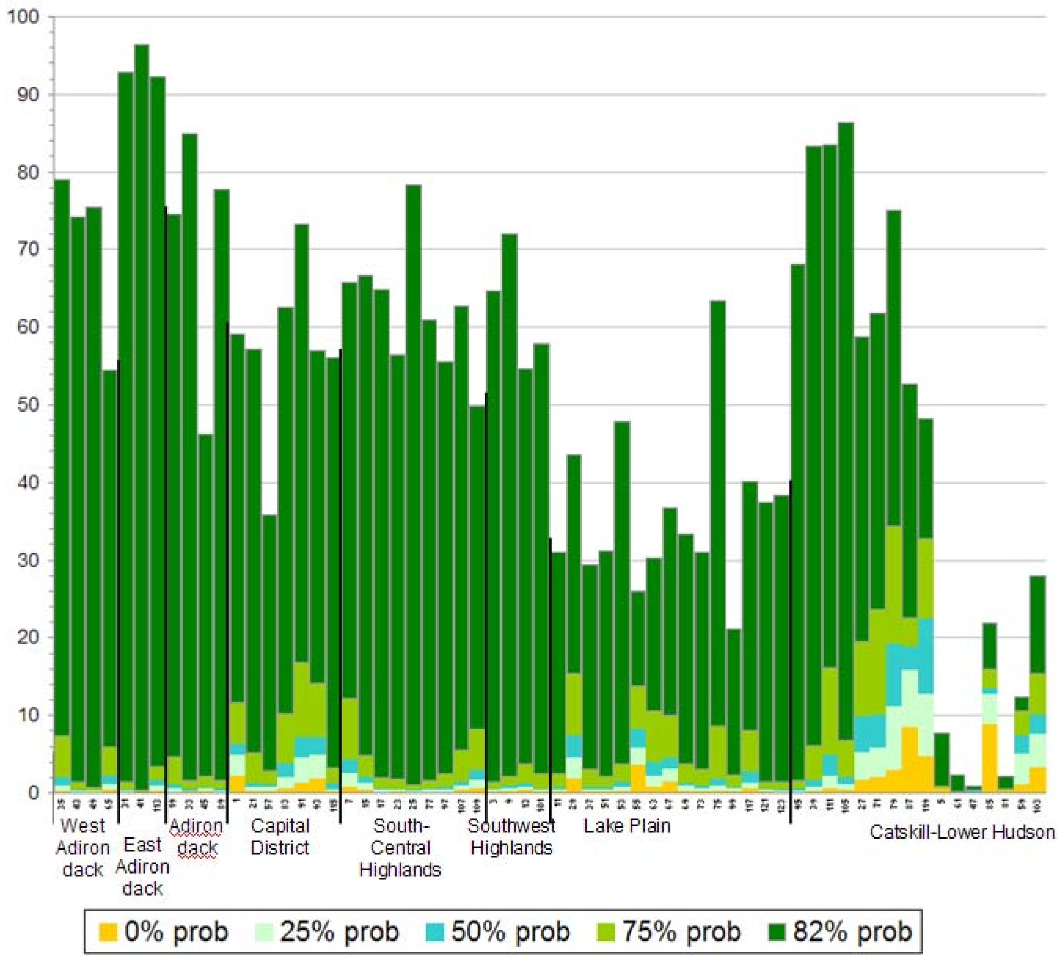

Figure 8: Percent forest in each county, shaded by the probability of forest being used for commercial forestry (based on local population density effects and thresholds identified by Wear et al. (1999) in Virginia and applied in New York, grouped by FIA unit, 2001 (forest), 2000 (population density).

In Figure 8, the dark green shade identifies that portion of the forest land in each county where the probability of commercial forestry is not impacted by human population densities and there is thus roughly an 82 percent probability of commercial forestry occurring. The height of the blue shade (including the orange and pale green) identifies that portion of forest land in each county where there is less than a 50 percent probability of commercial forestry occurring due to local human population densities.

Combining FIA Data with Geospatial Datasets

When data from FIA plots is overlaid with spatial context, forest pattern, and urbanization patterns, valuable information can be obtained. In this example, the forest occurring within the Wildland Urban Interface (WUI) designation represents one segment of forest land that is potentially impacted by urbanization. An analysis of FIA plot data (tree species, stand age, size class, invasive species, lichens, etc.) against WUI class shows which species are being affected, whether different stand ages or size classes tend to be associated with forest in the WUI area, and whether invasive species or other indicators of ecosystem health are associated with the WUI area (Fig. 9).

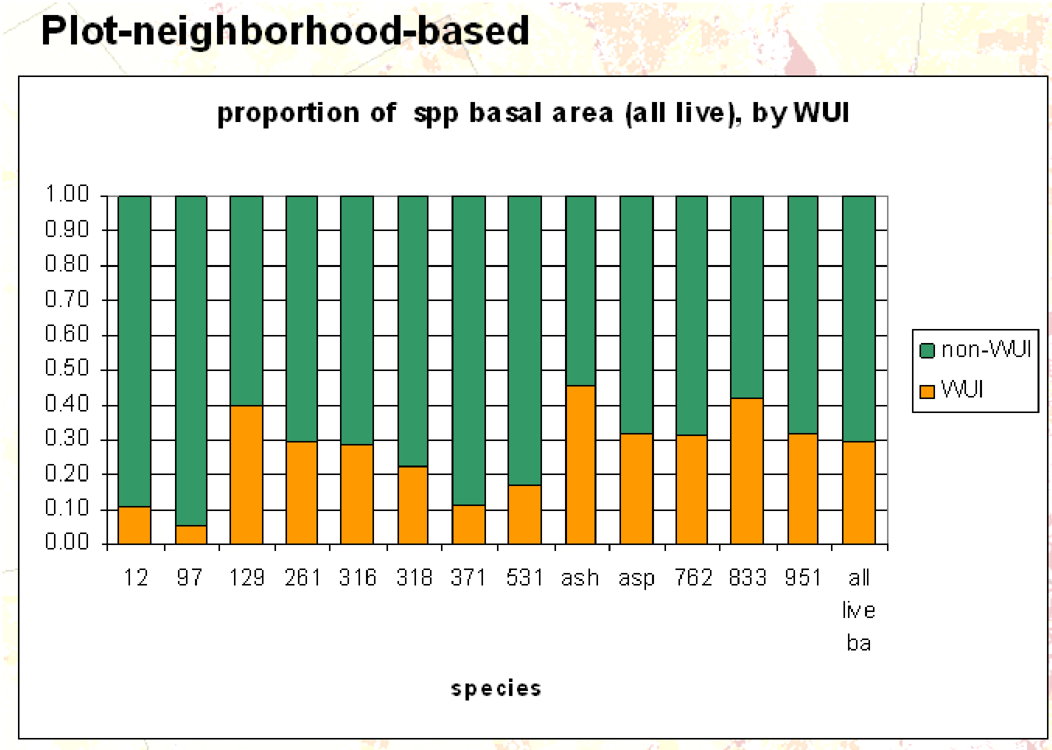

Figure 9: Proportion of species basal area (all live) occurring within the Wildland Urban Interface (WUI), New York, 2000-2005 (annual FIA plots), 2000 (WUI).

The effects of urbanization on forest land are highly dependent on the time that urban development has existed, particularly with large biomass systems such as forested ecosystems. Thus, when looking at a graph of stand size or invasive species vs. housing density or WUI, we might be looking at a resulting effect of that urbanization. More likely, we are describing areas where future changes are expected. Thus an analysis of which species or forest types are most influenced by WUI status, population density, edge conditions, and patch size, probably provides the best look at which are most likely to exhibit future change, experience health problems, suffer a decrease in habitat quality, or be less sustainable in terms of any of the above criteria.

Conclusions

Informed interpretation of forest inventory data requires information regarding the spatial pattern and spatial context in which the forest land occurs.

Characterizing forest land by its landscape context provides information that is currently absent from most FIA state reports. FIA should begin to consistently monitor and report those aspects of fragmentation or urbanization that affect the structure, function, health or sustainability of forests and/or its capacity and value for providing the ecosystem services and products on which we rely.

Information presented in this paper provides examples of what could be done. These have been chosen to provide a suite of relevant, consistent, standardized fragmentation and urbanization measures. Choice of which fragmentation or urbanization metrics to use in a particular state or region will depend on issue priorities, intended use, spatial scale of interest, and the accuracy requirements reflecting the intended use. Wherever both published guidelines and appropriate datasets are available, these can be used to generate relatively specific management-relevant maps and issue-focused analyses based on the best and most current available research. Qualifying statements accompanying the example maps clarify the assumptions and limits of what is expressed in the map while allowing a valuable look at our current best interpretation of impacts.

Using satellite imagery-based datasets in fragmentation analyses in conjunction with FIA data requires an understanding of the difference between the forest definition used by FIA and that expressed by the classified imagery. The relationship between FIA and NLCD2001 percent forest (Fig. 1) illustrates the potential magnitude of these differences. NLCD2001 data provides information on forest cover distribution largely independent of information on developed land uses and roads. This independence is sometimes noted in individual studies as land cover and land use are observed to have separate and independent effects on wildlife, water, and forest ecosystem processes. Thus having land cover and land use information separately available for landscape analyses will likely enable, rather than hinder, more specific application of results. The only caveat is that for the NLCD impervious cover variable, the land cover under trees and shadows is generally not included. As this may also be important, modeling percent total impervious cover to generate values closer to those derived from photo-interpretation may be necessary.

The metrics presented in this paper are simple to obtain. Their strength is in the use of multiple metrics simultaneously, in their relevance with respect to issues of concern, in the use of thresholds identified in the literature to aid interpretation, and in their analysis with FIA data.

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