UNDERSTANDING TRENDS IN OBSERVATIONS OF FOREST DISTURBANCE AND THEIR UNDERLYING CAUSAL PROCESSES

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Abstract.—Estimates of forest canopy areal extent, configuration, and change have been developed from satellite-based imagery and ground-based inventories to improve understanding of forest dynamics and how they interact with other Earth systems across many scales. The number of these types of studies has grown in recent years, yet few have assessed the multiple change processes underlying observed forest canopy dynamics across large spatio-temporal extents. To support these types of assessments, a more detailed and integrated understanding of the geographic patterns of forest change processes across the contiguous United States (CONUS) is needed.

This work uses forest age estimates from U.S. Forest Service ground inventory data and a novel data set from the North American Forest Dynamics project, which provides a dense temporal record (1984-2005) of forest canopy history across the United States, as well as ancillary geospatial data sets on forest change processes (wind, insect, fire, harvest, and conversion to suburban/urban land uses) across the CONUS. Forest area is estimated and causal processes of forest change are shown through time across multiple scales.

INTRODUCTION

For more than half a century, decadal snapshots of forest canopy characteristics have been available from the Forest Inventory and Analysis (FIA) Program. Annual FIA inventories and remote-sensing satellite imagery have recently begun to meet the need for data that are consistent across large spatial and temporal extents, at finer spatial and temporal grains (Cohen and Goward 2004, Gillespie 1999). However, we still lack data and understanding regarding the causal processes underlying observed forest canopy changes. It is important to know not just where and when forest canopy losses occur, but also the underlying process to help determine whether the losses are temporary or permanent and how the process influences other Earth systems across many scales (Reams et al. 2010).

Natural (fire, wind, insect) and human-managed (harvest) forest disturbances and forest land conversion affect millions of hectares of forest land, but the spatial and temporal trends of these phenomena are not well documented (Smith and Darr 2004). Although data are available on a single process for static points in time, there are few that focus on multiple processes through time (Birdsey and Lewis 2003). A current synthesis on the trends of specific forest canopy change processes including fire, insects, wind storms, harvests, and forest land conversion is lacking at fine spatial and temporal resolutions. This work demonstrates the need for this information below a coarse regional-decadal resolution and attempts to create an integrated geographic model of all these phenomena.

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METHODS

To synthesize data on forest canopy change and causal processes across different studies, common spatial boundaries must be used. We used the six historical FIA regions of the Northeast (NE), North Central (NC), Southeast (SE), South Central (SC), Intermountain West (IW), and Pacific (PAC) (see map insert, Fig. 2). These boundaries allow for comparison of newer data sets with historical data available only at coarse regional scales.

More than 20 years of forest age history data from FIA inventories and the North American Forest Dynamics (NAFD) project are discussed in the context of the underlying forest causal processes that they might have captured. NAFD provides a comprehensive look at forest disturbance rates for areas sampled biennially across the conterminous United States at a 30-m resolution from 1985 to 2005 (Goward et al. 2008). Forest age, often used as a proxy for disturbance history, has been collected by FIA on more than 125,000 ground plots (0.7 ha) laid out on a 5-km sampling grid across the conterminous United States. One-tenth of these plots are remeasured each year in the western United States. One-seventh to one-tenth of them are revisited each year in the eastern United States. However, measurement frequency and spatial sampling schemes varied through time and across regions prior to 1999 (Gillespie 1999).

To interpret the regional forest change estimates in the context of possible underlying causal processes, we compiled tabular data of forest area affected by each process to illustrate their trends through time. To judge the need for finer spatial and temporal resolution data we utilize NAFD forest history maps and geospatial data on recent insect infestations, harvests, forest fires, wind storms, and suburban/urban conversion of forest land (Table 1). These data are assembled into a single geographic information system geodatabase to enable multi-scale analysis on the patterns of forest change processes and forest canopy changes, and their overlap through time and space.

RESULTS

The more than 20 years of forest history captured in both FIA and NAFD data show some similarities across regions (Fig. 1). In general, NAFD disturbance rates are higher than FIA estimates within regions, with the exception of the SE region.

Regional trends for forest fire, insect infestations, suburbanization, harvest, and canopy cover changes vary by decade and region (Fig. 2). Regional-decadal scale statistics on change processes were found to have limited utility in explaining similar-scale canopy change trends. Coarse-scale observations and reporting confounded the signatures of localized canopy change events that overlap in space and time. Data inconsistencies through time and space raised questions on the reliability of the data. Comparing different data sources for both forest fires and suburbanization revealed large differences in area estimates that may have implications for end users.

Assembling available geospatial data into a single geodatabase produced a better integrated geographic model providing insights into the frequency and overlap of multiple forest change processes across the CONUS (Fig. 3). Mapping each change process individually revealed a unique signature of local spatio-temporal variability, suggesting that no one sampling scheme will adequately capture the canopy change resulting from all of the processes. Overlay analysis suggests that because of the limited number and location of NAFD samples, the benefit of the NAFD data occurs not in aggregate calculations but in the new perspective they offer on forest history events at the scale of landscapes and individual patches. Data gaps and inconsistencies through space and time in the various data on forest change processes make quantitative linkages with NAFD maps and wall-to-wall analysis difficult. For example, data on harvest area suggest harvesting affects more forest area in the CONUS than any other process; however, its spatial and temporal characteristics were found to be the most poorly characterized.

Table 1.—Data used to build an integrated geodatabase of forest change processes

Change process	Measurement method	Data source	Spatial		Temporal	
			Grain	Extent	Grain	Extent
Fires	Landsat, NDVI change	MTBS http://MTBS.gov	30-m grid	national	annual	1984-2007
Hurricanes and tornadoes	Ground measurements-wind speed	U.S. National Hurricane Center http://www.nhc.noaa.gov/pastall.html	lines	national	annual	1851-2008
Suburbanization/urbanization	Decadal census – number of new housing units	Theobald 2005	100-m grid	national	decadal	1940-2030
Suburbanization/urbanization	Landsat, Land use change	NLCD Retrofit Change Data http://www.mrlc.gov/changeproduct.php	30-m grid	national	decadal	1992-2001
Suburbanization/urbanization	Landsat, Land use change	NLCD 2001/2006 Land cover change http://www.mrlc.gov/nlcd2006_downloads.php	30-m grid	national	5 years	2001-2006
Harvests	Timber Product Output Surveys	USFS FIA http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int2.php	county polygons or >	sampled -national	5- to 10- year cycles	1997-2007
Pests and pathogens	Digitized aerial sketches of insect damage	U.S. Forest Health Program http://www.fs.fed.us/r3/resources/health/fid_surveys.shtml	polygon <1 ha	sampled -national	annual	WA and OR: 1984-2005; CA: 1994-2008; AZ: 2000-2009; NM: 1998-2009; states in the NC and NE regions: 1997-2009; NV, UT, and southern ID: 1991-2008; Northern ID, MT, ND: 2000-2008; most of Wyoming, CO, SD, NE, KS: 1994-2009
Southern Pine Beetle	Aerial Spot Detection Surveys	Williams and Birdsey 2003	county polygons	SE and SC states (except OK)	annual	1987-2004

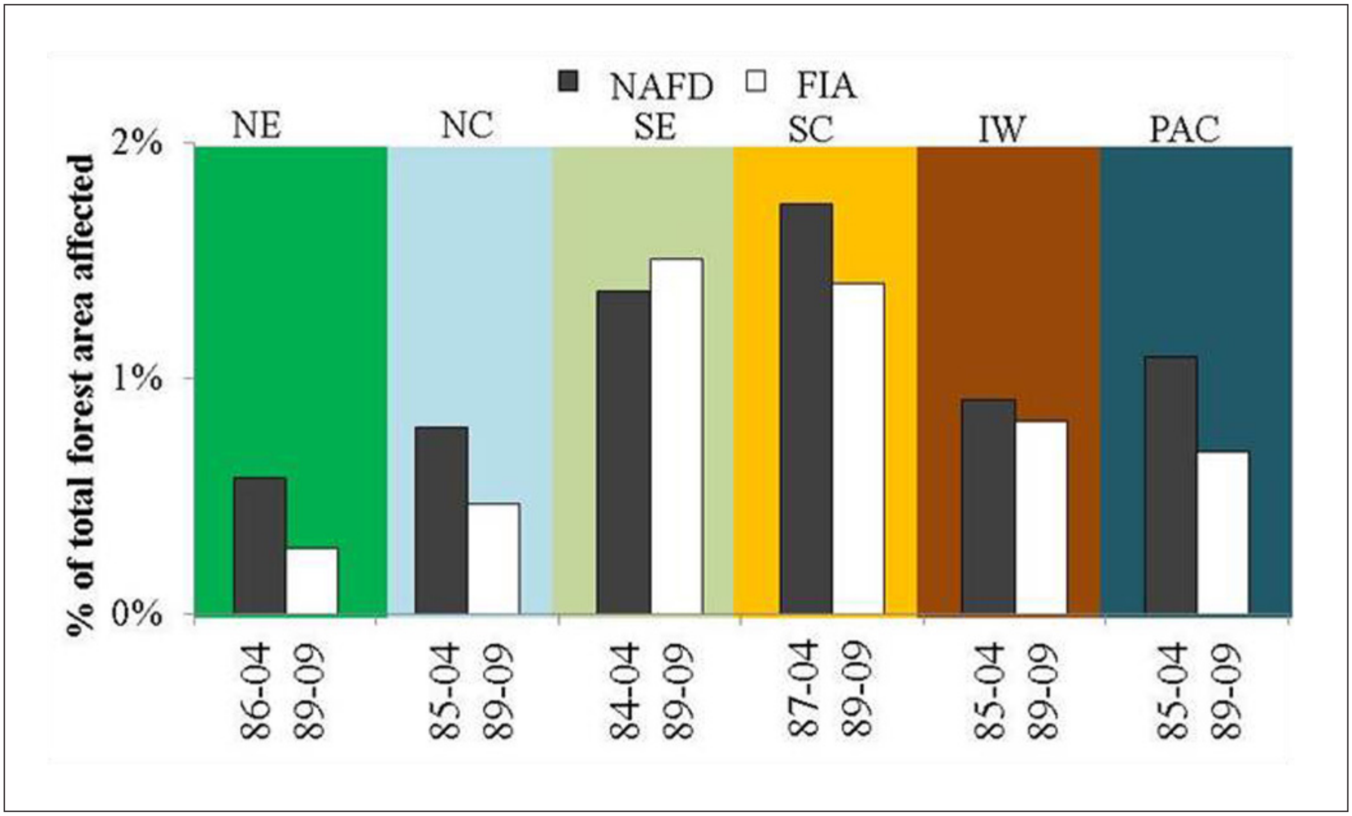

Figure 1.—Averaged annual forest change rates from FIA stand age, reported in the most recent inventory data and NAFD forest history maps over two decades for six regions of CONUS.

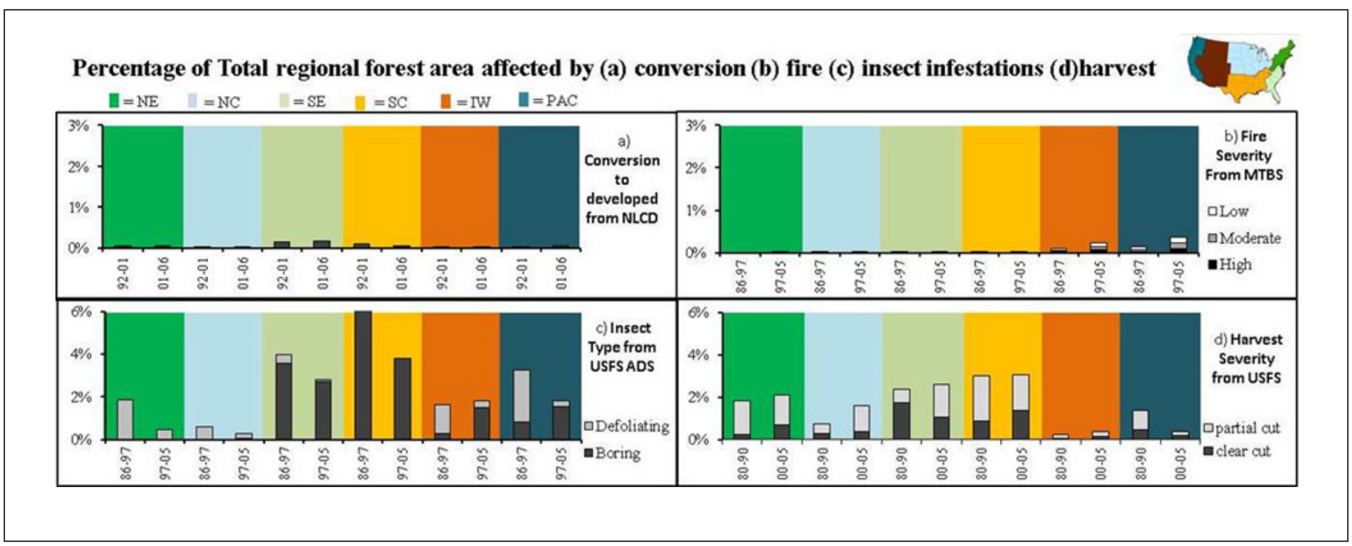

Figure 2.—Averaged annual rates calculated as a percentage of total forest area in the region using total forest area per region from Smith et al. (2009). Reported areas for individual disturbance processes are not mutually exclusive and can lead to double counting.

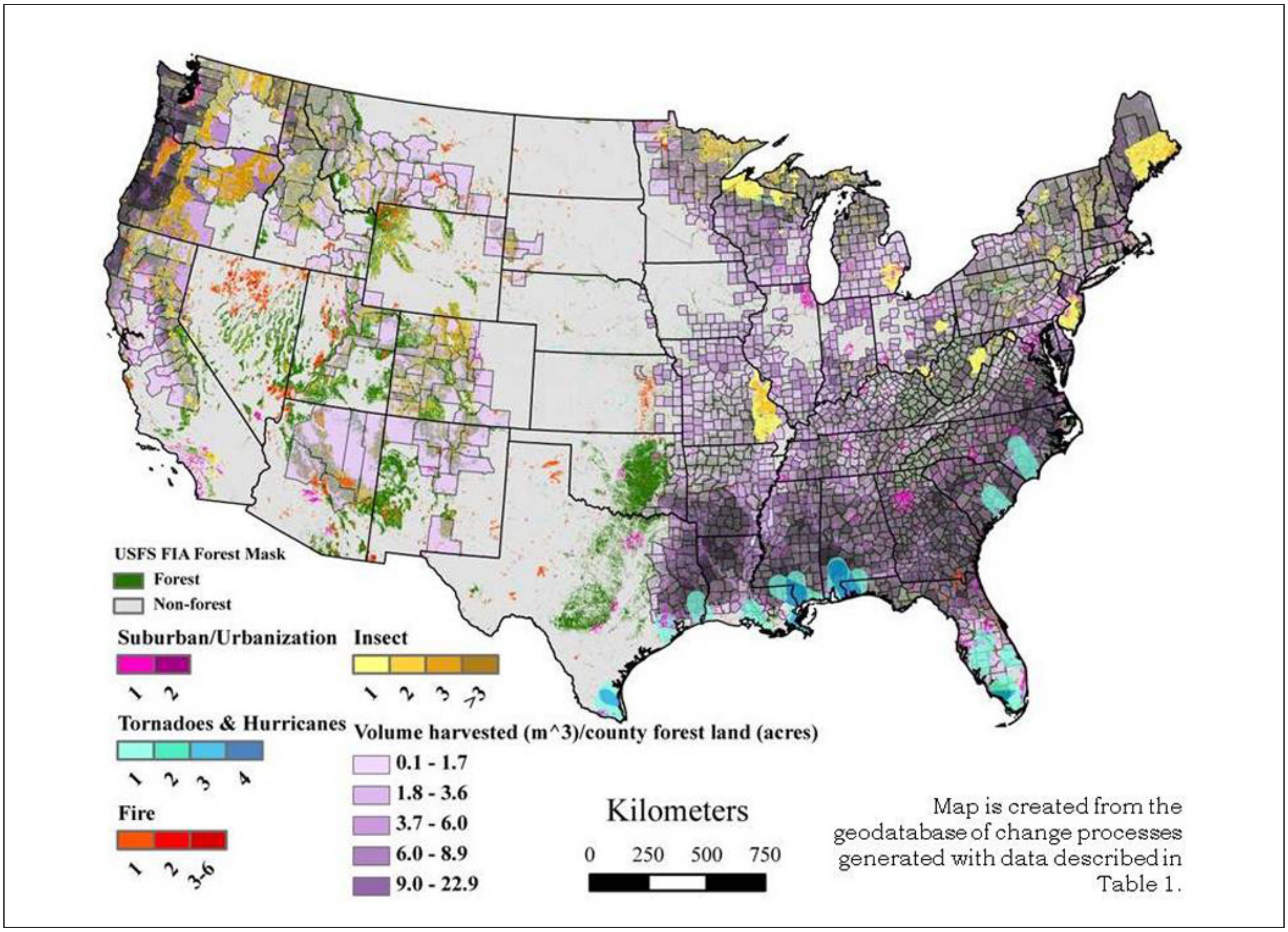

Figure 3.—Overlap of five forest change processes (fire, harvest, insects, windstorms, and suburbanization) over roughly two decades. Specifics on temporal and spatial characteristics of data vary with each change process and are available in Table 1.

DISCUSSION

Rates of forest canopy disturbance vary with differing underlying causal processes. This work found estimated disturbance rates from FIA and NAFD observations of forest stand age differ. The differing estimates may be related to the different methodologies used by FIA and NAFD and their capability to capture different underlying causal processes. The spatial and temporal patterns of the underlying causal processes are necessary to interpret rates of forest canopy from different remote sensing and ground inventory data products.

Estimates of canopy change and change processes have traditionally been available at decadal-regional scales, which hinder analyses of smaller-scale ecological processes and canopy observations within a landscape matrix. Estimates of forest area affected by individual change process, assembled from tabular data, revealed trends that vary both within and across regions through time. However, the coarse resolution of these data made linkages with regional-scale canopy change observations from FIA and NAFD problematic.

Consolidating the many data on forest change processes into one geospatial database allowed for both aggregate calculations and preservation of information on local patterns. Finer-scale observations of canopy change and causal processes revealed new insights into these dynamic processes. However, data gaps and inconsistencies preclude robust quantitative analysis. This work represents a first step towards a more integrated geographic model of forest change processes and canopy change observations.

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