Perspectives of Maine Forest Cover Change from Landsat Imagery and Forest Inventory Analysis (FIA)

Steven Sader, Michael Hoppus, Jacob Metzler, and Suming Jin

ABSTRACT

A forest change detection map was developed to document forest gains and losses during the decade of the 1990s. The effectiveness of the Landsat imagery and methods for detecting Maine forest cover change are indicated by the good accuracy assessment results: forest—no change, forest loss, and forest gain accuracy were 90, 88, and 92%, respectively, and the good correlation of mapped areas of forest cover loss with forest inventory analysis (FIA) tree size class decrease at the county level. The combination of annually collected permanent FIA plots with accurate statewide forest change maps offers a complementary perspective of Maine's forest resource.

Keywords: remote sensing, landsat, FIA, forest change

Forest Inventory and Analysis (FIA), a program of the USDA Forest Service (USFS), is responsible for forest inventory and monitoring in the United States. Congress mandates, through the Forest and Rangeland Renewable Resources Planning Act of 1974 and the McSweeny-McNary Forest Research Act of 1928, that FIA continuously determine the extent, condition, and volume of timber, growth, and depletions of the nation's forestland (Hoppus and Lister 2005). The FIA is primarily a field-based plot system (1 plot per 6,000 ac of forest). One limitation of the current survey program is that the data generally are not presented in a spatially explicit manner. Although some researchers have applied geostatistical procedures (*k*-nearest neighbors) and other methods to extrapolate and map predicted forest distributions from FIA plot data (Lister et al. 2000, Haapanen et al. 2004), the options for spatial analysis of FIA data in a geographic information system (GIS) are somewhat limited. GIS users of FIA data in the northeast are increasingly interested in how much forestland is being harvested and how much is converted to other land uses such as residential housing. Although estimates of change and forest conversion are possible with FIA data, the lack of spatial specificity limits landscape and local level analyses and comparative studies at finer scales that might otherwise be accomplished in a GIS (Hoppus and Lister 2005).

Remote Sensing Roots in Forest Inventory

It is, perhaps, a forgotten or little-known fact that remote sensing in forestry began as a forest inventory tool. This is easy to see from the early publications of notable foresters like Cornwall (1925), Seely (1929), Weber (1931), and, later, Nash (1948), among others, who advanced the development of aerial tree and stand volume tables as forest inventory tools. These early forest researchers exploited the important link between photogrammetry (direct measurements on aerial photos) and forest inventory through regression analysis and double sampling. These successful methods, applied to forest inventory, seem to be somewhat of a lost art and science in modern day. The Society of American Foresters accredited forestry schools, over the past two decades, have been including less photogrammetry in the curricula (Sader and Vermillion 2000) and we see less direct connection between remote sensing measurements and forest inventories (perhaps with the exception of new research with light detection and ranging imaging).

Aerial photography has been used for decades in FIA as a means to interpret and stratify forest versus nonforest composition of sample plots and to develop expansion factors to extrapolate forest estimates to the county reporting level. In the past several years, most of the FIA units have used medium spatial resolution satellite imagery (e.g., Landsat Thematic Mapper [TM] imagery) to stratify FIA plots (Hansen and Wendt 2000, Hoppus et al. 2000). However, except for increasing the precision of the plot estimates of area, stratification does not play a direct role in estimating forest area or forest biomass change. Some opportunities may be missed here because monitoring forest disturbances over large forest tracts is, perhaps, one of the best-suited applications of medium-resolution satellite remote sensing in forestry (Bauer et al. 1994, Cohen et al. 1998, Franklin et al. 2000, Sader et al.

2003). Can we take better advantage of the powerful spatial and temporal perspective of relatively low cost, medium-resolution satellite sensors to improve that important link between remote sensing and forest inventory?

Forest Cover Change from Satellite to Ground

Maine is the most forested state in the United States with 90% of the land area in forest cover and over 95% of this forest is privately owned (Maine Forest Service 1999, Laustsen et al. 2003). The private forests of northern Maine have been actively logged for over 100 years (Irland 2000). Maine is the first state in the United States to have completed 5 years of forest inventories under the FIA annualized inventory program (Laustsen et al. 2003). The USFS Northeastern Research Station was interested in evaluating low cost, medium spatial resolution satellite imagery to support the FIA program (Hoppus and Lister 2005). A forest cover and change detection map was developed by the Maine Image Analysis Laboratory at the University of Maine to provide information about the status of forest cover (2000) in Maine and to document spatially explicit forest cover gains and losses during the decade of the 1990s. In this article, we report the forest cover and change map accuracy, explore forest changes from a new spatial perspective (township level), and compare county level forest cover loss from Landsat with FIA ground plot data.

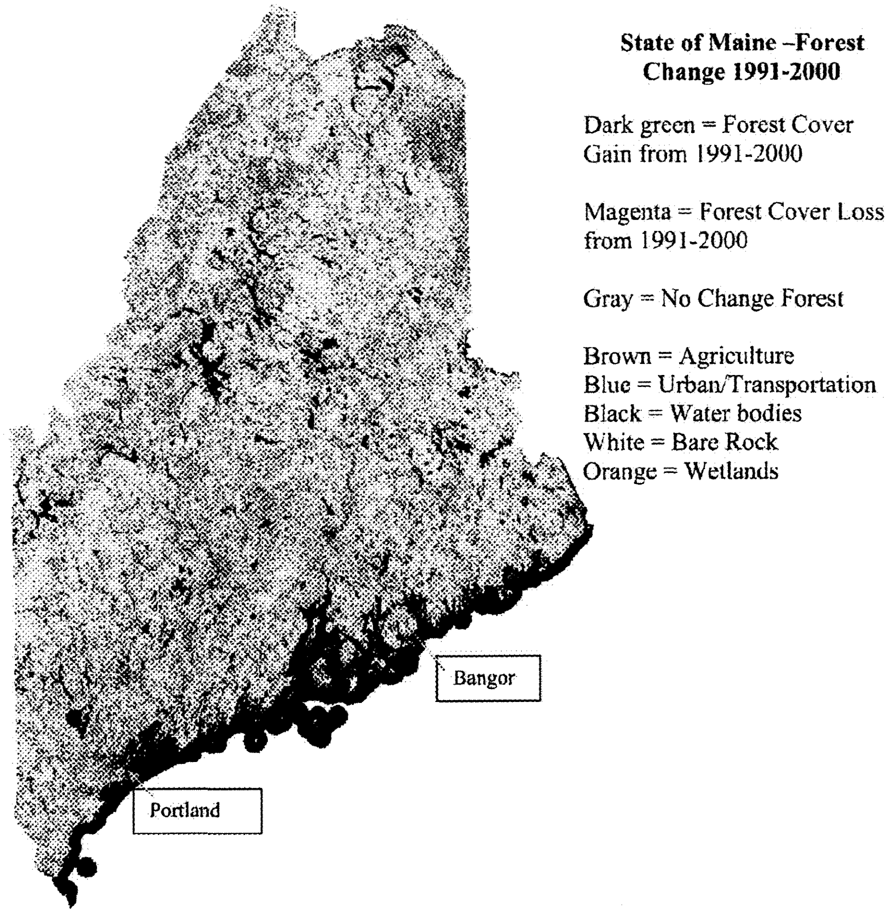

Figure 1. Maine forest cover and change detection map—1991–2000.

Maine Forest Cover and Change Detection Map (1991–2000)

Each Landsat pixel represents ¼ ac on the ground. Statewide mosaic images were prepared from 1991 Landsat TM and 2000 Enhanced Thematic Mapper Plus (ETM+) bands 3, 4, and 5 that were geometrically and radiometrically corrected. An unsupervised classification procedure (Isodata clustering) was performed (Erdas 1999). Wetlands and agricultural areas were extracted from the Maine land cover map (Hepinstall et al. 1999), and clouds and water were eliminated before clustering. The clusters were stratified into forest and nonforest classes aided by visual interpretation of multidate change detection images (Sader et al. 2003) and where aerial photography was available. Clusters classes were labeled into four categories indicating biomass losses (disturbance or harvesting) and gains (regeneration) and no change in forest cover:

- High-medium biomass 1991—low biomass 2000 (forest cover loss)
- Low biomass 1991—high-medium biomass 2000 (forest cover gain)
- High-medium biomass 1991—high-medium biomass 2000 (no change forest)
- Low biomass 1991—low biomass 2000 (no change nonforest)

Transportation data files were downloaded from the Maine Office of GIS website (e.g., all highways and primary roads). The vector road data were converted to raster and resampled to 30 m to match the resolution of the forest change map. Many logging roads did not appear in the transportation data. The detailed methods used to create the Maine forest cover and change detection map (Figure 1) have been reported elsewhere (Sader et al., in press).

Forest cover gain (green, Figure 1) in northern Maine represents forests harvested throughout the 1980s and regenerated by the 1990s. Much of the harvesting included clearcut salvage logging in the wake of the 1970s spruce budworm epidemic (Maine Forest Service 1999). The larger regeneration stands in the 1990s are concentrated in the northwest, north central, and eastern regions of Maine under primarily industrial and nonindustrial private forest (NIPF) ownership. Forest cover loss (magenta, Figure 1) patterns are well distributed throughout the state. Logging activity in the 1990s had shifted from large clearcuts to partial harvest systems (Maine Forest Service 1999). However, small clustered clearcuts (category 1; less than 35 ac with a minimum 250-ft forest separation zone) appeared for the first time on the northern Maine landscape (Figure 2, point A), after the implementation of the Maine Forest Practices Act (FPA), in 1991 (Maine Forest Service 1995, Sader et al. 2003).

Forest separation zones can be harvested 10 years after the date of the FPA, category 1 clearcuts (Maine Forest Service 1995). The Landsat imagery is capable of detecting even the narrow, linear harvests in

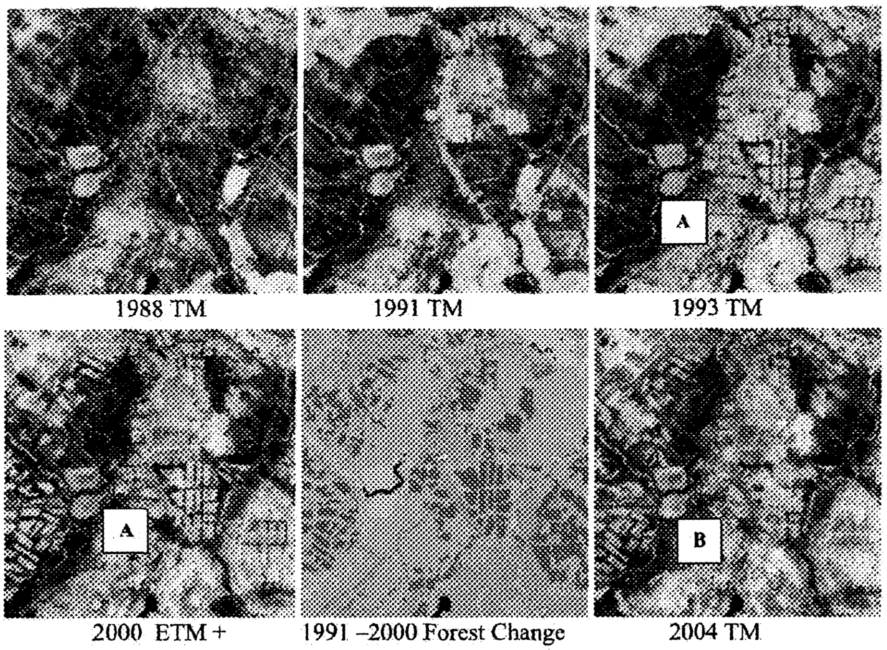

Figure 2. Landsat TM and ETM+ color composite images (1988, 1991, 1993, 2000, and 2004) for a selected area (approximately 24,000 ac) in northern Maine and 1991–2000 forest cover and change map (lower middle: gray = forest no change, green = forest gain [1990s regeneration], magenta = forest loss [1990s harvest], orange = wetland, and red = road). FPA, category 1 clearcuts are depicted at point A (1993 and 2000 image) and harvesting in the separation zones occurred (point B, 2004 image) after the 10-year no-harvest restriction expired.

the separation zones (point B, Figure 2). Compared with the 1980s harvests (1990s forest cover gain), the 1990s harvest areas (magenta, Figure 1) appear more dispersed in the northern and eastern region. Sader et al. (in press) reported that mean harvest patch size was significantly larger and patches were more compact in the 1980s compared with the 1990s. In the higher-populated southern and coastal regions of Maine, the forest harvest blocks were smaller compared with the northern and eastern working forest regions (Figure 1). Much of the forest cover loss in southern Maine represents a combination of urban/suburban development (Figure 3) and small woodlot harvesting.

Forest Cover and Change Map Accuracy

Color infrared aerial photos from 1991 (1:40,000) and 2001 (1:32,000) were available for a large region in northern Maine to conduct an accuracy assessment of the forest cover and change map. One hundred and seventy-eight random photo sample plots were selected and interpreted by a USFS forester who was not involved in the processing or development of the forest change map. The accuracy for forest and nonforest classes overall was 83% (kappa 0.77). The producer's accuracy (1-omission error) and user's accuracy (1-commission error) were calculated for the forest classes. No change forest, forest loss, and forest gain accuracy were 90, 88, and 92%, respectively (Table 1). We consider the forest cover and change map to be of sufficient accuracy to support the analysis of statewide spatial forest distribution, forest cover loss and gain estimates, and comparisons with FIA county data that follow.

Forest Cover Loss Index Map for Maine Townships

For each township, we calculated the percentage of the harvested area of total forest area available to create a "forest cover loss index." This perspective helps in visualization of the harvest intensity spatially across the entire state of Maine (Figure 4A). The forest cover loss index depicts a range from light (less than 1%) to heavy (more than 25%) disturbance from 1991 to 2000. The clusters of townships with high forest cover loss (yellow, orange, and red colors) in south central Maine (along the Interstate 95 corridor) and the coastal region are quite apparent. The township format offers a convenient "landscape" unit for aggregating the forest change measurements and it might be useful as a potential sampling frame to complement statewide forest inventory and monitoring. The Maine counties map (Figure 4B) with the forest cover loss index (Figure 4A) is provided for visual reference of the forest cover change distributions throughout each county.

Comparison of Landsat Forest Cover Loss with FIA Ground Plot Estimates

Evaluating the forest cover change map by comparing it with statistical estimates of volume, basal area, or tree size class, derived from FIA plots, is not straightforward. The dates of satellite image acquisition (1991–2000) do not match the dates of the recent annual ground surveys (1999–2004). The forest statistics for Maine provided by the FIA program do not include an explicit estimate of forest size class or volume change for areas smaller than the county level in standard state reports (Griffith and Alerich 1996). The current survey design requires that the plots be acquired annually, 20% per state per year; therefore, the county estimates that this study uses to summarize plot data in "2003" actually were acquired over a 5-year period (1999–2004).

Net area changes in three FIA stand size classes (sawtimber, pole-timber, and seedling/sapling) were compared with the area of mapped forest cover loss for each of 16 Maine counties. Only net losses can be calculated from FIA tabular data and no information on where in the county the changes are taking place is provided. Figure 5 compares the area of timberland by county that decreased one or more FIA stand size classes with the map-based area of forest cover loss. Some error is introduced by the use of FIA-defined timberland, which is productive forest excluding urban and reserved forest. In Maine, 96% of the forestland is timberland; therefore, the error should be small. The agreement between the map-based cover loss and the plot-based area estimate of size class decrease is surprisingly good for most of the Maine counties considering map error, plot sampling error, the mismatch in data acquisition dates, and the different loss category definitions (Figure 5). Two counties, Lincoln and Cumberland, had no FIA estimate for size class decrease. The R^2 value for forest cover loss against FIA size class decrease was 0.73 for the 14 counties with data. One out-

Figure 3. Changes in forest cover and land use in southern Maine between 1998 and 2003 (approximately 115 ac within the scene). Polygon A shows an area of heavy partial harvesting and B shows conversion to a housing subdivision. (Source: USGS digital orthophoto downloaded from Maine Office of GIS website.)

lier was Aroostock County, where the mapped forest cover loss area was extremely low compared with the FIA plot estimates. The large predicted area of forest that dropped a size class or two in Aroostook County may indicate timber harvesting that occurred from 2000 through 2004, after the 2000 Landsat image was recorded. The R^2 value for the 13 counties without Aroostock was 0.90.

Conclusion

The effectiveness of the Landsat imagery and methods for detecting Maine forest cover change are indicated by the good accuracy assessment results and the reasonably high correlation of mapped areas of forest cover loss with FIA county level estimates of tree size class decrease. The continuous Landsat coverage allows for spatial analysis of forest distribution, disturbance or harvest

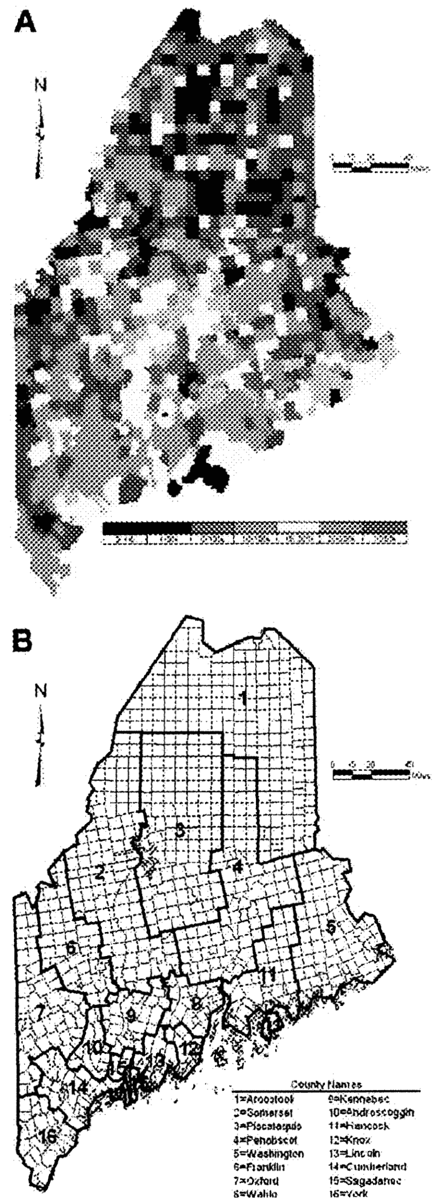

Figure 4. Forest cover loss from 1991 to 2000 (A) by township and the location of 16 Maine counties (B).

Table 1. Error matrix and accuracy of Landsat forest, nonforest, and change classes.

	Photo interpretation reference points							
Landsat	Forest—no change	Forest gain	Forest loss	Road	Low forest—no growth	Water	Wetland	Total
Forest	66	1	4	1	1	1		74
Forest gain	2	22		1			1	26
Forest loss	5		28	2	2		2	39
Road		1		10	3		2	16
Forest—no growth				1	1			2
Water						12	1	13
Wetland							8	8
Total	73	24	32	15	7	13	14	178
Producer's accuracy	0.90	0.92	0.88					
Overall accuracy = 0.83								

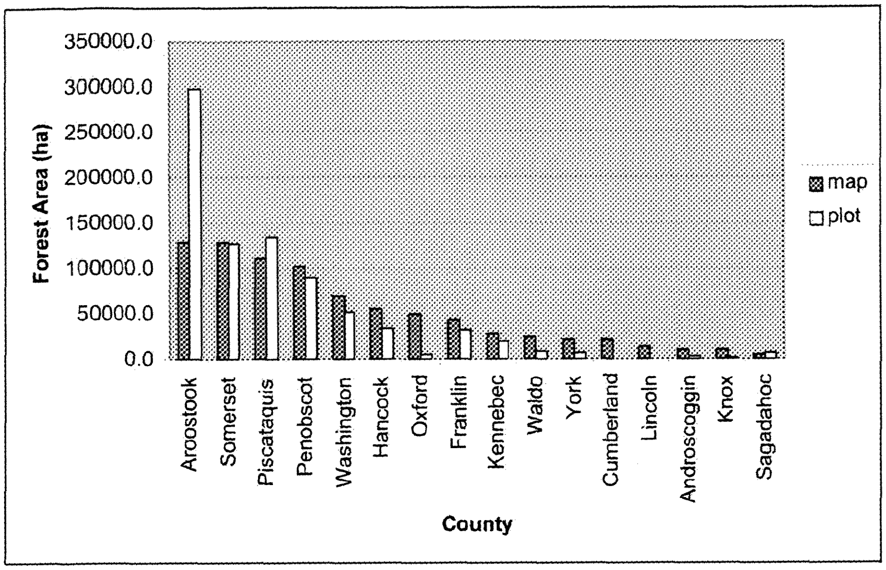

Figure 5. Area of timberland by county that decreased in FIA size class compared with Landsat forest cover loss area.

(forest cover loss), and regeneration (forest cover gain) that is useful in evaluating location-specific and statewide trends in forest change. As the FIA program continues, the number of remeasured georeferenced forested plots in Maine will increase to almost 3,000. The combination of annually collected permanent plots with accurate statewide forest change maps offers a complementary perspective of Maine's forest resource. We encourage forest mensurationists, remote sensing specialists, and FIA program leaders to continue exploring the direct links between remote sensing measurements and plot-based forest inventory to take advantage of the strengths of both approaches.

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