Are forest disturbance rates and composition influenced by changing ownerships, conservation easements and land certification?

Introduction

The state of Maine is undergoing a major shift in forestland ownership and transitioning into new oversight mechanisms, such as forest certification and Working Forest Conservation Easements (WFCE). Timber harvesting has increased from 100,000 hectares to over 200,000 hectares annually with the primary harvesting method shift from clearcut to partial harvest (McWilliams et al. 2005). These phenomena in addition to global economic forces are all shaping the current and future forest. Hagan et al. (2005) suggested that various landowner groups will manage their lands to varying degrees of sustainability and that the frequent landownership changes that interrupt management plans could lead to higher and less sustainable harvesting rates. The establishment of forest certification programs and WFCEs are encouraging steps towards sustainable forest management and for protecting areas from development; however, to our knowledge no studies have examined, on a statewide scale, how these new paradigms will affect sustainable forest harvest rates over time.

Most of Maine's industrial forest landowners have been replaced by a mix of corporate structures collectively known as Timberland Investment Management Organization (TIMO) and Real Estate Investment Trust (REIT) (Irland 2000, Hagan et al. 2005, MFS 2005). TIMO and REIT are limited liability corporations who utilize timber resources in addition to holding forestlands as a commodity and for potential real estate transactions (Binkley et al. 1996, Irland 1996). In 1994, industry represented the largest single landowner type with about 59%

ownership of forestlands, and financial investors (TIMO and REIT) only accounted for 3.2% (Irland 1996, Irland 2000). By 2007, TIMO/REIT owned 42% of Maine's commercial forestlands while industrial ownership continued to decrease to 16% (Noone 2009). The recent changes in Maine's forest landscape and ownership patterns require frequent monitoring to assess factors influencing forest management and current forest conditions (McWilliams et al. 2005).

Threats to water quality and biodiversity, imposed by development pressure and forest fragmentation, helped to usher in a new conservation era in the northeastern US, with large conservation easements established to protect forestland from development (Stein et al. 2005). A Working Forest Conservation Easement essentially removes development rights from the land, but allows the forest to be managed for timber, recreation, or other uses (Sader et al. 2002). Forest certification is the process whereby an independent third party assesses the quality of a landowner's forest management practices in relation to a set of predetermined requirements (Rametsteiner and Simula 2003). "The ultimate goal of certification is to provide assurances to markets and consumers that the forest products they buy come from well managed forests" (The Maine Forest Certification Initiative 2005, p. 10). There are two major competing international certification schemes today; the Forest Stewardship Council (FSC) and the Programme for Endorsement of Forest Certification (PEFC) and the umbrella certifications endorsed by PEFC, such as the Sustainable Forestry Initiative (SFI) in the U.S. Although FSC certification is currently recognized by virtually all environmental groups as the most rigorous in promoting higher environmental and management standards, SFI certification has gained credibility by becoming an independently run organization that has adopted a 3rd party accreditation program similar to FSC (Taylor 2005).

Monitoring forest conditions and landscape connectivity beyond an individual ownership receives minor consideration in certification standards or in WFCE stewardship assessments. This individual ownership focus may be a limitation for landscape-scale wildlife habitat analysis and biodiversity planning purposes (Hagan et al. 2005, Sader and Legaard, 2008). Understanding landscape dynamics in areas of mixed ownerships and across ownership boundaries is an important component of ecosystem management (Turner et al. 1996). Medium resolution Landsat time-series satellite imagery, integrated with ancillary data in a geographic information system (GIS), are available to examine how different landownership types, conservation partnerships (WFCE), or forest management oversight efforts (certification) might influence forest disturbance rates and trends. Past studies found that satellite based monitoring is an effective agent for mapping disturbances across large landscapes and multiple landownership boundaries (Turner et al. 1996, Cohen et al. 2002, Jin and Sader 2006, Healey et al. 2006, Spies et al. 2007).

Healy et al. (2008), in the Pacific Northwest states, compared regional forest disturbance rates between federal and private land ownerships, but no studies to date have examined at a statewide scale whether disturbance rates significantly differ following major ownership changes, or under new conservation and sustainable management paradigms. The goals of this research are to quantify forest disturbance rates between 2000 and 2007, as detected by Landsat, and to relate these to possible influencing factors including landowner type, ownership stability, forest certification, and WFCEs. Specific objectives include the evaluation of differences in disturbance rates (percent forest area disturbed) between: (1) land holdings under various landowner groups; (2) forestland under stable ownership and forestland that has changed owners once or more; (3) certified and non-certified forestlands; and (4) forestland managed under a

WFCE and forestland not in an easement. Additionally as a fifth objective, forest cover type proportions in 2007 will be compared for public, and private landowner groups, as it is anticipated that the proportion of coniferous forest available for harvest may be variable because of their high value, past harvest history, and the different fiscal requirements for certain landowner types. The majority of the forest disturbances in Maine detected by Landsat are related to harvesting, although natural disturbances (windfall, fire, insect, and disease mortality) may be included. This paper uses the terms disturbance and harvesting interchangeably.

Methods and Materials

The 7.2 million hectares of forestland in Maine represents the entirety of the study area. Approximately 95% of Maine's forests are privately owned. Maine is part of the Acadian Forest, a forest type that is intermediate between the boreal and the northern temperate forests (Seymour et al. 2002). The forests of Maine are dominated by spruce-fir (*Picea rubens, Abies balsamea*), northern hardwoods (*Acer rubrum, Acer saccharum, Betula papyrifera, Betula alleghaniensis, Fagus grandifolia, Populus tremuloides, Quercus rubra*), and white pine/red pine (*Pinus strobus, Pinus resinosa*) forest types (Seymour et al. 2002, McWilliams et al. 2005).

Landsat Data Acquisition

Eight Landsat scenes, based on the Landsat Worldwide Reference System, provide complete coverage for the state of Maine (Figure 1). Two statewide maps were produced using Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images: (1) 2000-2007 forest change, and (2) 2007 forest cover type (Noone, 2009). The forest change and forest type maps were assembled from Landsat images acquired during summer, hardwood "leaf-on" conditions.

Due to rapid vegetative regrowth in Maine, an intermediate image date was required to detect partial canopy disturbances. For the northwest part of the state (Landsat path 12, Figure1), the image intervals were four and three years (2000-2004-2007). For the east, central and south (Landsat path 10 & 11, Figure 1), the intervals were five and two years (2000-2005-2007). Images with the least cloud cover were identified and purchased from the U.S. Geological Survey (USGS). Frequent cloud cover during the relatively short hardwood "leaf-on" period required the use of some secondary images for particular dates to fill in data gaps (clouds and cloud shadows). In total 29 TM and ETM+ and 14 TM images were used to create the change and cover type maps.

Forest Change Map 2000 - 2007

All Landsat images were geo-referenced to the previously rectified 1991 Landsat TM scene used to produce the Maine GAP land cover map (Hepinstall et al. 1999). Each image was georectified using a second-order polynomial transformation applied to 25-35 well distributed ground control points. Nearest neighbor resampling and root mean square error (RMSE) was less than 10 m, except for one scene in eastern Maine with persistent heavy cloud cover and scant man-made reference points where RMSE approached 15m. The RMSE achieved here is considered acceptable (Coppin and Bauer 1994). The RMS error is only a statistical estimate of the average fit. There are methods and procedures that we followed to insure that we had a good spatial fit, in addition to RMSE, for example, the importance of having a good spatial distribution of points, including edges of each scene and points collected in scene overlap areas. In addition, we overlaid roads and streams from an independent data set (USGS) to make sure that these features matched up perfectly throughout the statewide mosaicked image.

Clouds and cloud shadows were delineated using a visual, screen digitizing procedure followed by the application of a binary mask to eliminate all cloud-contaminated areas from further data processing steps. A forest mask was developed from the Maine Gap land cover map (Hepinstall et al. 1999) to stratify forest and non forestlands. Forestland in this study is defined as lands having 10% or greater stocking or canopy cover (Helms 1998). To improve the detection of light canopy disturbance and the consistency of image interpretation during subsequent analyses, all images were transformed into a common radiometric scale using a relative radiometric normalization procedure (Canty et al., 2004; Sader and Legaard, 2008).

Several investigations into the use of vegetation indices to map forest change in northern Maine have indicated that the Normalized Difference Moisture Index (NDMI) is effective in detecting and mapping canopy disturbance (Wilson and Sader, 2002; Sader et al., 2003; Jin and Sader, 2005). NDMI images were calculated from normalized TM/ETM+ images using near infrared (NIR), band 4 (0.76-0.90 μm), and the mid-infrared (MIR), band 5 (1.55-1.75 μm) (Equation 1):

Equation 1.

$$NDMI = \frac{(NIR)-(MIR)}{(NIR)+(MIR)}$$

A three-date NDMI unsupervised (ISODATA clustering) classification was performed to produce a thematic forest change map for each Landsat scene (Figure 1). Unsupervised classification uses a multivariate method to aggregate pixels of distinct spectral characteristics into a user-defined quantity of groups or clusters (Sader et al. 2003, ERDAS 2008). Hame (1991) found unsupervised classification methods to be appropriate for large study areas where little information is known about the landscape conditions. A convergence threshold of 0.995

with 100 iterations was applied to create 55 cluster groups. The number of iterations limits the computer from performing an infinite number of cycles while the convergence threshold represents the maximum percentage of pixels allowed to stay unchanged between iterations (ERDAS 2008). The 55 cluster classes were found to be more than adequate to differentiate the spectral variation among forest change and no change groups (Sader et al. 2003). Ancillary datasets such as visually interpreted, individual Landsat color composite images, 1990s black and white digital orthophotos, and 2007 National Agricultural Inventory Program (NAIP) aerial photographs (1 meter, true color), aided grouping the cluster classes into 4 classes representing; forest biomass or canopy cover increase 2000-2007, biomass decrease 2000-2004/5, biomass decrease 2004/5-2007, and no change.

Reference to the ancillary imagery helped to improved cluster class identification and reduced confusion between light partial harvests and changes induced by other factors (e.g. plant phenological differences, natural disturbances, topographic shadowing, or atmospheric effects) (Franklin et al., 2000; Wilson and Sader, 2002; Sader et al., 2003). The forest change or disturbance maps derived for each Landsat TM were mosaicked to form a seamless statewide coverage. The forest biomass increase class was not used in the analysis stage due to the inability to date the origin of any disturbances detected before 2000. Both biomass decreases classes were combined for the analysis.

Figure 1. here

Agreement Assessment of the 2000 – 2007 Forest Change Map

For an agreement (accuracy) assessment of the statewide change map, a trained image interpreter familiar with the Maine forest landscape, evaluated change and no change class occurrence at 750 random points (375 located in mapped forest change, and 375 located in no-change). Three dates of Landsat RGB-453 color composite imagery and 2007 NAIP images were used to assess per-pixel change and no change against the 2000-2007 statewide forest change map. Any upward bias in agreement can be minimized when interpretation samples are randomly selected within change and no change strata, which is unknown (blind) to the image interpreter (Cohen et al. 2002; Hayes et al. 2008; Sader and Legaard 2008, Healey et al. 2008).

An error matrix was developed using randomly selected sample points to access the agreement between the mapped forest change, no change classes and visually-interpreted ancillary imagery, described earlier. The error matrix included the overall agreement representing the correctly classified interpretation points divided by the total number of interpretation points. Omission error, related to the producer's agreement and commission error, related to the user's agreement were calculated to provide additional statistics about the sources of error and the reliability of individual map classes (Congalton 1991, Congalton and Green 1999).

The overall agreement between the forest change map and image interpretations was 85%. User's agreement for the forest change and no change classes was 83% and 87%, respectively, while the producer's agreement for the forest change and no change classes was 86% and 83%, respectively (Table 1). More detailed methods to create and assess the quality of the forest change map were reported by Noone (2009).

Table 1. here

2007 Forest Cover Map Development

A four-band image (TM bands 3, 4, 5, and NDMI), was prepared for each of the eight 2007 Landsat scenes. Landsat bands 3, 4 and 5 were shown to be an optimal subset in northern forest regions for forest type mapping (Benson and DeGloria 1985, Horler and Ahern 1986).

The forest mask was applied and clouds removed from the images. An unsupervised classification was run on primary and secondary TM images from each of the 8 Landsat scenes in Maine.

Unsupervised cluster classes were interpreted and grouped into 4 classes: coniferous dominant forest, deciduous dominant forest, mixed forest (>25% coniferous and >25% deciduous), and recently disturbed (harvested) forest where the regeneration cover type could not yet be discerned. In a similar fashion, as with the change map, forest cover type classification was guided manually by the visual interpretation of Landsat composite images (RGB 453), 2007 NAIP aerial photos, and digital orthophoto quadrangles from the mid 1990s. Following unsupervised classification procedures, Landsat scenes were mosaicked to create a contiguous 2007 forest cover type map (Noone, 2009).

Agreement Assessment of the Forest Cover Type Map

The USDA Forest Service Forest Inventory and Analysis (FIA) program is responsible for collecting forest inventory data throughout public and private forested areas in the U.S. We used 2003-2007 FIA plot data, percent coniferous and deciduous basal area per plot, to assess agreement with the TM mapped cover type. FIA ground plots consist of a center sub-plot with 3 branching satellite sub-plots, each 0.017 hectare in size (Bechtold and Scott, 2005). An FIA plot will usually fall within a 3x3 TM pixel block (90m x 90m), but due to GPS and image registration errors that can be additive, an FIA plot may fall anywhere within a 5x5 or even a 7x7 pixel block (Cooke 2000, Cooke 2002). Additionally, when average values from the 4 sub-plots are used as reference data, the area actually sampled on the ground represents only 8% of a 3x3 pixel block. Positional error and scale mismatch between FIA plots and TM pixel blocks result in instances where FIA plot data are not representative of the true forest cover type within sample units selected for map accuracy assessment. This will most commonly occur where heterogeneous environmental conditions induce fine-scale spatial patterns on the ground and on the map.

Because erroneous comparisons between map and reference data labels can produce unreliable and misleading accuracy estimates (Foody 2009, 2010), we elected to compare FIA plot data to 3x3 pixel blocks where blocks were composed of a single forest cover type. We eliminated FIA plots containing non-forest conditions to further reduce errors associated with forest edge. Similar measures have been adopted by others when using FIA data to calibrate models of forest attributes or to validate forest attribute maps (e.g., Musy et al. 2006, Pierce et al. 2009). In total, 746 FIA plots were used as a reference source. Producer's accuracies ranged from 63-86% and user's accuracies ranged from 69-83%. Overall agreement was 77% (Table 2). Table 2. here

Geographic Data Merging and Processing

Several data sets including digital elevation, conservation lands, ownership, forest certification status, county and township boundaries were acquired from various sources. Methods used to create intermediate maps to examine forest disturbance rates and trends are described in the following sections.

Harvestable Timberlands

To determine disturbance rates, the amount of forest disturbed within a time period was divided by the total amount of forest that was considered harvestable. Harvestable timberland was determined using a combination of factors. The GAP (Hepinstall et al. 1999) derived forest mask removed non-forest areas, additionally forest areas over approximately 1,100 meters in elevation and areas under ecological reserve (extracted from the conservation lands data layer) were removed from harvestable timberlands. Land Use Regulation Commission (LURC) mountain protection areas over 1,100 meters are considered sensitive because of fragile soils and associated problems with erosion; thus, harvesting requires a special permit in this zone and occurs infrequently. These areas excluded 80,081 hectares from the analysis, mostly in western Maine. Additionally, 109,265 hectares within the eco-reserve system, created by the Maine Bureau of Parks and Lands, were excluded as timberlands because no harvesting is allowed in these areas.

Forest Owner Type

Landownership data for 2000 and 2007, acquired from J.W. Sewall Co. in Old Town, Maine, were used to develop a spatial dataset of forestlands that had either changed ownership or remained under stable ownership. To assess forest disturbance rates, landowner types were grouped into broad categories, similar to a study by Hagan et al. (2005). Stable landowner groups include: conservation, industry, TIMO/REIT, old-line non-industrial, public, tribal, small, and other non-industrial. Landowner change groups include: industrial to TIMO/REIT; industrial to non-industrial; various landowners to conservation or public; non-industrial to new owners; and TIMO/REIT to new owners (including TIMO/REIT). To focus the study on the major land units, landowners holding less than 80 hectares, were excluded from the analysis. The small landowner group individuals owned less than 800 hectares, but greater than 80 hectares. The non-industrial landowners represented the most diverse group, including family-based corporations and contractors. Old-line non-industrial ownerships were generally family-owned, dating back a few decades or more while industrial landowners are typically multinational corporations who manage their lands for a steady supply of wood to their large mills (Irland 2000). Public forestlands include all lands owned by the federal, state or municipal (town) government. Conservation landowners include land trusts and other non-government organizations (NGO's), for example, The Nature Conservancy and the Appalachian Mountain Club.

Forest Cover Type Proportion in 2007

In addition to comparing forest disturbance rates, we were interested in determining if the proportion of the forest cover types differed on land held by the various ownership groups. The landowner and forest cover type data layers were cross-referenced in the GIS to calculate the proportion of cover types in 2007. The 2007 forest type proportions were compared among public, and other private landowner groups.

Forest Certification

Up-to-date information regarding forest certification was compiled using the Forest Stewardship Council (FSC) archive (http://www.fscus.org/), the Sustainable Forest Initiative (SFI) archive (http://www.sfiprogram.org/), a 2004 J.W. Sewall Co. ownership file, and information from publications by the Maine Forest Service (MFS 2005, The Maine Forest Certification Initiative 2005). Certification status was appended to spatial owner information for analysis. In Maine, there has recently been an increasing occurrence of dual-certification under both FSC and SFI schemes. The FSC standards are generally considered more stringent and difficult to obtain and maintain; therefore, all lands that were dual certified were considered as FSC lands for a FSC vs. SFI disturbance rate comparison.

Comparisons of disturbance rates for certified and non-certified forests included all forests that were certified by 2007. Not all certified forest landowners in 2007 were also certified in 2000. For this study, it is assumed that these landowners were managing their forests similarly to certification standards before the transition into certification. Only large private landowners (>2,000 hectares) were included in the certified and non-certified groups.

Working Forest Conservation Easements

Information on current WFCE was compiled from various Maine Forest Service publications (MFS 2005), in addition to spatial data layers that were obtained from the Maine Office of GIS and the Maine Bureau of Parks and Lands. Disturbance rates were compared between forestlands managed under a WFCE and non-easement land. Only the WFCE in unorganized townships under LURC jurisdiction were included in the analysis to avoid comparing a few very large corporate easements with the many small easements owned by NGOs or land trusts. The two smallest WFCE were excluded from the analysis due to their small area of forestland holdings and their high disturbance rates, uncharacteristic of the other larger WFCE. Only large private landowners (>2,000 hectares) were included in the non-easement group and all easement holdings in the analysis were greater than 2,000 hectares.

Statistical Analysis

Statistical tests determined if significant differences in disturbance rates existed between stable forest lands and forestlands that changed ownership, various landowner groups, WFCE and non-easements, and certified versus non-certified. Due to apparent differences in the distributions of disturbance rates between individuals within groups, resulting in group distributions with non-normality, nonparametric tests were used because of their less restrictive assumptions regarding population distributions. Data transformation to a normalized distribution was attempted, but not applied due to the difficulty in interpreting the results. Expecting differences, in certain cases, in population distributions resulting from the nature of various landowner groups and sample sizes (see Table 3), a median test was run in addition to the

Kruskal-Wallis test to corroborate test results. If a significant difference in disturbance rates was observed a Wilcoxon test was applied to test for differences between groups. The nonparametric tests used the disturbance percentages (over the 7 year study period) of each sample (individual landowners) from within the various landowner groups. All statistical tests were evaluated for significance with an alpha level of 0.05. The tribal group was removed from statistical analysis due to a small sample size (Table 3). The other non-industrial and small landowner groups were also removed from analysis due to the lack of inferential information regarding the groups.

Statistical tests were run on the coniferous forest cover type proportions of the various ownership groups. Tribal, other non-industrial and small landowners were excluded for reasons previously mentioned.

Table 3. here.

Results

Ownership Disturbance Rates

Forestlands that changed owners in the seven year time frame were found to have similar disturbance rates to those of stable landowners (Kruskal-Wallis P=0.433, median P=0.936). There were no significant differences observed in disturbance rates between the landowner change groups using the Median (P=0.322) and the Kruskal-Wallis (P=0.1683) tests. Lands that were originally owned by a TIMO/REIT and sold to a new owner had the highest disturbance rates (17%) of all landowner change groups. Industry lands sold to either TIMO/REIT or, non-industrial, and any forestlands sold to public/conservation had similar disturbance rates between 13-14% (Table 4).

Table 4. here

For stable landowners, TIMO/REIT were found to have the highest disturbance rates (20%), compared to the intermediate disturbance rates of industrial (13%), old-line non-industrial (14%), conservation (9%), and other non-industrial (13%). Lower rates were attributed to small landowners (7%), public (5%), and tribal (4%) (Table 4). A significant difference in disturbance rates was observed among the five stable landowner groups in the analysis (Kruskal-Wallis $P<0.0001$, median $P<0.0001$). A Wilcoxon multiple comparisons test was applied to further examine which groups had significantly different disturbance rates (Table 5). Public lands disturbance rates were significantly lower than all other landowner groups, except the conservation group. The only other significant difference observed was between TIMO/REIT and conservation landowners, the latter having lower disturbance rates (Table 5).

Table 5. here

Forest Certification and WFCE Disturbance Rates

Prior to 1990, there were no lands in Maine certified under an internationally recognized certification scheme. In 2007 of harvestable timberland area, for the major landowners in this study, there were 1.4 million hectares under FSC (or FSC and SFI) certification, 1.3 million hectares under SFI certification (SFI only), and 1.6 million hectares not certified. Disturbance rates on SFI lands (16%) were found to be slightly higher than Non-certified lands (15%) and FSC certified lands (14%) (Table 6). A Kruskal-Wallis test indicated no significant differences in disturbance rates between SFI, FSC and Non-certified lands ($P=0.178$). A median test, however, contradicted this result ($P=0.015$).

Seven conservation easements of varying sizes protect 759,690 hectares from development, leaving 3.6 million hectares of harvestable forestland owned by major landowners not under a conservation easement in 2007. The majority of the forestland under a WFCE in 2007 was represented by several large easements: Pingree Associates – 308,448 hectares, Downeast Lakes Land Trust Partnership – 126,262 hectares, West Branch – 113,312 hectares, Katahdin Forest Project – 78,813 hectares, and Katadhin Iron Works – 14,973 hectares (MFS 2005). The disturbance rate for WFCE (15.9%) slightly exceeded that of Non-easement lands (14.8%) (Table 6), although the difference was not significant (Kruskal-Wallis P=0.682, median P=0.160).

Table 6. here

Forest Cover Type Proportions of Ownership Groups

A forest cover type map represents forest conditions for only a snapshot in time. In 2007, the coniferous forest cover type comprised 44% of public forestland, compared to 30% of TIMO/REIT forestland and 25% of non-industrial private forestland (Figure 2). The proportion of public forestland under deciduous cover type was lowest at 17%, compared to 25% and 30% on TIMO/REIT and non-industrial private forestlands, respectively. The proportion of recently disturbed land was significantly less on public lands than on private or TIMO/REIT lands. Mixed forest cover type varied (28-35%) less than coniferous and deciduous cover types amongst owner groups. Kruskal-Wallis and median test results ($p<0.0001$, $p<0.0001$ respectively) revealed significant differences between percent coniferous composition of group samples. A Wilcoxon test was then run to determine between which groups there were significant differences in coniferous composition. Non-industrial private forestland owners had significantly different amounts of coniferous forestlands than public (p=0.034), conservation (p=0.005) and old-line non-industrial (<0.001) landowners while TIMO/REIT lands had significantly different coniferous forestlands than conservation lands (0.041).

Figure 2. here

Discussion

Ownership Disturbance Rates

Jin and Sader (2006) reported landownership disturbance rates and trends from 1991-2004 on a 1.6 million hectare study area in northwestern Maine private forestland and found: (1) higher disturbance rates on TIMO/REIT lands, and (2) lower disturbance rates on lands managed by stable owners and higher disturbance rates on forestlands that changed owners at least once between 1991-2000. Our results also indicate higher disturbance rates on TIMO/REIT lands; however, no significant difference was observed between stable and non-stable landowners in this statewide study. The highest disturbance rates were observed by the TIMO/REIT group for both stable and land owner change groups. The TIMO/REIT group now represents the largest landowner type in Maine, and the largest landowner in the stable and landowner change groups, which was not the case in the earlier, smaller region study of Jin and Sader (2006). Thus the recent dominance of the TIMO/REIT owners in both stable and changing ownership groups likely influenced the no statistical difference finding in disturbance rates between the two groups.

The frequent change of ownership (within decadal time frames, for example) has been cited as a potential deterrent to sustainable forest management on private ownerships (Hagan et al. 2005, Land and Water Associates 1995). Comparing disturbance rates between stable and non-stable ownerships over a short time frame (7 years) may not be a reliable indicator of a trend in sustainable forest management. Longer-term studies that approach a timber rotation cycle would be more revealing of timber sustainability trends. The Landsat TM archive, dating back to the mid-1980s, is only beginning to approach the desired timeframe for a retrospective study of sustainable harvest trends (Cohen and Goward, 2004).

Financial investment firms (TIMO/REIT) seek to maximize returns and often plan on holding the land for short periods of 8-12 years before selling (Hagan et al. 2005, MFS 2005). Our study found that between 2000 and 2007 industry and TIMO/REIT landowners were the most likely groups to sell their forestlands. At the onset of the major landowner changes, Binkley et al. (1996) predicted that financial investment owners would offer many benefits by implementing more intensive silvicultural practices to increase their land values. McWilliams et al. (2005) reported that planting, pre-commercial thinning, and conifer release occurred only on about 5 percent of the timberland in Maine. Silvicultural practices cannot be evaluated from our results. However, the high turnover of TIMO/REIT lands to other owners and the higher disturbance rates of TIMO/REIT from 1991-2004 in northern Maine (Jin and Sader 2006) and in our statewide study (2000-2007), may suggest a short-term management priority, less likely to include intensive silvicultural investments. The lower disturbance rates observed in the other non-industrial, NGO and public groups, were expected due the group's priorities that are less influenced by timber profit (Hagan et al. 2005).

Forest Certification and Conservation Easements

Disturbance rates between certified and non-certified lands revealed marginal statistical differences. Forest certification, in general, does not limit harvesting; only requiring that specific sustainable forest management practices are utilized. Additionally, many of the certified lands have only become certified recently (within the study period) and any trend in disturbance rates may not be detectable over the short time frame.

The WFCEs in Maine are owned by a variety of landowner types who have varying objectives. The majority of the forestlands under a WFCE in 2007 was represented by several large easements. An insignificant difference between disturbance rates of easement and non-easement lands is not surprising because most of the large private WFCE have few restrictions regarding harvesting (beyond state regulations), with the occasional exceptions of no clearcutting clauses or restricted harvest buffer zones around watercourses (Sader et al. 2002). Easement holders or grantees tended to accept any conditions or forest management treatments that are contained in a professionally written forest management plan (Mortimer et al. 2007). The slightly higher disturbance rates found in WFCE may lend support to the suggestion of Hagan et al. (2005) that some landowners may harvest at greater rates prior to the establishment of a WFCE. This trend, however, cannot be confirmed due to the short time frame of the study and the recent completion of easement transactions. Longer pre- and post-easement time frames are required to track the timing of harvest rate changes on WFCE, compared to non-easement land.

Forest disturbance rates reported in this study are likely under-estimated due to longer than preferred Landsat image acquisition gaps. Some light partial harvests may not be detected when images dates are more than 2-3 years apart (Wilson and Sader 2002, Jin and Sader 2005, Healy et al. 2006). Gaps of 4-5 years in the first image acquisition sequence (2000 to 2004/2005) were due to a lack of available cloud-free images and financial constraints ($425 per Landsat scene at the time) to purchase multiple marginal secondary scenes. Readers should note that as of January 2009, the USGS Landsat data archive is available for unlimited free data download.

Forest Cover Type

The overall cover type map agreement (77%) with FIA plot data was considered acceptable for a statewide forest vegetation map, but we acknowledge there are inherent difficulties in using sub-pixel inventory data to evaluate Landsat derived maps (Xu et al. 2009, Riemann et al. 2010). Often researchers have avoided comparisons of sub-pixel FIA plot data with satellite-derived cover maps because the magnitude of error associated with mismatches in scale and location is unknown. Additionally, the reflectance signature that the satellite records from above the canopy may not always be best represented by the forest volume or basal area parameter used in the assessment of agreement with FIA plots (Franklin et al. 2001, McRoberts 2011). Recent stereo, color infrared aerial photography was not available for use as the preferred reference source for map accuracy assessment. Fortunately, we found the extensive FIA plot data records to be a suitable reference source.

To partially mitigate the difficulties inherent in the use of FIA plot data, we restricted our forest cover agreement assessment to homogeneous 3x3 pixel blocks. It is widely recognized that this practice introduces a positive bias in map accuracy assessment (Hammond and Verbyla 1996, Fassnacht et al. 2006), but more precisely, our results constitute a valid assessment for pixels that are not adjacent to a mapped edge (Stehman 2001). Map accuracy is likely lower for edge pixels or pixels adjacent to an edge, but the difficulties inherent in comparing FIA plot data to TM pixel blocks are likely to have the greatest effect in these areas as well. Because inaccurate reference data or erroneous comparisons to reference data can have dramatic and unpredictable effects on map accuracy assessment (Foody 2009, 2010), we elected to restrict analysis to homogeneous areas rather than present accuracy estimates subject to an unknown and possibly large degree of error.

Much of the lack of agreement between the forest cover map and FIA data occurred primarily between mixed forest and hardwood type or mixed forest and softwood type, owing to the difficulty in defining the subtle spectral differences among compositional boundaries. Hepinstall et al. (1999) used aerial videography as reference imagery for their 1993 cover type map of Maine, and similarly had difficulty in obtaining mixed forest composition agreement due to the subjectivity in determining the compositional thresholds of a mapped mixed forest class. Studies in Minnesota (Franco-Lopez et al. 2001), Texas (Unger et al. 2008), and California (Franklin et al. 2001) have experienced similar difficulties as well.

On public, old line non-industrial, and conservation lands there was a lower deciduous and recently disturbed cover type component and a higher percentage of coniferous forest cover type than on TIMO/REIT or other private landowner groups. TIMO/REIT forest cover type proportions were more similar to non-industrial private forestlands. Public land management may be less dependent upon profit from timber harvesting because public access, conservation and recreational uses are major management priorities (Hagan et al. 2005). Fiscal requirements and forest management objectives between public and private lands may have influenced the differences in the proportion of forest composition types observed in 2007.

In reference to the 1995 U.S. Forest Service forest inventory data, Griffith and Alerich (1996) noted that the northern hardwood forest (2.6 million hectares) replaced spruce-fir (2.4 million hectares) as the dominant forest type in Maine. The decline in poletimber forest and increase in sapling area was more dramatic for the spruce-fir type in the unorganized townships (McWilliams et al. 2005). This suggests that forest composition trends on harvested spruce-fir sites are becoming stocked with other species (MFS 1995). Our data, indicating an increase in mixed forest composition, may at least partially reflect the loss of spruce-fir dominant overstory and an increase in the hardwood component in previous conifer dominated stands.

Conclusions

Remote sensing methods provide an effective and economical means to monitor and evaluate the changing forest conditions of large multi-ownership forestlands. We believe that this is the first statewide study of its kind to explore the question of harvesting rates being influenced by changing ownership, forest certification and easement status.

These results indicate statistically significant differences in forest disturbance rates between public land ownership and all other landowners except the conservation landowner group, and between conservation lands and TIMO/REIT lands. No statistical difference was found between stable forestland disturbance rates and landowner change disturbance rates. Industry and TIMO/REIT landowners were more active in selling forestland while TIMO/REIT landowners were most active in purchasing forestland. Lands managed under a WFCE or certification scheme had similar disturbance rates to forestlands that were not certified or managed under a WFCE. SFI certified lands had a slightly higher disturbance rate compared to non-certified forest holdings and FSC certified lands, but the differences were only marginally statistically significant. Public, old line non-industrial and conservation forestlands contained a higher proportion of coniferous forest and lower component of deciduous forest compared to other privately owned forests in the state.

Future studies using the Landsat archive are recommended to evaluate the intensity of disturbances (e.g., light versus heavy harvesting), and how disturbance intensity may affect residual stand composition and regeneration stocking. Ecologically relevant or management-informative forest patch metrics could provide useful surrogate indicators of forest diversity, structure and fragmentation for the purposes of monitoring patterns and trends (e.g., changes in the size and configuration of late successional or large diameter forests) across large landscapes and ownership boundaries. FIA data may at times be the only available means to evaluate a remotely sensed, thematic map at a statewide scale; however, the authors observe there are inherent difficulties when evaluating 30m pixel data with sub-pixel plot data and recommend further studies on successfully integrating FIA data as a reference source to evaluate vegetation map accuracy.

The fixed costs associated with certification represent a landowner's objective to manage their land for years to come and an indication of corporate environmental responsibility. The increase in certified area is an important and encouraging step for the State of Maine, which has seen a massive shift in landownership over the last two and a half decades. Forest management plans; however, have been interrupted on the 1.6 million hectares of land that changed hands between 2000 and 2007. Replacement of industry ownership by TIMO/REIT and the continuation of large land sales throughout the state may promote higher harvesting rates over short time periods. This situation will present a challenging future for forestland managers and state policymakers attempting to balance sustainable harvesting and biodiversity maintenance in a changing environment.

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