INVENTORY OF MODERATE AND INTENSIVE TIMBER CLEARINGS DETECTED VIA REMOTE SENSING IN NEW HAMPSHIRE BETWEEN 2000 AND 2018

FEMC

Forest Ecosystem Monitoring Cooperative

Last updated: February 18, 2020

Inventory of moderate and intensive timber clearings detected via remote sensing in New Hampshire between 2000 and 2018

Published February 18, 2020
Version 1.0
Forest Ecosystem Monitoring Cooperative
South Burlington, VT, USA
femc@uvm.edu
(802) 656-2975

Alexandra Kosiba[a,b] and James Duncan[a,b]

[a] Forest Ecosystem Monitoring Cooperative, 705 Spear Street, South Burlington, VT, USA
[b] University of Vermont, Rubenstein School of Environment and Natural Resources, 81 Carrigan Drive, Burlington, VT, USA

DOI: https://doi.org/10.18125/56igk7

Cover image: FEMC with Google™, Digital Globe imagery

Preferred Citation
Kosiba, AM and Duncan JA. 2019. Inventory of moderate and intensive timber clearings detected via remote sensing in New Hampshire between 2000 and 2018. Forest Ecosystem Monitoring Cooperative: South Burlington, VT. https://doi.org/10.18125/56igk7
Available online at https://www.uvm.edu/femc/file/info/10344.

Acknowledgements
The Forest Ecosystem Monitoring Cooperative (FEMC) is thankful to US Forest Service White Mountain National Forest personnel Clare Mendelsohn, Royer Boyer, and Katie White and New Hampshire Department of Natural and Cultural Resources (NH DNCR), Division of Forest and Lands Forest Health Specialist Kyle Lombard for providing data on known timber harvests, and Karen Bennett and Alicia Carlson (UNH Cooperative Extension) for providing the 'Intent to Cut' data. We appreciate the project oversight provided by Kyle Lombard and Brad Simpkins (NH DNCR) and the helpful inputs on this report by Matthias Nevins (FEMC).

We appreciate of the long-term funding from the U.S. Department of Agriculture, Forest Service State & Private Forestry, Vermont Agency of Natural Resources and the University of Vermont that made this report possible.

Table of Contents

Executive Summary

Timber clearing is used for both forest management and to convert forestland to another use (e.g., agriculture or development). Examining the rate, extent, and timing of timber clearing in the state of New Hampshire (NH) is integral to understanding patterns of silviculture and forest conversion.

In 1995, a group from the University of New Hampshire analyzed the amount of intensive timber clearing (e.g., clearcutting) in NH, but did not evaluate the timing or post-harvest outcome, and a follow-up analysis has not been completed since. Here, we provide a follow up to those initial assessments and specifically evaluate (1) the number, timing, and size of moderate (>20ft^2/ac residual basal area) and intensive (<20ft^2/ac residual basal area) timber clearings (>3 ac in size) in NH between 2000 and 2018 detected via remote sensing, (2) the proportion of those clearings determined to be intensive (i.e., clearcuts), and (3) the likely post-harvest outcome (i.e., silviculture or land use conversion).

Comparison to available spatial data for known silvicultural clearcuts showed that our inventory had few commission errors (1.7% by area), indicating that these results do not overestimate moderate and intensive timber clearing area overall. However, the remote sensing inventory could not distinguish between moderate (>20ft^2/ac residual basal area) and intensive (<20ft^2/ac residual basal area) timber clearings. Using a subset of clearings, we determined that slightly more than half were intensive cuts. Omission errors (9% by area) indicated that this inventory may have missed some timber clearings, particularly those <10 ac in size.

Overall, we found 203,832 acres of moderate and intensive timber clearing over the 18-year period, with 55% classified as intensive timber clearings and the remainder (44%) classified as moderate. Annually, this equated to 11,324 ac (0.2% of the state's forestland) cleared in moderate or intensive clearings, with about 6,197 ac (0.08% of the state's forestland) estimated to be intensive clearings. These values do not include low intensity harvests that may not be detected via remote sensing (e.g., single tree selection, thinning, etc.). We found that more than 80% of cuts occurred on private, non-conserved lands where rates of timber clearing were the highest. Further, the amount of timber clearing has been increasing overtime; this was not due to increased land conversion rates, but more land managed for silviculture. Statewide, 80% of the harvest area was for silvicultural purposes rather than land use conversion. Annual rates of timber clearing were similar across counties and years, but the proportion that may have been cleared for non-silvicultural purposes varied spatially. Annually, we estimated the amount of forestland conversion to be approximately 2,285 ac/yr (0.04% of forestland).

Background

New Hampshire is about 83% forested. Of this, about 72% of the forestland is privately owned, with the remainder in public ownership (e.g., federal, state, or municipal) (Morin 2018). With this distribution of landowners, it can be difficult for forest managers and policymakers to assess and track spatiotemporal patterns of forest management and conversion across the state. Although the amount of forestland in the state has remained stable at ~81% since 2007, this follows a slow decline in forest cover since the 1960s (Morin 2018). There is concern that the state could continue to lose more forestland to development and other land uses. Understanding the spatial patterns and post-harvest outcomes of timber clearings, in particular intensive clearings (i.e., clearcuts), is a critical first step.

Forest managers utilize silvicultural clearcutting in a variety of ways as an even-aged forest management technique to regenerate a desirable mix of shade intolerant and mid-tolerant tree species, promote early successional forest conditions (often for wildlife priorities), increase short-term economic yields, or to rehabilitate forest stands comprised of less desirable timber (Ward et al., 2013). On the ground, these goals could be achieved through a range of applications including, large clearings, strip cuts, patch cuts, or a combination of these approaches. As the forests in NH mature following widespread land clearing in the early 20th century, the age, size, and species diversity of the state's forestland have declined. Thus, timber clearing can be a useful tool to promote both structural and compositional diversity at a landscape scale. Understanding the amount of early-successional forests created each year through timber clearing can help managers assess if the desired forest diversity is being achieved.

Forest clearing is employed for land-use conversion as well; for example, to expand agricultural land or for planned development. When forests are cut and converted to another land use, these areas may remain non-forested in perpetuity, and lose important ecological functioning they once provided. Thus, the trajectory of a timber clearing can have two distinct post-harvest outcomes: (1) the area is allowed to regrow as forest, or (2) the area is maintained for other non-forest purposes. Understanding the amount of timber clearing and whether cleared patches are allowed to regrow is critical in understanding land use change and forest conversion rates.

A previous inventory was conducted in 1995 that found that approximately 49,907 ac was cleared between 1980 and 1995 (Rubin and Justice, 1995); however, a follow-up assessment has not been conducted since. The authors did not examine the spatiotemporal patterns of these cuts, analyze intensity of clearing, or examine post-harvest outcomes. Shortly after this study was completed, a large (>1000 ac) clearcut in the state caused public outcry (NH DRED, 1996). In anticipation of updating the NH Forest Action Plan, the NH Division of Forest and Lands solicited an updated inventory of statewide timber clearing from the Forest Ecosystem Monitoring Cooperative (FEMC). Here, we inventoried the amount, extent, timing, and trajectory of moderate and intensive timber clearings in NH between 2000 and 2018 detected via remote sensing by utilizing available spatial datasets and ancillary information on the location of known timber clearings.

Methodology

Identification of forest change

We utilized the Global Forest Change spatial dataset produced by Hansen et al. (2013; Version 1.6) that identified locations of forest loss and gain between 2000 and 2018. Briefly, this dataset was created from time-series analysis of Landsat satellite imagery to characterize forest extent, loss, and gain at a 30 m (0.22 ac) spatial resolution. Forest loss was defined as a stand-replacing disturbance or change from a forest to non-forest state. Pixels of forest loss also contained the year of detection, between 2001 and 2018. For more information on this data product, refer to https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.6.html.

To identify locations of possible timber clearing in the state of NH, we grouped forest loss pixels that had the same year of loss into polygons. We restricted possible timber clearings to those ≥3.0 ac in size based on the previously established methodology (Rubin and Justice, 1995). Note that the Global Forest Change dataset only aimed to detect stand-replacing disturbance per 0.22 ac pixel; therefore, low intensity harvests, like thinning, crop-tree release, single tree selection, small gap selection, or shelterwood harvests were likely not detected or removed from analysis due to the size threshold. We summarized resulting timber clearing polygons by various criteria: statewide, as well as by county, year, and land ownership type. A timber clearing polygon was assigned to a county or land ownership type based on the location of its centroid. We converted the forest extent dataset by Hansen et al. (2013) to create a forest-non/forest image, where pixels with ≥30% tree cover were considered forest. We used this forest cover dataset to estimate the proportion of forestland cut.

Accuracy assessment

We conducted two forms of accuracy assessment of our resulting timber clearing inventory: (1) a comparison to known silvicultural clearcuts to estimate the omission error rate (i.e., missed detection) and (2) a comparison to historic satellite and aerial imagery for a random subset of possible timber clearings to estimate of overall accuracy and the commission error rate (i.e., erroneous inclusion). The resultant omission and commission error rates were used to define confidence intervals around the estimates of area cleared.

We combined USFS White Mountain National Forest (WMNF) timber harvest data (1993-2014; USFS 2018b), supplemented by harvest data from the USFS Data Extract Tool (USFS 2018a), with Timber Sales data from the State of NH Division of Forest and Lands (NH DRED 2018). From these, we selected only polygons with a harvest prescription of "clearcut" or "stand clearcut". We used Google Earth Pro™ historical imagery to check that a clearing occurred in that location (non-cuts were removed), as well as verify the boundaries and year of harvest. When necessary, we re-digitized the extent to more accurately align with the imagery and updated the harvest year. This last step was especially important for the Timber Sales data from the state of NH. These polygons did not contain information on the year of harvest, rather the year the parcel was sold. For these polygons, we used historical imagery to estimate the harvest year. As historical images were not available for all locations each year, when a clearing occurred between two image years (e.g., 2004 and 2008), we assumed that it occurred mid-way between these years (2006). Once we confirmed the size and harvest year of all known clearings, we selected only those polygons with a harvest year between 2001 and 2018 and ≥3.0 ac in size to align with the previous inventory criteria (Rubin and Justice, 1995).

The resulting dataset contained 241 known silvicultural clearcuts that we used to evaluate the detection accuracy of our timber clearing inventory. Specifically, we assessed if our inventory correctly identified or failed to identify known clearcuts (omission error rate). When the timber clearing inventory correctly identified a known clearcut, we compared the year of detection to the harvest year to assess temporal accuracy. Note that both the omission error rate and the temporal accuracy assessment only include comparison with known intensive silvicultural clearcuts, and not moderate intensity timber clearings. Further, these known harvests were not uniformly distributed throughout the state (the majority were located in WMNF).

To assess if the timber clearing inventory erroneously detected cuts when they did not occur (commission error rate), we randomly selected 1,550 polygons (8.1%) from the possible timber clearing inventory to evaluate for accuracy. For each of these polygons, we used Google Earth Pro™ and ESRI imagery to determine if there was (1) intensive timber clearing (i.e., defined as a residual basal area of <20ft^2/ac based on the previous inventory criteria (Rubin and Justice, 1995)), (2) a moderate timber clearing (>20ft^2/ac residual basal area), or (3) no timber clearing. The 'moderate timber clearing' category was assigned to polygons that were harvested, but it was uncertain if they constituted intensive clearings (i.e., clearcuts). We used the visualizations provided by McGaughey and Tootell (ND) to estimate 20 ft^2/ac residual basal area in the imagery.

For the polygons that we assigned to be some sort of timber clearing (intensive or moderate), we evaluated the most likely reason for each cut using the available imagery: (1) forestry-related, (2) for development, or (3) for agricultural purposes. We primarily assigned the post-harvest outcome based on the pattern of the forest clearing (e.g., inclusion of reserves, amount of residuals), inclusion of other infrastructure (e.g., roads, power lines, etc.), and imagery post-harvest. We considered any land use change that did not include added infrastructure as "agriculture"; for example, gravel pits. Cuts that occurred more recently had comparably fewer years of imagery post-harvest to evaluate. This information was used to examine the relative proportion of silviculture to land use change in the state.

Results and Discussion

We first discuss the accuracy assessment of the inventory, as the findings from this step provide important context to the discussion of spatiotemporal patterns in clearing, ownership, and post-harvest outcome that follow.

Accuracy of timber clearing inventory

We detected 88% of the 241 known silvicultural clearcuts (omission rate of 12%; Table 1) using this timber clearing inventory. When we computed the omission error by area rather than count, the omission error rate was 9%, suggesting that the estimates presented here underestimate the total area cleared by 9%. Of the 30 cuts that this inventory failed to detect, the majority (22 cuts) were detected partially or over multiple years, and due to the size restriction (i.e., ≥3.0 ac) were removed from the final set of possible timber clearings (Figure 1). In fact, 67% of the known clearcuts that were missed were <10 ac in size. Only 8 known clearcuts (3% of the total) were completely missed. Thus, by removing small clusters of pixels for our timber clearing inventory, we removed some harvested areas. However, this step was necessary to remove small areas of disturbance that would not likely constitute a moderate or intensive timber clearing (Figure 1). These areas may constitute a low intensity harvest, like single tree selection or small gap creation. We did find different rates of omission by county and year. However, the known clearcuts were limited in geographic scope (most occurred on federal lands in WMNF) and total number (241 cuts), such that these yearly and geographic differences should be interpreted with caution.

Table 1. Accuracy assessment results of omission errors derived by comparing the results of this inventory with 241 known silvicultural clearcuts provided by the WMNF and the State of NH. Results are presented both by polygon count and by area. Of the 30 known clearcuts missed, 22 were partially detected and only 8 were fully undetected (3% of the total).

Assessment	Count	Percent of count	Total area (ac)	Percent of total area
Positive detection	211	87.5%	2,491	91.2%
Missed detection	30	12.5%	242	8.8%

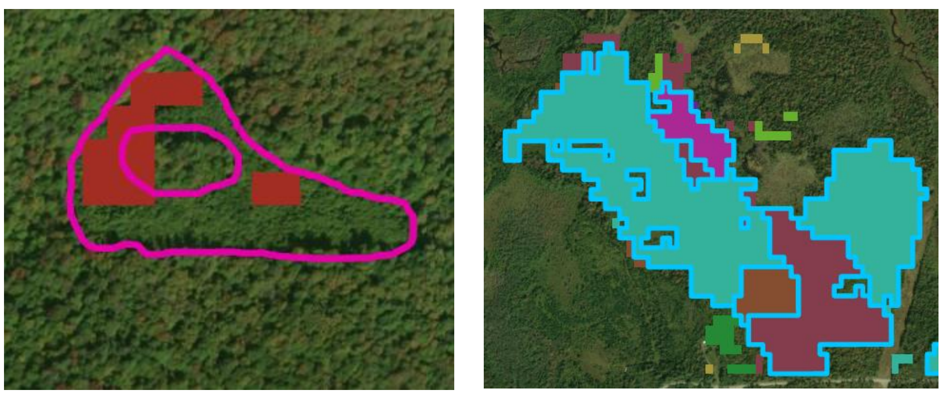

Figure 1. Examples of timber clearing detection using the Hansen et al. (2013) dataset (Version 1.6). (Left) Example of a known silvicultural clearcut in WMNF (pink outline) that was not fully detected by this timber clearing inventory. However, the cut was partially detected in the original dataset before size thresh-holding (red pixels). Note that a single pixel is 0.22 ac in size. (Right) Example of the original dataset before and after size thresh-holding. Solid pixels show forest loss according to the Hansen et al. (2013) dataset (different colors represent different detection years). The blue outlines denote what we considered to be moderate and/or intensive timber clearings for this inventory. Note the many single or small clusters of pixels above and below the blue outlines. These clusters were too small to be included based on the size threshold (≥3.0 ac).

Of the 1,550 timber clearing polygons we assessed for commission error accuracy, only 2.4% incorrectly identified a clearing when there was no evidence of one in the historical imagery. The commission errors were slightly smaller (1.7%) when examined by polygon area rather than count (Table 2). Of the 36 polygons that misidentified a timber clearing, over half occurred in the last year of the analysis (2018) and another 20% occurred in 2017 (Figure 2). This suggests that the imagery we used to assess the accuracy of the timber clearing inventory were not as recent as those used to create the Global Forest Change dataset. As new images are made available, we can re-assess these commission errors for 2017 and 2018. Overall, most of the misclassifications occurred on smaller polygons; the mean size of misclassified polygons was 8 ac compared to 11 ac for those that were correctly identified. Commission errors varied by county, ranging from no commission errors in Belknap, Hillsborough, Rockingham, and Strafford Counties to a 6.0% commission error rate in Grafton County (Figure 3).

Table 2. Accuracy assessment results of commission errors derived by comparing the timber clearing inventory with historical imagery. Results are presented both by polygon count and by area. While the timber clearing inventory only erroneous identified 36 polygons (2.4% of cuts, 1.7% by area), many positive detections were not intensive timber clearings (i.e., <20 ft^2/ac residual basal area).

Assessment	Count	Percent of count	Total area (ac)	Percent of total area
Intensive timber clearing	850	54.8%	9,063	54.7%
Moderate timber clearing	664	42.8%	7,221	43.6%
No timber clearing	36	2.4%	276	1.7%

Figure 2. Results of the commission error accuracy assessment by year detected according to the Global Forest Change dataset (Hansen et al. 2013). At set of 1,550 polygons from the timber clearing inventory were assessed if they were intensive (<20 ft^2/ac residual basal area) or moderate (>20 ft^2/ac residual basal area) timber clearings, or if no clearing occurred at that location (error) based on available historical imagery.

While this inventory did well at detecting some level of timber clearing, of the 1,514 polygons that correctly identified a clearing based on the historical imagery, slightly more than half (55%) were determined to be intensive timber clearings (i.e., residual basal area of <20 ft^2/ac; Figure 4). The other half (44%) were determined to be moderate clearings (i.e., >20 ft^2/ac residual basal area). We were unable to classify timber clearing intensity using remote sensing; as these results were based on a subset of timber clearing polygons, caution should be used when interpreting the amount of possible clearcutting. Further, the ratio of intensive to moderate clearings detected varied by county and year (Figure 2, Figure 3).

Using the results of our accuracy assessment, the values presented here are unlikely to overestimate the amount of timber clearing overall (<2% commission error rate by area), but these results do include both moderate and intensive timber clearings. We estimate that slightly more than half of the values presented here represent intensive timber clearings. Further, this inventory could not detect low-intensity timber clearings, like single tree or small group selection. While those types of clearing may have detected by the original dataset (Hansen et al. 2013), discontinuous pixels and clearings <3.0 ac in size were removed from further analysis (see Methods section). At the same time, the results presented here may underestimate cleared area (9% omission rate by area). These error rates were used to define the upper (omission rate) and lower (commission rate) bounds of the values presented here.

Spatiotemporal patterns of timber clearing inventory

Spatial patterns

The timber clearing inventory detected 203,832 ac of clearing representing 3.9% of the state's forestland between 2000 and 2018 across 19,090 polygons (Table 3, Figure 4). Based on our accuracy assessment, this equated to 111,553 ac of intensive timber clearing (<20ft^2/ac residual basal area) and 88,876 ac of moderate timber clearing (>20ft^2/ac residual basal area). However, as the ratio of intensive to moderate clearings were assessed on a subset of polygons (1,514), these values should be interpreted with caution. Further, the classification of 'moderate' and 'intensive' was performed using aerial imagery and therefore may be subjective. Annually, this equated to 11,324 ac (0.2% of the state's forestland) overall, with 6,197 ac classified as intensive and 4,937 ac classified as moderate timber clearing. Using the harvest report data from the NH Department of

Revenue Administration (2016), approximately 198,758 ac of forestland were harvested (any intensity) per year between 2008 and 2016, which equates to 3.8% of the forestland in NH.

We found that individual moderate and intensive clearings ranged from 3 to 445 ac in size (Figure 5). Clearings greater than 250 ac were rare (<0.4% of all clearings). Nearly all of the clearings identified (94.7%) were less than 50 ac in size and 66.6% were less than 10 ac. The average size (± SE) of clearings detected was 10.7 ± 0.1 ac, and this only varied slightly by location (Table 3). Across the 10 NH counties, the average size of timber clearings ranged from 9.0 ± 0.3 in Rockingham County to 12.4 ± 0.2 in Coös County (Table 3). Along with largest average cut, Coös County had the largest total area cut (72,212 ac; 4,012 ac/yr), proportion of forestland cut (6.6% total, 0.36% per year), number of cuts (5,844), and single cut (445 ac).

Figure 3. Examples of recent timber clearings of varying intensities detected with the timber clearing inventory (blue lines): (left) a moderate timber clearing (>20ft^2/ac residual basal area) and (right) an intensive timber clearing (<20ft^2/ac residual basal area). Note that the input dataset (Hansen et al. 2013), which used remote sensing to detect forest disturbances, aimed to detect stand-replacing disturbance and therefore did not include all harvesting.

The values presented here are greater than what was detected in the previous inventory for the time period 1980-1995: 49,907 ac across 1734 cuts (Rubin and Justice, 1995). Per year, this equated to 3,327 ac or 0.06% of the state's forestland. However, the previous inventory only aimed to detect intensive timber clearings (e.g., clearcuts). To provide comparable values from our timber clearing inventory (2000-2018), we extrapolated from our clearing intensity assessment to estimate that 6,197 ac/yr (55%) were intensive clearings, or a little less than double the amount found in the previous inventory. There are a few possible explanations to explain the increase in timber clearing area detected here compared to the previous inventory: the amount of timber clearing may have increased since the previous inventory; the amount of intensive clearing that we calculated could be inflated based on our extrapolation of a 55% intensive clearing rate by area; or, there may have been clearings that were not detected in the previous inventory based on the methodology.

There were other notable differences between the two inventories. In the previous inventory, the authors detected a larger maximum cut size (700 ac) and average cut size (28.8 ± 1.0 ac) than the inventory presented here. Statewide, they found comparatively fewer cuts in the southern part of the state compared to this assessment. The authors also found that 64% of the cuts occurred in Coös County (Rubin and Justice, 1995); in our inventory, Coös comprised 35% of the statewide clearings.

Table 3. Summary of timber clearing inventory statistics presented by county and statewide. Note that a polygon was considered in a county based on the location of its centroid.

County	Total area (ac)	% of area forestland	Total area intensive (ac)	Ave. annual area (ac/yr)	N polygons	% of forestland per yr	Average polygon area ± SE (ac)	Maximum polygon size (ac)
Belknap	10,480	4.7%	4,976	582	940	0.26%	11.1 ± 0.3	99
Carroll	15,625	2.8%	7,530	868	1574	0.16%	9.9 ± 0.3	130
Cheshire	10,003	2.4%	3,952	556	1006	0.14%	9.9 ± 0.4	122
Coös	72,212	6.6%	44,838	4,012	5844	0.36%	12.4 ± 0.2	445
Grafton	22,768	2.2%	12,523	1,265	2352	0.12%	9.7 ± 0.3	169
Hillsborough	18,951	4.1%	10,981	1,053	1983	0.23%	9.6 ± 0.3	122
Merrimack	25,975	5.0%	11,179	1,443	2507	0.28%	10.4 ± 0.3	271
Rockingham	11,027	3.1%	6,715	613	1225	0.17%	9.0 ± 0.3	83
Strafford	6,345	3.2%	2,644	353	687	0.18%	9.2 ± 0.4	123
Sullivan	10,446	3.3%	6,327	580	972	0.19%	10.7 ± 0.5	167
Statewide	203,832	3.9%	111,553	11,324	19,090	0.22%	10.7 ± 0.1	445

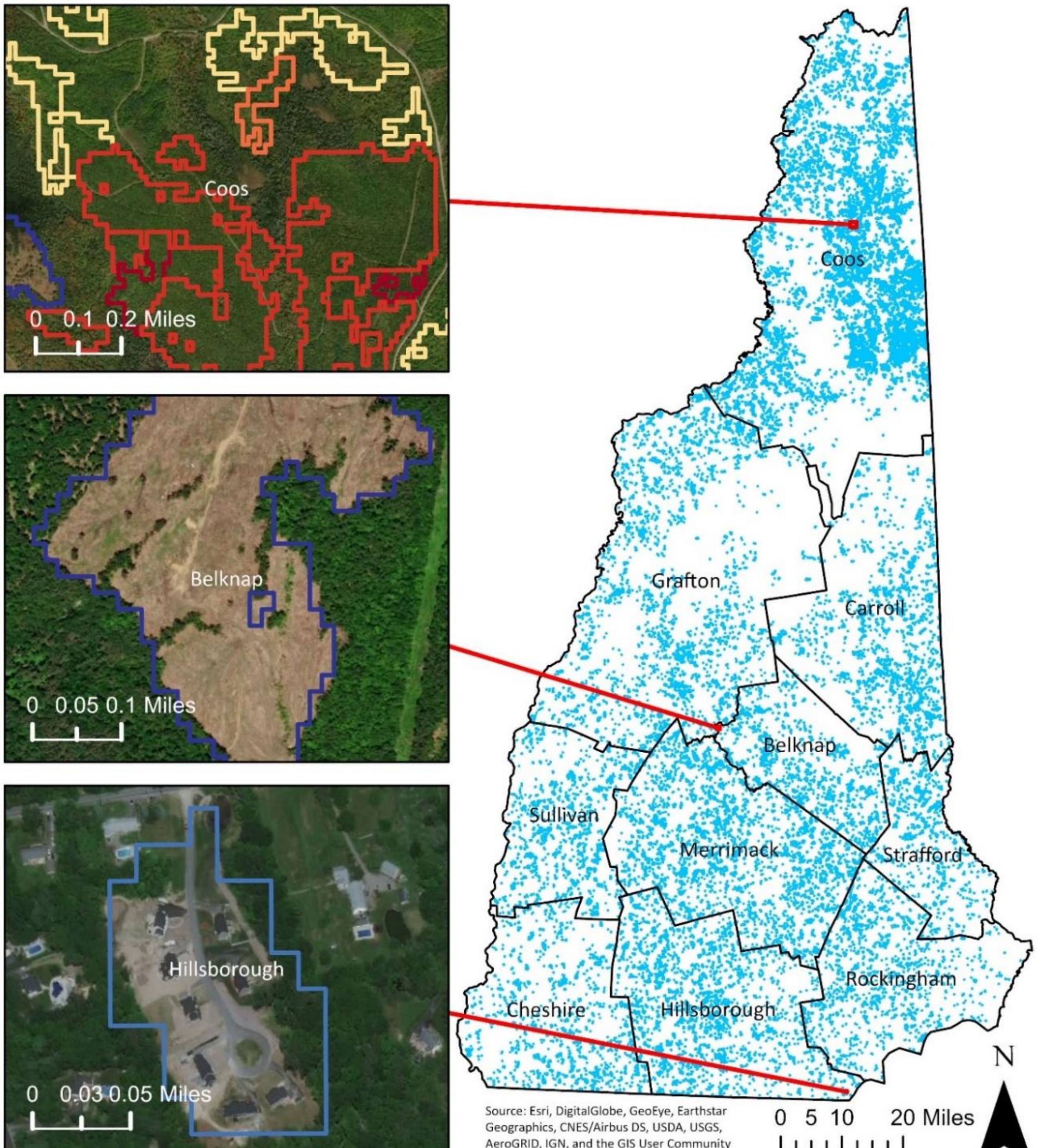

Figure 4. Locations of moderate and intensive timber clearings (blue polygons, enhanced for visibility) detected in New Hampshire between 2000 and 2018 using the Global Forest Disturbance dataset (Hansen et al. 2013). The inset maps on the left show examples of the range of clearings detected, with different outline colors denoting different years of detection: (top) a large, multi-year timber clearing, (middle) a single intensive timber clearing, and (bottom) timber clearing for planned development. Note that for the top image, the cutting occurred in the early 2000s and the underlying imagery shows that forest regrowth has occurred.

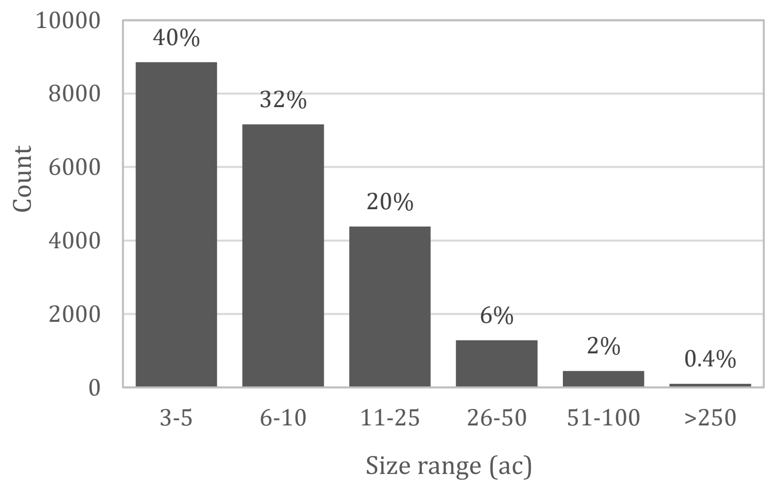

Figure 5. Histogram of the number of moderate and intensive timber clearing polygons detected per size class range (ac). The proportion of the total number of clearings depicted statewide is shown per size class range. Note that a clearing that occurred over multiple years were considered distinct clearings.

Patterns by landownership

Most of the moderate and intensive timber clearings (80.2%) occurred on private, non-conserved lands, such as private woodlots, farms, or residential areas (Table 4). The average size of clearings among owner types did vary more than it did by county: municipal/county lands had the smallest sized cuts, while land owned by other public/quasi-public entities had the largest average size. This latter grouping, designated by the data source, included entities like water and sewer districts and school forests. That said, the range in average clearing size across these disparate ownerships is still quite small. Note that we did not evaluate whether the cut occurred when the land was under the current ownership (ownership data from 2017). For example, a forest parcel could have been harvested in 2001 and subsequently sold to a different type of owner; since our landownership data was from 2017, the area would be classified as occurring on land under the new owner. We also found that private, non-conserved lands experienced clearing at a higher rate than other landowner types: 4.9% of forestland on private, non-conserved lands was cleared compare to 0.9% of forestland on Federal lands.

Table 4. Results of statewide moderate and intensive timber clearing inventory reported by land ownership entity. Land ownership data from the Society for the Protection of NH Forests (2017).

Entity	Total area (ac)	Percent of statewide total	Percent of forestland cut in ownership	Average polygon size ± SE (ac)
Federal (WMNF)	6,981	3.4%	0.9%	10.8 ± 0.6
State of NH	20,794	10.2%	4.5%	11.7± 0.4
Municipal/County	3,345	1.6%	1.9%	8.2 ± 0.3
Other public/quasi-public entity	211	0.1%	2.8%	12.4 ± 4.0
Private conservation organization	9,025	4.4%	2.2%	9.5 ± 0.5
Private, non-conserved lands	163,476	80.2%	4.9%	10.7 ± 0.1

Patterns over time

The least amount of moderate and intensive timber clearing detected in this inventory occurred in 2003 (4,446 ac), and the peak occurred in 2017 with 17,323 ac detected (Figure 6). There was a significant positive trend in the total amount detected over time ($P=0.003$), equating to an additional 415 ac cleared per year. Broken down by the proportion of intensive compared to moderate timber clearings assessed for a subset of polygons (Figure 2), we found that the rate of intensive clearings has not increased over time, but that moderate clearings had ($P=0.01$). When we examined timber clearings over time by estimated post-harvest outcome, we found that the amount of forest cut for agriculture or development had not increased over time.

Because of the methodology and technical issues with remotely-sensed imagery, the year of detection is uncertain and may contain error, but was found to be within two years of the actual occurrence (Figure 7). Of the timber clearings, 38% were detected in the same year the clearing occurred. The dataset slightly overestimated the harvest year by an average (±SE) of 0.49 ± 0.06

years. Therefore, we think that there is a high degree of accuracy within 2 years of the year detected.

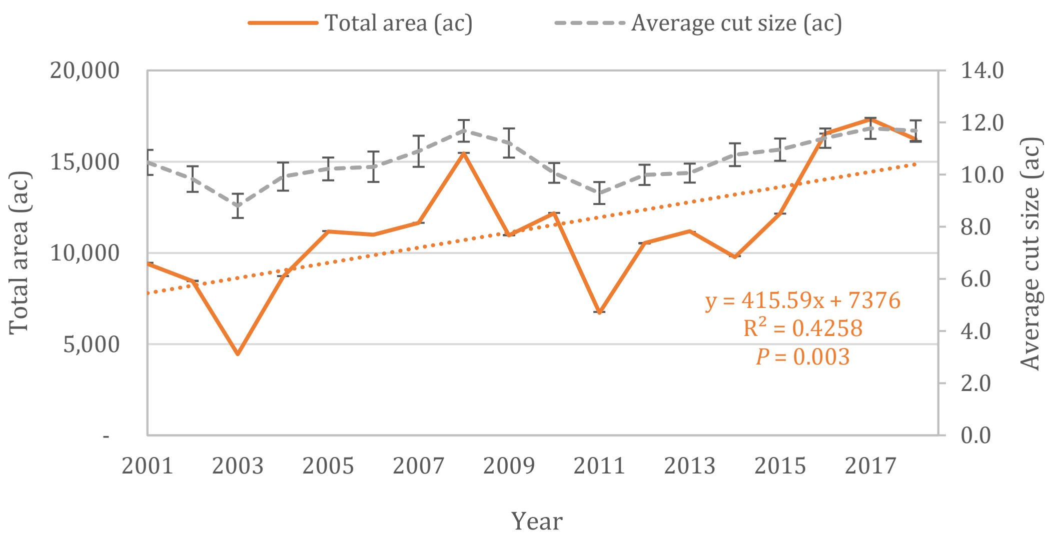

Figure 6. Statewide moderate and intensive timber clearing inventory identified through remote sensing displayed by the year detected and total acreage (left axis) and as the average (±SE) cut size (right axis). Upper and lower error bars for the total area are derived from the omission and commission error rates, respectively. There is a significant positive linear trend in the total area cleared over time, but not in the average cut size.

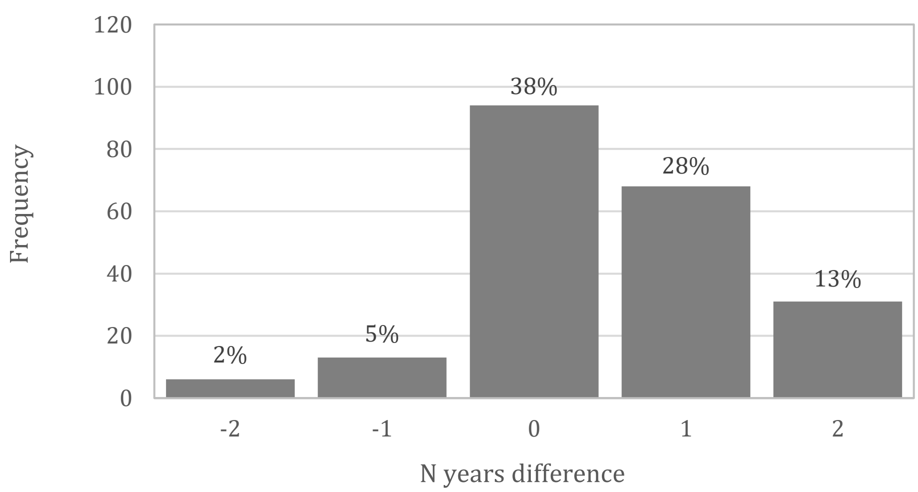

Figure 7. Number of years' difference between the harvest year for a set of known silvicultural clearcuts and detection year for the timber clearing inventory. The mean difference in year (±SE) was 0.49 ± 0.6 years.

Patterns by post-harvest outcome

Of the 1,514 timber clearings we assessed in the accuracy analysis that were identified to be clearings (either moderate or intensive clearing), we determined that 75% were likely for timber management purposes (80% by area), rather than for land use conversion. Of the 25% (20% by area) that appeared to be for land use conversion, we estimated that 15% were for development (11% by area) and the remaining 10% (9% by area) for agricultural or other non-structural development purposes (e.g., gravel pits, yards). The total estimated forestland conversion (2000-2018) was 40,765 ac (2,285 ac/yr), with 22,421 ac (1,246 ac/yr) for development and 18,344 ac (1,019 ac/yr) for agriculture or other non-structural development purposes. This equated to an annual conversation rate of 0.04% of NH's forestland. This is lower than the amount in the 2010 statewide assessment (NH DRED) where it was projected that 5,227 ac/yr would be converted from forestland.

These proportions were not uniform across the 10 NH counties or over time (Figure 8, Figure 9). Rockingham had the highest proportion of post-harvest outcomes suggesting land conversion, with the majority assessed as development. Statewide, NH DRED (2010) reported that in 2001 7% of harvested area were 'terminal harvests' (i.e., for land use change) and the highest rates were found in Rockingham and Strafford Counties (approximately 30% of the total harvested area for land use change purposes). We found similar patterns, but a higher rate statewide – about 20% of the clearings were for land use change, which includes both development and non-development purposes. This higher rate may be because we assessed outcomes for multiple years post-harvest. While Coös had the highest amount of timber clearing, our assessment suggests that most was for forestry purposes. We also found that the average size of cuts assessed to be for land use conversion purposes were smaller (8 ac) than those for forestry (12 ac).

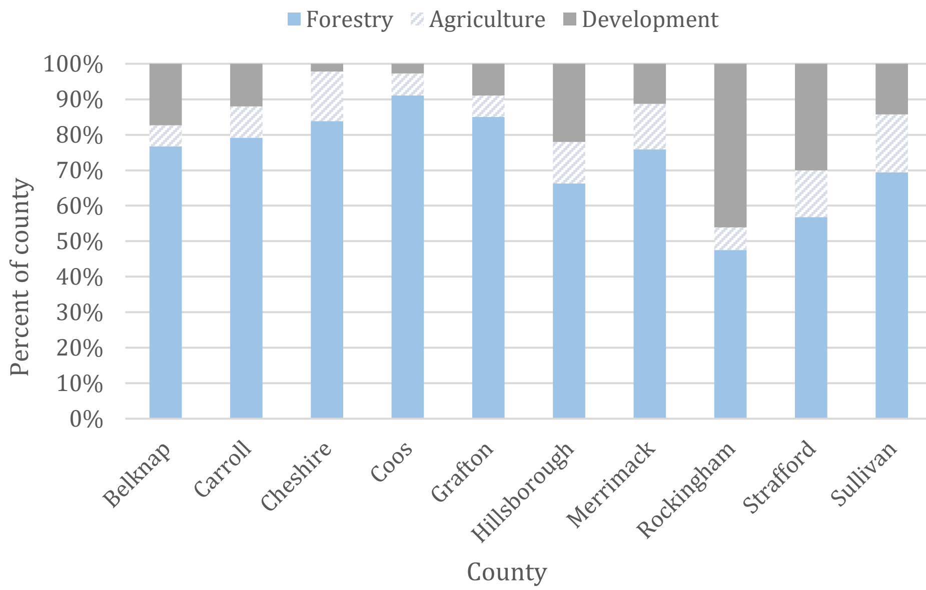

Figure 8. The proportion of post-harvest outcomes per county derived from the subset of timber clearings assessed in the commission error accuracy assessment (1,550 polygons). Colors indicate the likely reason for the observed cut: forestry (dark blue), development (light blue), or agricultural/non-development (gray). Note that these post-harvest outcomes are visual estimates based on forest harvest patterns, additional infrastructure, and post-harvest images.

Over time, the relative proportion of forestland cut for land use change has remained steady (Figure 9). A report by the USFS using Forest Inventory and Analysis data found that the amount of forestland in NH has declined since 2012 (Morin 2018). However, we found no significant trend in the amount of timber clearing for forest conversion (area classified with a post-harvest outcome as agriculture and development combined; P=0.5). Conversely, the amount identified for forest management purposes has increased – and this increase is statistically significant (P=0.03). Land utilized for silviculture and allowed to regrow retains important ecosystem services that land converted to other uses does not, and further creates early successional forests that are important for wildlife and landscape diversity. If we combine our assessment of area total forestland cleared intensively per year (6,197 ac/yr) to the proportion that we assessed to be for silvicultural purposes (80%), this equates to the creation of approximately 4,958 ac (or 0.08% of NH's forestland) per year of early successional forests.

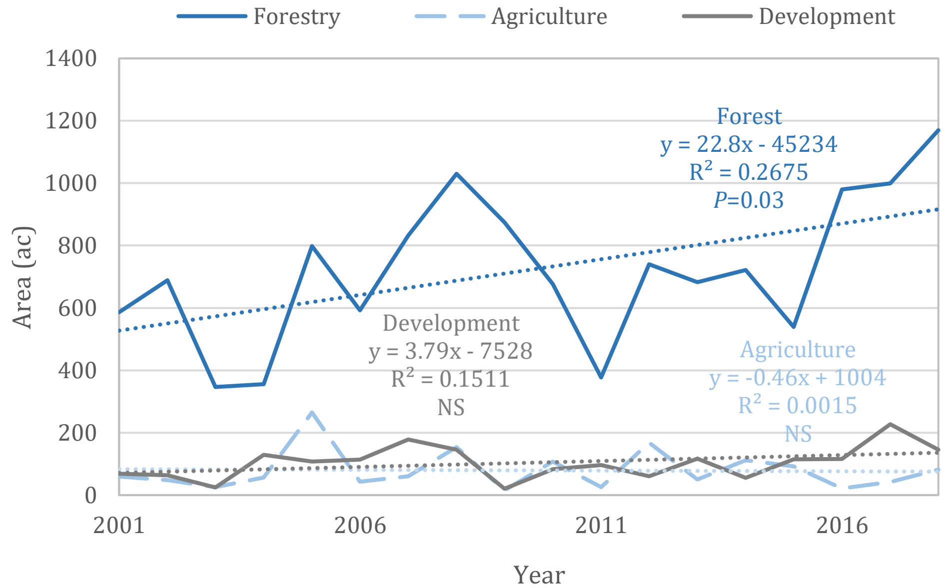

Figure 9. Post-harvest outcomes were evaluated for 1,514 polygons in the timber clearing inventory. Note that these post-harvest outcomes are visual estimates based on forest harvest patterns, additional infrastructure, and post-harvest images. Linear models were fit to each category. The amount of timber clearing for forestry showed a significant increase over time; the other two post-harvest outcomes (singularly or in combination) did not.

Future directions and areas for improvement

This analysis demonstrates the utility of the Global Forest Change dataset (Hansen et al. 2013) for detecting moderate and intensive timber clearings. However, it comes with limitations. The timber clearing inventory presented here missed a number of known silvicultural clearcuts (9% by area) and we are unsure why, but it was likely the result of satellite image inputs. The biggest limitation in remote sensing analyses is the temporal resolution of composite satellite images. Satellite images over New England often contain clouds and as a result, multiple years of images are needed to create a cloud-free, statewide land cover image. The authors of the Global Forest Change dataset that we utilized for this assessment caution that some of the underlying Landsat imagery has not been fully validated (Hansen et al. 2013). While we found that the dataset did not overestimate the amount of moderate and intensive timber clearings statewide, we were unable to effectively distinguish between these two levels of clearing intensity. Nearly half of the polygons we classified as ‘moderate timber clearings’, but we were unable to definitively assess if the amount of residual basal area qualified these polygons to be officially defined as an intensive timber clearings (residual basal area <20 ft^2/ac). With additional data on clearing locations and associated residual basal area, we would be able to more accurately detect the threshold between intensive and moderate clearings, as well as define an upper limit of residual basal area that can be detected as 'moderate' cuts.

Another issue is the shape and exact extent of the timber clearings detected. Using this remote sensing dataset, 30 m square pixels were converted to vector polygons. As a result, the resulting timber clearing polygon did not always capture the extents correctly. With the increase in satellites capable of finer resolution and more frequent return times (e.g., SENTINEL-2), there is the possibility that future assessments will be improved, particularly for detecting more exact extents and a wider range of clearing intensities.

There are a number of possible options for improving the accuracy of this analysis. Field validation that includes a range of clearing intensities and recovery dynamics could enhance the accuracy assessment. Additional polygons of known timber clearings, particularly in counties that were not well represented in the omission error analysis, would help us understand spatial patterns of detection failure.

Conclusions

This timber clearing inventory provides valuable information for understanding and managing the forestlands in the state of NH. The resulting data on moderate and intensive timber clearing detected via remote sensing allows for a more in-depth exploration of spatiotemporal trends and patterns across the landscape, including potential drivers of timber clearing activities and implications for the long-term management of NH forests. We found that the average size of moderate and intensive timber clearings has not varied significantly over time or by location, but that the total annual amount of clearing has increased since 2001. Based on our assessment of a subset of polygons, this increase may not be due to land use conversion, but by an increase in forestry-related clearing. Responsible management of forestland for timber provides many ecosystem services (e.g., carbon storage and sequestration, wood products) that the same parcel cannot provide once it has been converted to a non-forest state.

In this analysis, we have demonstrated that an available product, the Global Forest Change dataset (Hansen et al. 2013), can be used to remotely detect moderate and intensive timber clearings in the state of NH. We found that commission errors were low (<2%), suggesting that this dataset does not overestimate timber clearing. However, those detections included both moderate and intensive timber clearings. At this point, we are not able to remotely distinguish between these clearing levels. Slightly more than half (55%) of the timber clearing area detected was assessed as 'intensive'. When we extrapolated the annual amount of intensive clearing and the proportion estimated to be for silviculture, we assessed that a very small amount (0.08% of the state's forestland) of early successional forests were added each year. Also, the inventory did miss some known silvicultural clearcuts (9% omission rate by area), and as a result may underestimate timber clearings, particularly for small parcels (i.e., <10 ac). As new iterations of this dataset are released, this analysis could be updated.

Lastly, these results indicate that large timber clearings may be less of a concern than perceived by the general public; smaller timber clearings (<50 ac) made up a majority of the cutting statewide and cuts >250 ac were rare (Figure 5). Based on the accuracy assessment, it is less likely that the inventory failed to detect large cuts; more often it did not detect smaller-sized cuts.

Data

All data have been made available on the FEMC data archive at https://www.uvm.edu/femc/data/archive/project/NHForestClearing, and an online map viewer for the data is available at https://arcg.is/1085vu.

References

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. Science 342 (15 November): 850–53. Data available on-line from: http://earthenginepartners.appspot.com/science-2013-global-forest.

McGaughey, R.J. and Tootell, C. ND. Treatment visualization project. Montana Department of Natural Resources. Available at: http://forsys.cfr.washington.edu/EnVision/Examples/Treatment%20Visualization%20Project.html

Morin, R.S. 2018. Forests of New Hampshire, 2017. Available at: https://www.fs.fed.us/nrs/pubs/ru/ru_fs163.pdf

Multi-Resolution Land Characteristics Consortium (MRLC). 2003. National Landcover Dataset Percent Tree Canopy (Version 1.0). Available at: https://www.mrlc.gov/nlcd01_data.php [Accessed 17 May 2018].

New Hampshire Department of Resources and Economic Development (NH DRED), Division of Forests and Lands. 1996. New Hampshire Forest Resources Plan. Available at: https://www.nh.gov/nhdfl/documents/nhfrp01.pdf

New Hampshire Department of Resources and Economic Development (NH DRED), Division of Forest and Lands. 2010. New Hampshire Statewide Forest Resource Assessment. Available at: https://www.nh.gov/nhdfl/documents/nh-statewide-assessment-2010-update.pdf

New Hampshire Department of Resources and Economic Development (NH DRED), Division of Forests and Lands. 2018. Timber sales data. Available at: by request.

NH Department of Revenue Administration. 2016. Intent to cut data.

Olofsson, P., Holden, C. E., Bullock, E. L. and Woodcock, C. E. (2016). Time series analysis of satellite data reveals continuous deforestation of New England since the 1980s. Environmental Research Letters, 11 064002.

Palmer, J.F. 2008. The perceived scenic effects of clearcutting in the White Mountains of New Hampshire, USA. Journal of environmental management, 89(3), pp.167-183.

Pasquarella, V.J., Elkinton, J.S. and Bradley, B.A. 2018. Extensive gypsy moth defoliation in Southern New England characterized using Landsat satellite observations. Biological Invasions, pp.1-7.

Rubin, F. and Justice, D. 1995. New Hampshire Timber Clear Cut Inventory. Complex Systems Research Center, University of New Hampshire, Durham, NH. 12pp.

Society for the Protection of NH Forests. 2017. Conservation/Public Lands Layer. Available at: http://www.granit.unh.edu/data/search?dset=consnh/nh [Accessed 12 October 2018].

USFS. 2018a. Data Extract Tool: Timber Harvests. Available at: https://data.fs.usda.gov/geodata/webapps/EDW_DataExtract/ [Accessed 1 June 2018]

USFS. 2018b. White Mountain National Forest (WMNF) timber sale history. Available at: by request.

Ward, T.S., Worthley, T.E., Smallidge, P.J., and Bennett, K.P. 2013. Northeastern Forest Regeneration Handbook: A Guide for Forest Owners, Harvesting Practitioners, and Public Officials. USDA Forest Service, State and Private Forestry: NA–TP–03–06.

Forest Ecosystem Monitoring Cooperative

Providing the information needed to understand, manage, and protect the region's forested ecosystems in a changing global environment