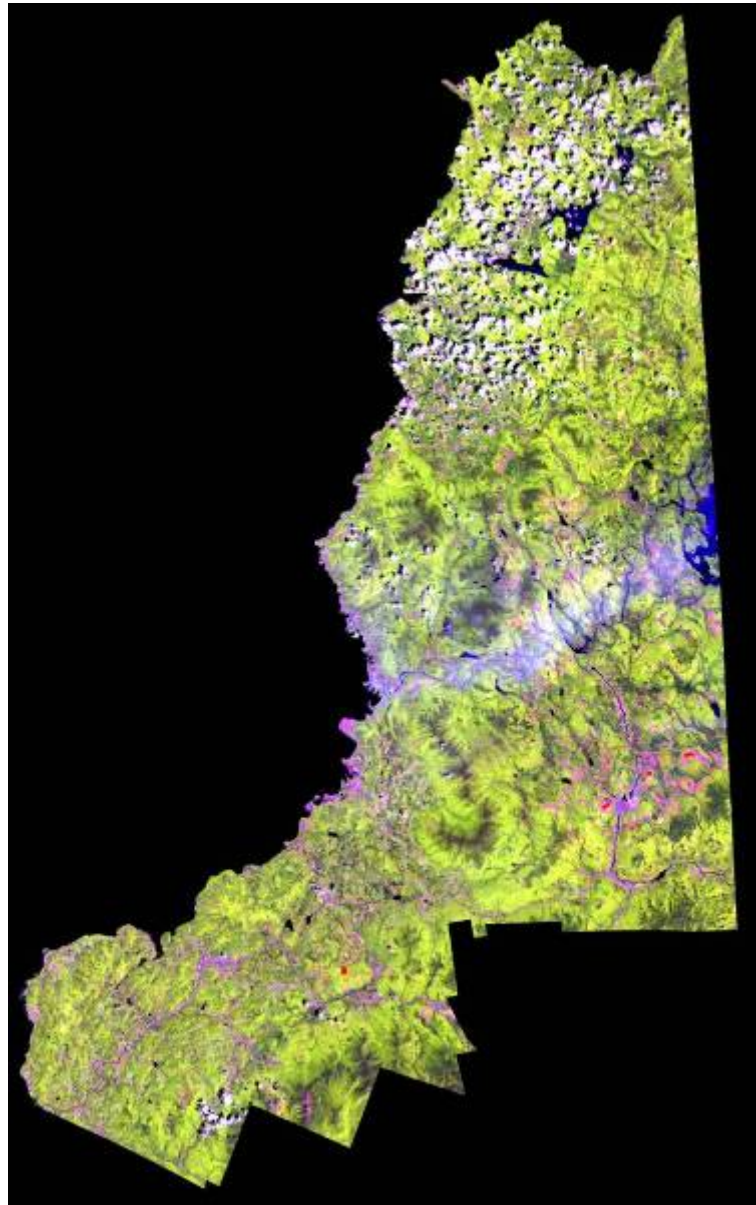


North Country Timber Harvest Trends Study

*A Project of the Society for the Protection of N.H.
Forests
Research Department*

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Table of Contents

	<u>Page</u>
Project Background	4
Study Area Definition	5
Silvicultural Clearcuts v. Liquidation Cutting	5
Study Methodology	7
Introduction	7
Methodology	7
Ground-Truthing	11
Study Findings	12
Integrating the Data Into a Temporal and Spatial Mosaic	12
Ice Storm Influence on Harvests	14
Success in Detecting a Range of Harvest Intensity	16
High Elevation Harvest	17
Forest Cover and Soils Utilization	19
Differences on Public and Private Conservation Land	19
What's Next	20
Appendix A	21
Technical Reports on GIS and Remote Sensing Process	
Appendix B	
Table 1: Forest Land Base Calculations	39
Table 2: Operable Land Base Harvest Calculations	40
Table 3: Percent Operable Land Base Harvests	41
Table 4a: Acres Major Forest Cover Types	42
Table 4b: Acres Harvested by Forest Cover Types	43
Table 5a: Acres Important Forest Soils Groups by Municipality	44
Table 5b: Acres Harvested by Soil Group	45

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Project Background

Since 1901 the Forest Society has sought to protect New Hampshire's forestland by promoting science-based forestry—which is to say, sustainable timber harvesting practices. The forest resources in the state are a critically important key to our economic and environmental health, and the Forest Society has always taught and advocated best management practices in working forests, both private and public.

In 2005, stories began to percolate out of the North Country about timber cutting occurring on a scale that recalled the liquidation practices common in the White Mountains a century ago. Concerns about the future of the North Country's forests were voiced by long-time residents, wildlife biologists, and forest managers alike.

Liquidation cutting raises a number of concerns. The forest regeneration that does occur is lower quality. It fosters erosion. Where selective harvesting often benefits wildlife by creating diverse habitat, over-cutting large tracts can leave land without much habitat value. And it strips the land of any economic value other than development for decades, removing it from the active inventory of working forest. For those who care about the future of New Hampshire's forest products industry, it seemed important to understand just how widespread such cutting might be.

In response to these concerns, the Forest Society embarked on a research project to get the facts. Dartmouth College, with its 27,000-acre forest property in Second College Grant and its unique perspective on North Country forestry, became a natural partner in this effort. A collaborative project emerged, with Dr. Richard Birnie, a respected scientist and former Dean of Graduate Studies and Chair of the Dept of Earth Sciences, to conduct a state-of-the-art analysis of North Country forests using a combination of remote sensing and GIS technology.

The overarching goal of the study was to assess the rate of ongoing cutting within 41 municipalities "North of the Notches" with the goal of understanding whether that cutting might be exceeding a sustainable rate of growth and replenishment in the region's forest resource base.

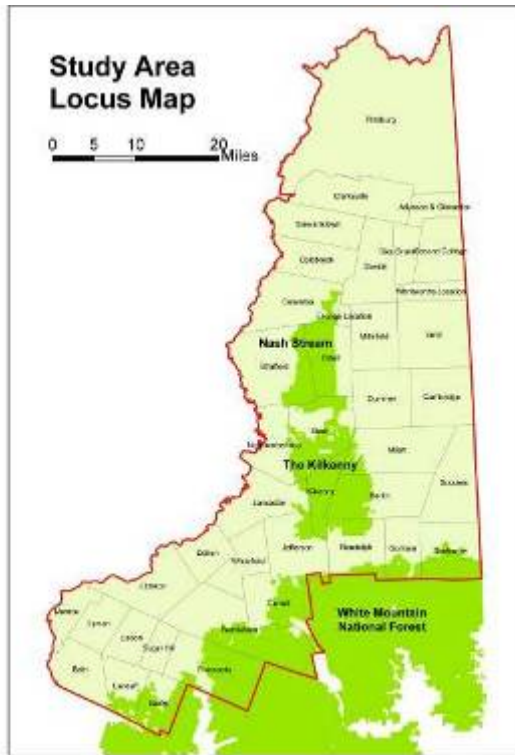
From the standpoint of remote sensing science, the project also had two working goals:

- Generally, to evaluate the usefulness of satellite data to identify areas of harvest operations over a period of time; and,
- Specifically, to learn whether or not it would be possible to detect a range of light, moderate, and heavy cutting with reasonable accuracy.

Other, similar work has been done in Maine in 2003 by Professor Steve Sader¹ and others at the University of Maine at Orono, but in the field of remote sensing, detecting patterns and intensity of forest harvest was and continues to be highly experimental. Thus, it is important to understand this study as "cutting edge" and exploratory.

¹ Sader, Bertrand, and Wilson, Satellite Change Detection of Forest Harvest Patterns on an Industrial Forest Landscape, American Society of Foresters, 2003

Study Area Definition



The interest area selected for this study involves 41 municipalities covering more than 2,000 square miles of the North Country. While the analysis might have been limited to purely industrial forest lands further north, preliminary scouting of the region also indicated intensive harvest operations in the southwestern towns, centering around Whitefield, but also extending southwest into Munroe, Lyman, and Bath.

A decision was also made early on not to include the White Mountain National Forest, largely to limit the size of the study area, and because the national forest boundary makes a logical stopping point in the analysis. However, the Kilkenny and the state's Nash Stream Forest were included for the sake of landscape continuity within the study area, and to allow comparison of harvest activities on those tracts.

Silvicultural Clearcuts v. Liquidation Cutting

For the purposes of this study, and before laying out the details of this study, it is important to qualify the difference between silvicultural clearcutting as a forest management tool, and liquidation cutting of forest land.

Outside of the world of forestry, the term “clearcutting” often carries a negative connotation. Like other large-scale, intensive forestry activities, the visible change that occurs with clearcutting operations may be disturbing to aesthetic sensibilities; this is understandable. However, as a silvicultural practice, clearcutting is a time-tested method of regeneration for even-aged stands of timber by releasing seedlings of desirable tree species. The goal is to create growing space to be filled promptly by a new tree crop. In New Hampshire's North Country, small-scale clearcutting and its cousins—shelterwood cuts, strip cuts, group selection harvests, and patch cuts—are among the most basic tools available to the forest manager, especially on sites where production of spruce-fir and paper birch-aspen is favorable. These



methods are often used not only for regenerating forests, but also to improve the diversity of habitat for certain wildlife.



Liquidation cutting, by contrast, is not a silvicultural practice; it has no view to the future. The land is cleared of merchantable wood, and short-term gain takes precedence over long-term productivity. There is also a difference of scale: traditional forestry prescriptions for clearcutting would be carefully calculated in proportion to the size of the area to achieve regeneration of the desired tree species often involving less than 50 acres. Liquidation cutting entails progressive operation across many hundreds of acres of forest land, potentially leading to square miles of cleared land in the space of only a few years on large land holdings. While silvicultural clearcutting fits into a carefully planned mosaic of forestry decisions and a commitment to decades of ongoing wood flow into markets, liquidation cutting leaves a landscape with no commercial timber, devoid of diverse wildlife habitat, and with very few economically viable opportunities available to the landowner going into the future.

The aerial photo above shows a portion of the town of Success in late summer, 2006. The lighter tone areas in the photo are liquidation cuts. The yellow line is about a mile long, giving a sense of the scale of these operations.

Important note: Throughout the remainder of this report and in the appendices, the terms “harvest”, “operation”, “cutting”, and so on are used in an intermingled and generic way to describe the occurrence “timber harvest” as detected by the analysis of satellite imagery. Generally, these terms should be understood in the context of the goal of the study, which is to identify areas that are “predominately cleared” by various forestry prescriptions and occur within the study area in varying scales. No distinction is made between conventional forestry activities or liquidation cutting. Rather, that difference can only be inferred given the typical scales of activity, as described above. See also the section on **Study Findings** further on in this report.

Study Methodology

Introduction

Satellite imagery is becoming better known in ordinary life; many people can now enjoy Google Earth fly-overs online, with its continuous mosaic of satellite images. This project relied upon one of the federal government's workhorse satellite image providers: Landsat, which has been collecting digital information about the land for the last 34 years under a program of the National Oceanic and Atmospheric Administration. Special cameras on the Landsat satellite "see" the earth in ways the human eye cannot see, accumulating spectral information that can be processed in remote sensing software to reveal subtle differences in temperature, moisture, and other environmental parameters. For use in GIS mapping, this data is coded into a seamless grid, with each pixel measuring 30 by 30 meters. In plain terms, the resolution with which Landsat "sees" the ground is then about one-fifth acre. More information on Landsat can be found at <http://landsat.gsfc.nasa.gov/>

One might ask, why not use aerial photography which has been a mainstay of forest management planning for decades? It is much more detailed and methods of interpretation for forestry purposes are well-tested and reliable. There are two good reasons: no library of aerial photography exists spanning the time period selected for the study, and the manual methods of delineation would be hugely labor intensive if the photos did exist.

Methodology

The following discussion will provide an introduction to and overview of the processes typical of remote sensing analysis used in this project in order to help frame the context for summaries presented later in this report. For more insight into the methods and processes used in this study to detect predominately cleared harvests, see **Appendix A** which contain technical reports prepared by Dick Birnie.

It is important to note that the remote sensing contribution to this project proceeded in two distinct phases, or parts as there are described in the appendices. The initial effort focused on only 28 of the 41 municipalities in the study area due to cloud-obscured data in the satellite imagery available. The emphasis in the first part of Dick's work sought to answer three objectives:

- to evaluate the usefulness of Landsat satellite data to identify areas of harvest operations in northern New Hampshire over a 13 year period (1992 – 2005)
- to receive feedback from forest professionals on the success and accuracy of the analysis
- to consider further studies based on the results and feedback .

In this vein, this effort was a pilot project and somewhat experimental. After input from two progress reviews by a select group of forestry professionals and land managers, the decision was made to push forward with the intention of expanding work done in the pilot phase to all municipalities in the study area, and to investigate using Landsat imagery to detect a range of

harvest activity and operations with three levels of intensity: light removals (e.g., selective harvests), moderate harvesting (e.g., strip cuts, group selection, etc.), and heavy cutting (e.g., patch cuts, clearcuts, and larger predominately cleared operations that could indicate liquidation cutting.

A large part of the art and science Dick Birnie contributed to this project involves the “training” of this data to best reflect actual conditions on the ground, in other words, to refine what the imagery “sees” in terms of spectral data to help us humans “see” what is invisible to the naked eye, both in terms of patterns on the computer screen and in the statistics that ride with the data. The two images below show the results of refining the “spectral image” of a large clearcut near Success Pond. Each image is about two miles square. The image on the left is a 1-meter resolution digital aerial photo taken from the National Agricultural Imaging Program (NAIP); features in and around the harvest area are quite distinct, including skidder trails, haul roads, and remaining forest canopy. The image on the right is created from LANDSAT imagery. The pink areas are color-enhanced to reveal the predominately cleared portions of the scene; although the resolution of the image is 30-meters, even the haul roads are detected. Note also that three darker softwood stands left within the clearcut appear in both images with remarkable similarity.



Using Dartmouth’s extensive library of satellite data, the remote sensing analysis initially used imagery spanning 18 years to establish a trendline for harvest history in the North Country, divided into three time periods: 1988 to 1992, 1992 to 1999, and 1999 to 2005. These time periods allowed us to maximize cloud-free images to process and thus yielded the most consistent information across the region.

While the details of remote sensing science and technique are beyond the scope of this report, the concept of “maximum likelihood” is probably the most accessible aspect of the remote sensing work directed by Dick Birnie. The goal of a maximum likelihood analysis is to find the best correspondence possible between what the satellite data say should be on the ground, and what is actually out there. To do this, portions of the satellite images are selected that we believe represent certain types of land cover; in the case of this study, we are looking for predominately cleared forest land. Selections are based in part on what the satellite is picking up in spectral

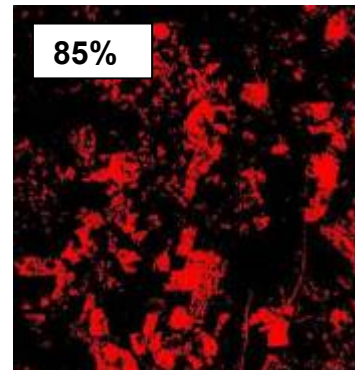
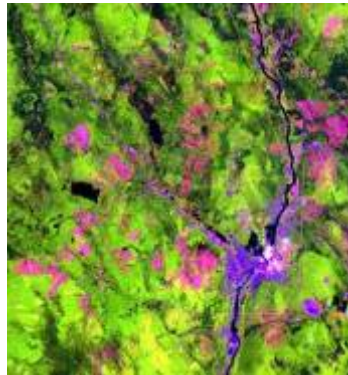
energy reflected from the earth, but also by way of shapes and other visual cues that might indicate a harvest site.

In order to account for landscape features that might “trick” the remote sensing software into classifying areas as cleared forest land that actually are not, a GIS processing filter was developed. For each time period, a land cover filter was burned into the maximum likelihood classification output in order to minimize errors of commission. In other words, this data filters out any areas that have similar spectral signatures to cleared forest land, and thus should not be counted.

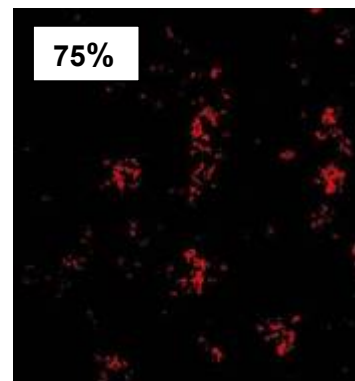
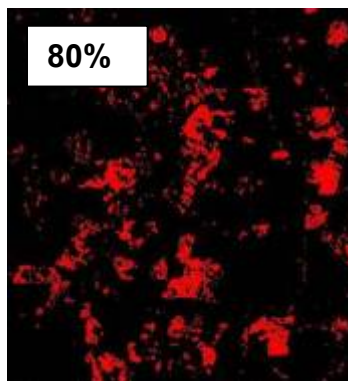
The following components make up the land cover filter (with notes on data source):

- Wetlands (NWI² palustrine emergent and palustrine scrub/shrub)
- Peatlands (WAP³ habitat feature)
- Alpine Communities (WAP habitat feature)
- Talus Slopes (WAP habitat feature)
- Cliff Communities (WAP habitat feature)
- Ski Areas (hand digitized)
- Utility Line Right of Ways (utility lines buffered according to size)

After filtering, we then performed a statistical analysis on those sites, further refining the classification of the satellite data using moisture and vegetation indices that help differentiate open ground from forest canopy. This exercise helps to “point to” the pixels in the images that have the highest likelihood of being predominately cleared land.



The results of this stage of analysis can then be translated visually into percent probability maps that can be compared with the original imagery, as shown is the series of images to the right. The upper left panel shows a 2005 Landsat image about 9 by 9 miles in extent, with Berlin appearing in the lavender color in the lower right quadrant.

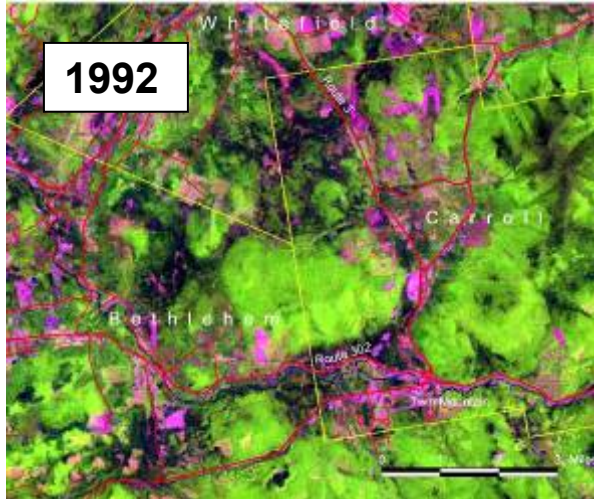


The other three panels are

² Refers to US Fish & Wildlife Service National Wetland Inventory

³ Refers to NH Fish & Game Department Wildlife Action Plan data, 2006.

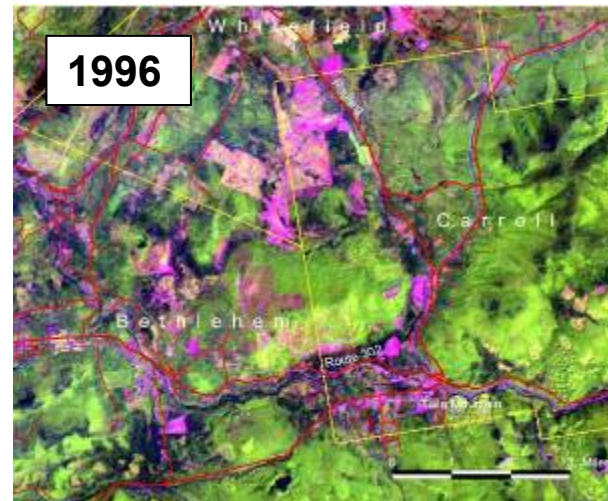
maximum likelihood of harvest signatures extracted from our probability analysis. As can be seen, the 80% image most closely matches the “real” satellite scene. Further refinement along these lines settled on 81% as the best match for this time period. This is where human eyes and minds work to help verify what the computer tells us.



In 1992, several small harvests are visible. Note the squarish pink areas near Route 3 and close to Whitefield.

By 1996, a large clearcut operation of more than 1,000 acres appears in the upper center of the image. Note also the reddish L-shaped harvest signature towards the center; this is an area of relatively heavy harvest, but not a clearcut. The small harvest sites seen in 1992 now appear as light green, indicating regeneration of young trees proceeding.

To get an idea of how the time series can reveal the extent and distribution of harvests in a broad area, the images to the right show cutting activity in the Whitefield area for three different time periods. The scene covers an area of about 65 square miles. Again, pink indicates predominately cleared ground surfaces, while green and yellow colors show vegetation of various types and densities. Darker green is typically conifer forest cover. Some of the pink areas are open fields and other non-forest land cover. The Ammonousuc River can be seen along the bottom of the image.



By 2005, regeneration is beginning to change the spectral image in the area of the large clearcut, and other harvests during the interim appear, including the inverted L-shaped tract near the center of the image, and a fairly intensive harvest but not a clearcut to the east.

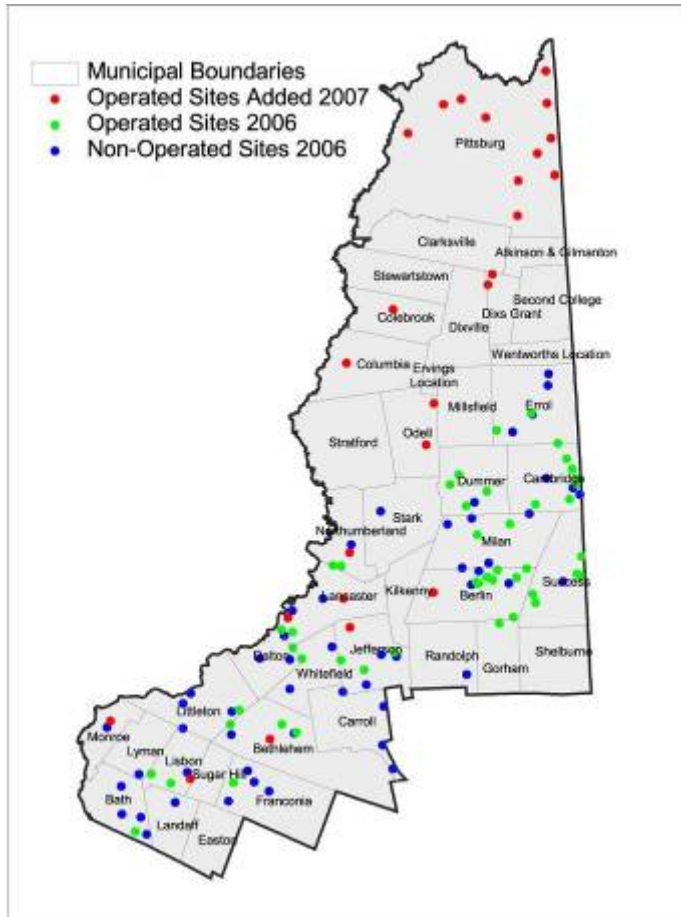


Thus, using the refined satellite imagery, a detailed harvest history can be documented over time that closely reflects the dynamic and changing year-to-year pace of actual forest management on the ground. And remember: because each grid cell is roughly equal to a

quarter acre, we can measure the acreage being operated over time as well fairly closely.

Ground-Truthing

A crucial step in remote sensing is field checking to determine accuracy. Upland Forestry of Bristol, Vermont was contracted to confirm that on-the-ground conditions matched the interpretation of the satellite data. In other words, if the imagery showed a predominately cleared area, was it in fact cleared of timber? And if the imagery showed extensive forest cover, was it in fact forested?



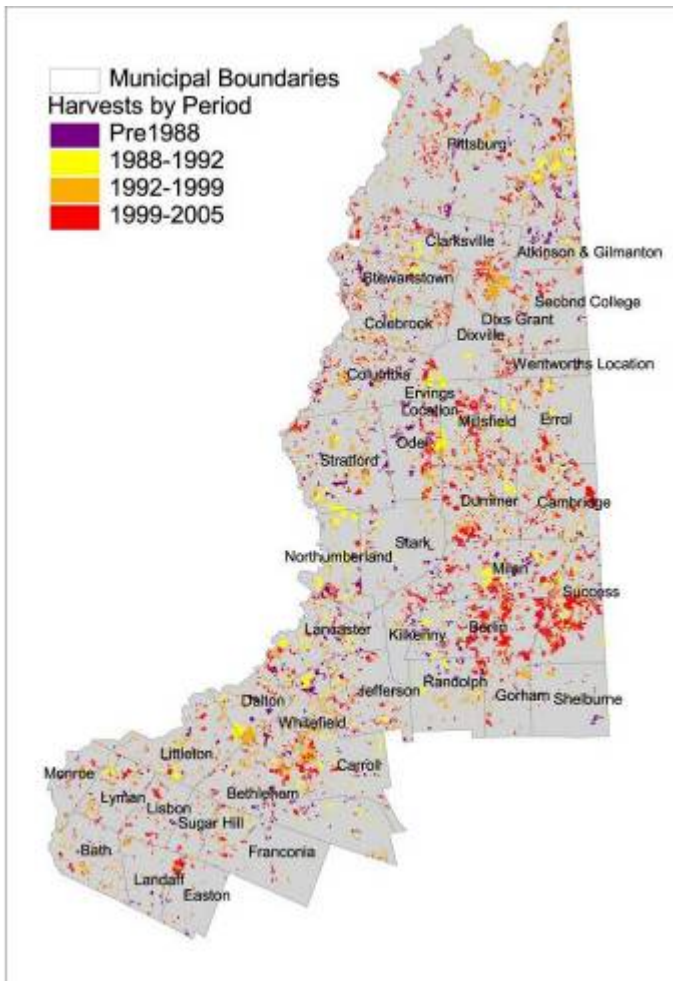
After obtaining landowner permission, Upland Forestry staff visited approximately 100 randomly selected sites, half deemed operated and half not operated to verify both ends of the range. As part of this work, Upland Forestry documented forest characteristics found at each site, including forest type (hardwood, softwood, mixed), age class (sapling, pole, mature, mixed), operational class (light, moderate, heavy or not operated), and operational age (keyed to time periods used in this study). These data were compared to the satellite imagery as part of the effort to define crown closure and thus identify light and moderate harvest removals in addition to predominately cleared forest operations (see discussion of results of this analysis below).

After the field work, the accuracy assessment returned a 94% accuracy rate, which is considered excellent in the field of remote sensing.

Study Findings

The discussion of study results that follows focuses first on the obvious question of the extent and degree of harvest activity over the three time periods. However, several other interest areas were also addressed along the course of the project, including questions of the influence of the 1998 ice storm on harvest statistics, a look at high elevation harvest activity, and whether cutting has been biased on terms of impacts on forest cover type and productive forest soils.

Integrating the Data into a Temporal and Spatial Mosaic



Merging the data developed for the four time periods, a temporal and spatial mosaic of predominately cleared harvest activity can be mapped for the region, as shown in the figure at the left.

Pre-1988 harvests are fewer in number than any other period, and scattered fairly evenly across the region. Harvests from 1988 to 1992 are the most numerous per year, typically larger in size, and evenly distributed. 1992 to 1999 are less numerous than the previous period, but with concentrations evident in the Pittsburg/Dixs Grant area and in the southwest quarter of the study area.

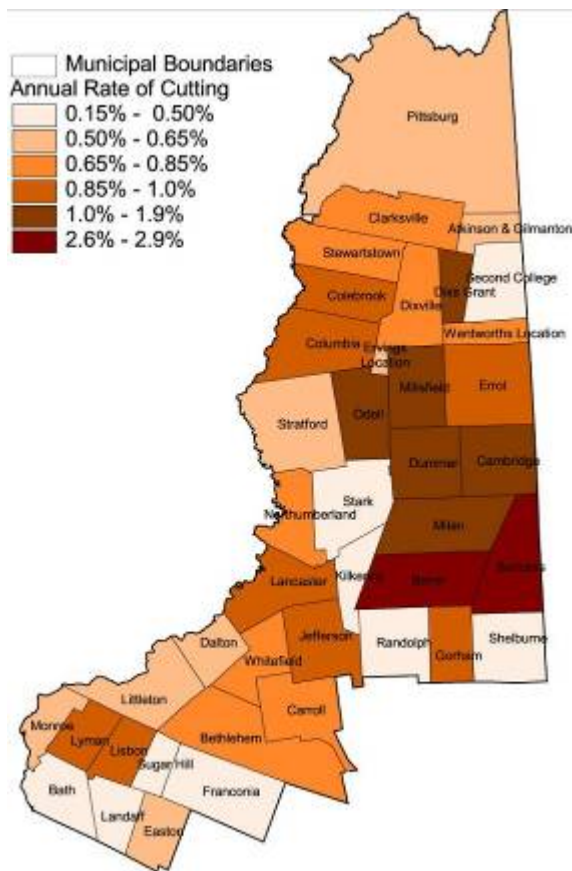
Finally, 1999 to 2005 harvests increase to the highest number per year, with a significant concentration of large harvests in the southeast quarter of the study area. The effects of liquidation cutting in Success, Berlin, and Milan are very clear; however, extensive heavy cutting is also apparent in the Phillips Brook area of Odell, as well as broadly in Millsfield, Dummer, and Cambridge.

The details in the data at municipal scale also tell us something about whether sustainable rates of cutting are occurring at the local level. The data show that the percentage of operable forest land base harvested increased significantly over the three time periods, with two municipalities exceeding an annual 2.5% per year rule-of-thumb removal rate in the 1999 to 2005 period. The 2.5% factor assumes a rotation period of 40 years on softwood and intolerant hardwood stands, after harvest.

The table below lists North Country municipalities in rank order by acres harvested in the 1999 to 2005 period. If the scale of harvest we see recently in Success and Berlin were true for a large part of the North Country, there clearly would be huge cause for concern, but the majority of municipalities are experiencing harvests well within the bounds of sustainability. But what we see now appears to be local problem directly linked to liquidation cutting.

Municipality	Acres Operable Forest Land*	Acres Cut 1999-2005	Average Annual Acres Cut	Percent Operable Forest Base Cut	Annual Rate of Cutting
Success	28,427	4,866	811	17.1%	2.9%
Berlin	31,584	5,012	835	15.9%	2.6%
Dummer	26,892	3,052	509	11.3%	1.9%
Millsfield	24,030	2,693	449	11.2%	1.9%
Milan	32,991	3,510	585	10.6%	1.8%
Cambridge	29,297	2,692	449	9.2%	1.5%
Odell	21,204	1,866	311	8.8%	1.5%
Dixs Grant	8,858	600	100	6.8%	1.1%
Lancaster	22,204	1,319	220	5.9%	1.0%
Jefferson	21,966	1,253	209	5.7%	1.0%
Colebrook	17,654	996	166	5.6%	0.9%
Columbia	28,281	1,550	258	5.5%	0.9%
Errol	32,826	1,790	298	5.5%	0.9%
Lyman	15,001	808	135	5.4%	0.9%
Gorham	16,045	861	144	5.4%	0.9%
Lisbon	12,809	683	114	5.3%	0.9%
Clarksville	33,976	1,748	291	5.1%	0.9%
Carroll	24,555	1,237	206	5.0%	0.8%
Wentworths Location	9,858	495	83	5.0%	0.8%
Stewartstown	23,786	1,125	188	4.7%	0.8%
Dixville	21,541	977	163	4.5%	0.8%
Whitefield	15,780	715	119	4.5%	0.8%
Northumberland	14,982	633	106	4.2%	0.7%
Bethlehem	37,975	1,542	257	4.1%	0.7%
Erving's Location	2,099	82	14	3.9%	0.7%
Atkinson & Gilmanton	9,726	369	62	3.8%	0.6%
Pittsburg	158,213	5,939	990	3.8%	0.6%
Stratford	36,006	1,234	206	3.4%	0.6%
Easton	15,730	532	89	3.4%	0.6%
Littleton	24,926	823	137	3.3%	0.6%
Monroe	10,117	328	55	3.2%	0.5%
Dalton	13,391	415	69	3.1%	0.5%
Second College	22,974	663	111	2.9%	0.5%
Sugar Hill	8,197	236	39	2.9%	0.5%
Kilkenny	7,279	202	34	2.8%	0.5%
Franconia	19,908	515	86	2.6%	0.4%
Bath	16,237	414	69	2.5%	0.4%
Landaff	15,420	325	54	2.1%	0.4%
Randolph	23,419	428	71	1.8%	0.3%
Shelburne	20,445	186	31	0.9%	0.2%
Stark	27,908	251	42	0.9%	0.1%
Total	984,517	58,322	7,123		

*Operable forest land was estimated by removing all land area with elevations > 2,700', steep slope areas >35%, and tax parcels <5 acres in size from the gross forest land base determined by GRANIT land cover data.



The data above can be translated into spatial using the GIS to help visualize the harvest trends across the region on a municipal scale. The map at the right displays the annual rate of cutting as a percentage of operable forest land base, taken from the table above (1999 – 2005). The classification system is quantile, which breaks down the range of data into five equal parts; an extra class has been broken out of the top class to highlight the highest rates of cutting.

Note the concentration of higher annual rate of cutting in the central part of the region, and especially Berlin and Success which appear to be exceeding a 2.5% removal rate on operable forest land. The municipalities in the next tier down (1% to 1.9% indicate that relatively heavy harvesting has been the norm for the period (a measured by predominately cleared land in this study), but the annual rate is running significantly behind Berlin and Success where liquidation cutting is ongoing.

The two earlier time periods (1988 – 1992, 1992 – 1999) do not show either the rate of cutting or the geographic concentration of municipalities seeing heavy cutting. It should be noted, however, that in terms of acres harvested, Pittsburgh, Dixs Grant, and Whitefield do stand out in the 1992-1999 period.

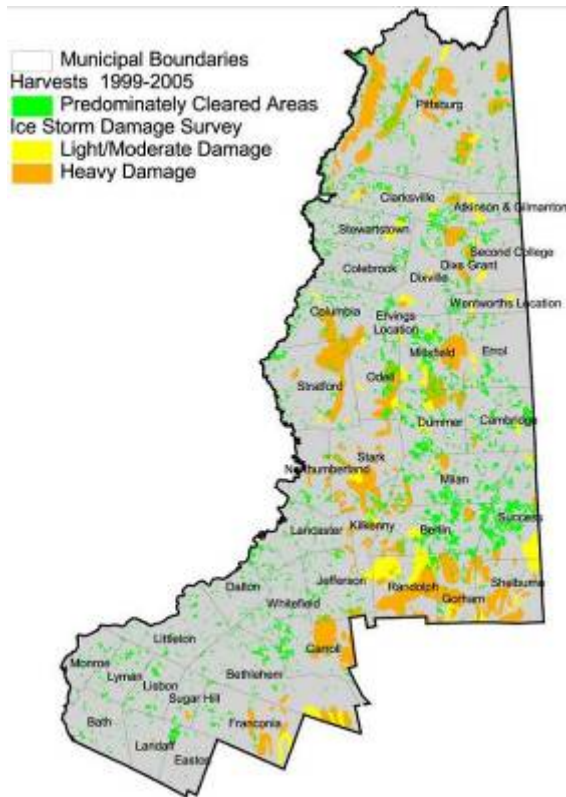
Ice Storm Influence on Harvests

Large-scale disturbances in forests are relatively rare in New England, but they do occur, most often as major weather events such as hurricanes. In January 1998, a series of freezing rainstorms persisted over several days affected New Hampshire, Vermont, Maine, and New York, as well as several Canadian provinces. The result was a heavy build-up of ice on tree branches and varying degrees of damage to forest stands, ranging from trees being bent over to loss of branches to entire canopies broken off. The severity of the damage was directly related to slope aspect and elevation. Trees on south and southeast slopes and elevations of 1300 to 1600 feet were most affected. Most damage occurred in hardwood stands, although some softwood stands were also damaged.⁴

Damage to forest stands in the state was mapped from aerial and ground surveys conducted over time by the DRED Division of Forests and Lands and by the US Forest Service during the summer of 1998, and was mapped according to USFS National Aerial Survey Spatial Database standards, which codes for damage severity and patterns. Approximately 544,000 acres of

⁴ Excerpts from *Ice Storm '98 Revisited*, Karen Bennett, UNH Cooperative Extension.

forest land in New Hampshire were mapped as ice-damaged due to this storm. Of that area, 166,645 acres or about 30% of all ice-damaged forests are found in the North Country study area delineated in this report. 166,645 acres of ice-damaged stands accounts for about 15% of the total forest land base in the North Country. Statewide, about 25% of forest damage was rated “light” and 75% as “moderate to severe”. In the study area, the damage severity ratio was similar.



Salvage harvests on the ice-damaged stands in the region began in 1998, ramped up significantly during 1999, and finished in 2000.⁵

The GIS harvest data do indicate extensive cutting in the vicinity of Dixs Grant, Dixville and Clarkville in the 1992-1999 period – within an area of severe ice storm damage – but it is not known whether these operations may have been salvage harvests in 1998.

Using the 1999 – 2005 harvest data, we do see some harvest activity that may have been a response to ice storm damage. The areas hit by the ice storm and predominately cleared harvests detected in this study are shown in the map at the left. Harvests in that time period are shown in green, with significant overlap on ice damaged forest land in Odell, Millsfield, Dummer, and to some extent, in Pittsburg.

Overall, acreage harvested on ice damaged stands from 1999 – 2005 amounts to only 17,510 acres, or about 10% of all ice-damaged stands in the study area. 82% of those operations occurred on areas classified as moderately to severely damaged, which tends to indicate salvage harvest activity. About 25% of all harvests on ice-damaged areas occurred on public land, with the balance on private land, or land that was private in the 1999 – 2001 time period (to account for major changes in the land ownership of tracts such as the Connecticut Headwaters land protection project).

The total area predominately cleared in harvest activity for the study area 1999 – 2005 is about 55,000 acres. Although we cannot directly attribute harvesting on ice-damaged areas to be salvage operations due to variability in severity and patterns of damage within each area mapped, the 17,510 acres noted above does represent about one-third of all cutting in that time period. Furthermore, in looking at the harvest figures for the preceding time period of 1992 – 1999, it is interesting to note that the difference between the two time periods is about 17,000 acres. Since salvage harvests would necessarily be aggressive in term of tree removals, it stands to reason that they will be detected as predominately cleared harvests in the satellite data.

⁵ Personal communication, Karen Bennett, UNH/CE, 2008.

Thus, it may well be the case the ice storm of 1998 caused a bump in what may otherwise be a plateau of harvesting at approximately 38,000 acres per year. Only comparison with data from a similar study of 2005 – 2010 harvests will tell the whether there is a trend, or a weather disturbance-related anomaly in the harvest history data.

Success in Detecting a Range of Harvest Intensity

In terms of the experimental goal in the second phase of this study to use satellite imagery to track forest harvests over time, we feel very comfortable with the results of the image analysis in identifying areas that are predominately cleared during timber harvests. However, the accuracy assessment showed less success in reliably picking out harvests of moderate and low intensity. We can see small patch cuts and some strip cuts fairly well, but selective removals just don't change the image spectrum enough to be well documented. Selective removals are invisible to detection.



The two images above are located along the Maine border in southeast Pittsburgh. The image on the left is an aerial photo; on the right is the same area but displayed as Landsat imagery, classified to show areas that are predominately cleared. The larger clearcut operations in the right half of each scene are clearly evident. The smaller patch cuts of only a few acres each also appear in both images. However, the strip cuts in the upper left of the left image and associated with the clearcut operations do not appear as cleared forest land.

The issue has more to do with the resolution of the satellite imagery than the methodology; 30-meter pixels mean that openings created by harvest would need to be more than 100 feet across to be readily identified. Actually, the openings needs to be four or five grid cells across to be “seen” in the maximum likelihood analysis discussed above. It will not be long, however, before 2- or 5-meter satellite imagery becomes publicly available, which will allow all types of timber

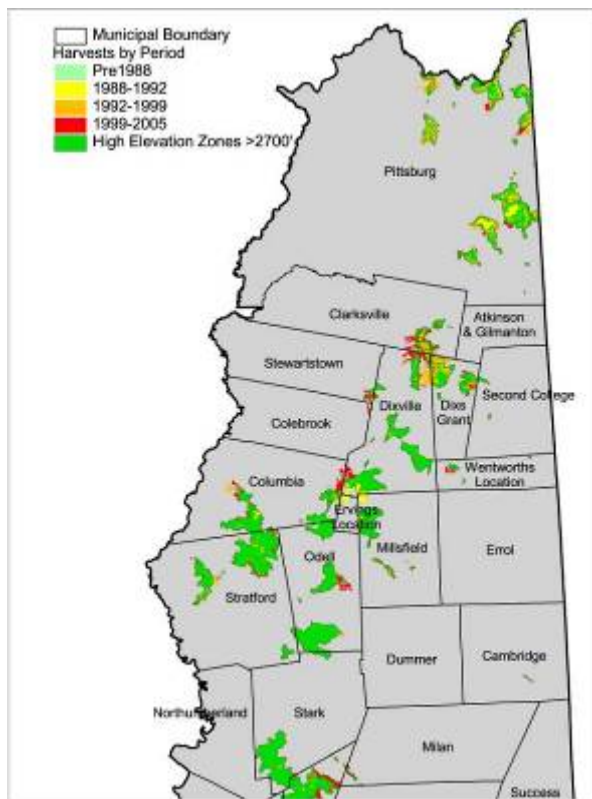
harvest to be identified “on the fly”. Other, intermediate resolution satellite data are currently available that would be worth testing against the study goals, but these data tend to be quite costly at regional scale, and are probably beyond the reach of most agencies and organizations.

High Elevation Harvest

One unexpected finding of this project is that considerable timber harvest has been occurring above 2,700’ elevation during all three periods. While much of the cutting has taken place in eastern Pittsburgh from 1988 to 1999, the boundary area shared by Dixville, Dixs Grant and Clarksville is also involved from 1992 to 2005. Generally, about 6,100 acres, or 27% of private land above 2,700’ has been harvested heavily since 1988. Some areas in eastern Pittsburgh have approached 50% have been cleared since 1992, and nearly 40% of high elevation forests were cut since 1992 in the boundary area mentioned above.



High Elevation Spruce/Fir Forests in the North Country
Photo credit: Dan Sperduto/TNC for Natural Heritage Bureau



The extent and distribution of harvests in high elevation areas mentioned above is shown by time period in the figure to the left. The green areas represent land 2,700’ and higher, as derived from 1:100,000 scale topographic data from GRANIT.

The aerial photo to the right zooms in on the Clarksville/Dixville border area, showing harvests over two time periods. Some harvests above 2,700' during the time series in our study were subject to a voluntary memorandum of understanding (MOU) between the state Division of Forests and Lands and various individual private landowners. This MOU lays out forest management criteria to specifically protect high elevation spruce/fir forests which are the dominant forest type due to climatic and soils conditions. It is well-recognized that these forests provide essential habitat for a variety of wildlife species.



Due to the sensitive character of high elevation land, a special program forestry practices is spelled out in the agreement . The MOU provisions address access roads and skid trails, harvesting operations and methods, and maintenance of forest composition and structure in a sustainable fashion. Management areas are defined in the MOU as a contiguous area lying above 2,700' elevation.

For any management area, the forest composition and structure goals include:

- 60% of the area should consist of stands with an average diameter at breast height (DBH) 4" or greater, to provide habitat for species requiring middle-aged and mature forest classes.
- 30% of the area should consist of stands with an average DBH measuring less than 4", to provide habitat for species requiring you forest age classes, and to ensure a supply of new, middle-aged stands in the future.
- 10% of the area should remain unharvested, to meet the habitat needs of species requiring old stands, and dead and down woody material.
- Silvicultural practices should maintain or increase the proportion of softwood type.

The high elevation land MOU expires with change of ownership, but several new landowners have signed agreements as recently as 2002⁶. Nevertheless, satellite data show significant areas have been predominately cleared since 1992. It is not within the scope of this study to gather more information on harvest activities in the high elevation areas. More detailed assessment on the ground, along with consultations with landowners and the Division of Forests and Lands, would be necessary to determine if the management goals for high elevation lands are being met,

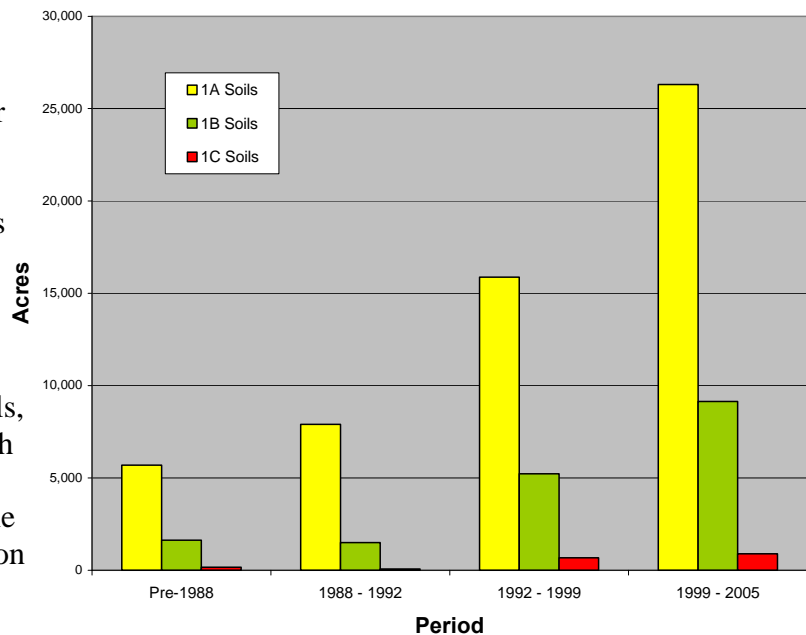
⁶ Personal communication, Susan Francher, DRED Division of Forests and Lands, July 2008.

Forest Cover & Soils Utilization

Using GRANIT land cover data, we find that forest cover types are being harvested at different rates over time across the study area, but do not appear to be exceeding a gross sustainable harvest ratio. Softwood cover type has the least land area in the region, but is harvested at the highest rate; about 57,000 acres (24% of total area) of the cover type has been harvested since 1988. Conversely, only about 25,000 acres (5% of total area) of hardwood cover type –which comprises about 50% of forest cover in the region -- has been harvested since 1988. About 10% of mixed hardwood and softwood forests have been operated since 1988. Overall, the average annual harvest rate is about 1.25%, or half of a rule of thumb maximum of 2.5% per year.

The North Country enjoys some of the most productive forest soils in the state. We compared the pattern of harvests to the location of the best soils in the region, to learn whether more acres are being operated on a particular soil type in relation to other soils. We found that harvests are occurring in direct proportion to the extent of these soils across the region: 75% on the prime northern hardwood soils, 23% on less fertile hardwood/softwood soils, and about 2% on the sandy outwash plains with its mixed softwood component and excellent white pine growing soils in the southern portion of the study area.

Acres Harvested by Forest Soil Type and Time Period



See **Appendix B** for additional data tables on the analysis of forest cover types and soils.

Differences on Public and Private Conservation Lands

The study also examined whether cutting on public and private conservation lands has been significant during any of the three time periods. Conservation easements that protect working forests often stipulate sustainable harvesting practices. The total area of protected land in the region is approximately 512,246 acres, or about 40% of the total land base. Private conservation land amounts to 205,428 acres with harvests since 1988 of only 2,820 acres, or 1.4% of that land area. Public conservation land totals about 322,800 acres, with harvests since 1988 of 15,630 acres, or about 5% of that land area. In contrast, the total harvest area on unprotected land since 1988 is 120,900 acres, or 13% of private, non-conserved forest land. The privately owned 171,500 acre Connecticut Headwaters land, conserved in 2003, was counted as unprotected in that time period.

On the subject of private lands, since we have digital tax parcel data for 29 of 41 municipalities in the study area, we also checked the range of parcel sizes being harvested over time against these data, using a threshold of five acres or greater parcel size as a baseline. The average number of parcels being harvested per year has not changed appreciably since 1988, but we do see more reliance on parcels in the 100-acre range since 1992, with 25% increase in the smaller parcel sizes to about 35 per year. The numbers of harvests on larger parcels greater than 500 acres have stayed fairly constant on an annual basis – in the range of 12 to 15 per year.

What's Next?

Any good experimental study should yield many other questions begging to be answered, and this project is no exception. We have just scratched the surface of use of large-scale satellite imagery to document forest management activities, but even so, what we now have as baseline data on 20 years of harvest history in the North Country shows great potential to help forest and community planners alike in times ahead when New Hampshire's northern forest resources are deployed in new directions, such as generating electricity or the production of ethanol.

Based on our findings, we are left with questions such as: What is the future of the land parcels within the large-scale "predominantly cleared" areas? With all timber value removed, will these parcels be subdivided into building lots, and is that trend already underway? Is the mosaic of harvests creating a structural habitat with varied age classes that is beneficial? Which plant and wildlife species are the winners and losers? What is the effect of cutting patterns as we see them on water quality and water quantity? Are these cutting patterns significant in the context of climate change?

Finally, but very importantly, in the two years since this study was started, much has changed in terms of context. Two long-time paper mills are now quiet, and one of the paper machines in the big Rumford mill has shut down. Skyrocketing fuel costs are beginning to cause pain in the entire North Country forestry infrastructure; loggers and truckers are caught in the middle of shrinking markets and the rising cost of operations; the shrinking value of the dollar has altered the international wood markets while a housing slump is influencing demand.

Although some of the cutting history can now be seen, remote sensing cannot look around the corner to see the future. The key question then becomes: How will society steward the region's resources to meet an unknown future?

Appendix A: Technical Summary of Image Analysis and GIS Processing

This appendix contains two reports from Dr. Birnie who provided the technical assistance and production on the remote sensing science used in this study.

Part 1 addresses the initial effort to identify predominately cleared forest land (harvest operations), which was limited to 28 towns due to cloud-obscured satellite data. This effort was intended as an experimental pilot project to determine the usefulness of the Landsat data in this research.

Part 2 of the report that follows covers a second effort to identify three levels of harvest activity – light, moderate, and heavy cutting. See also discussion in the body of this report.

Report on the Northern New Hampshire Operated Forest Lands, a Preliminary Study Part 1: Image Processing

September 7, 2006

This report is a general summary for

Submitted to: The Society for Protection
New Hampshire Forests
(partial draft submitted to
Jenn Alford at SPNHF in
April, 2006)

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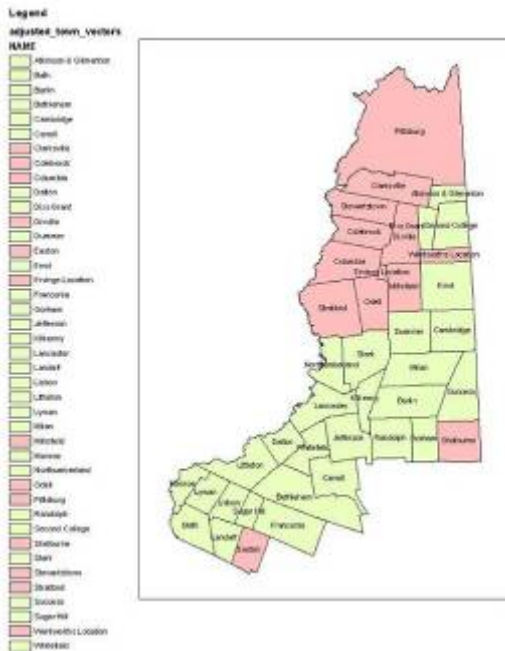
Introduction and Acknowledgements

This project began with a conversation among Kevin Evans, Director of Woodlands, Dartmouth College, and Dan Sundquist and Peter Ingraham, Society for Protection of New Hampshire Forests (SPNHF) and Dick Birnie (Department of Earth Sciences, Dartmouth College). The group expressed an interest in determining whether the forests of northern New Hampshire are being harvested in a long term sustainable way. Dick Birnie suggested that he undertake a pilot project to explore the application of satellite remote sensing to determining the rate of harvesting over the last 13 years. Birnie worked on this project without compensation and was joined at Dartmouth by an undergraduate student, Andrew Argeski, who was supported during the summer of 2005 on a Northern Forest Internship administered by the Office of Outdoor Programs, Dartmouth College.

In addition to the dedicated work of Andrew Argeski, the author acknowledges the help and advice of his excellent colleagues at Dartmouth including Heather Carlos and Andrew Elmore. The author also acknowledges the close collaboration and vital assistance of his colleagues at the Society for Protection of New Hampshire Forests (SPNHF). These colleagues include Peter Ingraham, Jenn Alford, and Dan Sundquist. They provided extensive help in reviewing the classifications, arranging for the field verification study. In particular, Jenn Alford provided extensive vector processing support and valuable advice for the image processing part of the project. The GIS analysis of the classifications was undertaken by Jenn Alford and will be a second part of this report.

Most of the data processing in this study was done using ENVI, version 4.2, while some was done using ArcMap 9.1.

Study Area



Colleagues at SPNHF identified an area of 41 towns and unincorporated townships in northern New Hampshire on which to focus the study (Figure 1). Because cloud free Landsat satellite data were not available for all towns over the time period of the study, we decided to focus on 28 towns that were largely cloud free during the time period (Figure 1). We were disappointed that we were unable to analyze all towns and townships is this initial Pilot study, but the analysis of the full area will be a high priority in any follow on studies.

Figure 1: Cloud-free towns (green) and clouded towns (red)

Landsat Satellite Data

Our full study area is included in Landsat Path13 Row 29 (WRS-2). We assembled the following scenes for analysis:

- Sept 9, 1988 (Thematic Mapper)
- July 16, 1991 Thematic Mapper)
- June 16, 1992 (Thematic Mapper)
- August 30, 1996 (Thematic Mapper)
- August 20, 1998 (Thematic Mapper)
- August 31, 1999 (Enhanced Thematic Mapper)
- October 20, 2000 (Thematic Mapper)
- September 8, 2002 (Thematic Mapper)
- June 20, 2005 (Thematic Mapper)

Several of the scenes were ruled out because of extensive cloud cover, and the October 20, 2000 scene was ruled out because of hardwood senescence. Because land cover data are available for 1992, we elected to begin the study at that point. The following five scenes were used for the study (Figure 2):

- June 16, 1992 (Thematic Mapper)
- August 30, 1996 (Thematic Mapper)
- August 31, 1999 (Enhanced Thematic Mapper)
- September 8, 2002 (Thematic Mapper)
- June 20, 2005 (Thematic Mapper).

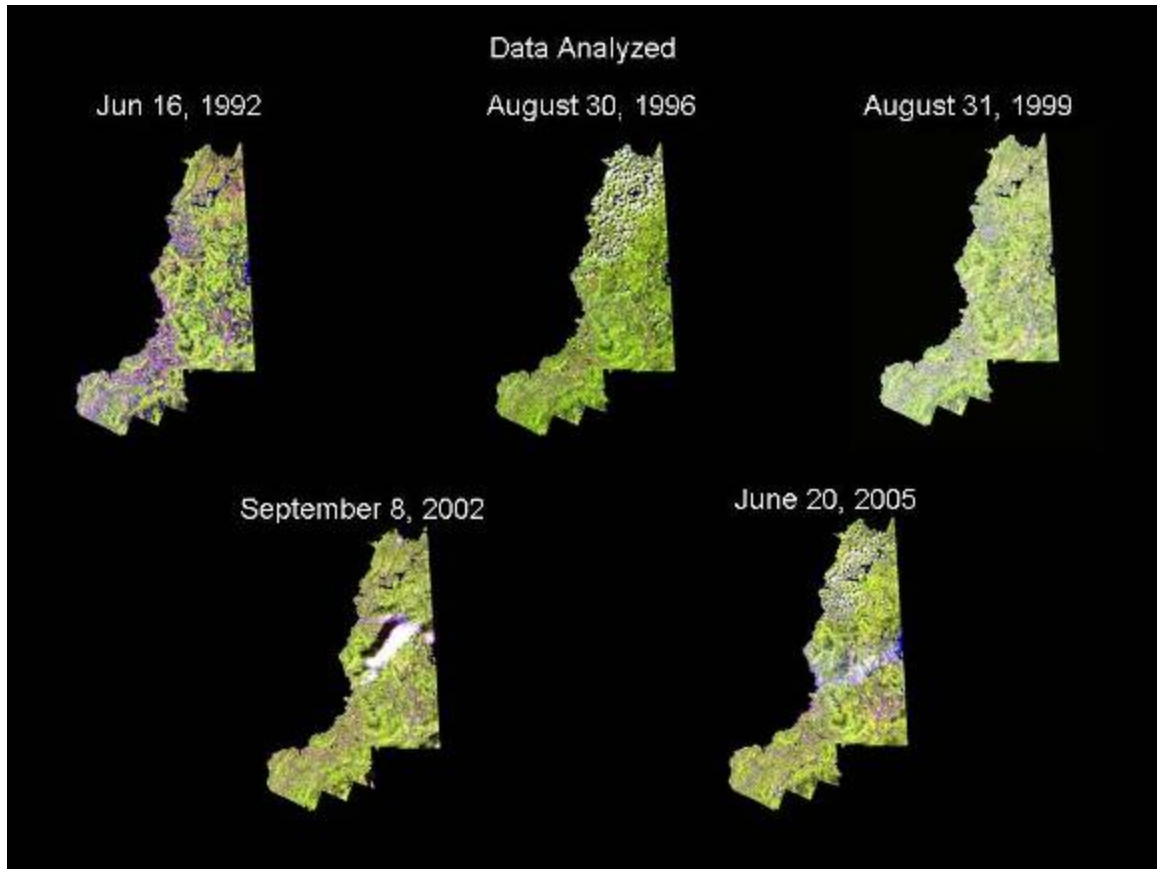


Figure 2: Landsat Scenes of northern NH used in this study

Initial Land Cover

Peter Ingraham of SPNHF provided the Dartmouth colleagues land cover classifications for the starting point of the analysis. These classifications were produced by the Spatial Analysis Laboratory of the University of Vermont as part of the U.S. Fish and Wildlife Service (USFWS) Gap Analysis Project (www.uvm.edu/envnr/sal/lc.html). These data were produced using multiple scenes of Landsat 5 data during the spring, summer, and fall of 1992 and 1993. The seven classification cover types are shown in Figure 3. The overall accuracy of the aggregated seven class Land Cover map for Vermont and New Hampshire was 80% (www.uvm.edu/envnr/sal/lc.html).

Landcover Classification

- USFWS Gap Analysis Project – UVM (for vertebrate species habitat models)
- from spring/summer/fall 1992/1993 Landsat 5 data

Class (value)	Concise Definition
developed/barren (3)	Urban developments, sand mines, gravel pits, quarries, exposed rock/talus
forest - coniferous dominant (11)	coniferous species contribute $\geq 65\%$ total stand species
forest - deciduous dominant (12)	deciduous species contribute $\geq 65\%$ total stand species
forest mixed (13)	neither coniferous nor deciduous species contribute $\geq 65\%$ total stand species
open water (21)	non-vegetated, perennial open water areas
non-forested upland (2)	agricultural lands, old fields, recent clear-cuts, grasslands
non-forested wetland (24)	emergent to scrub wetlands

(from Table 1 www.uvm.edu/envr/sa/1c.html)

Figure 3: Starting Land Cover classification of study area

We took the three forest classes 11, 12, and 13 (coniferous, deciduous, and mixed respectively) (Figure 3) as forested at the start of the study period. All other classes were considered un-forested at the time of the initiation of the study (June, 1992). The initial land cover data were, therefore, converted into a binary data set, forested and un-forested (Figure 4). All un-forested pixels were masked out of the satellite data and never considered for analysis as operated.

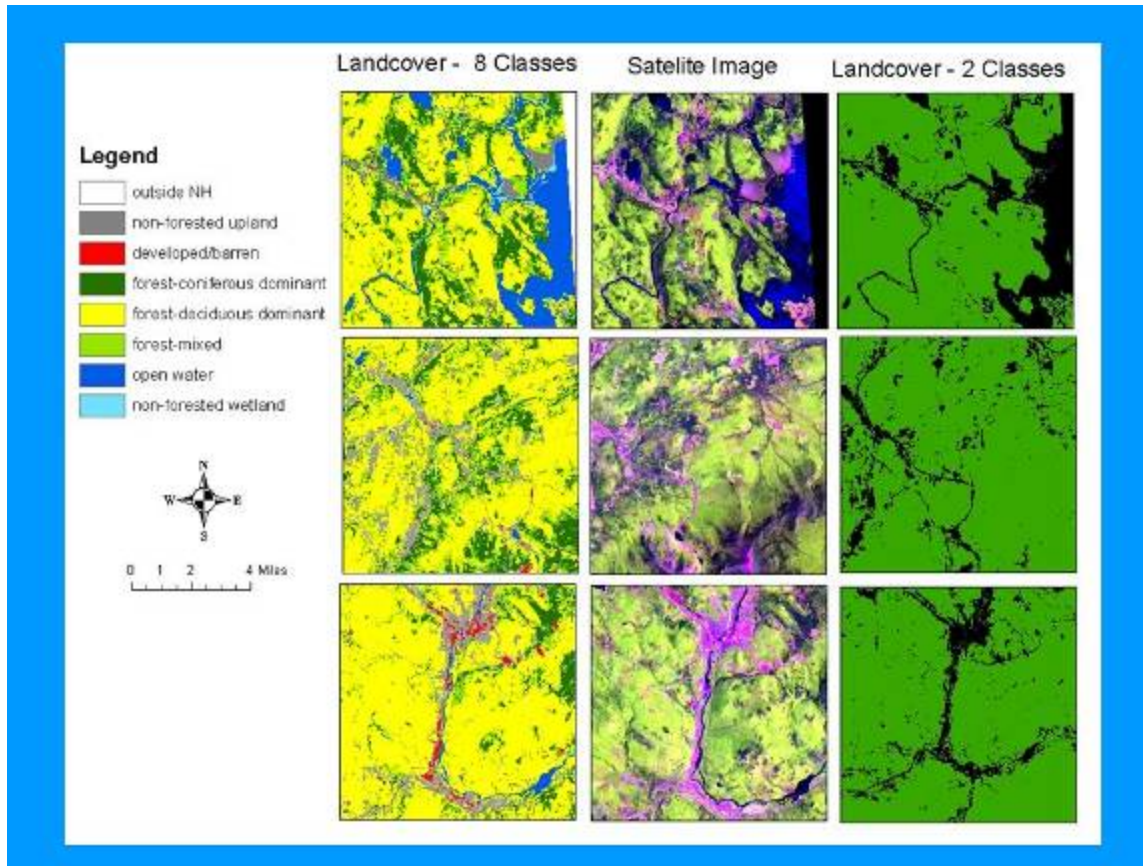


Figure 4: Conversion of land cover to binary data for the Lake Umbagog region (top), Whitefield, NH, region (middle), and the Berlin-Gorham region (bottom).

Registration of Data

The New Hampshire State Plane (feet) with the NAD 83 Datum (NHSP) was the standard projection for all data in this study. In this projection, an image pixel is approximately 93.5 feet square.

The satellite data obtained from the U.S. Geological Survey were projected in UTM Zone 18, WGS 84 coordinates. While these registrations are acceptable for some work, I re-registered them to improve the registration accuracy. The June 20, 2005 data were re-registered by choosing 16 Ground Control Points (GCP's) on USGS topographical maps and then projected to NHSP. The RMS error for this registration was 1.04 pixels.

Then, other images were registered to the June 20, 2005 image:

- September 8, 2002 to June 20, 2005, 12 GCP's, RMS = 0.60 pixels
- August 31, 1999 to June 20, 2005, 12 GCP's, RMS = 0.68 pixels
- August 30, 1996 to June 20, 2005, 12 GCP's, RMS = 0.67 pixels
- June 16, 1992 to June 20, 2005, 12 GCP's, RMS = 0.65 pixels

Calibration of Satellite Data

The satellite data are obtained from the U.S. Geological Survey in 8-bit digital number (DN) values from 0 to 255. These data were converted to radiances at the sensor and exoatmospheric reflectance according to the standard methods outlined in Figure 5 and Figure 6.

Calibration – Part 1 *

Convert data from DN to radiance

$$L_{\lambda} = (((L_{max} - L_{min}) / Q_{calmax}) * Q_{cal}) + L_{MIN}$$

where

- L_{λ} = spectral radiance at sensor aperture in $W/(m^2 \cdot sr \cdot \mu m)$
- Q_{cal} = quantized calibrated pixel value in DN
- Q_{calmin} = minimum quantized calibrated pixel value (DN=0) corresponding to L_{min}
- Q_{calmax} = maximum quantized calibrated pixel value (DN=255) corresponding to L_{max}
- L_{min} = spectral radiance that is scaled to Q_{calmin} in $W/(m^2 \cdot sr \cdot \mu m)$
- L_{max} = spectral radiance that is scaled to Q_{calmax} in $W/(m^2 \cdot sr \cdot \mu m)$

or

$$L_{\lambda} = G_{scale} * Q_{cal} + B_{scale}$$

where

- G_{scale} (gain) = $((L_{max} - L_{min}) / Q_{calmax})$ (ref. * Table I)
- B_{scale} (bias) = L_{min} (ref. * Table I)

*Chander, G. and Markham, B., 2003, Revised Landsat-5 TM radiometric calibration procedures and post calibration dynamic ranges. IEEE Transactions on Geosciences and Remote sensing, v. 41, no. 11, p. 2674-2677.

Figure 5: Data conversion from DN to Radiance

Calibration – Part 2 *

Convert data from radiance to reflectance

$$pp = ((\pi * L_{\lambda} * d^2) / (E_{sun} * \cos \Theta_s))$$

where

- pp = planetary reflectance (unitless)
- L_{λ} = spectral radiance at sensor's aperture
- d = earth-sun distance in astronomical units (ref. * Table III)
- E_{sun} = mean solar exoatmospheric irradiances (ref. * Table II)
- Θ_s = solar zenith angle in degrees

*Chander, G. and Markham, B., 2003, Revised Landsat-5 TM radiometric calibration procedures and post calibration dynamic ranges. IEEE Transactions on Geosciences and Remote sensing, v. 41, no. 11, p. 2674-2677.

Figure 6: Data conversion from radiance to reflection

The conversion of the data to reflectances reduces inter-scene variations due to time of year. For further information on these calibration methods refer to Chander and Markham, 2003, and Landsat 7 Science Data Users Handbook).

Since the training data used in this study are derived from the image being classified, then both will be on the same relative scale; therefore, further calibration and correction for atmospheric effects are unnecessary (Song et al., 2001).

Classification Techniques

The Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Moisture Index (NDMI) are well established indices used in satellite remote sensing studies (Figure 7). Color composite images of these indices have been used to detect forest change in Maine (Sader and Winne, 1992; Wilson and Sader, 2002; and Sader et al., 2003). Earlier work supervised by Birnie (Miller et al., 1998) used NDVI along with principal components analysis to document land cover changes in northern New England.

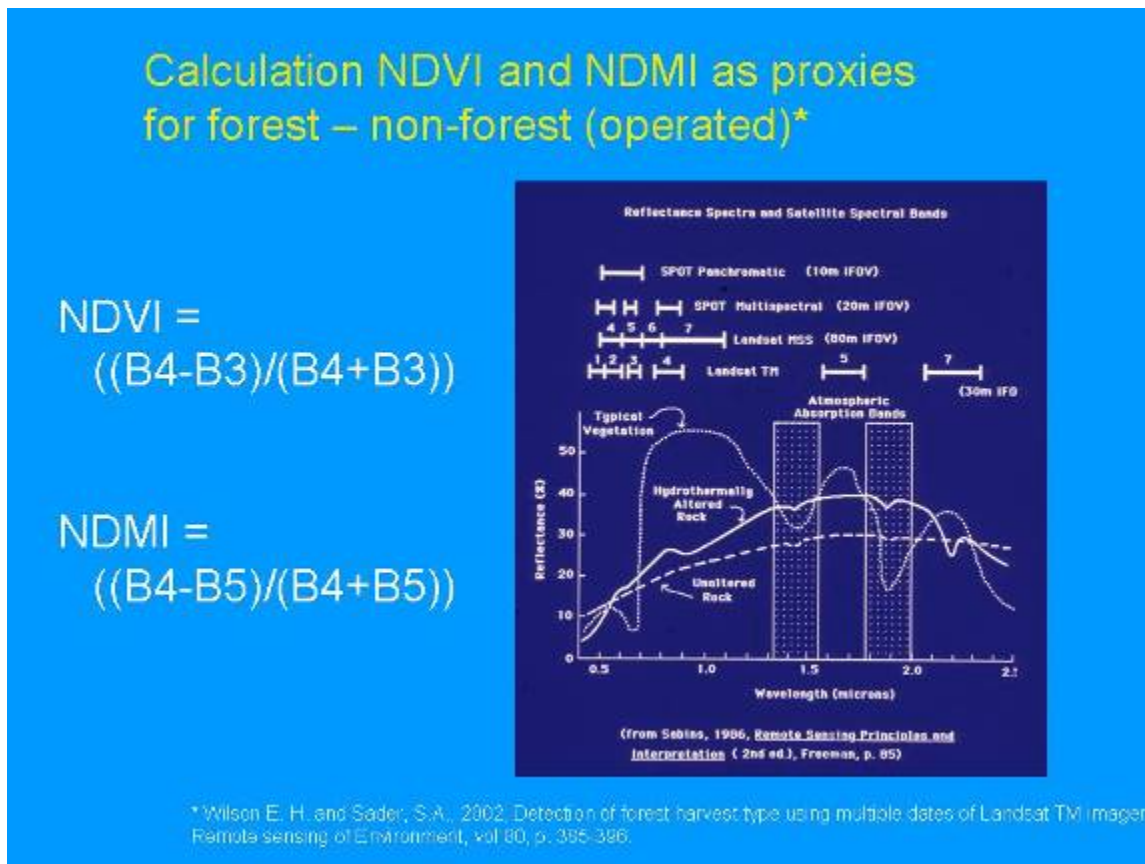


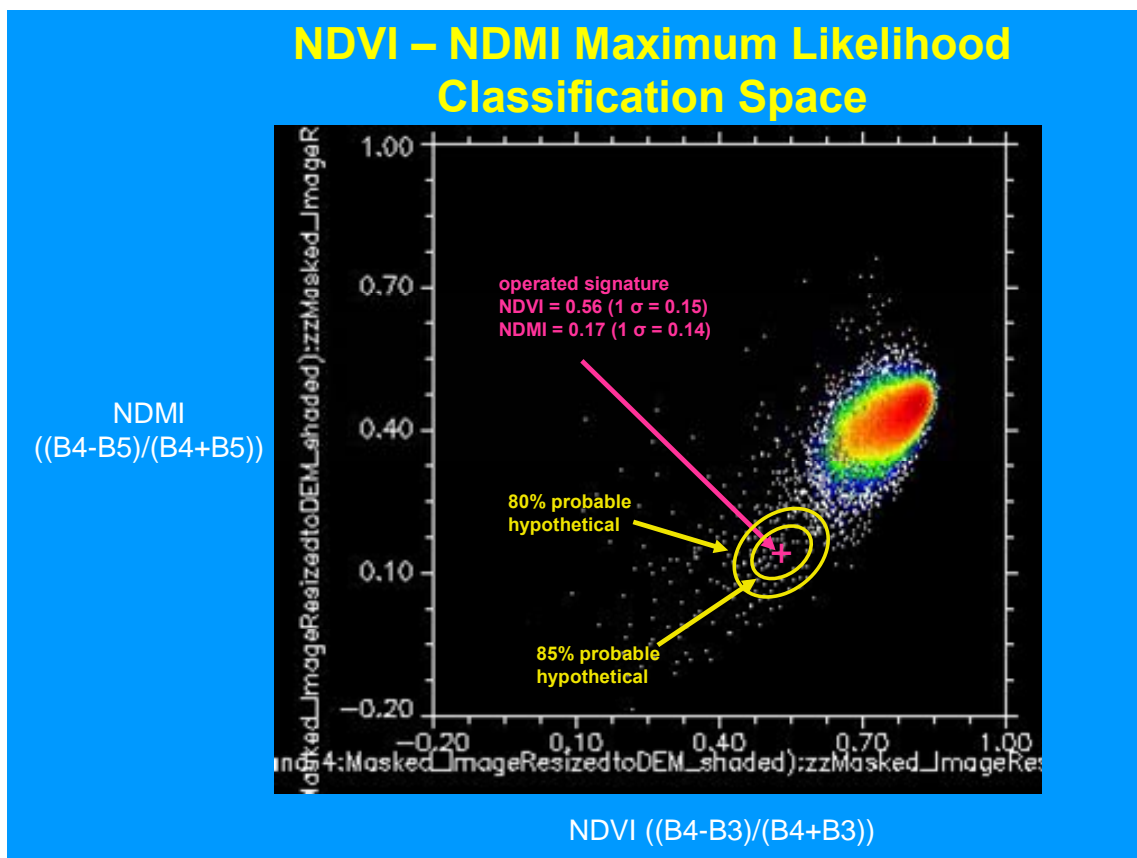
Figure 7: Calculation of NDVI and NDMI

In this study, a maximum likelihood classifier (Jensen, 1986, p.212-214) was used to classify each year's image. The maximum likelihood classifier assigns each pixel to a pre-identified

class based on the class to which it most probably belongs. In the case of this study, there are only two classes, operated and unoperated. Any pixel not classified as operated is assumed to be unoperated. The statistical distribution (mean and variance-covariance matrix) of the operated class was determined by extracting the NDVI and NDMI values of many pixels in operated areas. This statistical distribution is also known as the spectral signature. These operated areas were identified by careful study of the images. The number of pixels used to establish the operated spectral signature for each year is summarized below.

2005, 8856 pixels
 2002, 7413 pixels
 1999, 8171 pixels
 1996, 7217 pixels

Based on the variance-covariance matrix of the operated pixels for a given year, probability contours can be drawn about the mean NDVI and NDMI values. This establishes a two dimensional classification space (NDVI vs. NDMI) (Figure 8).



Figure

8: NDVI – NDMI Maximum Likelihood Classification Space

The higher the probability threshold assigned to a particular classification, the fewer the pixels will be classified (Figures 8 and 9). Multiple probabilities were tested and based on extensive

study and input from colleagues at SPNHF including Dan Sundquist, Director of Research, and colleagues at Dartmouth including Kevin Evans, Director of Woodland Operations, the following probability thresholds were established as representing the best classifier of operated land:

2005, 80.0%
2002, 81.0%
1999, 82.5%
1996, 84.0%

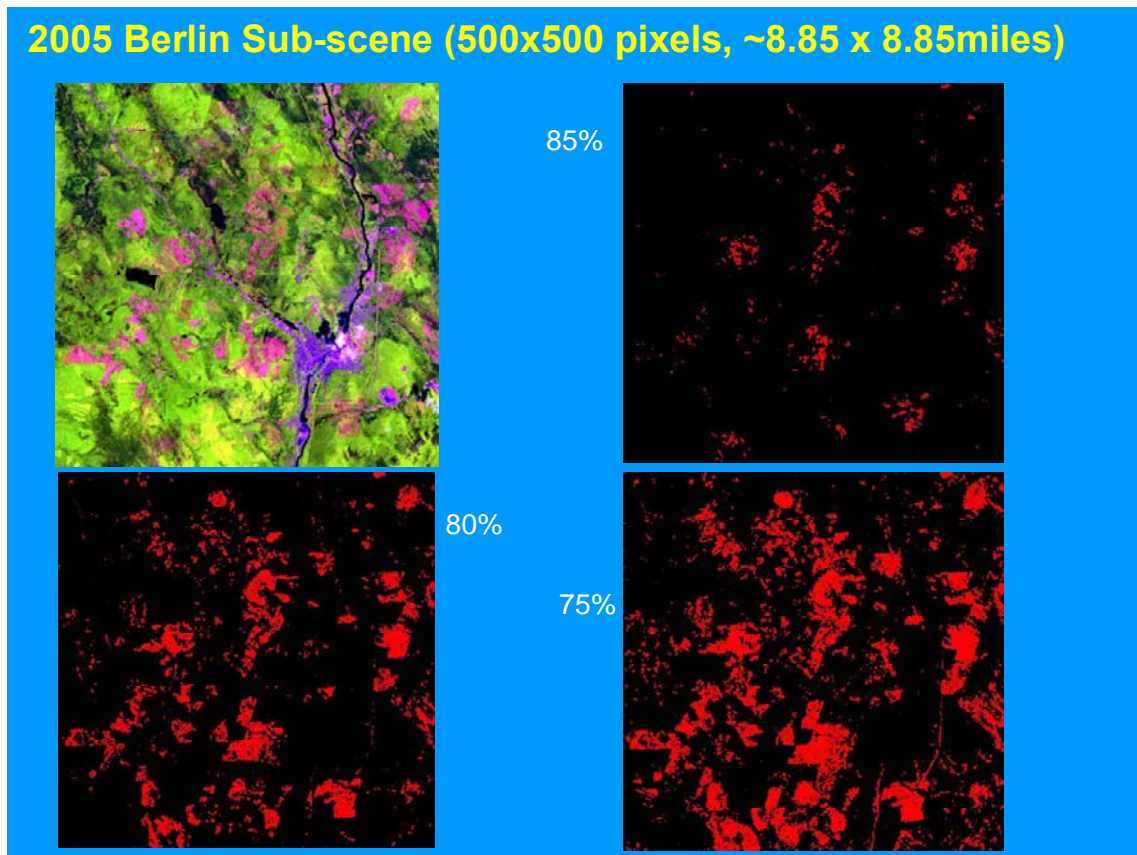


Figure 9: Classified pixels (red) for three different probability thresholds.

For each year (1996, 1999, 2002, and 2005) a classified image was provided to SPNHF. This was a binary image showing areas of operated pixels (white in Figure 10) and unoperated pixels (black in Figure 10).

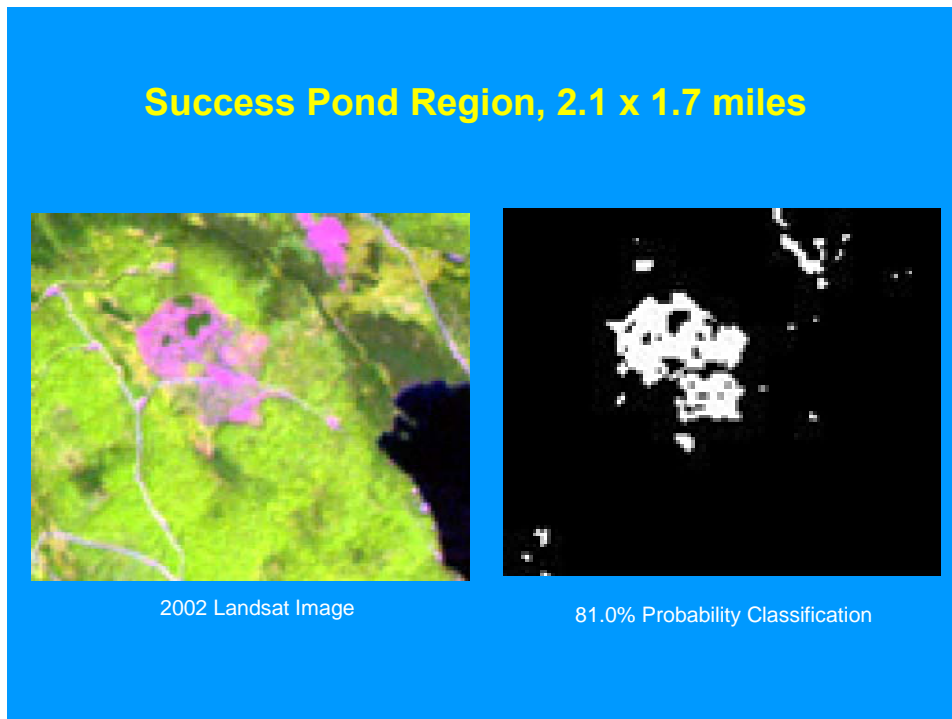


Figure 10: Operated pixels (white at right) for the Success Pond Region.

Colleagues at SPNHF used these classified images to extract statistics for acreage operated by township and by year. These subsequent GIS calculations and operations were conducted at SPNHF

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Part 2: Study Area Expansion & Analysis of Spectral Signatures of Varying Levels of Timber Harvest

Acknowledgments

This work is a continuation of the work accomplished in a Preliminary Study in the time period May 2005 to July 2006. A report on The Preliminary Study was provided to SPNHF (Birnie, 2006).

For the work reported on herein, the author acknowledges the help and advice of his excellent colleagues at Dartmouth, in particular Heather Carlos. The author also acknowledges the close collaboration and vital assistance of his colleagues at the Society for Protection of New Hampshire Forests (SPNHF). These colleagues include Adam Bronstein and Dan Sundquist. They provided extensive help in reviewing the classifications and arranging for the field verification study. In particular, Adam Bronstein provided extensive vector processing support and valuable advice for the image processing part of the project. Most of the data processing in this study was done using ENVI 4.3 and ArcMap 9.2

Study Area Delineation

The work reported on herein has three foci:

1. The Preliminary Study has been expanded to include data from 1988.
2. The Preliminary Study has been expanded to include all 41 towns in the study area (Figure 1).
3. This study will analyze the spectral signatures of light, moderate, and heavy cut areas.

Preliminary Study

Colleagues at SPNHF identified an area of 41 towns and unincorporated townships in northern New Hampshire on which to focus the study. In the Preliminary Study, five scenes were analyzed:

- June 16, 1992 (Thematic Mapper)
- August 30, 1996 (Thematic Mapper)
- August 31, 1999 (Enhanced Thematic Mapper)
- September 8, 2002 (Thematic Mapper)
- June 20, 2005 (Thematic Mapper).

However, since cloud-free Landsat satellite data were not available for all towns on these dates, this pilot study was limited to 28 towns that were largely cloud free during the time period. The Full Study Area includes 28 towns in the Preliminary Study (green) and the 13 towns added to the present study (red). (see Figure 1 in Part 1).

Results Part 2: All 41 Towns

The Preliminary Study attempted to minimize the time between years studied; and to this end, data from 1992, 1996, 1999, 2002, and 2005 were analyzed. However, due to significant cloud cover in the August 30, 1996, September 8, 2002, and June 20, 2005, data, the Preliminary Study was limited to only 28 towns which were largely cloud free in all of the years that were analyzed. Critical areas, the town of Pittsburg for example, were omitted due to cloud cover. In order to expand the study to all 41 towns, the time between scenes will be increased. Data for the following years were summarized:

1988 – starting point, “time zero”
1992
1999
2005

1988 to 1992 Data

The Preliminary Study employed initial forest cover data produced by the Spatial Analysis Laboratory of the University of Vermont as part of the U.S. Fish and Wildlife Service (USFWS) Gap Analysis Project (www.uvm.edu/envnr/sal/lc.html). These data were produced using multiple scenes of Landsat 5 data during the spring, summer, and fall of 1992 and 1993. The overall accuracy of the aggregated seven class Land Cover map for Vermont and New Hampshire was 80% (www.uvm.edu/envnr/sal/lc.html). Forest Classes 11, 12, and 13 (coniferous dominant, deciduous dominant, and mixed respectively) were used to represent the forested pixels at the initial time (1992) of the Preliminary Study. Recent clear cuts were lumped with agricultural lands, old fields, and grasslands (Class 2 – non-forested upland) in the 1992 land cover classification, so it was not possible to extract clear cuts alone for the 1992 starting time..

To determine clear cut acreages in the 1988 to 1992 period, the New Hampshire Timber Clear Cut Inventory – 1995 (New Hampshire GRANIT, 1995) was used. This study is based on visual interpretation of Landsat Thematic Mapper (TM) and SPOT imagery and has an overall accuracy of 92% (New Hampshire GRANIT, 1995). This study defined clear cut as a minimum of 3 acres, residual basal area of $< 20 \text{ ft}^2/\text{acre}$, and harvested in the last 10-15 years.

The clear cut vector data were overlain on largely cloud-free Landsat TM data for September 9, 1988, and June 16, 1992. By visual interpretation, I was able to determine whether the clear cut polygons mapped in the New Hampshire Clear Cut Inventory – 1995 were cut, prior to 1988, between 1988 and 1992, or between 1992 and 1995. During the course of studying these images and the vector data, I identified a number of areas that I believed were cut in the 1988 – 1992 time period but had been missed in the New Hampshire GRANIT (1995) study. I created and added polygons representing these areas. Since, in other time periods, SPNHF is limiting operated areas to be four acres or larger, I removed all polygons less than four acres from the inventory (17 polygons from an original 1046 polygons, average size = 3.3 acres).

A new field, Cut_Hist, was added to the New Hampshire Clear Cut Inventory – 1995 and assigned one of four possible attributes to each of the 1029 polygons (total = 40,048 acres):

- 0 = a GRANIT 1995 polygon not seen as cut in the 1988 and 1992 satellite data, therefore cut 1992 - 1995 (23 polygons, total = 1,753 acres, average = 76.2 acres)
- 1 = a GRANIT 1995 polygon not seen as cut in 1988 and seen as cut in 1992, therefore cut 1988-1992 (419 polygons, total = 14,210 acres, average = 33.9 acres)
- 2 = a GRANIT 1995 polygon seen as cut in 1988 and 1992, therefore cut pre-1988 (518 polygons, total = 17,368 acres, average = 33.5 acres)
- 11 = not present in GRANIT 1995 data, but interpreted by me to have been cut 1988-1992 (68 polygons, total = 6,711 acres, average = 98.7 acres)
- 99 = a forest inclusion within a clear cut, attribute 0 in the GRANIT 1995 FieldCC (only one polygon, 6 acres)

In conclusion, 20,922 acres were cut between 1988 and 1992 (attributes 1 and 11) (487 polygons, average = 43.0 acres) and the average per year activity was 5,231 acres/yr.

The digital data described above are included in the “1995_GRANIT_Clear_Cut_for_SPNHF” directory:

41_Towns_ClearCut_GRANIT_1995_4_acre_min_NH83

1992-1999 Time Period:

For the 1992-1999 time period, the August 31, 1999 Landsat TM scene was used. This is the same scene used in the Preliminary Study, and the training sites were expanded into the new areas (Pittsburg etc, see Figure 1).

A total of 97 training polygons (16,027 pixels) were selected, and a maximum likelihood classification was performed. After discussion and inspection with staff at SPNHF, an 85 % maximum likelihood probability threshold was used. Classifications were then processed by clumping and majority filtering.

In conclusion, 52,029 acres were identified as cut in the 1999 image. These data were filtered at SPNHF as described below.

The digital data described above are included in the “1999_Tifs_for_SPNHF” directory:

85_MaxLike_class_clump_maj5x_Aug31'99.tif (binary classification image)

Aug31'99__fiveband.tif (raw Landsat data, TM Bands 3, 4, and 5, NDVI, and NDMI)

These classifications were then sent to SPNHF and filtered with secondary land cover mask and a further majority filters by Adam Bronstein. Following this processing, verification sites were selected by Adam Bronstein for field checking by Upland Forestry.

To best prepare our 1992 UVM GAP forest land base to minimize errors of commission, a set of land cover filters were used.

1999-2005 Time Period

The data for this time period were considered in two groups:

June 20, 2005 image data for the 28 towns analyzed in the Preliminary Study
(shown in green in Figure 1)

September 24, 2005 image data for the 13 towns that were clouded in the June 20,
2005 image (shown in red in Figure 1).

In the June 20, 2005 image (28 towns only), 65,010 acres were identified as cut. These data were processed at SPNHF in the Preliminary Study by Jennifer Alford-Teaster and they have been sent again to SPNHF for the secondary land cover mask and a further majority filters by Adam Bronstein.

The digital data described above are included in the “Jun20’05_Tifs_for_SPNHF” directory:

Jun20’05_28_towns_MaxLike80Maj.tif (binary classification
image)

Jun20’05_28_towns_fiveband.tif (raw Landsat data, TM Bands 3, 4, and
5, NDVI, and NDMI)

The September 24, 2005 was used for the 13 originally clouded towns (shown in red in Figure 1). Within this masked image, 34 new training polygons (10,318 pixels) were selected, and a maximum likelihood classification was performed. After discussion and inspection with Adam Bronstein at SPNHF, a 90 % maximum likelihood probability threshold was used. Classifications were then processed by clumping and majority filtering.

In the September 24, 2005 image (13 towns only), 33,721 acres were identified as cut. These data were filtered at SPNHF as described below.

The digital data described above are included in the “Sept24’05_Tifs_for_SPNHF” directory:

90_maxlike_class_clump_maj_Sep24’05.tif (binary classification
image)

clouded_mask_new_Sep24’05_fiveband.tif (raw Landsat data, TM Bands

3, 4, and 5, NDVI, and NDMI)

Both images were combined for results for 2005 for the full study area (41 towns) by merging the two scenes together.

Land Cover Filtering

In order to account for landscape features that might “trick” our software into classifying areas as clear cuts that actually are not, a filter was developed. For each time period, a land cover filter was burned into the maximum likelihood classification output in order to minimize errors of commission.

The following components make up the land cover filter:

- Wetlands (NWI palustrine emergent and palustrine scrub/shrub)
- Peatlands (WAP habitat feature)
- Alpine Communities (WAP habitat feature)
- Talus Slopes (WAP habitat feature)
- Cliff Communities (WAP habitat feature)
- Ski Areas (hand digitized)
- Utility Line Right of Ways (utility lines buffered according to size)

Post Processing

- 1.) To eliminate overlap and data relics, harvest data (for each time period) was erased with the previous series of harvest data. For example, 1992-1999 was erased with 2005 and 1988-1992 was erased with the 1992-1999 series.
- 2.) A four by four majority filter was run over each time series twice to smooth and clump the data.
- 3.) Image-derived raster datasets were then converted into vector format.
- 4.) Acreages of harvested polygons were calculated and all polygons with values less than five acres in size were discarded.

Results Part 3: Harvest Intensity Signatures

As a final step, the study analyzed the spectral signatures of the operated areas. In the Preliminary Study, cleared areas or “operated areas” were lumped together regardless of the method of harvest. Clear cuts and partial cuts were not distinguished, and all were tabulated by area as operated. In the new study, ground truth data collected by Upland Forestry in the fall of 2005 along with image interpreted sites chosen by Dan Sundquist and Adam Bronstein were used as ground truth for the following operational classes:

light = < 30% closure removal

moderate = 30 – 80% crown closure removal

heavy (clear cut) = > 80% crown closure removal

(See main body of report for discussion of success in identifying these three spectral signature.)

End Appendix A.

Appendix B follows next page.

Appendix B: Data Tables

Table 1 -- Forest Land Base Calculations

Municipality	Land Acres	Forest Land Base (Acres)	Percent of Land Base Forested	Operable Forest Base (Acres)	Percent of Land Base Operable	Percent of Forest Land Base Operable
Atkinson & Gilmanton	12,280	10,444	85%	9,726	79%	93%
Bath	24,140	17,431	72%	16,237	67%	93%
Berlin	39,264	33,475	85%	31,584	80%	94%
Bethlehem	57,976	48,220	83%	37,975	66%	79%
Cambridge	32,634	30,070	92%	29,297	90%	97%
Carroll	32,079	27,689	86%	24,555	77%	89%
Clarksville	38,597	35,688	92%	33,976	88%	95%
Colebrook	25,927	18,107	70%	17,654	68%	97%
Columbia	38,895	33,814	87%	28,281	73%	84%
Dalton	17,608	13,916	79%	13,391	76%	96%
Dixs Grant	12,816	12,325	96%	8,858	69%	72%
Dixville	31,346	29,056	93%	21,541	69%	74%
Dummer	30,703	27,283	89%	26,892	88%	99%
Easton	19,925	18,113	91%	15,730	79%	87%
Errol	38,680	33,878	88%	32,826	85%	97%
Erving's Location	2,402	2,214	92%	2,099	87%	95%
Franconia	42,031	30,182	72%	19,908	47%	66%
Gorham	20,375	17,869	88%	16,045	79%	90%
Jefferson	31,995	24,358	76%	21,966	69%	90%
Kilkenny	16,432	12,949	79%	7,279	44%	56%
Lancaster	31,986	23,081	72%	22,204	69%	96%
Landaff	18,136	16,288	90%	15,420	85%	95%
Lisbon	16,795	13,454	80%	12,809	76%	95%
Littleton	31,952	25,985	81%	24,926	78%	96%
Lyman	18,191	15,608	86%	15,001	82%	96%
Milan	40,765	34,047	84%	32,991	81%	97%
Millsfield	28,679	26,704	93%	24,030	84%	90%
Monroe	14,335	11,111	78%	10,117	71%	91%
Northumberland	22,854	16,270	71%	14,982	66%	92%
Odell	28,579	26,179	92%	21,204	74%	81%
Pittsburg	180,088	164,504	91%	158,213	88%	96%
Randolph	30,104	27,965	93%	23,419	78%	84%
Second College	26,470	25,341	96%	22,974	87%	91%
Shelburne	30,696	28,160	92%	20,445	67%	73%
Stark	37,636	34,040	90%	27,908	74%	82%
Stewartstown	29,607	24,972	84%	23,786	80%	95%
Stratford	50,744	44,602	88%	36,006	71%	81%
Success	36,160	31,950	88%	28,427	79%	89%
Sugar Hill	10,911	8,609	79%	8,197	75%	95%
Wentworth's Location	11,757	10,943	93%	9,858	84%	90%
Whitefield	21,897	15,813	72%	15,780	72%	100%
Total	1,284,446	1,102,707	86%	984,517	77%	89%

*Operable forest land was estimated by removing all land area with elevations > 2,700', steep slope areas >35%, and tax parcels <5 acres in size from the gross forest land base determined by GRANIT land cover data.

Table 2 – Operable Land Base Harvest Calculations

Municipality	Acres Predominately Cleared					Average Annual	Average Annual	Average Annual
	Pre-1988	1988-1992	1992-1999	1999-2005	Total All Periods	1988-1992	1992-1999	1999-2005
Atkinson & Gilmanton	96	64	313	369	842	16	45	62
Bath	87	36	755	414	1,292	9	108	69
Berlin	741	648	840	5,012	7,241	162	120	835
Bethlehem	714	409	1,428	1,542	4,093	102	204	257
Cambridge	127	299	1,351	2,692	4,469	75	193	449
Carroll	157	411	1,085	1,237	2,890	103	155	206
Clarksville	349	33	959	1,748	3,089	8	137	291
Colebrook	162	126	1,099	996	2,383	32	157	166
Columbia	565	69	926	1,550	3,110	17	132	258
Dalton	318	342	910	415	1,985	86	130	69
Dixs Grant	0	10	323	600	933	3	46	100
Dixville	0	256	781	977	2,014	64	112	163
Dummer	1	325	1,499	3,052	4,877	81	214	509
Easton	115	51	132	532	830	13	19	89
Errol	35	944	1,125	1,790	3,894	236	161	298
Erving's Location	33	221	0	82	336	55	0	14
Franconia	136	16	536	515	1,203	4	77	86
Gorham	10	3	591	861	1,465	1	84	144
Jefferson	202	246	836	1,253	2,537	62	119	209
Kilkenny	205	1	19	202	427	0	3	34
Lancaster	511	434	962	1,319	3,226	109	137	220
Landaff	156	0	406	325	887	0	58	54
Lisbon	90	0	269	683	1,042	0	38	114
Littleton	260	381	1,149	823	2,613	95	164	137
Lyman	82	227	578	808	1,695	57	83	135
Milan	569	537	924	3,510	5,540	134	132	585
Millsfield	61	698	887	2,693	4,339	175	127	449
Monroe	47	72	435	328	882	18	62	55
Northumberland	334	1,007	412	633	2,386	252	59	106
Odell	530	413	809	1,866	3,618	103	116	311
Pittsburg	2,970	589	7,954	5,939	17,452	147	1,136	990
Randolph	414	420	746	428	2,008	105	107	71
Second College	136	79	301	663	1,179	20	43	111
Shelburne	147	19	240	186	592	5	34	31
Stark	301	264	397	251	1,213	66	57	42
Stewartstown	577	258	1,198	1,125	3,158	64	171	188
Stratford	800	494	1,716	1,234	4,244	124	245	206
Success	146	461	1,261	4,866	6,734	115	180	811
Sugar Hill	3	0	167	236	406	0	24	39
Wentworth's Location	112	0	126	495	733	0	18	83
Whitefield	622	332	1,604	715	3,273	83	229	119
Total	12,921	11,195	38,049	54,965	117,130	2,799	5,436	9,161

Table 3 – Percent Operable Land Base Harvested

Municipality	Operable Forest Base (Acres)	Acres Predominately Cleared				Percent Operable Forest Removed			
		Pre-1988	1988-1992	1992-1999	1999-2005	Pre-1988	1988-1992	1992-1999	1999-2005
Atkinson & Gilmanton	9,726	96	64	313	369	1.0%	0.7%	3.2%	3.8%
Bath	16,237	87	36	755	414	0.5%	0.2%	4.6%	2.5%
Berlin	31,584	741	648	840	5,012	2.3%	2.1%	2.7%	15.9%
Bethlehem	37,975	714	409	1,428	1,542	1.9%	1.1%	3.8%	4.1%
Cambridge	29,297	127	299	1,351	2,692	0.4%	1.0%	4.6%	9.2%
Carroll	24,555	157	411	1,085	1,237	0.6%	1.7%	4.4%	5.0%
Clarksville	33,976	349	33	959	1,748	1.0%	0.1%	2.8%	5.1%
Colebrook	17,654	162	126	1,099	996	0.9%	0.7%	6.2%	5.6%
Columbia	28,281	565	69	926	1,550	2.0%	0.2%	3.3%	5.5%
Dalton	13,391	318	342	910	415	2.4%	2.6%	6.8%	3.1%
Dixs Grant	8,858	0	10	323	600	0.0%	0.1%	3.6%	6.8%
Dixville	21,541	0	256	781	977	0.0%	1.2%	3.6%	4.5%
Dummer	26,892	1	325	1,499	3,052	0.0%	1.2%	5.6%	11.3%
Easton	15,730	115	51	132	532	0.7%	0.3%	0.8%	3.4%
Errol	32,826	35	944	1,125	1,790	0.1%	2.9%	3.4%	5.5%
Erving's Location	2,099	33	221	0	82	1.6%	10.5%	0.0%	3.9%
Franconia	19,908	136	16	536	515	0.7%	0.1%	2.7%	2.6%
Gorham	16,045	10	3	591	861	0.1%	0.0%	3.7%	5.4%
Jefferson	21,966	202	246	836	1,253	0.9%	1.1%	3.8%	5.7%
Kilkenny	7,279	205	1	19	202	2.8%	0.0%	0.3%	2.8%
Lancaster	22,204	511	434	962	1,319	2.3%	2.0%	4.3%	5.9%
Landaff	15,420	156	0	406	325	1.0%	0.0%	2.6%	2.1%
Lisbon	12,809	90	0	269	683	0.7%	0.0%	2.1%	5.3%
Littleton	24,926	260	381	1,149	823	1.0%	1.5%	4.6%	3.3%
Lyman	15,001	82	227	578	808	0.5%	1.5%	3.9%	5.4%
Milan	32,991	569	537	924	3,510	1.7%	1.6%	2.8%	10.6%
Millsfield	24,030	61	698	887	2,693	0.3%	2.9%	3.7%	11.2%
Monroe	10,117	47	72	435	328	0.5%	0.7%	4.3%	3.2%
Northumberland	14,982	334	1,007	412	633	2.2%	6.7%	2.7%	4.2%
Odell	21,204	530	413	809	1,866	2.5%	1.9%	3.8%	8.8%
Pittsburg	158,213	2,970	589	7,954	5,939	1.9%	0.4%	5.0%	3.8%
Randolph	23,419	414	420	746	428	1.8%	1.8%	3.2%	1.8%
Second College	22,974	136	79	301	663	0.6%	0.3%	1.3%	2.9%
Shelburne	20,445	147	19	240	186	0.7%	0.1%	1.2%	0.9%
Stark	27,908	301	264	397	251	1.1%	0.9%	1.4%	0.9%
Stewartstown	23,786	577	258	1,198	1,125	2.4%	1.1%	5.0%	4.7%
Stratford	36,006	800	494	1,716	1,234	2.2%	1.4%	4.8%	3.4%
Success	28,427	146	461	1,261	4,866	0.5%	1.6%	4.4%	17.1%
Sugar Hill	8,197	3	0	167	236	0.0%	0.0%	2.0%	2.9%
Wentworth's Location	9,858	112	0	126	495	1.1%	0.0%	1.3%	5.0%
Whitefield	15,780	622	332	1,604	715	3.9%	2.1%	10.2%	4.5%
Total	984,517	12,921	11,195	38,049	54,965	1.3%	1.1%	3.9%	5.6%

*Operable forest land was estimated by removing all land area with elevations > 2,700', steep slope areas >35%, and tax parcels <5 acres in size from the gross forest land base determined by GRANIT land cover data.

Table 4a – Acres Major Forest Cover Types

Municipality	Forest Land Base (Acres)	Acres Softwood	Percent Softwood	Acres Hardwood	Percent Hardwood	Acres Mixed	Percent Mixed
Atkinson & Gilmanton	10,444	1,111	10.6%	6,888	65.9%	2,865	27.4%
Bath	17,431	4,843	27.8%	8,249	47.3%	3,841	22.0%
Berlin	33,475	6,516	19.5%	19,794	59.1%	6,666	19.9%
Bethlehem	48,220	13,055	27.1%	24,777	51.4%	12,498	25.9%
Cambridge	30,070	6,153	20.5%	16,055	53.4%	5,222	17.4%
Carroll	27,689	5,125	18.5%	16,107	58.2%	5,799	20.9%
Clarksville	35,688	4,206	11.8%	22,145	62.1%	8,184	22.9%
Colebrook	18,107	6,532	36.1%	4,728	26.1%	4,846	26.8%
Columbia	33,814	6,117	18.1%	17,492	51.7%	9,323	27.6%
Dalton	13,916	3,832	27.5%	7,234	52.0%	2,656	19.1%
Dixs Grant	12,325	1,781	14.4%	5,806	47.1%	4,143	33.6%
Dixville	29,056	4,805	16.5%	16,016	55.1%	8,225	28.3%
Dummer	27,283	5,572	20.4%	13,396	49.1%	4,757	17.4%
Easton	18,113	4,390	24.2%	9,985	55.1%	4,049	22.4%
Errol	33,878	8,493	25.1%	14,881	43.9%	7,416	21.9%
Erving's Location	2,214	161	7.3%	1,250	56.5%	897	40.5%
Franconia	30,182	10,467	34.7%	14,824	49.1%	11,076	36.7%
Gorham	17,869	1,759	9.8%	13,505	75.6%	2,170	12.1%
Jefferson	24,358	5,178	21.3%	13,403	55.0%	5,078	20.8%
Kilkenny	12,949	3,491	27.0%	8,456	65.3%	4,381	33.8%
Lancaster	23,081	7,163	31.0%	9,629	41.7%	4,477	19.4%
Landaff	16,288	3,098	19.0%	8,607	52.8%	3,884	23.8%
Lisbon	13,454	4,188	31.1%	6,324	47.0%	2,859	21.3%
Littleton	25,985	5,759	22.2%	12,895	49.6%	5,981	23.0%
Lyman	15,608	3,317	21.2%	8,500	54.5%	3,194	20.5%
Milan	34,047	10,994	32.3%	14,672	43.1%	7,345	21.6%
Millsfield	26,704	3,727	14.0%	17,277	64.7%	4,978	18.6%
Monroe	11,111	3,300	29.7%	5,180	46.6%	2,263	20.4%
Northumberland	16,270	2,275	14.0%	10,604	65.2%	3,089	19.0%
Odell	26,179	6,655	25.4%	12,109	46.3%	8,219	31.4%
Pittsburg	164,504	29,391	17.9%	74,950	45.6%	57,231	34.8%
Randolph	27,965	3,053	10.9%	19,247	68.8%	5,418	19.4%
Second College	25,341	5,553	21.9%	11,811	46.6%	6,867	27.1%
Shelburne	28,160	6,808	24.2%	16,358	58.1%	5,005	17.8%
Stark	34,040	6,322	18.6%	20,084	59.0%	7,498	22.0%
Stewartstown	24,972	6,523	26.1%	10,362	41.5%	6,887	27.6%
Stratford	44,602	7,171	16.1%	26,107	58.5%	11,033	24.7%
Success	31,950	11,198	35.0%	13,560	42.4%	6,880	21.5%
Sugar Hill	8,609	1,177	13.7%	5,212	60.5%	1,833	21.3%
Wentworths Location	10,943	2,653	24.2%	4,906	44.8%	3,173	29.0%
Whitefield	15,813	5,201	32.9%	4,848	30.7%	3,393	21.5%
Total	1,102,707	239,110	21.7%	568,234	51.5%	275,602	25.0%

Table 4b – Acres Harvested by Forest Cover Type

Municipality	Softwood				Hardwood				Mixed Matrix			
	Acres cut pre-1988	Acres cut 1988-1992	Acres cut 1992-1999	Acres cut 1999-2005	Acres cut pre-1988	Acres cut 1988-1992	Acres cut 1992-1999	Acres cut 1999-2005	Acres cut Pre 1988	Acres cut 1988-1992	Acres cut 1992-1999	Acres cut 1999-2005
Atkinson & Gilmanton	9	4	51	4	139	77	78	235	56	17	99	39
Bath	2	2	181	139	106	41	102	182	0	0	73	109
Berlin	9	31	233	1,504	723	598	139	2,407	44	93	90	943
Bethlehem	24	8	499	341	812	684	204	747	37	57	212	207
Cambridge	40	41	372	692	100	233	234	1,254	59	160	144	434
Carroll	1	14	222	302	182	576	102	520	2	133	53	84
Clarksville	31	12	262	287	236	174	181	981	129	60	252	673
Colebrook	22	9	258	416	112	94	99	230	30	68	149	198
Columbia	13	21	177	32	559	133	233	637	109	130	161	561
Dalton	4	29	171	185	394	438	386	123	11	99	60	49
Dixs Grant	0	10	170	174	0	10	84	232	0	8	293	246
Dixville	0	83	161	140	0	177	61	437	0	277	215	480
Dummer	1	42	182	405	0	234	217	2,021	0	85	62	437
Easton	1	0	61	60	117	74	17	262	3	0	18	233
Errol	7	85	305	542	46	697	152	712	52	395	138	370
Erving's Location	0	52	0	14	30	77	0	26	2	168	0	43
Franconia	1	7	203	98	146	41	82	260	7	3	123	101
Gorham	0	0	97	134	10	3	254	609	0	0	52	112
Jefferson	27	11	217	251	156	325	119	626	14	61	86	234
Kilkenny	0	0	98	7	226	1	56	644	2	0	140	64
Lancaster	38	76	322	687	479	472	94	195	35	218	92	184
Landaff	0	0	78	73	169	0	53	108	7	0	83	97
Lisbon	0	0	138	260	89	0	29	281	2	0	37	142
Littleton	2	49	316	263	259	465	278	273	17	26	205	201
Lyman	6	1	95	174	70	243	144	369	6	13	76	218
Milan	67	90	371	1,263	537	708	100	1,438	103	262	118	686
Millsfield	17	97	122	330	48	539	182	1,980	24	490	111	318
Monroe	1	0	83	155	79	84	91	87	1	0	37	81
Northumberland	8	27	64	201	416	1,380	130	328	6	141	56	61
Odell	15	13	162	533	527	232	98	811	113	160	179	565
Pittsburg	312	135	2,518	690	1,824	574	1,853	2,728	1,225	526	3,178	1,927
Randolph	2	9	97	66	444	342	234	164	10	89	165	183
Second College	44	25	58	184	60	15	82	241	39	64	91	249
Shelburne	6	5	20	38	143	16	104	137	20	3	19	35
Stark	1	8	84	20	322	300	74	226	5	58	104	43
Stewartstown	45	2	275	443	573	276	219	332	92	46	279	252
Stratford	22	16	364	265	765	731	255	695	140	136	485	347
Success	29	117	534	1,608	114	332	157	1,910	38	232	153	994
Sugar Hill	0	0	41	36	3	0	30	118	0	0	23	47
Wentworth's Location	15	0	29	60	67	0	26	328	30	0	24	132
Whitefield	26	83	386	265	822	236	108	107	59	72	78	110
Total	848	1,214	10,077	13,341	11,904	11,632	7,141	26,001	2,529	4,350	8,013	12,489

Table 5a – Acres Important Forest Soil Groups by Municipality

Municipality	Land Acres	Acres 1A Soils	Percent 1A Soils	Acres 1B Soils	Percent 1B Soils	Acres 1C Soils	Percent 1C Soils
Atkinson & Gilmanton	12,280	6,627	54.0%	1,056	8.6%	564	4.6%
Bath	24,140	8,207	34.0%	2,917	12.1%	1,986	8.2%
Berlin	39,264	9,998	25.5%	5,349	13.6%	576	1.5%
Bethlehem	57,976	16,292	28.1%	3,073	5.3%	1,015	1.7%
Cambridge	32,634	14,014	42.9%	6,331	19.4%	1,665	5.1%
Carroll	32,079	5,839	18.2%	1,920	6.0%	1,662	5.2%
Clarksville	38,597	20,219	52.4%	6,213	16.1%	213	0.6%
Colebrook	25,927	10,157	39.2%	6,392	24.7%	1,137	4.4%
Columbia	38,895	16,284	41.9%	6,497	16.7%	709	1.8%
Dalton	17,608	7,478	42.5%	1,750	9.9%	432	2.5%
Dixs Grant	12,816	3,598	28.1%	3,101	24.2%	43	0.3%
Dixville	31,346	4,854	15.5%	5,945	19.0%	135	0.4%
Dummer	30,703	19,726	64.2%	2,266	7.4%	389	1.3%
Easton	19,925	1,902	9.5%	969	4.9%	952	4.8%
Errol	38,680	17,088	44.2%	5,633	14.6%	1,164	3.0%
Erving's Location	2,402	1,007	41.9%	491	20.4%	0	0.0%
Franconia	42,031	5,641	13.4%	1,252	3.0%	1,971	4.7%
Gorham	20,375	5,748	28.2%	4,333	21.3%	676	3.3%
Jefferson	31,995	12,025	37.6%	2,837	8.9%	729	2.3%
Kilkenny	16,432	11	0.1%	21	0.1%	0	0.0%
Lancaster	31,986	9,853	30.8%	510	1.6%	777	2.4%
Landaff	18,136	6,785	37.4%	2,167	12.0%	400	2.2%
Lisbon	16,795	5,986	35.6%	1,979	11.8%	1,681	10.0%
Littleton	31,952	16,907	52.9%	1,296	4.1%	957	3.0%
Lyman	18,191	6,375	35.0%	5,167	28.4%	331	1.8%
Milan	40,765	16,597	40.7%	1,765	4.3%	1,519	3.7%
Millsfield	28,679	16,720	58.3%	2,356	8.2%	227	0.8%
Monroe	14,335	4,251	29.7%	3,103	21.6%	1,056	7.4%
Northumberland	22,854	6,731	29.5%	1,645	7.2%	889	3.9%
Odell	28,579	11,795	41.3%	4,173	14.6%	1	0.0%
Pittsburg	180,088	89,873	49.9%	21,641	12.0%	1,840	1.0%
Randolph	30,104	8,256	27.4%	6,424	21.3%	176	0.6%
Second College	26,470	8,687	32.8%	4,675	17.7%	305	1.2%
Shelburne	30,696	2,245	7.3%	7,071	23.0%	1,811	5.9%
Stark	37,636	6,780	18.0%	3,429	9.1%	963	2.6%
Stewartstown	29,607	8,593	29.0%	10,483	35.4%	494	1.7%
Stratford	50,744	16,471	32.5%	8,134	16.0%	1,386	2.7%
Success	36,160	15,355	42.5%	5,732	15.9%	895	2.5%
Sugar Hill	10,911	6,629	60.8%	1,811	16.6%	195	1.8%
Wentworths Location	11,757	4,023	34.2%	2,832	24.1%	109	0.9%
Whitefield	21,897	6,732	30.7%	2,067	9.4%	515	2.4%
Total	1,284,446	462,357	36.0%	166,806	13.0%	32,544	2.5%

Note: Totals do not add to 100% because not all forest soils groups are presented in this table.

Table 5b – Acres Harvested by Soil Group

Municipality	Acres Harvested on 1A Soils					Acres Harvested on 1B Soils					Acres Harvested on 1C Soils				
	Pre-1988	1988-1992	1992-1999	1999-2005	Total	Pre-1988	1988-1992	1992-1999	1999-2005	Total	Pre-1988	1988-1992	1992-1999	1999-2005	Total
Atkinson & Gilmanton	39	89	213	327	668	12		2	8	23	21	0	11	13	45
Bath	34	38	262	76	410	28	0	100	71	199		2	7	29	37
Berlin	155	94	244	2339	2,832	21		308	1,009	1,339			7	36	43
Bethlehem	115	286	777	894	2,072	48	24	204	119	395	0		22	6	28
Cambridge	49	210	534	958	1,751	36	104	346	563	1,049	22	11	99	129	260
Carroll	26	150	270	555	1,001		10	304	184	498		0	64	80	144
Clarksville	200	208	479	920	1,807	22	10	237	394	663			8	0	8
Colebrook	70	122	387	353	932	67	14	293	289	664		0	11	13	24
Columbia	314	106	463	612	1,495	92	13	144	366	614	1	0	1	8	10
Dalton	140	302	401	143	986	4	71	286	34	395	0	4	9	22	35
Dixs Grant	0	37	27	250	314		4	125	196	326				0	0
Dixville		141	94	157	392		8	199	270	476		0			0
Dummer	1	552	999	2,170	3,722		4	33	341	378		1		2	3
Easton	1		43	69	113	0		3	0	3	0		1	9	10
Errol	41	649	495	943	2,128	3	165	165	305	638	4	1	26	93	123
Erving's Location	16	111		13	140	20	25		25	70					0
Franconia			129	308	437			61	17	78	11		91	19	122
Gorham			347	202	549	10	3	66	376	455			0	29	29
Jefferson	77	241	260	821	1,399	5	16	107	77	205	1	2	4	10	17
Kilkenny					0					0					0
Lancaster	133	488	270	410	1,301		17	2	20	39	40	7	25	71	143
Landaff	2		79	81	162	11		15	27	53			94	24	118
Lisbon	81		145	179	405	1		10	108	120			21	12	33
Littleton	243	180	617	465	1,505	11	6	44	30	90			9	10	19
Lyman	60	7	291	257	615	22	141	114	330	606			1	10	11
Milan	310	722	381	1,636	3,049	21	23	44	215	304	6		42	31	80
Millsfield	76	585	501	1,857	3,019		97	21	142	260	3	0	1	5	9
Monroe	56		229	67	352		63	14	132	208	6				6
Northumberland	95	569	111	308	1,083		47	43		90		7	6	2	14
Odell	315	274	571	1,031	2,191	152	96	29	192	468					0
Pittsburg	1,892	435	3,206	3,134	8,667	265	11	576	913	1,766	36		29	62	127
Randolph	19	26	409	24	478	88	140	218	316	763			9		9
Second College	40	95	132	185	451	7	1	27	70	106		0		9	10
Shelburne			48		48		3	150	55	207		0	5	32	37
Stark	69	229	141	68	507		19	50	63	132	4	3	8	2	17
Stewartstown	117	11	362	430	920	352	209	405	426	1,392	2		3	3	8
Stratford	411	329	692	528	1,960	251	108	102	231	692	20	25	45	41	131
Success	107	556	684	2,895	4,242	24	8	168	968	1,168	11	4	8	91	115
Sugar Hill			127	148	275	3		2	42	47				4	4
Wentworths Location	83		53	261	397			7	166	173				1	1
Whitefield	310	60	395	233	998	53	39	202	56	350	0		25	2	28
Total	5,697	7,902	15,868	26,307	55,773	1,631	1,498	5,225	9,146	17,501	168	68	680	897	1,859