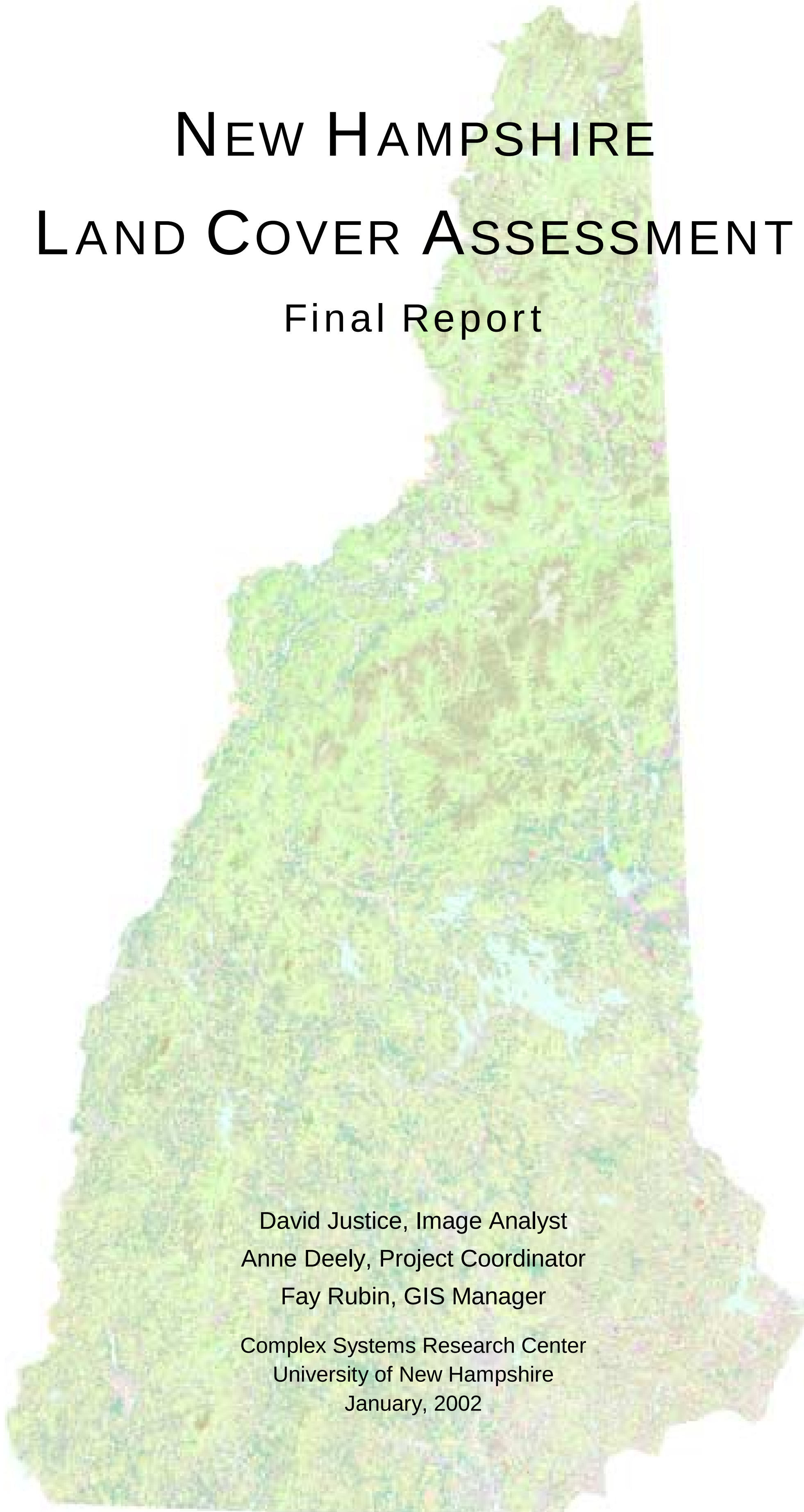

# NEW HAMPSHIRE LAND COVER ASSESSMENT

## Final Report


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## EXECUTIVE SUMMARY

Many organizations within the state and the region routinely need access to current and accurate information about New Hampshire's vegetative and physical features. In response to this need, the NH GRANIT staff at the Complex Systems Research Center, University of New Hampshire, conducted the New Hampshire Land Cover Assessment. The primary objective of the project was to generate a digital, statewide, 23-class land cover data set, developed from Landsat Thematic Mapper (TM) satellite imagery acquired over the period 1990-1999. Landsat 5 and 7 TM data were processed using a combination of traditional supervised and unsupervised classification methods. Data enhancements were achieved by utilizing supplemental sources archived in the GRANIT database, including Digital Orthophotoquads (DOQs), Digital Raster Graphics (DRGs), USGS Digital Line Graphs (DLGs) covering hydrography, NH Department of Transportation road centerlines, Digital Elevation Models (DEMs), SPOT panchromatic (10 meter resolution) images, public/conservation lands, US Fish & Wildlife Service National Wetlands Inventory (NWI) maps, and watershed boundaries.

A diverse coalition of agencies and organizations enabled the development of the land cover assessment through their financial support, cooperative field work, and data sharing. Field work conducted by project collaborators, including forestry professionals from the NH Department of Resources and Economic Development/Division of Forests and Lands, NH Fish and Game, and the U.S. Forest Service, was of great assistance, both in maintaining objectivity and in making the greatest use of limited resources. These organizations as well as the USDA Natural Resources Conservation Service, the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), and the NH Space Grant Consortium provided the financial support necessary to undertake the effort. The UNH Cooperative Extension provided assistance by sharing land management plans and supporting volunteer activities.

The product of the mapping effort is a digital land cover data layer covering the state of New Hampshire. The accuracy assessment indicates an overall accuracy of the aggregate, 7-class data of 95.9%, and an accuracy of 82.2% at the full 23-class level. A supplemental product of the effort is a body of field data focused on the state's forested areas that provides a valuable data resource to a wide variety of users.

The land cover data set is available to resource managers, wildlife managers, foresters, educators, and the general public from the NH GRANIT website (www.granit.sr.unh.edu). It is also available on CD/ROM upon request.

**Keywords:** land cover, land use, land characterization, land resources, remote sensing, image processing.

## INTRODUCTION

New Hampshire is the fastest growing state in the Northeast - its population has doubled since 1950, and will have tripled by 2020 (Sundquist and Stevens 1999). This population growth necessarily results in new development, including homes, schools, roads, and businesses, and the associated conversion of other land cover types (like forest and farmlands) to residential, commercial and industrial land uses. Accurate and timely data are needed in order to inventory and monitor these changing land use/land cover patterns.

It is well documented that satellite imagery, and specifically Landsat Thematic Mapper (TM) imagery, delivers a useful tool for regional land cover characterizations (Vogelmann, et al., 2001, Zhu, et al., 2000). It provides a data source for mapping large areas at a relatively low cost, and with a level of detail sufficient for many natural resource planning and management applications. Because it is acquired on a standard, 16-day cycle, it also provides a means to maintain and update land cover characterizations on a regular basis.

A number of previous efforts have utilized satellite imagery to produce land cover data for the state of New Hampshire. A project by researchers at the University of New Hampshire, and funded by the Environmental Protection Agency, was successful in deriving statewide land cover based on 1988-90 data sources (Rubin et al., 1993). A regional effort at the University of Vermont generated a broad land cover assessment for both New Hampshire and Vermont using 1992-93 imagery (Capen, et al., 2000). And at the federal level, the National Land Cover Data Set (Vogelmann, et al., 2001) used 1994-95 image sources to develop classified land cover data in generalized categories. Each of these products delivers useful data for trend analysis, but none is adequate in terms of data currency and/or classification detail to deliver the necessary data to state and local resource managers.

The New Hampshire Land Cover Assessment was undertaken to produce a current, statewide, digital land cover data set from 30-meter resolution Landsat 5 and 7 TM images. The imagery was processed to derive a 23-class land cover classification. The classification scheme was developed in collaboration with our project partners, and generally coincides with the USGS Anderson Level III scheme while providing a particular emphasis on the forested and agricultural classes (Table 1).

## METHODS

Overview

Development of the statewide land cover data set progressed through a sequence of steps, from image acquisition and pre-processing through classification and accuracy assessment (Figure 1). The image classification phases included both traditional supervised and unsupervised techniques, which were supported by a body of training sites comprising newly-collected field data augmented by archived information. Data for the entire state were processed as a series of regional subsections corresponding to the geographic extents of the source images. Individual accuracy assessments were completed for each region, to assure satisfactory results at each processing stage. Finally, the regional classifications and accuracy assessments were compiled into a statewide data set.

Computer resources used throughout this project included the following hardware components: Silicon Graphics workstation platforms, a Dell Precision 420 workstation and a Dell Inspiron laptop computer. A number of software packages were utilized, including ERDAS Imagine, which was used for the bulk of the image processing tasks, and ESRI Arc/Info 7.x/8.x and ArcView 3.x, which were used for all phases of the geographic database management. For field navigation, we used Trimble PRO-XRS GPS receivers, each capable of receiving real time differential corrections (DGPS) via the U.S. Coast Guard beacon service and commercial satellite subscriptions. Trimble Pathfinder Office was used to complete global positioning tasks such as waypoint transfer and post-processing differential corrections (necessary when DGPS was not available).

Data Sources and Data Pre-processing

Twelve Landsat Thematic Mapper images, WRS path 12-13, row 29-30, spanning the years 1990-1999, were selected as the basis for the initial land cover classification (Table 2). The images were chosen to capture differing phenological conditions throughout the year. Each image was georeferenced to New Hampshire State Plane Coordinate feet (North American Datum of 1983, or NAD83) and terrain corrected. Georeferencing and terrain correction were performed either prior to the data purchase by the data vendors (USGS, EROS Data Center, or ImageLinks, Inc., Melbourne, FL) or post-purchase by UNH researchers. The images were then subset to comprise the geographic extent of three primary study areas, generally representing the southeast, southwest and northern areas of the state. Finally, the 6 reflective bands (1-5, and 7) from the most recent summer (leaf on) and spring (leaf off) image were “layer stacked,” or combined, into a single 12-band data set to be used in the initial, generalized classification for each region. The additional images were utilized in later processing stages.

Ancillary data comprised numerous holdings from the GRANIT archive, including panchromatic Digital Orthophotoquads (DOQs), Digital Raster Graphics (DRGs), USGS Digital Line Graphs (DLGs) covering hydrography, NH Department of Transportation road centerlines, Digital Elevation Models (DEMs), SPOT panchromatic (10 meter resolution) images, public/conservation lands, US Fish & Wildlife Service National Wetlands Inventory (NWI) maps, and watershed boundaries (Figure 2).

Topographic Stratification

Previous efforts have suggested that preliminary topographic stratification can improve the accuracy of the results by offering the opportunity to isolate specific landscape characteristics (Rubin et al., 1993). Accordingly, topographic processing was initiated in the coastal region of the state where the 12-band, “layer-stacked” image was subset into three topographic categories: southeast facing slope (slope greater than 10% and azimuth between 45 - 225 degrees, clockwise), northwest facing slope (slope greater than 10% and azimuth between 225 – 45 degrees, clockwise) and flat (slope less than 10%). Large scale (1:24,000) USGS DEMs were used to isolate these three categories. Based on the preliminary coastal classifications, it was determined that using three slope categories in the remainder of the state would yield no appreciable increase in classification accuracy while requiring a significant increase in processing time and effort. Therefore, in the southwest and north regions, only two slope categories were subset: slope greater than 10%, and flat (slope less than 10%). Each aspect/slope stratum was then classified separately. Figure 1 presents a generalized diagram of the iterative classification process as applied to each aspect/slope category in each region. However, minor variations to this process may have occurred based on individual circumstances.

Training Sites Selection/Verification

In order to conduct supervised classifications, we utilized a body of training site data to represent the various targeted land cover classes. Some of these training sites were archived as a result of previous projects. However, a substantial amount of new data - over 1400 points - were collected to fill both regional and class-specific gaps, particularly in the forested and agricultural classes.

The image analyst identified candidate sites from the imagery based on its inherent characteristics. Typically, this involved observing color patterns and trying to account for the biological and spectral variability in the data. Additional forested sites, including beech/oak and hemlock, were selected based on DRED forest stand type maps. In each case, the image analyst identified points and used the ERDAS Imagine RegionGrow tool to select groups of spectrally similar pixels to form the training site. The resulting region in effect produced the representative signature used for the classifications. Generally, to be accepted as training sites, regions were required to contain 15 or more pixels, with a standard deviation across all image bands of 5 or less. Within the accepted pixel groupings, individual pixels were selected for subsequent verification.

In the case of the forested classes, 2-4 individual pixels were selected from each grouping for field sampling. The x-y coordinates of the pixel centroids were loaded into Trimble Pro-XRS GPS receivers (capable of real time differential correction, or DGPS, via Coast Guard beacon or satellite signal), which were then used to navigate to each training site point. In the rare case where DGPS was not available, the operator navigated to within 150 +/- feet of the point, collected position fixes, and corrected the position through standard post-processing. The corrected point was then visually evaluated to determine if it was located within the training site polygon and was either accepted or discarded based on this position.

Once at the forested site, a 10 basal area factor (BAF) prism was used to tally all overstory trees within the variable radius plot. As the project developed, additional data were collected at each site for the southwest and northern regions (Figure 3). Ultimately, the prism tally was summarized and averaged by training site polygon, and the appropriate forest class label was calculated for each polygon according to the classification rules (Table 1). Field data collection for both the training site phase and the subsequent accuracy assessment was performed by GRANIT staff, assisted by professional foresters from the Division of Forests & Lands and the Fish & Game Department. Additionally, a corps of volunteers assisted the professional staff in the collection of field data in the southwest region (Figure 4).

Because the agricultural sites tended to be more homogeneous than the forested, a single point was sufficient for the field effort to identify the cover type. Again, GPS was used to navigate to the x-y coordinate, and the land cover was recorded. Additional information was not collected at these sites.

Table 3 reports the total number of field verified training sites available to the project for each land cover category, and Figure 5 shows the distribution of training site locations. The clustered nature of the data in the southern regions is a result of our attempt to restrict our activities to properties open to public access in order to avoid landowner permission issues. While relieving access issues, this approach also offered a secondary benefit as many of these properties had existing forest stand type information associated with them. This information was useful for targeting training sites to represent particular forested classes. In the north region, we received cooperation from several of the larger landowners through a direct liaison in the New Hampshire Fish and Game Department, who accompanied us to these forested training sites.

Data for a significant number of the non-forest and non-agricultural sites were amassed from pre-existing sources, such as DOQ's, DRG's, NWI, archived training sites from previous projects, and local knowledge, and did not require field work. For example, most of the training sites for cleared areas, such as disturbed and sand dunes, were developed from these sources. The wetland training sites were largely developed from the archived points and NWI data.

## General Classification

A standardized procedure was utilized in each region of the state to produce a preliminary classification. First, a general classification was conducted by topographic stratum to group land cover types into five broad categories, including forested/coniferous, forested/deciduous, forested/mixed, agricultural/cleared, and wetlands/water. The processing began by applying archived training sites, primarily retrieved from past image classification projects, in order to create representative signatures. A supervised, maximum likelihood classification was then applied to the regional image, and the resulting classes were visually evaluated using DOQs, other ancillary data sets, and local knowledge. Acceptable classes were carried through to the final generalized data set, while unacceptable classes were retained for further processing (see Figure 1).

The unacceptable classes were subsequently used to mask various image band combinations and/or band transformations. (See Table 4a for a listing of bands/transformations used for each subset classification.) This step was followed by unsupervised classifications using the "isodata" cluster routine. At each iteration, the classes were evaluated as described above, and either archived for incorporation in the final product or retained for additional processing. As many as four supervised and unsupervised classification iterations using various image date/band derivatives were run on the resulting data subsets. Finally, each of the classifications was recoded to reflect the appropriate land cover value and mosaicked to generate the complete, region-wide generalized land cover data set.

Class-Specific Processing

With the generalized classification available, the analyst next addressed class-specific categories (e.g., wetland, forest, and agricultural types). Again, this was accomplished through a series of image subsets, masks and classification iterations to generate the final product. The additional images were introduced into the processing stream during this phase.

Each class-specific procedure was initiated by creating a "layer stack" of various image bands/band derivations, as reported in Table 4b. The bands were selected in part by applying the Imagine Signature Separability tool to the layer stack and using the Transformed Divergence measure as a basis for the selection. The tool reports metrics ranging from 0 - 2,000, with values equal to 2,000 reflecting signatures that are totally separable and values of 0 identifying signatures that are not separable. Once the appropriate bands were selected, the image composite was masked to retain pixels of interest (i.e., the forest specific classification retained forested classes from the generalized land cover). This was followed by an iterative process of classifications using a combination of techniques to derive the final data for that class.

The series of classifications typically began with a supervised classification, using both the archived training sites and the training sites collected for this project (Figure 5; Table 3). In the southeast, the three forested classes (conifer, deciduous, and mixed) from the generalized land cover were processed independently. However, since it was determined that there was no appreciable improvement in classification quality achieved by this separation, the three forested classes were processed together in the remaining regions.

As in the general classification, the class-specific scenario proceeded through a series of iterative classifications, with acceptable results saved for the final data layer and with unsatisfactory results used to mask subsequent data sets. For the forested classes, 2,794 training signatures were used to support the 14 iterations required to achieve an acceptable data layer. Note that some of these signatures were used redundantly; that is, the same training site was used to produce signatures for multiple images. For the cleared classes, 542 signatures were used while 12 classifications were run to develop an acceptable subset. And finally, 6 classifications and 126 signatures were implemented to complete the wetland data layer. (The wetland processing required many fewer training signatures due to our reliance on NWI data. We also utilized the Isodata routine more extensively for these classifications, which reduced the number of signatures necessary.)

Wetlands processing in the north region progressed in a slightly different manner than in the remainder of the state. After several classification attempts, it became clear that many forested wetlands, usually dominated by spruce/fir, were being confused with the upland spruce/fir class. While some classes from these processing iterations proved "usable" and thus were retained, many were not. Accordingly, we opted to use the NWI data as a mask to select the wetlands for class specific processing. All pixels coincident with the NWI data were classified into either the forested or open wetland classes. These were then added to "usable" wetland data set to create the entire wetland class for the north region.

Following each classification, either supervised or unsupervised, the image analyst evaluated each class to determine its "correctness." Classes that were deemed accurate carried through to the final classification and poor classes were omitted. The analyst relied on ancillary data, such as NWI, DOQ, and DRG sources, as well as local knowledge, to determine the apparent reliability of each class. Ultimately, each of the "accepted" classified data layers was mosaicked into a single data set.

Finally, several post-processing refinements were applied to the provisional land cover data in the ESRI GRID environment. These enhancements included ancillary data overlay and data filtering. First, paved roads from the NH Department of Transportation road data (resident in the GRANIT data base, 2001) were "burned in" to the provisional land cover data set, effectively overwriting any coincident class. Secondly, DLG hydrography data were used to update double banked river, lake and pond edges. In many cases, this corrected problems in areas that were incorrectly mapped as conifer forest.

The forested classes were also modified based on existing topographic data. Elevation data from USGS digital elevation models were used to recode forest classes based on the U.S. Forest Service's species elevation thresholds (Burns and Honkala 1990). Beech/oak above 2,500 feet and other hardwoods above 3,000 feet were recoded to paper birch/aspen; white/red pine above 1,500 feet and hemlock above 2,400 feet were recoded to spruce/fir; and any forested class above 4,200 feet was recoded to alpine (krumholz).

The fruit orchard class was also developed at this processing stage. Because past results indicated that spectral image classification of orchards was unlikely to yield acceptable results, orchard polygons were screen-digitized from DRG and DOQ images (where available), converted to the Arc/Info grid data structure and incorporated into the overall classification during post-processing.

Lastly, several filtering iterations were applied to the data set to remove speckling and produce minimum map units of one acre. In order to maintain the integrity of linear features, filtering was preceded by the RegionGroup command such that the majority filter would only operate on groups of pixels smaller than approximately 1 acre (5 pixels). This filter was next followed by a second RegionGroup and contiguous pixels fewer than 5 were finally Nibbled to remove those pixels that were not eliminated by the majority filter. This filtering processed the data set to its completed, final form.

Accuracy Assessment

A total of 975 sites were evaluated for the accuracy assessment. More than 600 of these sites were field visited, and others were evaluated using ancillary data such as NWI maps and DOQs. All sites classified as forest, and most classified as wetland, were field visited using Trimble Pro-XRS GPS units receiving real-time corrections. At forested sites, field crews recorded stand information and conducted up to five 10 BAF prism tallies to quantify stand composition. Figure 5 shows the geographic distribution of the assessment sites.

As with the classification itself, the accuracy assessment was conducted separately for each of the three geographic regions. In each region we attempted to sample 30 sites per land cover class, but this was not always achievable because of limited area covered by the class (such as with pitch pine), because of a post-data collection re-classification, or for other reasons. Conversely, some classes received higher than the targeted sampling levels, again because of the post-data collection re-classification. In order to limit distortion due to disparate sample sizes among classes, we randomly selected 20 sites from each class in each region to tabulate in the statewide error matrices. This yielded a total of 60 sites per class for the full error matrices (though some classes, particularly those like tundra that are regionally focused, still have fewer sample sites).

Error matrices were generated for the 23-class Level 3 classification, as well as the 17-class Level 2 and 7-class Level 1 aggregates. In each case, user's and producer's accuracies were calculated (Congalton and Green 1999). While these matrices provide valuable data, the traditional metrics alone did not appear to give potential users sufficient information on the magnitude and nature of errors. For example, a forested site containing a high percentage of beech and oak but tabulated to belong to the "mixed forest" class would be considered wrong in a traditional error matrix if classed as beech/oak. We felt it was important to identify broader ranges of "right" and "wrong" so that users could interpret the data most effectively. To address this, we created rules to assess the accuracy using fuzzy sets and the linguistic scale developed by Woodcock and Gopal (1992, 1994, 2000). The scale defines values ranging from 1 through 5 to indicate the extent to which an incorrect classification is "wrong", as follows:

(1) *Absolutely wrong*: This answer is absolutely unacceptable. Very wrong.
(2) *Understandable but wrong*: Not a good answer. There is something about the site that makes the answer understandable but there is clearly a better answer. This answer would pose a problem for users of the map. Not right.
(3) *Reasonable or acceptable answer*: May not be the best possible answer but it is acceptable; this answer does not pose a problem to the user if it is seen on the map. Right.
(4) *Good answer*: Would be happy to find this answer given on the map. Very right.
(5) *Absolutely right*: No doubt about the match. Perfect.

Woodcock's and Gopal's rating of (2) was interpreted here to describe incorrect classifications that were understandable from an image processing perspective, but that would still be problematic for users. For example, the spectral characteristics of hay/pasture may be very similar to disturbed areas, and therefore it may be understandable that they are sometimes confused in the classification, but these land uses are so different that this incorrect classification would be problematic to users of the data.

Table 5 contains the fuzzy set rules developed for this project. For forested sites, the rules for assigning a linguistic value to each sample site are quantitative, based on the proportions of basal area made up by different species. For non-forested sites, the rules are qualitative, based on how acceptable certain classifications may be at a given site. For example, for an open wetland, classification as open wetland would be absolutely right (5), classification as forested or tidal wetland would be a good answer (4), classification as open water would be understandable but wrong (2), and all other classifications would be absolutely wrong (1).

Each site was thus assigned a range of ratings based on the linguistic scale, and the rating that applied to the classification was identified. The accuracy of the map was then evaluated in terms of the how frequently the category assigned in the map was the best choice for the site (5), and how frequently the category assigned was acceptable (3-5) (Gopal and Woodcock 1994).

## RESULTS

The primary result of this project is a 23-class, statewide digital land cover data layer (Figures 6 and 7). The data, archived in the GRANIT database, are accompanied by Federal Geographic Data Committee (FGDC)-compliant metadata. In addition, the project generated a body of field work that may be used for future analyses, including several thousand accurately positioned forested points with attributes describing species composition, size classes, and stand structure.

Table 6 presents acreage by land cover class and county for the entire state. As expected, the majority of the state (77.6% of total area, or 81.1% of land area) was mapped in the forested classes (not including forested wetlands) (Figure 8a). Grafton (84.7%) and Coos (84.3%) counties were the most heavily forested in the state, while Rockingham (58.6%) and Strafford (66.2%) were the least forested.

Deciduous forest was the most prominent forest class, covering approximately 32.9% (42.5% of total forest land) of the state. The majority of deciduous forest was either beech/oak or other hardwoods (Figure 8b). Mixed forest was also prominent, representing 26.3% of the state and 33.9% of the forestland. Finally, coniferous forests accounted for 18.2% of the state (23.6% of the total forest land), mostly composed of the white/red pine and spruce/fir classes.

Developed land was another class of significance, occupying 4.4% of the state. Table 6 shows that the most developed counties are Hillsborough (10.8%) and Rockingham (9.4%), and that the least developed is Coos county (1.1%). Slightly less of the state (4.1%) was mapped as agriculture. Most agricultural land (91.1% of total agricultural land) is in hay/pasture, while only 6.5% is in row crops and 2.4% is in fruit orchards. Grafton, Hillsborough, and Merrimack counties included the highest total acreage of agricultural land, while the least amount was mapped in Carroll and Strafford counties.

The classification achieved an overall accuracy of 82.2% at the full, 23-class level. Table 7 summarizes the results of the accuracy assessment in an error matrix, and shows user's and producer's accuracy percentages for each class. User's accuracy, or the percentage of occurrences in which a given map label correctly described the reference site, ranges from lows of 28.6% for paper birch/aspen, 53.3% for beech/oak, and 62.5% for mixed forest, to highs of 100% for water, tidal wetland, bedrock/vegetated, sand dune, and tundra. Producer's accuracy, or the percentage of occurrences in which reference sites were assigned a correct map label, ranges from lows of 28.6% for paper birch/aspen, 39.7% for mixed forest, 53.2% for other hardwoods, to highs of 100% for transportation, pitch pine, alpine, water, tidal wetland, bedrock/vegetated, sand dune, and tundra.

When collapsed to the 17-class level, the classification achieved an 88.7% overall accuracy, as shown in Table 8. Here too, there are broad ranges among the user's and producer's accuracies. Deciduous forest, whose components other hardwoods and paper birch/aspen fared relatively poorly at the third level classification, achieved a 94.8% user's accuracy and a 90.7% producer's accuracy. Coniferous forest, whose component hemlock fared relatively poorly at the third level classification, achieved an 81.9% user's accuracy and a 97.3% producer's accuracy.

At the aggregate, 7-class level, the classification achieved 95.9% overall accuracy (Table 9). User's accuracy ranged from 91.3% for developed to 100% for water and tundra, and producer's accuracy ranged from 89.9% for barren to 100% for water and tundra. Though the 23- and 17-class accuracy assessments show that it was difficult to distinguish between certain forested classes, the classification was consistently accurate in distinguishing forest from non-forest, achieving 99.0% producer's and 97.5% user's accuracy for forest.

Results of the fuzzy set assessment are summarized in Table 10. The "Max" and "% Max" columns correspond directly to the major diagonal and user's accuracy in the traditional error matrix; that is, they represent the number of sites that were correctly labeled on the map, and the percentage of sites with a given map label that were correctly validated by the reference data. The next columns expand the definition of correct from "max" (absolutely right, or those sites that were given a rating of 5) to include labels that were considered "right" (good answers, or those labels that were given ratings of 4 or 5) and, even more broadly, to those that were considered "reasonable or acceptable answers" (those labels that were given ratings of 3, 4, or 5).

The overall accuracy of the full classification increases to 89.1% when the "good answers" are included as "right," and to 92.0% when "reasonable or acceptable answers" are included as well. Particular improvement is seen in the forested categories - the accuracy of other beech/oak increases from 53.3% to 56.7% to 76.7%, and hemlock increases from 65% to 73.3% to 83.3%. Open wetland also improves dramatically, from 75% to 93.3%. Paper birch/aspen remains the least accurate class, due at least in part to its relatively small sample size.

## DISCUSSION

The project successfully mapped the targeted land cover classes in New Hampshire. When used at an appropriate scale, users will have access to reliable data, with an overall accuracy approaching 96% for the general classification and exceeding 82% for the 23-category classification. This product represents the most comprehensive and current land cover classification available for the region, and provides researchers with a reliable and well-documented data resource.

The standard accuracy assessment demonstrates a high degree of success in discriminating between deciduous and conifer classes. This was anticipated from the outset, due to the significant differences in the spectral properties evidenced by these two aggregate classes. The accuracies decline as more detail is introduced into the classification and species-level mapping is attempted, and particularly in the hardwood classes. There are several reasons for this decline in accuracy. In part, the difficulty may have resulted from our inability to acquire source imagery representing optimal phenology necessary to distinguish among the deciduous classes. Although Landsat satellites acquire data on a 16-day cycle, potentially yielding more than 20 scenes a year for a given area, in actuality, cloud cover and other sub-optimal conditions eliminate many of these. In fact, only eight usable October images were archived between the years of 1990 and 1998, and five of these were used in this project. In addition, though we expected that October images would provide the greatest deciduous phenological variation, the acquisition cycle is not always able to capture the short autumnal senescence.

The spatial resolution of the imagery also contributes to the difficulty of accurately delineating forest species classes. Landsat images are composed of pixels that are 30 meters square, and therefore can delineate features 900 $m^2$ (0.2 acres) or larger. (In fact, we have found that five-pixel blocks (one acre) are the minimum acceptable mapping unit from Landsat imagery.) However, the New Hampshire landscape seldom contains homogenous areas that large. Instead, the landscape, especially forested areas, contains a heterogeneous mix of land cover types. While single pixel blocks may be covered by forest (and accurately depicted as such through image classification), each block tends to be composed of a mosaic of different forest species classes covering much smaller areas, which cannot be captured using Landsat data.

There are also problems inherent in the targeted classification scheme (see Table 1). For example, the class definitions specify that a stand must be 75% deciduous to be labeled deciduous or 65% coniferous to be labeled coniferous. Therefore, a stand comprising 55% beech/oak and 45% hemlock would be incorrectly labeled if it were labeled as either of those classes. Instead, the “correct” label for this stand is mixed forest. To some degree, these problems are at least partially addressed using the fuzzy accuracy assessment. For example, researchers looking for hemlock stands may be disappointed to discover that the user’s accuracy is only 65 %. If they are willing to accept forest stands with a minimum 50% hemlock basal area regardless of broad type (i.e., mixed forest), the class accuracy increases to 73.3%. Likewise, accepting a minimum hemlock basal area of 40% would yield a class accuracy of 83.3%. Not all classes make improvements of this magnitude with the fuzzy accuracy. Classes such as urban remain constant, while others, such as mixed forest, only marginally improve. However, we feel that the fuzzy set assessment provides a useful tool and that the relaxed requirements will be of interest to many data users.

The assessment of forested classes shows that the highest degree of success was achieved in mapping the white/red pine, spruce/fir and pitch pine classes. Each of these classes, and especially pitch pine, has a very distinctive spectral signature. Mapping paper birch/aspen was particularly problematic. Both user's and producer's accuracies for this class are poor, demonstrating both that areas mapped as paper birch/aspen were actually other cover types, and that areas mapped as other cover types were actually paper birch/aspen. Most of the errors of commission reveal confusion with other deciduous classes; that is, sites mapped as paper birch were in fact other deciduous classes. This is probably a result of the spectral similarity between these classes. Most of the errors of omission reveal confusion with mixed forest; that is, sites mapped as mixed forest were in fact paper birch/aspen. This probably reveals that inadequate training sites were used for mixed forest and paper birch.

Mapping hemlock was also somewhat problematic. While there were relatively few errors in which sites with other map labels were in fact hemlock, there were many sites labeled as hemlock which were in fact other classes - most frequently, mixed forest. Because the accuracy improves considerably when we expand the classification rules to accommodate the fuzzy assessment, we see that much of the error is derived from the classification "cut-offs" between coniferous forest and mixed forest. Similarly, mixed forest was often labeled as paper birch/aspen, white pine, or other forest types. Again, this seems to stem from the difficulty inherent in creating discrete labels for continuously varying land cover classes. We also had difficulty distinguishing between beech/oak and other hardwoods. Aggregating these classes improves the accuracy dramatically, demonstrating that these classes were most often confused only with each other.

While most of the error in the forested wetlands classes is a result of confusion with open wetlands, in some cases, forest labels were misapplied to forested wetland sites. However, all such cases occurred in the coastal region. The classifications of the other regions of the state, which are based upon more recent imagery, show higher accuracies in the wetland classes, suggesting that age of source imagery may be one cause of the error in the wetlands categories. Beaver activity can rapidly convert forests to forested wetlands, and forested wetlands to open wetlands. In addition, open and forested wetlands are simply endpoints along a continuum, and it may be difficult for field crews to make an accurate visual interpretation of the wetland type.

The agricultural classes showed a high level of accuracy (95% producer's accuracy and 95.8% user's accuracy) at the generalized classification level (Table 9). As can be seen from the fuzzy assessment, the errors that did occur in these classes were most frequently a result of confusion between row crops and hay/pasture. Data sources quickly become outdated due to the dynamic nature of farming activities, and may have caused some of this confusion. Practices like crop rotation make it difficult to accurately classify agriculture sub-classes. However, some agricultural sub-classes – including orchards – are less variable. As we expected, the orchard mapping was quite accurate because of our use of DRGs in conjunction with DOQs (where available). Past experience has shown that this class would have been extremely difficult to map reliably based on spectral properties alone, as orchards commonly are classified as hay/pasture or other cleared.

Although we were generally satisfied with the overall accuracy of this product, some of the specific forested classes were troubling. It is our intention to revisit the data sources in an attempt to improve the accuracy of both the paper birch/aspen and mixed forested classes. It is possible that a re-evaluation of the band combinations used in the classification of these categories may make it possible to improve their respective accuracies.

Also, we intend to continue our investigation into using radar imagery to predict relative forest densities. While the current classification maps broad forest types, little is known about the density of a given type (in this case expressed as basal area per acre). We will try to determine whether or not space borne radar imagery can assist in the mapping of forest densities in New Hampshire. It should be noted that the most appropriate radar data for this endeavor is at present not widely available, as the data we will use was acquired via the NASA Space Shuttle. However, with the launch of the NASDA ALOS satellite in 2003, L-band polarimetric radar data will become more commonly available. The results of this work will be discussed in an addendum to this report.

## CONCLUSION

The New Hampshire Land Cover Assessment produced an accurate, statewide land cover data layer that provides resource managers, planners, researchers, and the general public with a creditable overview of New Hampshire's landscape. The land cover data set is available in ASCII grid format from the NH GRANIT website (www.granit.sr.unh.edu). It is also available on CD/ROM upon request. The data are accompanied by FGDC-compliant metadata, providing users with full documentation on the derivation of the data set, its technical characteristics, and recommendations on its appropriate use.

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International Paper
Dartmouth College
Andorra Forest
Many other private landowners

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Figure 1.  Data Production Process.

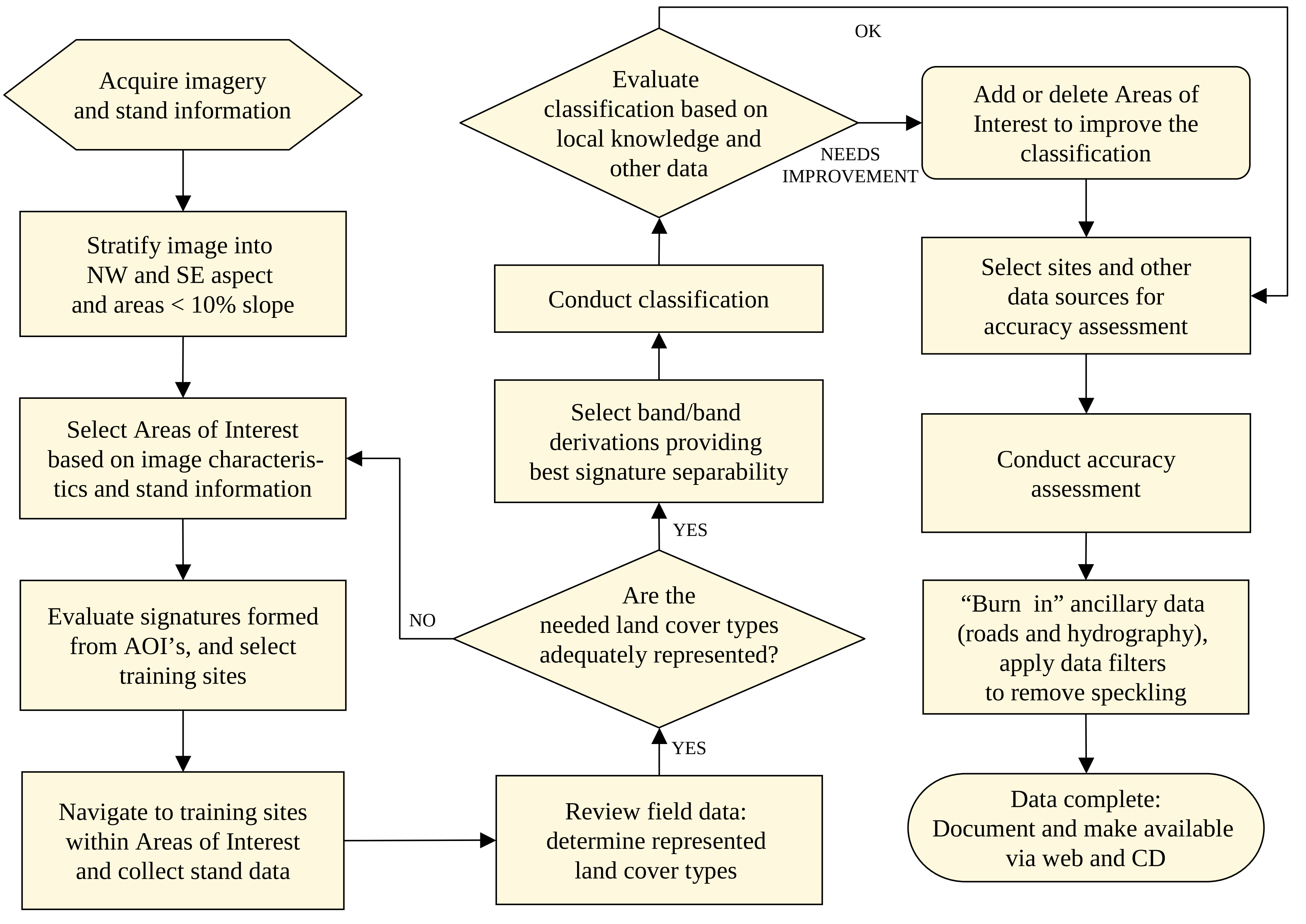


Figure 2. Examples of data sources used for the classifications (Pawtuckaway Lake and environs, Nottingham, NH).

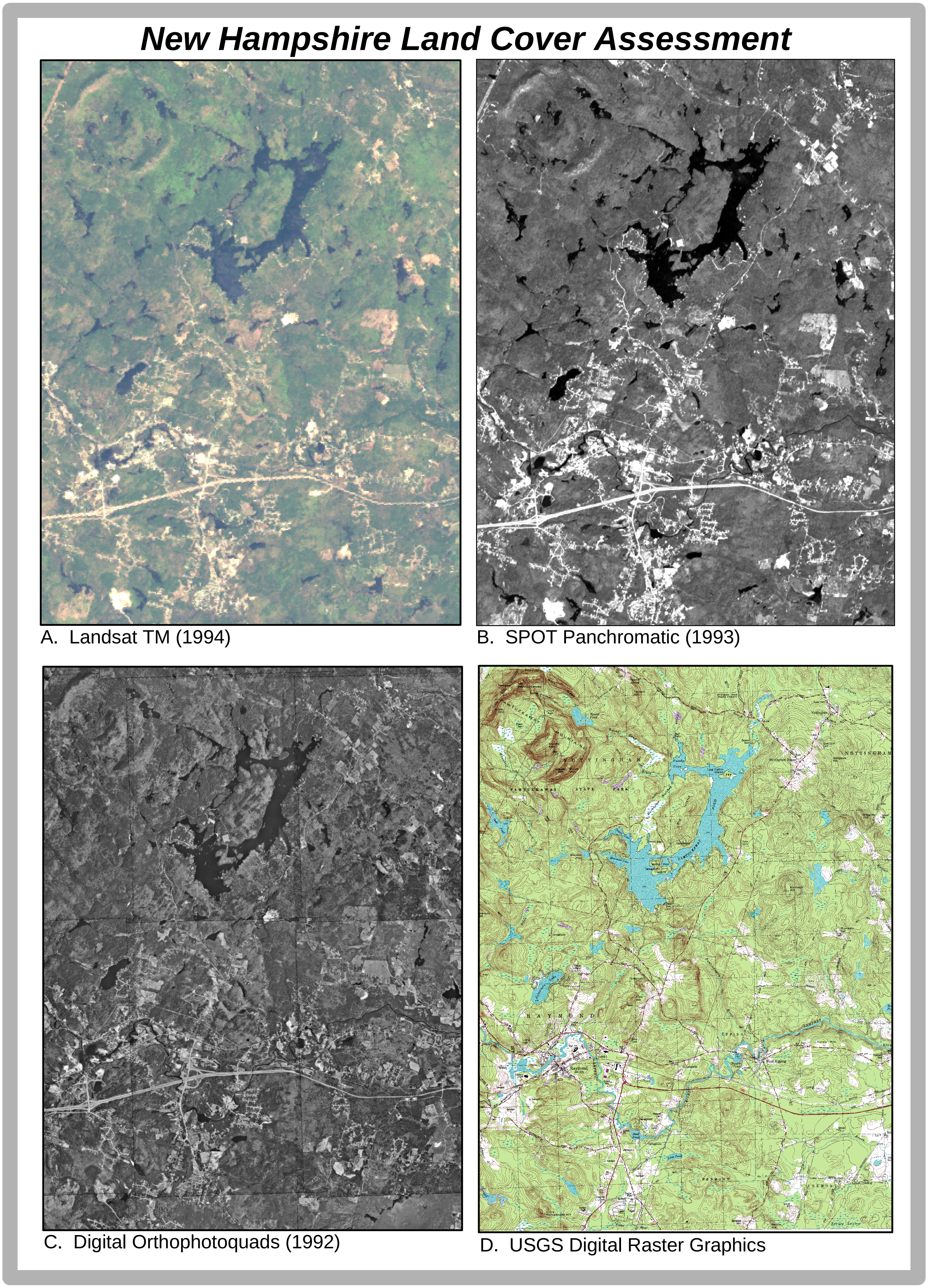
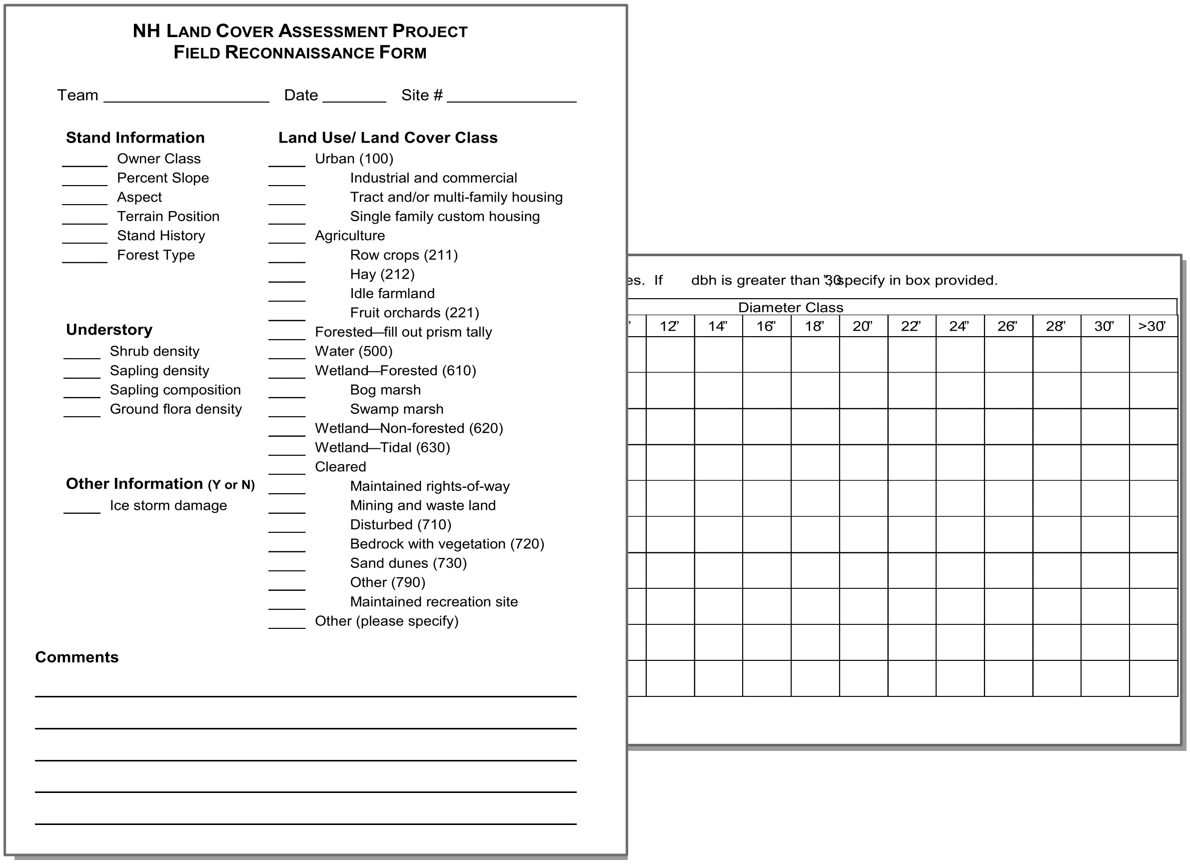


Figure 3.  Data collection forms used for training and accuracy assessment sites.



**NH LAND COVER ASSESSMENT PROJECT**
**FIELD RECONNAISSANCE FORM**

Team ________________ Date _______ Site # ______________

**Stand Information**
_____ Owner Class
_____ Percent Slope
_____ Aspect
_____ Terrain Position
_____ Stand History
_____ Forest Type

**Understory**
_____ Shrub density
_____ Sapling density
_____ Sapling composition
_____ Ground flora density

**Other Information** (Y or N)
_____ Ice storm damage

**Land Use/ Land Cover Class**
____ Urban (100)
____ Industrial and commercial
____ Tract and/or multi-family housing
____ Single family custom housing
____ Agriculture
____ Row crops (211)
____ Hay (212)
____ Idle farmland
____ Fruit orchards (221)
____ Forested—fill out prism tally
____ Water (500)
____ Wetland—Forested (610)
____ Bog marsh
____ Swamp marsh
____ Wetland—Non-forested (620)
____ Wetland—Tidal (630)
____ Cleared
____ Maintained rights-of-way
____ Mining and waste land
____ Disturbed (710)
____ Bedrock with vegetation (720)
____ Sand dunes (730)
____ Other (790)
____ Maintained recreation site
____ Other (please specify)

**Comments**

es. If dbh is greater than 30" specify in box provided.

| Diameter Class | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| " | 12" | 14" | 16" | 18" | 20" | 22" | 24" | 26" | 28" | 30" | >30" |
| | | | | | | | | | | | |
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Figure 4.  Field workers collecting data at forested sites.

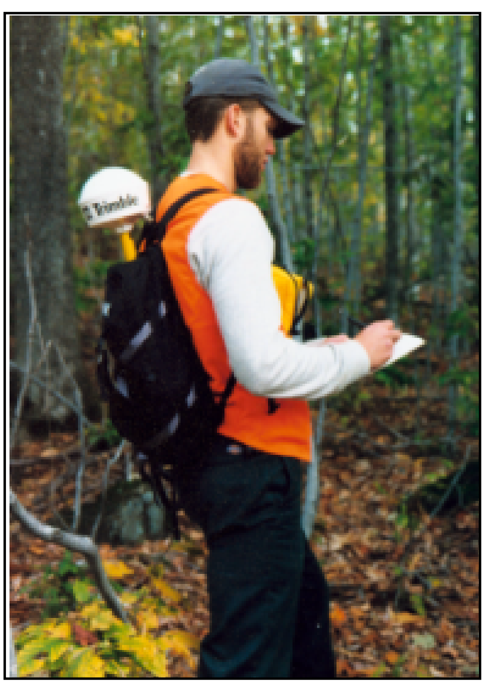

Figure 5. Locations of field sites, and approximate borders of classification regions. Field sites were visited outside the state to support the processing of data in adjoining study areas.

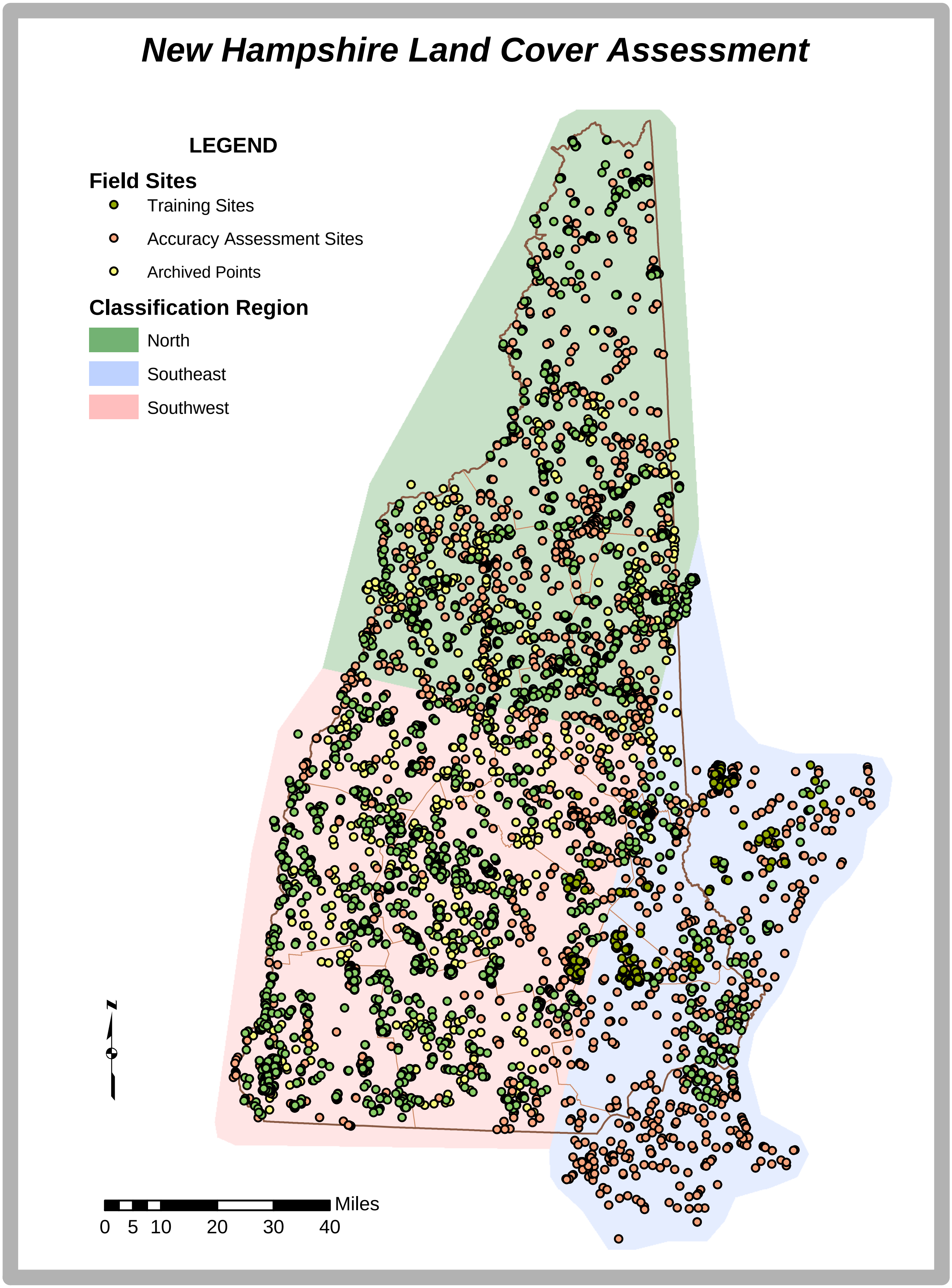

Figure 6. Level II statewide land cover map.

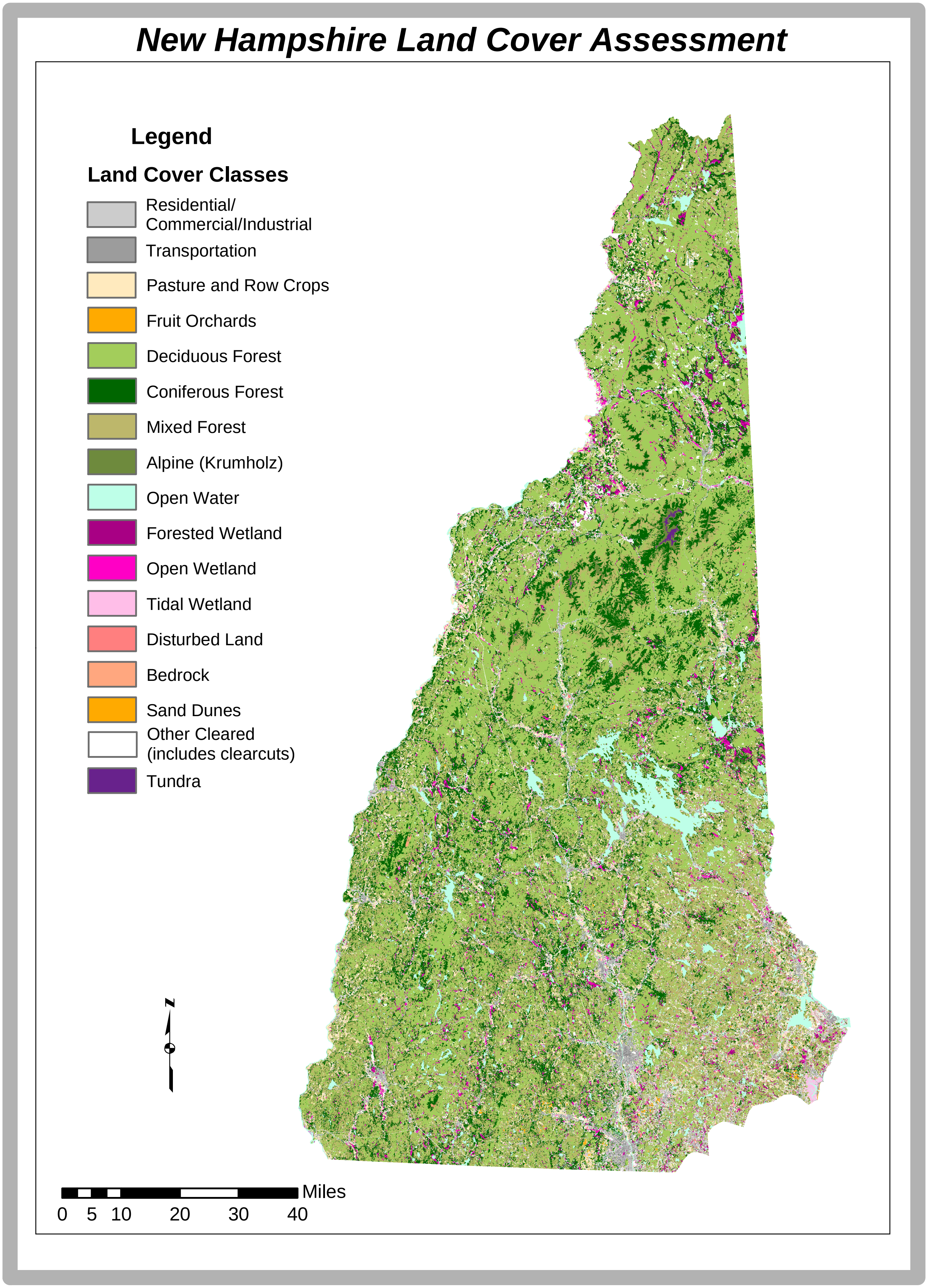

Figure 7. Level III land cover map of the Upper Contoocook watershed.

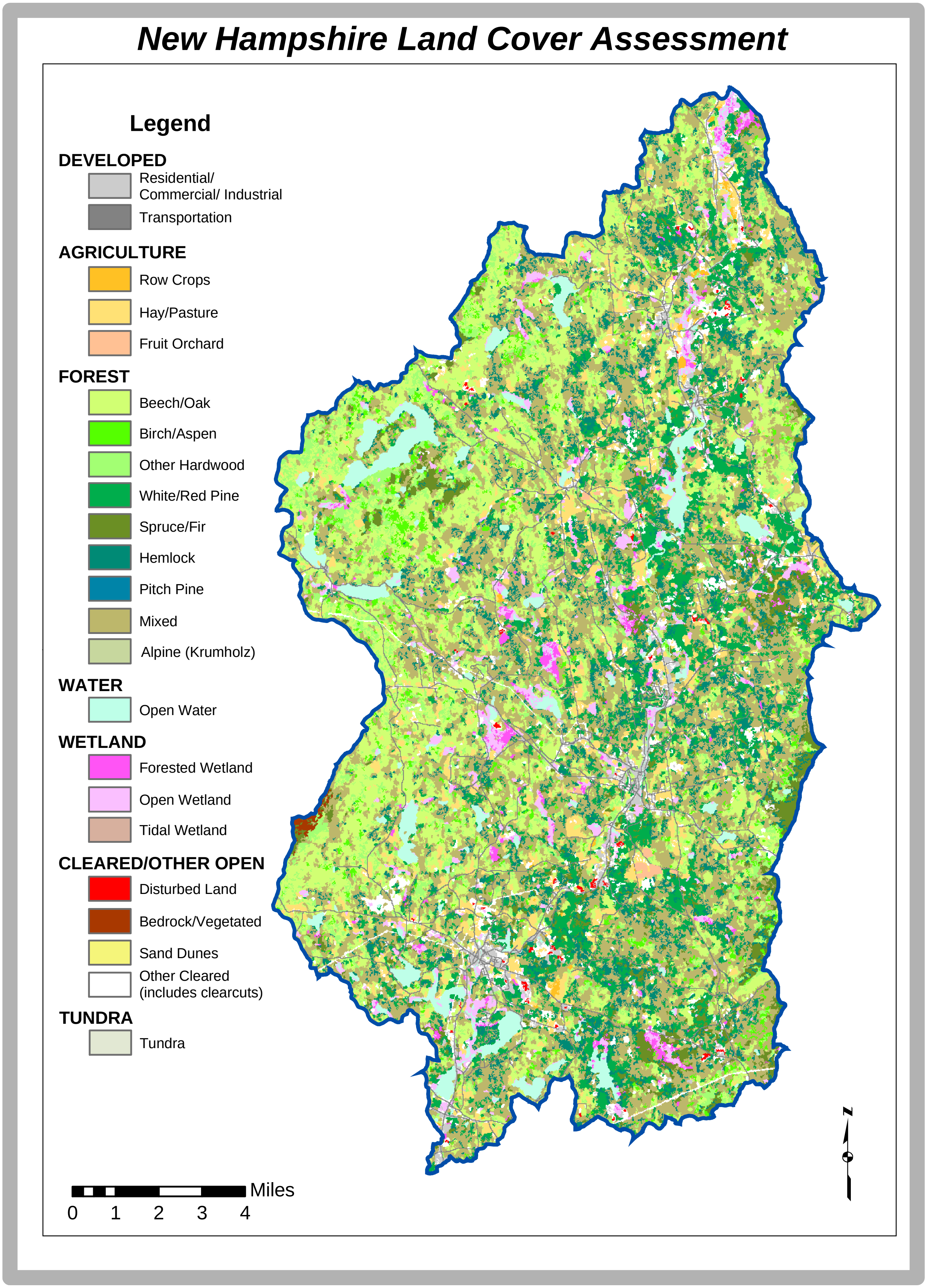

Figure 8. a) State area by land cover class. Total state area = 5,940,499 acres.
b) Forest area by forest class. Total forested area = 4,607,287 acres.

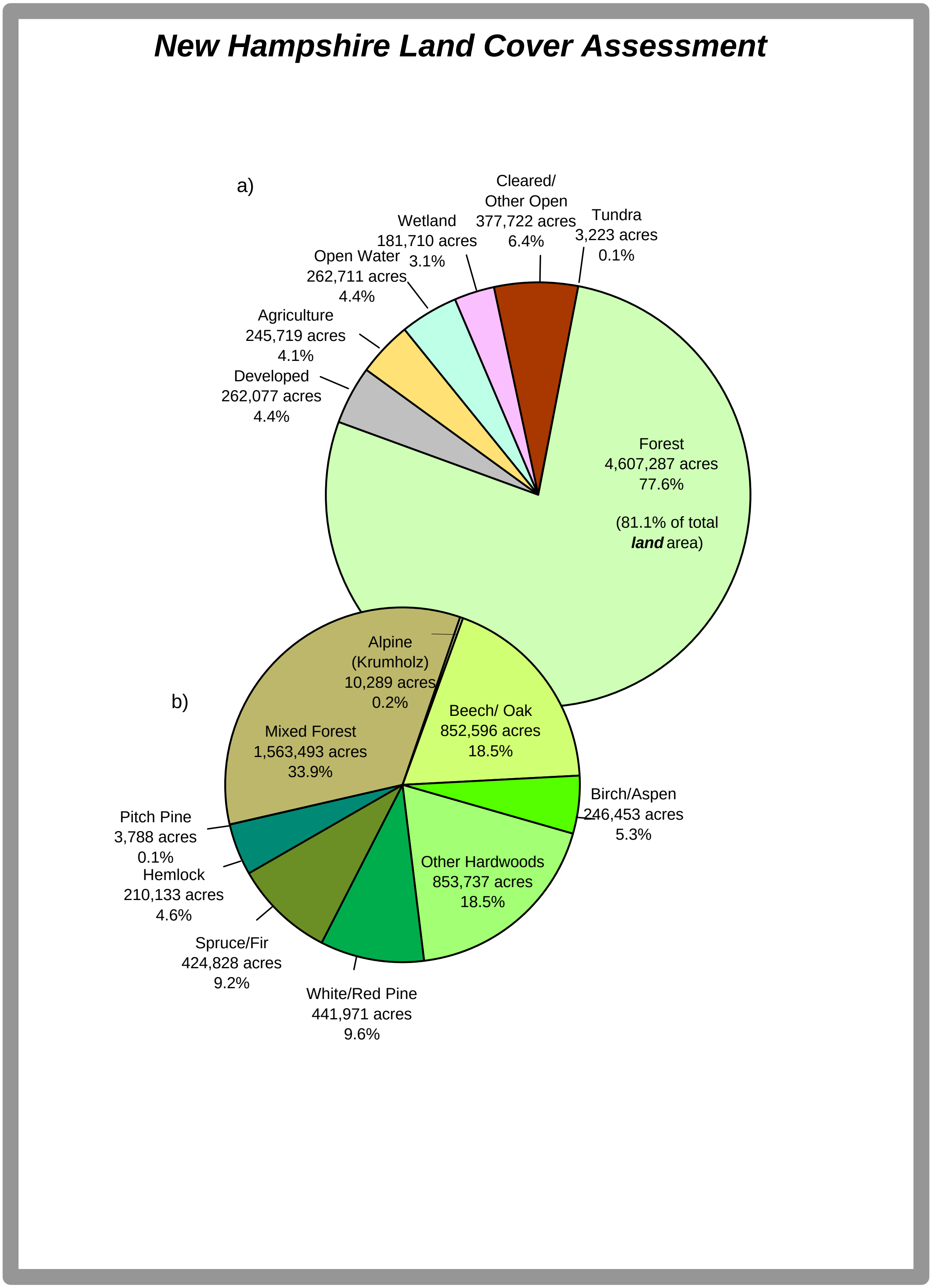

Figure 8. a) State area by land cover class. Total state area = 5,940,499 acres.
b) Forest area by forest class. Total forested area = 4,607,287 acres.

Table 1. NH Land cover assessment classification scheme.

| Level 1 | | Level 2 | | Level 3 | | |
|---|---|---|---|---|---|---|
| **1** | Developed land | | | | | |
| | | **10** | Residential/commercial/ industrial development | **100** | Residential/commercial/ industrial development | |
| | | **14** | Transportation | **140** | Transportation | |
| **2** | Active agricultural land | | | | | |
| | | **21** | Cropland and pasture | | | |
| | | | | **211** | Row crops | |
| | | | | **212** | Hay/pasture | |
| | | **22** | Orchards, fruit, and ornamental horticulture | **221** | Orchards | |
| **4** | Forest | Areas dominated by trees, the majority of which are greater than 10' tall | | | | |
| | | **41** | Deciduous forest | Forest stands comprising less than 25% coniferous basal area per acre | | |
| | | | | **412** | Beech/oak | Deciduous stands comprising at least 30% beech and oak basal area per acre |
| | | | | **419** | Other hardwoods | All deciduous stands not meeting the beech/oak definition |
| | | **42** | Coniferous forest | Forest stands comprising greater than 65% coniferous basal area per acre | | |
| | | | | **421** | White/red pine | Conifer stands in which white/red pine constitutes a plurality of the coniferous basal area |
| | | | | **422** | Spruce/fir | Conifer stands in which spruce/fir constitutes a plurality of the coniferous basal area |
| | | | | **423** | Hemlock | Conifer stands in which hemlock constitutes a plurality of the coniferous basal area |
| | | | | **424** | Pitch pine | Conifer stands in which pitch pine constitutes a plurality of the coniferous basal area |

Table 1. NH Land cover assessment classification scheme.

| Level 1 | | Level 2 | | Level 3 | | |
|---|---|---|---|---|---|---|
| | | **43** | Mixed forest | **430** | Mixed forest | Forest stands comprising more than 25% and less than 65% coniferous basal area per acre |
| | | **44** | Alpine (krumholz) | **440** | Alpine (krumholz) | Areas containing stunted vegetation, either hardwood or softwood, and occurring just below tree line in the White Mountains |
| **5** | Water | **50** | Open water | **500** | Open water | Lakes, ponds, some rivers, or any other open water |
| **6** | Wetlands | Areas dominated by wetland characteristics defined by the U.S. Fish and Wildlife Service National Wetlands Inventory. Basically hydric soils, hydrophytic vegetation and the hydrologic conditions that result in water at or near the surface for extended periods of the growing season. | | | | |
| | | **61** | Forested wetlands | **610** | Forested wetlands | Non-tidal wetlands characterized by woody vegetation 6m tall or higher |
| | | **62** | Non-forested wetlands | **620** | Non-forested wetlands | All other non-tidal wetlands, including those dominated by shrubs, emergents, mosses, or lichens |
| | | **63** | Tidal wetlands | **630** | Tidal wetlands | |
| **7** | Cleared/Other Open | | | | | |
| | | **71** | Disturbed | **710** | Disturbed | Gravel pits, quarries, or other areas where the earth and vegetation have been altered or exposed |
| | | **73** | Sand dunes | **730** | Sand dunes | Areas along the seacoast that are dominated by sand |
| | | **79** | Other cleared | **790** | Other cleared | Clear cut forest, old agricultural fields that are reverting to forest, etc. |
| **8** | Tundra | **80** | Tundra | **800** | Tundra | Areas dominated by short vegetation and occurring above tree line on Mt. Washington |

Table 2.  Primary imagery data sources.

| Image Type | Path | Row | Bands | Date | Source of Georeferencing/ Terrain Correction |
|---|---|---|---|---|---|
| Landsat 5 TM | 12 | 30 | 1-7 | 8-Sep-90 | CSRC |
| Landsat 5 TM | 12 | 30 | 1-7 | 14-May-94 | USGS |
| Landsat 5 TM | 12 | 30 | 1-7 | 24-Oct-95 | CSRC |
| Landsat 5 TM | 12 | 30 | 1-7 | 22-Jul-96 | USGS |
| Landsat 5 TM | 13 | 29 | 1-7 | 13-May-91 | USGS |
| Landsat 5 TM | 13 | 29 | 1-5, 7 | 6-Oct-92 | USGS |
| Landsat 5 TM | 13 | 29 | 1-7 | 12-Oct-94 | USGS |
| Landsat 7 ETM+ | 13 | 29 | 1-8 | 31-Aug-99 | ImageLinks, Inc. |
| Landsat 5 TM | 13 | 30 | 1-5, 7 | 6-Oct-92 | USGS |
| Landsat 5 TM | 13 | 30 | 1-7 | 28-Oct-94 | USGS |
| Landsat 5 TM | 13 | 30 | 1-7 | 14-Apr-98 | USGS |
| Landsat 7 ETM+ | 13 | 30 | 1-8 | 31-Aug-99 | ImageLinks, Inc. |

Table 3. Field verified training sites available for the classifications.

| Class | Southeast | Southwest | North | Archived | Total |
|---|---|---|---|---|---|
| Agriculture (aggregate) | 0 | 0 | 0 | 66 | 66 |
| Row crops | 5 | 45 | 31 | 26 | 107 |
| Hay/pasture | 31 | 66 | 54 | 74 | 225 |
| Beech/oak | 214 | 125 | 87 | 142 | 568 |
| Paper birch/aspen | 32 | 21 | 25 | 14 | 92 |
| Other hardwoods | 58 | 75 | 47 | 245 | 425 |
| Coniferous (aggregate) | 5 | 0 | 0 | 133 | 138 |
| White/red pine | 38 | 66 | 27 | 23 | 154 |
| Spruce/fir | 0 | 43 | 25 | 7 | 75 |
| Hemlock | 49 | 29 | 10 | 5 | 93 |
| Pitch pine | 2 | 2 | 6 | 0 | 10 |
| Mixed forest | 67 | 77 | 19 | 101 | 264 |
| Forested wetland | 8 | 0 | 0 | 107 | 115 |
| Non-forested wetland | 4 | 0 | 0 | 183 | 187 |
| Disturbed land | 0 | 0 | 1 | 13 | 14 |
| Bedrock/vegetated | 0 | 0 | 0 | 2 | 2 |
| Other cleared | 9 | 12 | 13 | 124 | 158 |
| **Total** | **522** | **560** | **345** | **1265** | **2692** |

Table 4. Bands and band transformations used for each subset classification.

**a. Generalized Thematic Mapper classification**

| Subset | Path/Row | Image date | Raw TM Bands | PC[1] Bands | TC[2] Bands | NDVI[3] | Band ratio |
|---|---|---|---|---|---|---|---|
| Southeast aspect | 12/30 | 7/22/1996 | 1-5,7 | 1,2 | | | |
| | 12/30 | 10/24/1995 | | 1,2 | | | |
| | 12/30 | 5/14/1994 | 1-5,7 | 1,2 | | | |
| | 12/30 | 9/8/1990 | | 1,2 | | | |
| | 13/29 | 8/31/1999 | 1-5,7 | | | 1 | |
| | 13/29 | 10/12/1994 | 1-5,7 | | 1,2,3 | | |
| | 13/29 | 5/13/1991 | 1-5,7 | | | | |
| | 13/30 | 8/31/1999 | | | | | |
| | 13/30 | 4/14/1998 | | | | | |
| | 13/30 | 10/28/1994 | | | | | |
| | 13/30 | 10/6/1992 | | | | | |
| | 13/30 | 8/31/1999 | 1-5,7 | | | | |
| | 13/30 | 4/14/1998 | 1-5,7 | | | | |
| | | | | | | | |
| Northwest Aspect | 12/30 | 7/22/1996 | 1-5,7 | | | | |
| | 12/30 | 10/24/1995 | | | | | |
| | 12/30 | 5/14/1994 | 1-5,7 | | | | |
| | 12/30 | 9/8/1990 | | | | | |
| | 13/29 | 8/31/1999 | 1-5,7 | | | 1 | |
| | 13/29 | 10/12/1994 | 1-5,7 | | 1,2,3 | | |
| | 13/29 | 5/13/1991 | 1-5,7 | | | | |
| | 13/30 | 8/31/1999 | 1-5,7 | | | | |
| | 13/30 | 4/14/1998 | 1-5,7 | | | | |
| | | | | | | | |
| Flat aspect | 12/30 | 7/22/1996 | 1-5,7 | 1,2 | 1 - 6 | 1 | |
| | 12/30 | 10/24/1995 | 1 | | | | |
| | 12/30 | 5/14/1994 | 1-5,7 | 1,2 | | | 5/4 |
| | 12/30 | 9/8/1990 | | | | | |
| | 13/29 | 8/31/1999 | 1-5,7 | 1,2,3 | | | |
| | 13/29 | 10/12/1994 | | 1,2,3 | | | |
| | 13/29 | 5/13/1991 | 1-5,7 | 1,2,3 | | | |
| | 13/30 | 8/31/1999 | 1-5,7 | | | 1 | |
| | 13/30 | 4/14/1998 | 1-5,7 | | 1,2,3 | | |
| | 13/30 | 10/28/1994 | 3,4,5 | 1,2,3 | 1,2,3 | | |
| | 13/30 | 10/6/1992 | 3,4,5 | 1,2,3 | | | |

[1] Principal Components Analysis transformation
[2] Tasseled Cap Transformation
[3] Normalized Difference Vegetation Index

Table 4. Bands and band transformations used for each subset classification.

**b. Class-specific Thematic Mapper classification**

| Subset | | Image date | Raw TM Bands | PC[1] Bands | TC[2] Bands | NDVI[3] | Band ratio |
|---|---|---|---|---|---|---|---|
| Agriculture | 12/30 | 7/22/1996 | 3-5, 7 | | 1,2 | 1 | |
| | 12/30 | 10/24/1995 | | | 1,2 | 1 | |
| | 12/30 | 5/14/1994 | | | 1,2 | 1 | |
| | 12/30 | 9/8/1990 | | | 1,2 | 1 | |
| | 13/29 | 8/31/1999 | | 1,2,3 | 1,2,3 | | |
| | 13/29 | 10/12/1994 | | 1,2 | | | |
| | 13/29 | 10/6/1992 | | 1,2 | | | |
| | 13/29 | 5/13/1991 | | 1,2 | | | |
| | 13/30 | 8/31/1999 | 1-5,7 | | 1,2,3 | | |
| | 13/30 | 4/14/1998 | 1-5,7 | | | | |
| | 13/30 | 10/28/1994 | | | 1,2,3 | | |
| | 13/30 | 10/6/1992 | 3,4,5 | | 1,2,3 | | |
| | | | | | | | |
| Forest | 12/30 | 7/22/1996 | | 1-3 | | 1 | |
| | 12/30 | 10/24/1995 | | 1-3 | | 1 | |
| | 12/30 | 5/14/1994 | | 1-3 | | 1 | |
| | 12/30 | 9/8/1990 | | | | | |
| | 13/29 | 8/31/1999 | | 1,2,3 | | | |
| | 13/29 | 10/12/1994 | | 1,2,3 | | | |
| | 13/29 | 10/6/1992 | | 1,2,3 | | | |
| | 13/29 | 5/13/1991 | | 1,2,3 | | | |
| | 13/30 | 8/31/1999 | | 1,2,3 | | | |
| | 13/30 | 4/14/1998 | | 1,2,3 | | | |
| | 13/30 | 10/28/1994 | | 1,2,3 | | | |
| | 13/30 | 10/6/1992 | | 1,2,3 | | | |
| | | | | | | | |
| Wetland | | | | | | | |
| | 12/30 | 7/22/1996 | 3-5, 7 | | | | |
| | 12/30 | 10/24/1995 | | | | | |
| | 12/30 | 5/14/1994 | 3-5, 7 | | | | |
| | 12/30 | 9/8/1990 | | | | | |
| | 13/29 | 8/31/1999 | 3-5,7 | | | | |
| | 13/29 | 5/13/1991 | 3-5,7 | | | | |
| | 13/30 | 8/31/1999 | | | 1-6 | 1 | |
| | 13/30 | 4/14/1998 | 1-5,7 | | | | |
| | 13/30 | 10/28/1994 | 1-5,7 | | | 1 | |
| | 13/30 | 10/6/1992 | 3,4,5 | | | 1 | |

[1] Principal Components Analysis transformation

[2] Tasseled Cap Transformation

[3] Normalized Difference Vegetation Index

Table 5. Rules for the application of the fuzzy set linguistic scale.

| Rating | |
|---|---|
| 5 | Absolutely right: No doubt about the match. Perfect. |
| 4 | Good answer: Would be happy to find this answer on the map. |
| 3 | Reasonable or acceptable: Not the best possible answer but acceptable; this answer does not pose a problem to the user if seen on the map. |
| 2 | Understandable but wrong: Not a good answer. There is something about the site that makes the answer understandable but there is clearly a better answer. This answer is problematic. |
| 1 | Absolutely wrong: This answer is absolutely unacceptable and completely wrong. |

| **Beech/Oak (412):** | |
|---|---|
| 5 | Deciduous stands comprising at least 30% beech and oak basal area per acre |
| 4 | Beech/oak BA greater than or equal to 30% regardless of broad type |
| 3 | Beech/oak BA greater than or equal to 15% and less than 30% regardless of broad type |
| 2 | Other forest |
| 1 | All other types |
| **Other Hardwoods (419):** | |
| 5 | All deciduous stands not meeting the beech/oak definition |
| 4 | All other deciduous stands |
| 3 | Mixed stands with softwood BA less than or equal to 35% |
| 2 | Other forest, row crops, hay/pasture, cleared other |
| 1 | All other types |
| **White/Red Pine (421):** | |
| 5 | Conifer stands in which white/red pine constitutes a plurality of the coniferous basal area |
| 4 | White/red pine BA greater than or equal to 50% regardless of broad type |
| 3 | White/red pine BA greater than or equal to 40% and less than 50% regardless of broad type |
| 2 | Other forest, forested wetlands |
| 1 | All other types |
| **Spruce/Fir (422):** | |
| 5 | Conifer stands in which spruce/fir constitutes a plurality of the coniferous basal area |
| 4 | Spruce/fir BA greater than or equal to 50% regardless of broad type |
| 3 | Spruce/fir BA greater than or equal to 40% and less than 50% regardless of broad type |
| 2 | Other forest, forested wetlands |
| 1 | All other types |
| **Hemlock (423):** | |
| 5 | Conifer stands in which hemlock constitutes a plurality of the coniferous basal area |
| 4 | Hemlock BA greater than or equal to 50% regardless of broad type |
| 3 | Hemlock basal area greater than or equal to 40% and less than 50% regardless of broad type |
| 2 | Other forest |
| 1 | All other types |
| **Pitch Pine (424):** | |
| 5 | Conifer stands in which pitch pine constitutes a plurality of the coniferous basal area |
| 4 | Pitch pine BA greater than or equal to 50% regardless of broad type |
| 3 | Pitch pine basal area greater than or equal to 40% and less than 50% regardless of broad type |
| 2 | Other forest, forested wetlands |
| 1 | All other types |

Table 5. Rules for the application of the fuzzy set linguistic scale.

| | |
|---|---|
| **Mixed Forest (430):** | |
| 5 | Forest stands comprising more than 25% and less than 65% coniferous basal area per acre |
| 4 | Coniferous BA less than 70% and greater than or equal to 65%; or coniferous BA greater than 20% and less than or equal to 25% |
| 3 | Coniferous BA less than 75% and greater than or equal to 70%; or coniferous BA greater than 15% and less than or equal to 20% |
| 2 | Other forest |
| 1 | All other types |
| **Alpine (krumholz) (440):** | |
| 5 | Alpine (krumholz) |
| 4 | Forest stands above 4200 feet in the White Mountains |
| 3 | None |
| 2 | None |
| 1 | All other types |
| **Developed (100):** | |
| 5 | Urban and built-up areas |
| 4 | Disturbed |
| 3 | None |
| 2 | None |
| 1 | All other types |
| **Row crops (211):** | |
| 5 | Row crops |
| 4 | Hay/pasture or orchards |
| 3 | None |
| 2 | Disturbed or other cleared (790) areas |
| 1 | All other types |
| **Hay/Pasture (212):** | |
| 5 | Hay/pasture |
| 4 | Row crops or orchards |
| 3 | Other cleared areas (790) |
| 2 | Urban and built up areas; disturbed areas |
| 1 | All other types |
| **Orchards (221):** | |
| 5 | Orchards |
| 4 | Row crops or hay/pasture |
| 3 | None |
| 2 | Other hardwood forest or mixed forest |
| 1 | All other types |
| **Water (500):** | |
| 5 | Open water |
| 4 | Non-forested wetlands or tidal wetlands |
| 3 | None |
| 2 | Forested wetlands |
| 1 | All other types |

Table 5. Rules for the application of the fuzzy set linguistic scale.

| | |
|---|---|
| **Forested wetlands (610):** | |
| 5 | Forested wetlands |
| 4 | Non-forested wetlands or tidal wetlands |
| 3 | None |
| 2 | Open water |
| 1 | All other types |
| **Non-forested wetlands (620):** | |
| 5 | Non-forested wetlands |
| 4 | Forested wetlands or tidal wetlands |
| 3 | None |
| 2 | Open water |
| 1 | All other types |
| **Tidal wetlands (630):** | |
| 5 | Tidal wetlands |
| 4 | Forested or non-forested wetlands |
| 3 | None |
| 2 | Open water |
| 1 | All other types |
| **Disturbed (710):** | |
| 5 | Disturbed |
| 4 | None |
| 3 | Sand dunes or other cleared (790) areas |
| 2 | Row crops or hay/pasture |
| 1 | All other types |
| **Sand dunes (730):** | |
| 5 | Sand dunes |
| 4 | Disturbed |
| 3 | Cleared/other open |
| 2 | None |
| 1 | All other types |
| **Other cleared (790):** | |
| 5 | Other cleared (clearcuts, old fields, etc.) |
| 4 | Disturbed, row crops, or hay/pasture |
| 3 | Sand dunes or orchards |
| 2 | Deciduous forest |
| 1 | All other types |
| **Tundra (800):** | |
| 5 | Tundra |
| 4 | Bedrock/vegetated |
| 3 | Alpine (krumholz) |
| 2 | none |
| 1 | All other types |

Table 6. Acreage summary by class and county.

| Land Cover Class | | County | | | | | | | | | | New Hampshire |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Belknap | Carroll | Cheshire | Coos | Grafton | Hillsborough | Merrimack | Rockingham | Strafford | Sullivan | |
| Residential/ Commercial/ Industrial | Acres | 4,704 | 5,348 | 6,956 | 4,002 | 9,434 | 28,137 | 13,397 | 14,210 | 4,344 | 4,556 | 95,089 |
| | % of County | 1.6% | 0.8% | 1.5% | 0.3% | 0.8% | 4.9% | 2.2% | 3.1% | 1.8% | 1.3% | 1.6% |
| Transportation | Acres | 9,704 | 11,227 | 13,219 | 8,880 | 19,509 | 33,615 | 21,685 | 29,591 | 11,780 | 7,777 | 166,987 |
| | % of County | 3.2% | 1.8% | 2.8% | 0.8% | 1.7% | 5.9% | 3.5% | 6.4% | 4.8% | 2.2% | 2.8% |
| Total: Developed | Acres | 14,408 | 16,576 | 20,175 | 12,882 | 28,943 | 61,752 | 35,082 | 43,801 | 16,124 | 12,333 | 262,077 |
| | % of County | 4.8% | 2.6% | 4.3% | 1.1% | 2.6% | 10.8% | 5.7% | 9.4% | 6.6% | 3.5% | 4.4% |
| Row Crops | Acres | 396 | 305 | 2,397 | 1,934 | 3,344 | 1,065 | 3,266 | 506 | 503 | 2,167 | 15,882 |
| | % of County | 0.1% | 0.0% | 0.5% | 0.2% | 0.3% | 0.2% | 0.5% | 0.1% | 0.2% | 0.6% | 0.3% |
| Hay/ Pasture | Acres | 13,075 | 10,468 | 24,212 | 19,058 | 40,643 | 31,418 | 34,190 | 19,636 | 10,535 | 20,676 | 223,909 |
| | % of County | 4.3% | 1.6% | 5.2% | 1.6% | 3.6% | 5.5% | 5.6% | 4.2% | 4.3% | 5.9% | 3.8% |
| Orchards | Acres | 181 | 31 | 15 | 0 | 189 | 2,532 | 790 | 1,853 | 277 | 62 | 5,929 |
| | % of County | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.4% | 0.1% | 0.4% | 0.1% | 0.0% | 0.1% |
| Total: Agriculture | Acres | 13,652 | 10,804 | 26,624 | 20,992 | 44,175 | 35,014 | 38,246 | 21,995 | 11,314 | 22,904 | 245,719 |
| | % of County | 4.5% | 1.7% | 5.7% | 1.8% | 3.9% | 6.1% | 6.3% | 4.7% | 4.6% | 6.5% | 4.1% |
| Beech/ Oak | Acres | 58,654 | 104,902 | 92,724 | 78,297 | 150,737 | 110,840 | 135,115 | 43,012 | 26,473 | 51,841 | 852,596 |
| | % of County | 19.5% | 16.5% | 19.9% | 6.7% | 13.5% | 19.4% | 22.1% | 9.2% | 10.8% | 14.7% | 14.4% |
| Birch/Aspen | Acres | 1,242 | 38,570 | 8,137 | 82,021 | 99,229 | 5,603 | 4,934 | 242 | 0 | 6,474 | 246,453 |
| | % of County | 0.4% | 6.1% | 1.7% | 7.0% | 8.9% | 1.0% | 0.8% | 0.1% | 0.0% | 1.8% | 4.1% |
| Other Hardwoods | Acres | 21,078 | 93,869 | 37,722 | 342,353 | 206,627 | 18,978 | 37,984 | 32,664 | 21,538 | 40,924 | 853,737 |
| | % of County | 7.0% | 14.8% | 8.1% | 29.2% | 18.5% | 3.3% | 6.2% | 7.0% | 8.8% | 11.6% | 14.4% |

| Land Cover Class | | Belknap | Carroll | Cheshire | Coos | Grafton | Hillsborough | Merrimack | Rockingham | Strafford | Sullivan | New Hampshire |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| White/Red Pine | Acres | 28,755 | 58,954 | 31,646 | 23,192 | 73,597 | 70,037 | 75,224 | 27,974 | 19,271 | 33,320 | 441,971 |
| | % of County | 9.6% | 9.3% | 6.8% | 2.0% | 6.6% | 12.3% | 12.3% | 6.0% | 7.9% | 9.4% | 7.4% |
| Spruce/Fir | Acres | 3,467 | 35,914 | 15,833 | 187,646 | 122,496 | 9,967 | 16,982 | 136 | 41 | 32,346 | 424,828 |
| | % of County | 1.2% | 5.6% | 3.4% | 16.0% | 10.9% | 1.7% | 2.8% | 0.0% | 0.0% | 9.2% | 7.2% |
| Hemlock | Acres | 9,165 | 24,835 | 33,373 | 12,457 | 45,542 | 26,442 | 30,858 | 4,944 | 1,955 | 20,563 | 210,133 |
| | % of County | 3.0% | 3.9% | 7.2% | 1.1% | 4.1% | 4.6% | 5.0% | 1.1% | 0.8% | 5.8% | 3.5% |
| Pitch Pine | Acres | 14 | 3,714 | 0 | 0 | 0 | 3 | 31 | 16 | 9 | 0 | 3,788 |
| | % of County | 0.0% | 0.6% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% |
| Mixed Forest | Acres | 79,360 | 146,623 | 154,309 | 255,453 | 246,430 | 159,019 | 165,211 | 163,596 | 92,730 | 100,761 | 1,563,493 |
| | % of County | 26.4% | 23.1% | 33.1% | 21.8% | 22.0% | 27.8% | 27.0% | 35.2% | 37.9% | 28.5% | 26.3% |
| Alpine (Krumholz) | Acres | 0 | 0 | 0 | 6,619 | 3,670 | 0 | 0 | 0 | 0 | 0 | 10,289 |
| | % of County | 0.0% | 0.0% | 0.0% | 0.6% | 0.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.2% |
| Total: Forest | Acres | 201,735 | 507,382 | 373,745 | 988,037 | 948,329 | 400,889 | 466,339 | 272,585 | 162,017 | 286,229 | 4,607,287 |
| | % of County | 67.1% | 79.8% | 80.1% | 84.3% | 84.7% | 70.2% | 76.3% | 58.6% | 66.2% | 81.0% | 77.6% |
| Open Water | Acres | 48,461 | 45,081 | 17,367 | 26,641 | 29,351 | 15,529 | 19,734 | 32,882 | 15,985 | 11,680 | 262,711 |
| | % of County | 16.1% | 7.1% | 3.7% | 2.3% | 2.6% | 2.7% | 3.2% | 7.1% | 6.5% | 3.3% | 4.4% |
| Forested Wetland | Acres | 1,498 | 9,031 | 3,023 | 20,835 | 4,963 | 4,711 | 3,994 | 12,385 | 3,706 | 1,133 | 65,278 |
| | % of County | 0.5% | 1.4% | 0.6% | 1.8% | 0.4% | 0.8% | 0.7% | 2.7% | 1.5% | 0.3% | 1.1% |
| Open Wetland | Acres | 5,181 | 10,332 | 9,624 | 28,262 | 12,166 | 12,903 | 15,192 | 8,640 | 4,671 | 4,227 | 111,197 |
| | % of County | 1.7% | 1.6% | 2.1% | 2.4% | 1.1% | 2.3% | 2.5% | 1.9% | 1.9% | 1.2% | 1.9% |
| Tidal Wetland | Acres | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5,120 | 115 | 0 | 5,235 |
| | % of County | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 1.1% | 0.0% | 0.0% | 0.1% |

| Land Cover Class | | County | | | | | | | | | | New Hampshire |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Belknap | Carroll | Cheshire | Coos | Grafton | Hillsborough | Merrimack | Rockingham | Strafford | Sullivan | |
| Total: Wetland | Acres | 6,679 | 19,363 | 12,647 | 49,097 | 17,129 | 17,614 | 19,186 | 26,145 | 8,492 | 5,359 | 181,710 |
| | % of County | 2.2% | 3.0% | 2.7% | 4.2% | 1.5% | 3.1% | 3.1% | 5.6% | 3.5% | 1.5% | 3.1% |
| Disturbed | Acres | 923 | 2,844 | 407 | 870 | 1,131 | 2,759 | 2,364 | 7,764 | 3,089 | 395 | 22,545 |
| | % of County | 0.3% | 0.4% | 0.1% | 0.1% | 0.1% | 0.5% | 0.4% | 1.7% | 1.3% | 0.1% | 0.4% |
| Bedrock/ Vegetated | Acres | 0 | 921 | 283 | 434 | 962 | 13 | 33 | 0 | 0 | 568 | 3,215 |
| | % of County | 0.0% | 0.1% | 0.1% | 0.0% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.2% | 0.1% |
| Sand Dunes | Acres | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 203 | 0 | 0 | 203 |
| | % of County | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Other Cleared | Acres | 14,930 | 32,828 | 15,271 | 70,021 | 49,484 | 37,586 | 30,164 | 59,793 | 27,844 | 13,888 | 351,808 |
| | % of County | 5.0% | 5.2% | 3.3% | 6.0% | 4.4% | 6.6% | 4.9% | 12.9% | 11.4% | 3.9% | 5.9% |
| Total: Cleared/ Other Open | Acres | 15,853 | 36,593 | 15,961 | 71,326 | 51,576 | 40,358 | 32,560 | 67,760 | 30,933 | 14,851 | 377,772 |
| | % of County | 5.3% | 5.8% | 3.4% | 6.1% | 4.6% | 7.1% | 5.3% | 14.6% | 12.6% | 4.2% | 6.4% |
| Tundra | Acres | 0 | 0 | 0 | 2,994 | 229 | 0 | 0 | 0 | 0 | 0 | 3,223 |
| | % of County | 0.0% | 0.0% | 0.0% | 0.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% |
| Total | Acres | 300,788 | 635,798 | 466,518 | 1,171,970 | 1,119,732 | 571,156 | 611,147 | 465,168 | 244,864 | 353,357 | 5,940,499 |

Table 7. Level 3 error matrix.

| CLASSIFIED DATA: Land Cover Class | | REFERENCE DATA: Resid./ Comm./ Indus. 110 | Transpor-tation 140 | Row Crops 211 | Hay/ Pasture 212 | Orchards 221 | Beech/ Oak 412 | Paper Birch/ Aspen 414 | Other Hardwood 419 | White/ Red Pine 421 | Spruce/ Fir 422 | Hemlock 423 | Pitch Pine 424 | Mixed Forest 430 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Resid./Comm./Indus. | 110 | **53** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Transportation | 140 | 3 | **17** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Row Crops | 211 | 0 | 0 | **53** | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hay/Pasture | 212 | 0 | 0 | 1 | **55** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Orchards | 221 | 2 | 0 | 0 | 0 | **37** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Beech/Oak | 412 | 0 | 0 | 0 | 0 | 0 | **32** | 0 | 27 | 0 | 0 | 0 | 0 | 1 |
| Paper Birch/ Aspen | 414 | 0 | 0 | 0 | 0 | 0 | 2 | **4** | 5 | 0 | 0 | 0 | 0 | 3 |
| Other Hardwood | 419 | 0 | 0 | 0 | 0 | 0 | 13 | 2 | **42** | 0 | 0 | 0 | 0 | 1 |
| White/Red Pine | 421 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **49** | 0 | 1 | 0 | 9 |
| Spruce/Fir | 422 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **45** | 0 | 0 | 8 |
| Hemlock | 423 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | **39** | 0 | 15 |
| Pitch Pine | 424 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **39** | 1 |
| Mixed Forest | 430 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 1 | 2 | 1 | 1 | 0 | **25** |
| Alpine (Krumholz) | 440 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Water | 500 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Forested Wetland | 610 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Open Wetland | 620 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tidal Wetland | 630 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Disturbed | 710 | 3 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bedrock/ Veg. | 720 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sand Dunes | 730 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other Cleared | 790 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Tundra | 800 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | | 61 | 17 | 56 | 65 | 38 | 47 | 14 | 79 | 54 | 48 | 41 | 39 | 63 |

Table 7.  Level 3 error matrix.

**REFERENCE DATA**

| **Land Cover Class** | | Alpine (Krumholz) | Water | Forested Wetland | Open Wetland | Tidal Wetland | Disturbed | Bedrock/ Veg. | Sand Dunes | Other Cleared | Tundra | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 440 | 500 | 610 | 620 | 630 | 710 | 720 | 730 | 790 | 800 | |
| Resid./Comm./Indus. | 110 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 2 | 0 | 60 |
| Transportation | 140 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| Row Crops | 211 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 60 |
| Hay/Pasture | 212 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 60 |
| Orchards | 221 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 40 |
| Beech/Oak | 412 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 |
| Paper Birch/ Aspen | 414 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| Other Hardwood | 419 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 60 |
| White/Red Pine | 421 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 |
| Spruce/Fir | 422 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 56 |
| Hemlock | 423 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 60 |
| Pitch Pine | 424 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40 |
| Mixed Forest | 430 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40 |
| Alpine (Krumholz) | 440 | **4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| Water | 500 | 0 | **20** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| Forested Wetland | 610 | 0 | 0 | **52** | 5 | 0 | 0 | 0 | 0 | 1 | 0 | 60 |
| Open Wetland | 620 | 0 | 0 | 11 | **45** | 0 | 1 | 0 | 0 | 1 | 0 | 60 |
| Tidal Wetland | 630 | 0 | 0 | 0 | 0 | **20** | 0 | 0 | 0 | 0 | 0 | 20 |
| Disturbed | 710 | 0 | 0 | 0 | 0 | 0 | **54** | 0 | 0 | 1 | 0 | 60 |
| Bedrock/ Veg. | 720 | 0 | 0 | 0 | 0 | 0 | 0 | **20** | 0 | 0 | 0 | 20 |
| Sand Dunes | 730 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **20** | 0 | 0 | 20 |
| Other Cleared | 790 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **56** | 0 | 60 |
| Tundra | 800 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **20** | 20 |
| Total | | 4 | 20 | 70 | 51 | 20 | 60 | 20 | 20 | 68 | 20 | |

Table 7. Level 3 error matrix.

| Land Cover Class | | Producer's Accuracy | User's Accuracy |
|---|---|---|---|
| Resid./Comm./Indus. | 100 | 86.9% | 88.3% |
| Transportation | 140 | 100.0% | 85.0% |
| Row Crops | 211 | 94.6% | 88.3% |
| Hay/Pasture | 212 | 84.6% | 91.7% |
| Orchards | 221 | 97.4% | 92.5% |
| Beech/Oak | 412 | 68.1% | 53.3% |
| Paper Birch/ Aspen | 414 | 28.6% | 28.6% |
| Other Hardwood | 419 | 53.2% | 70.0% |
| White/Red Pine | 421 | 90.7% | 81.7% |
| Spruce/Fir | 422 | 93.8% | 80.4% |
| Hemlock | 423 | 95.1% | 65.0% |
| Pitch Pine | 424 | 100.0% | 97.5% |
| Mixed Forest | 430 | 39.7% | 62.5% |
| Alpine (Krumholz) | 440 | 100.0% | 80.0% |
| Water | 500 | 100.0% | 100.0% |
| Forested Wetland | 610 | 74.3% | 86.7% |
| Open Wetland | 620 | 88.2% | 75.0% |
| Tidal Wetland | 630 | 100.0% | 100.0% |
| Disturbed | 710 | 90.0% | 90.0% |
| Bedrock/ Veg. | 720 | 100.0% | 100.0% |
| Sand Dunes | 730 | 100.0% | 100.0% |
| Other Cleared | 790 | 82.4% | 93.3% |
| Tundra | 810 | 100.0% | 100.0% |
| Overall Accuracy | | 82.2% | |

Table 8. Level 2 error matrix.

**REFERENCE DATA**

| **CLASSIFIED DATA** — **Land Cover Class** | | Resid./ Comm./ Indus. | Transport-ation | Agriculture | Orchards | Deciduous Forest | Coniferous Forest | Mixed Forest | Alpine (Krumholz) | Water | Forested Wetland | Open Wetland | Tidal Wetland |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 110 | 140 | 210 | 221 | 410 | 420 | 430 | 440 | 500 | 610 | 620 | 630 |
| Resid./Comm./Indus. | 110 | **53** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Transportation | 140 | 3 | **17** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Agriculture | 210 | 0 | 0 | **115** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Orchards | 221 | 2 | 0 | 0 | **37** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Deciduous Forest | 410 | 0 | 0 | 0 | 0 | **127** | 0 | 5 | 0 | 0 | 1 | 1 | 0 |
| Coniferous Forest | 420 | 0 | 0 | 0 | 0 | 0 | **177** | 33 | 0 | 0 | 4 | 0 | 0 |
| Mixed Forest | 430 | 0 | 0 | 0 | 0 | 9 | 4 | **25** | 0 | 0 | 2 | 0 | 0 |
| Alpine (Krumholz) | 440 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **4** | 0 | 0 | 0 | 0 |
| Water | 500 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **20** | 0 | 0 | 0 |
| Forested Wetland | 610 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | **52** | 5 | 0 |
| Open Wetland | 620 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | **45** | 0 |
| Tidal Wetland | 630 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **20** |
| Disturbed | 710 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bedrock/ Veg. | 720 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sand Dunes | 730 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other Cleared | 790 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tundra | 800 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | | 61 | 17 | 121 | 38 | 140 | 182 | 63 | 4 | 20 | 70 | 51 | 20 |

Table 8. Level 2 error matrix.

**REFERENCE DATA**

| **Land Cover Class** (CLASSIFIED DATA) | | Disturbed 710 | Bedrock/ Veg. 720 | Sand Dunes 730 | Other Cleared 790 | Tundra 800 | **Total** |
|---|---|---|---|---|---|---|---|
| Resid./Comm./Indus. | 110 | 5 | 0 | 0 | 2 | 0 | 60 |
| Transportation | 140 | 0 | 0 | 0 | 0 | 0 | 20 |
| Agriculture | 210 | 0 | 0 | 0 | 4 | 0 | 120 |
| Orchards | 221 | 0 | 0 | 0 | 1 | 0 | 40 |
| Deciduous Forest | 410 | 0 | 0 | 0 | 0 | 0 | 134 |
| Coniferous Forest | 420 | 0 | 0 | 0 | 2 | 0 | 216 |
| Mixed Forest | 430 | 0 | 0 | 0 | 0 | 0 | 40 |
| Alpine (Krumholz) | 440 | 0 | 0 | 0 | 0 | 0 | 5 |
| Water | 500 | 0 | 0 | 0 | 0 | 0 | 20 |
| Forested Wetland | 610 | 0 | 0 | 0 | 1 | 0 | 60 |
| Open Wetland | 620 | 1 | 0 | 0 | 1 | 0 | 60 |
| Tidal Wetland | 630 | 0 | 0 | 0 | 0 | 0 | 20 |
| Disturbed | 710 | **54** | 0 | 0 | 1 | 0 | 60 |
| Bedrock/ Veg. | 720 | 0 | **20** | 0 | 0 | 0 | 20 |
| Sand Dunes | 730 | 0 | 0 | **20** | 0 | 0 | 20 |
| Other Cleared | 790 | 0 | 0 | 0 | **56** | 0 | 60 |
| Tundra | 800 | 0 | 0 | 0 | 0 | **20** | 20 |
| Total | | 60 | 20 | 20 | 68 | 20 | |

| **Land Cover Class** | | **Producer's Accuracy** | **User's Accuracy** |
|---|---|---|---|
| Resid./Comm./Indus. | 110 | 86.9% | 88.3% |
| Transportation | 140 | 100.0% | 85.0% |
| Agriculture | 210 | 95.0% | 95.8% |
| Orchards | 221 | 97.4% | 92.5% |
| Deciduous Forest | 410 | 90.7% | 94.8% |
| Coniferous Forest | 420 | 97.3% | 81.9% |
| Mixed Forest | 430 | 39.7% | 62.5% |
| Alpine (Krumholz) | 440 | 100.0% | 80.0% |
| Water | 500 | 100.0% | 100.0% |
| Forested Wetland | 610 | 74.3% | 86.7% |
| Open Wetland | 620 | 88.2% | 75.0% |
| Tidal Wetland | 630 | 100.0% | 100.0% |
| Disturbed | 710 | 90.0% | 90.0% |
| Bedrock/ Veg. | 720 | 100.0% | 100.0% |
| Sand Dunes | 730 | 100.0% | 100.0% |
| Other Cleared | 790 | 82.4% | 93.3% |
| Tundra | 810 | 100.0% | 100.0% |
| Overall Accuracy | | 88.4% | |

Table 9.  Level 1 error matrix.

**REFERENCE DATA**

| CLASSIFIED DATA: Land Cover Class | | Developed 100 | Agriculture 200 | Forest 400 | Water 500 | Wetland 600 | Cleared/ Other Open 700 | Tundra 800 | Total |
|---|---|---|---|---|---|---|---|---|---|
| Developed | 100 | **73** | 0 | 0 | 0 | 0 | 7 | 0 | 80 |
| Agriculture | 200 | 2 | **153** | 0 | 0 | 0 | 5 | 0 | 160 |
| Forest | 400 | 0 | 0 | **385** | 0 | 8 | 2 | 0 | 395 |
| Water | 500 | 0 | 0 | 0 | **20** | 0 | 0 | 0 | 20 |
| Wetland | 600 | 0 | 2 | 2 | 0 | **133** | 3 | 0 | 140 |
| Cleared/Other Open | 700 | 3 | 4 | 2 | 0 | 0 | **151** | 0 | 160 |
| Tundra | 800 | 0 | 0 | 0 | 0 | 0 | 0 | **20** | 20 |
| Total | | 78 | 159 | 389 | 20 | 141 | 168 | 20 | |

| Land Cover Class | | Producer's Accuracy | User's Accuracy |
|---|---|---|---|
| Developed | 100 | 93.6% | 91.3% |
| All Agriculture | 200 | 96.2% | 95.6% |
| Forest | 400 | 99.0% | 97.5% |
| Water | 500 | 100.0% | 100.0% |
| Wetland | 600 | 94.3% | 95.0% |
| Cleared/Other Open | 700 | 89.9% | 94.4% |
| Tundra | 800 | 100.0% | 100.0% |
| Overall Accuracy | | 95.9% | |

Table 10. Results of the fuzzy logic assessment.

| Map Label | "Absolutely right" | | "Good Answers" | | "Reasonable or Acceptable Answers" | | Total |
|---|---|---|---|---|---|---|---|
| | Max (5) | % Max | Right (4-5) | % Right | Right (3-5) | % Right | |
| Residential/Commercial/Industrial | 53 | 88.3% | 58 | 96.7% | 58 | 96.7% | 60 |
| Transportation | 17 | 85.0% | 20 | 100.0% | 20 | 100.0% | 20 |
| Row Crops | 53 | 88.3% | 59 | 98.3% | 59 | 98.3% | 60 |
| Hay/Pasture | 55 | 91.7% | 57 | 95.0% | 60 | 100.0% | 60 |
| Orchards | 37 | 92.5% | 37 | 92.5% | 37 | 92.5% | 40 |
| Beech/Oak | 32 | 53.3% | 34 | 56.7% | 46 | 76.7% | 60 |
| Paper Birch/Aspen | 4 | 28.6% | 5 | 35.7% | 5 | 35.7% | 14 |
| Other Hardwood | 42 | 70.0% | 57 | 95.0% | 58 | 96.7% | 60 |
| White/Red Pine | 49 | 81.7% | 52 | 86.7% | 53 | 88.3% | 60 |
| Spruce/Fir | 45 | 80.4% | 49 | 87.5% | 52 | 92.9% | 56 |
| Hemlock | 39 | 65.0% | 44 | 73.3% | 50 | 83.3% | 60 |
| Pitch Pine | 39 | 97.5% | 40 | 100.0% | 40 | 100.0% | 40 |
| Mixed Forest | 25 | 62.5% | 27 | 67.5% | 28 | 70.0% | 40 |
| Alpine (Krumholz) | 4 | 80.0% | 5 | 100.0% | 5 | 100.0% | 5 |
| Water | 20 | 100.0% | 20 | 100.0% | 20 | 100.0% | 20 |
| Forested Wetland | 52 | 86.7% | 57 | 95.0% | 57 | 95.0% | 60 |
| Open Wetland | 45 | 75.0% | 56 | 93.3% | 56 | 93.3% | 60 |
| Tidal Wetland | 20 | 100.0% | 20 | 100.0% | 20 | 100.0% | 20 |
| Disturbed | 54 | 90.0% | 54 | 90.0% | 55 | 91.7% | 60 |
| Bedrock/ Veg. | 20 | 100.0% | 20 | 100.0% | 20 | 100.0% | 20 |
| Sand Dunes | 20 | 100.0% | 20 | 100.0% | 20 | 100.0% | 20 |
| Other Cleared | 56 | 93.3% | 58 | 96.7% | 58 | 96.7% | 60 |
| Tundra | 20 | 100.0% | 20 | 100.0% | 20 | 100.0% | 20 |
| Total | 801 | 82.2% | 869 | 89.1% | 897 | 92.0% | 975 |