MAPPING ICE STORM DAMAGE IN VERMONT USING SPOT/LANDSAT IMAGERY

A FINAL REPORT

presented to the

VERMONT DEPARTMENT OF FORESTS, PARKS AND RECREATION

by

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with the assistance of
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as part of the Research on Forest Ecosystems Effects of the Ice Storm of January 1998

October 14, 2000

Forests Affected by the 1998 Ice Storm

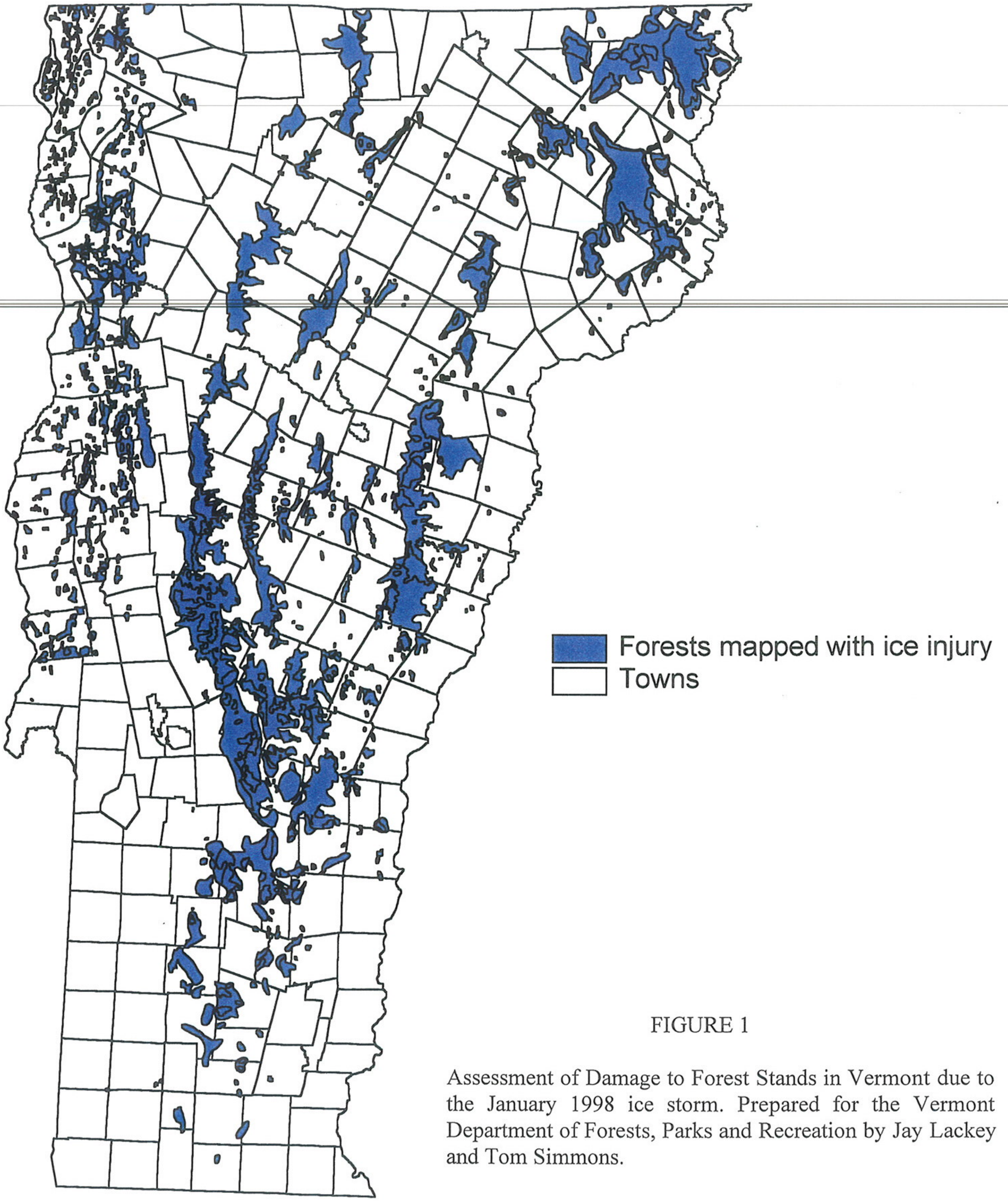

FIGURE 1

Assessment of Damage to Forest Stands in Vermont due to the January 1998 ice storm. Prepared for the Vermont Department of Forests, Parks and Recreation by Jay Lackey and Tom Simmons.

above the surrounding landscape thereby being unequivocally exposed to ice accumulation. Geologically, "Mount Philo is located along the Champlain thrust"(Stanley and Sarkisian, 1972:139) with the upper plate being composed of Monkton Quartzite. The Mount Philo thrust itself forms cliffs that are at least 700 feet (213.5m) along the western and southern edges of the park. Much of the Monkton Quartzite dips about 35 degrees to the northeast and strikes towards the northwest. A variety of glacial sediments covers the park and at one time Mount Philo was an island in the midst of lake water (Dodge, 1969). In 1998, that altitudinal difference above the surrounding farmland placed the entire park within the freezing layer, hence the reason for the extent of damage observed (Fig.2).

Prior to the ice storm, species content and health on Mt. Philo had remained virtually undisturbed throughout the 1990s, even though a localized tornado struck the campground on the northern face in 1993. In 1994, the Department of Forests, Parks and Recreation conducted a cruise data study of the western side of the park. This would become the baseline inventory against which the 1998 damage was assessed (Vile, 1999; pers. comm.).

Reconnaissance of the park on January 20, 1998 yielded a damage report of the extent of destruction with recommendations for salvaging or other responses (see Appendix A). "Nearly every tree ... was severely damaged, with more than half losing their crowns" (Vermont Agency of Natural Resources, 1999:7). The criteria used to determine the removal of birches was at least 50% crown loss, while that figure stood at 75% for oaks, maples and other hardwoods (Vile, 1999; pers. comm.). In the end, about one quarter of the park was logged and the entire red pine plantation was removed. Much of the salvaging was concentrated around the road especially at the base and the summit, in the campground and picnic designated areas. The extent of the clean-up efforts kept the park closed throughout 1998 - the only park for which this occurred.

3.0 DATA

Two main types of data were used - satellite imagery and ancillary information. These were supplemented by three visits to the field site during October and November 1999. Field observations included the identification and categorization of tree damage/recovery symptoms sixteen months after the ice storm. A Garmin III handheld GPS (Global Positioning System) was used for recording the locations.

Much of the ancillary data on Mount Philo was obtained from Chuck Vile of the Vermont Department of Forests, Parks and Recreation. These included the aforementioned stand inventory of western Mount Philo performed in 1994, as well as the initial reconnaissance of the ice storm damage of January 20, 1998. Aerial reconnaissance of the entire state in January and late July/August 1998 yielded a GIS-based layer of the areas of damage (see Fig.1) as a function of severity (Wilmot, 1999; pers. comm.). This layer was instrumental in validating the classification scheme produced in this study.

Four types of remotely sensed data were employed - three in the calibration phase and one for the validation. From the NAPP (National Aerial Photography Program), a 1992 colour infrared (CIR) photograph at the 1:40 000 scale was acquired primarily for use in species identification. At a smaller spatial scale, two SPOTView products were obtained for August 7, 1997 and July 14, 1998. These multispectral sensors acquire data at the green, red and near-infrared (NIR) wavelengths and have a spatial resolution of 20m. SPOTView data have been minimally geometrically and

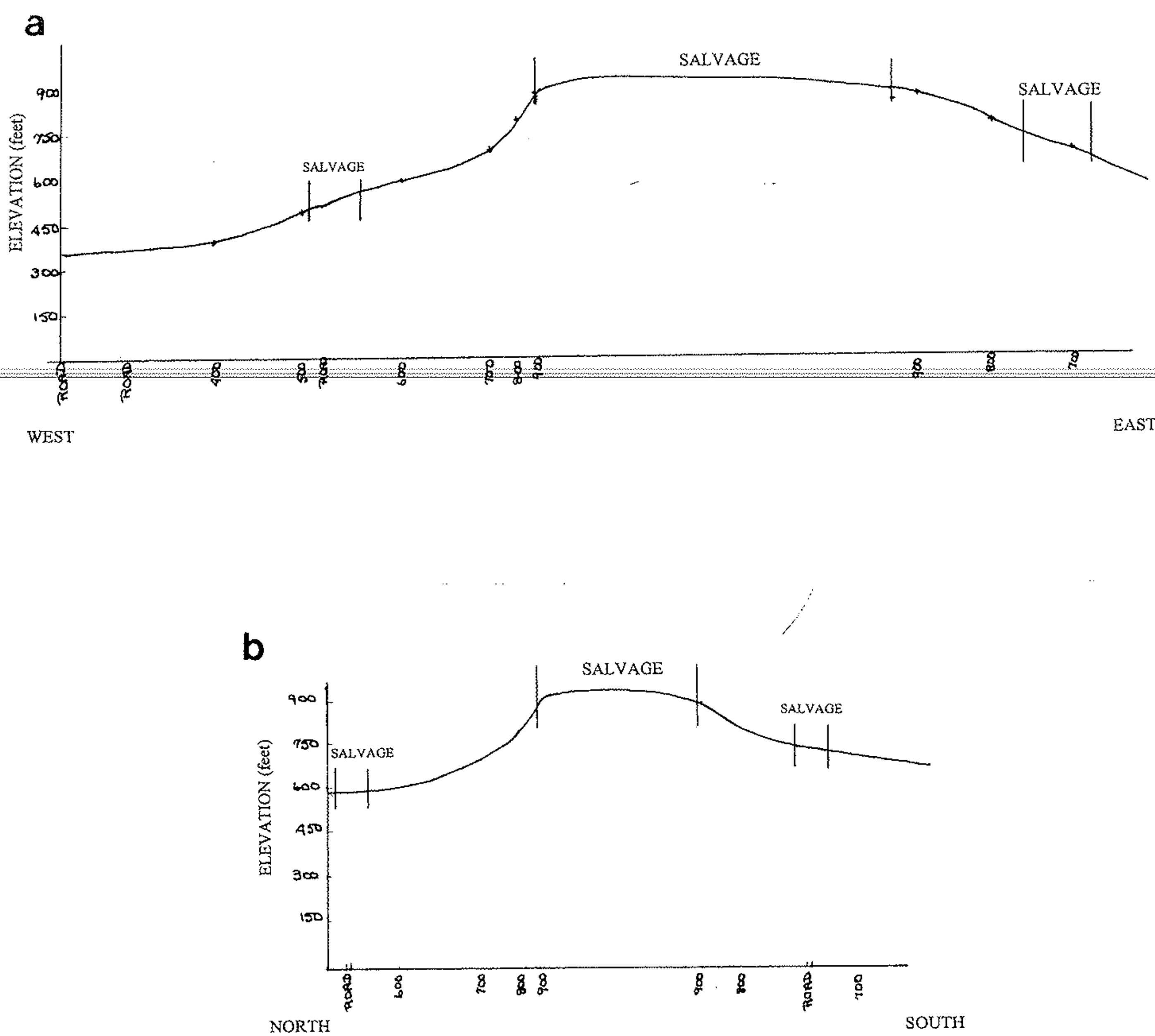

Figure 2 Profiles of Mount Philo State Forest Park from a) west to east and b) north to south across its widest extent.

radiometrically corrected, with the application of the State Plane Coordinate (SPC) System for Vermont and the North American Datum 1983 (NAD83) using the GRS80 spheroid. Radiances ($Wm^{-2}sr^{-1}\mu m^{-1}$) were computed using the gains and offsets included in the respective header files. Although the July 1998 image contained some high thin cirriform cloud it was selected (as opposed to using an August anniversary date) due to the much higher cloud coverage present on the other 1998 spring and summer imagery. The difficulty in obtaining a cloud-free image was related to the fact that the April-September 1998 period in Vermont was particularly rainy, thereby decreasing the probability of locating an essentially cloud-free image.

From the recently launched (April 1999) Landsat-7 satellite with the Enhanced Thematic Mapper (ETM+) sensor, two scenes were acquired for July 21 and September 23, 1999. The latter was chosen to coincide with field visits to the study site, while the former matched the July anniversary date of the 1998 SPOTView image. Both ETM+ scenes were Level1G processed at the Eros Data Centre (EDC) and involved geometric and radiometric correction to the WGS84 ellipsoid and UTM coordinate system. Absolute radiances were calculated using the LMAX and LMIN parameters included in the Calibration Parameter File. The ETM+ sensor acquires data over the visible (blue, green, red), infrared (NIR, two mid-infrared and two thermal infrared) bands and one broad band panchromatic range. The spatial resolution of these data was 30m.

Finally, Digital Orthophotography Quadrangles (DOQs) from the Vermont Mapping Program were used in the validation of the classification scheme. These data have a spatial resolution of 0.5m. DOQs for Chittenden County were flown on April 25, 1999 (Emory, 2000) and represent spring conditions 15 months after the ice storm. The images for the adjoining Addison County were acquired in 1995 during the same early spring timeframe.

4.0 METHODOLOGY

The methodology behind the development of an ice storm damage layer from remotely sensed imagery can be subdivided into five components - image querying and database creation; image manipulation and processing; training site selection; classification of damage and derivation of a damage syndrome and; validation.

Database creation

A database of the coordinates and description of the damage sites observed in the field was created. These coordinates were used to query the SPOT and Landsat imagery for the corresponding multispectral values. These radiances were added to the database, a copy of which has been included in Appendix B. Special emphasis was paid to species such as sugar maple, cedar, red oak, paper birch and red spruce/beech/maple combinations given the predominance of these types around the state. Teillon and Wilmot (1991) identify seven forest type groups across Vermont - Northern hardwoods (sugar maple, beech, yellow birch) which account for 61%; white and red pine (14.3%); spruce and fir (14.3%); aspen and birch (4.1%); oak and hickory (3.7%); elm, ash and red maple (2.2%) and; oak/pine (0.3%). It is interesting to note that while American beech and yellow birch sustained more damage than sugar maples and paper birch, sugar maples are the most frequently encountered species in Vermont (Miller-Weeks and Eagar, 1999) thereby biasing the perception of extensive damage in their favour.

Table 1 shows a comparison between the 1999 observed damaged species and the stands that were observed to be the most impacted in the weeks following the ice storm. Salvage operations in the summer of 1998 were fairly extensive over much of the site given its importance as a state park, and this may be part of the reason for some discrepancy between the damage species observed at the two time intervals. A second factor relates to the fact that the plot locations surveyed in 1998 did not entirely overlap with those observed in the field in 1999 as part of this study.

Image manipulation and processing

The images were manipulated in the image processing system ENVI. The Landsat ETM+ imagery was converted to State Plane Coordinates for Vermont for IHS sharpening with the higher resolution SPOT data. The 1998 aerially-derived map of the ice damage was also available in SPC-Vermont, hence the reason for conversion from UTM coordinates.

At the image processing stage, the main goal was to maximize inter-species differentiation as a precursor to quantifying the amount and spatial extent of change resulting from ice storm damage. This was accomplished via three techniques - image differencing, use of NDVI (Normalized Difference Vegetation Index) values and Principal Components Analysis (PCA). Using the two SPOTView images, colour infrared RGB (red, green, blue) composites showed that most inter-species differentiation was observed at the near-infrared wavelengths. A difference image (1997_{NIR} - 1998_{NIR}) at these wavelengths was created, as well as a corresponding one at the red wavelengths. The sign and magnitude of the differences at both wavelengths were crucial in species discrimination. The red and NIR wavelengths were manipulated ((NIR-RED)/(NIR+RED)) to provide the NDVI which was used to evaluate the health of the standing biomass. The differences between the NDVI images for 1997 and 1998 will be discussed in a later section.

The third image manipulation technique used was Principal Components Analysis. PCA is a transformation technique that is designed to reduce the dimensionality of the data and minimize the degree of correlation that tends to exist between the individual bands of a multispectral set of data. The technique results in new variables (images) called components which are generally independent of each other, such that the first component (PC1) explains most of the variability in the dataset, while PC2 explains most of the remaining variability, and so forth. In performing PCA on the 1997 and 1998 data, the covariance matrix was used in order to better capture the actual variations present in a given temporal dataset. A correlation matrix would have given each input band equal weighting without taking into account the variability within each image. RGB composites of the three components for each date were examined for selection of the colour composite which would best aid in the feature extraction needed for training site selection. For the 1997 data the PC123 RGB composite yielded excellent separability for transportation routes, crop differentiation, coniferous vs. deciduous species on Mt. Philo. For the 1998 images the PC231 RGB proved optimal for roadway, cropland and forested areas of Mt. Philo. The first two components (PC1 and PC2) of each period were found to maximize the variance in the data and were therefore instrumental during the classification stage.

Classification of areas of damage

The process of classifying the images to produce an ice storm damage layer consisted of selecting representative training sites (called regions of interest or ROIs in ENVI) that captured a)

TABLE 1: COMPARISON BETWEEN THE DAMAGED SPECIES OBSERVED IN JANUARY 1998 AND SEPTEMBER/OCTOBER 1999.

INITIAL RECONNAISSANCE	FIELD OBSERVATIONS
Red pine (*Pinus resinosa*)	Red pine (*Pinus resinosa*)
Scotch & Jack pine (*Pinus sylvestris L.*, *Pinus banksiana*)	Paper birch (*Betula papyrifera*)
Sugar maple (*Acer saccharum*)	Sugar maple (*Acer saccharum*)
Norway spruce (*Picea abies L.*)	American basswood (*Tilia americana*)
Hickory (*Carya Nutt.*)	Shagbark hickory (*Carya ovata*)
Red oak (*Querus rubra L.*)	Eastern hemlock (*Tsuga canadensis*)
Beech (*Fagus L.*)	Common mullein (*Verbascum thapsus*)
Black birch	Cedar
White pine (*Pinus strobus L.*)	
Hophornbeam (*Ostrya virginiana*)	

ice-related change at the NIR signatures in particular b) for the species of interest. These ROIs were then used to determine similar regions across the entire scene, i.e. the classification step. Initial training site selection was guided by the observed 1999 damage locations as well as the 1992 colour infrared photography. These initial ROIs included spruce/oak/white pine, oak/maple/beech, sugar maple, paper birch, red pine, Scotch pine, logging road and water.

The classification module requires the ROIs and selected images as inputs. The NIR and RED differenced images were selected based upon the feature separability they afforded especially in the case of the former. Two iterations of the classification stage were performed, with a number of hard classifiers being evaluated for their ability to capture areas of forested change. The methods evaluated included the Maximum Likelihood classifier, Minimum Distance classifier, Binary Encoding and Parallelepiped classifier. The latter is based on Boolean and/or logic with unknown pixels being assigned to the unclassified category. The maximum likelihood classifier assumes a Gaussian distribution in the training sites' statistics (Jensen, 1996). The Parallelepiped classifier yielded the best results in terms of separating water, urban areas and roads (all grouped together) from forested uplands, riparian vegetation and wetlands. The first iteration of the classified image was visually correct, but the actual percentages of individual tree species across the entire image were not representative of the species distribution characteristic of the state.

One of the reasons for the poor performance of the original training sites was the aforementioned fact that species tend to grow together so that the purity of a stand and therefore its corresponding spectral signatures are very much questionable. This was especially true for the adjacent stands of E. larch and Scotch pine as well as for red pine and white pine. Mixels (mixed pixels) are especially prevalent when using satellite imagery with a spatial resolution of 20m or coarser. Another compounding factor was that by using the species observed in 1999 to help guide ROI selection one of two problems may have arisen. Firstly, the trees left standing after salvaging may not reflect the original stand composition viewed on the 1997 imagery. Secondly, the extent of damage to the trees left standing was certainly not of the same order of magnitude as the salvaged species.

The evaluation and refinement phase involved performing a second iteration of the classification using ROIs derived from the spectral signatures in the NIR in 1997 and 1998, as well as the 1997 CIR and RGB composite of PC123 for 1997. The RGB composite of the 1997 data was particularly helpful in between species differentiation because of the contribution of the second component (PC2) which is overwhelmingly an NIR one. Scattergrams of the red vs. NIR wavelengths allowed for maximum separability between the coniferous and deciduous species in 1997, a feature which was conspicuously absent in 1998. Using these additional images, new ROIs were generated with lower standard deviations (i.e. purer representations of the feature type) and non-essential training sites (e.g. open pasture and water) were omitted. The new training sites included mullein, Scotch pine, white pine/Norway spruce, white pine, sugar maple, paper birch, red oak/beech/sugar maple, ash/basswood/other, red pine and white pine salvage areas. The use of a region called mullein refers to regions that were formerly a sugar maple/red oak/beech/paper birch mixture, which had undergone salvage cutting in 1998 and by 1999 were areas dominated by infestations of this wooly plant. The significance of this species will become more apparent in the next section.

5.0 RESULTS & DISCUSSION

Damage syndrome

The final classified image of ice damage (Fig.3) represents the application of the damage syndromes for the species used as ROIs for Mt. Philo. A damage syndrome can be defined as compilation of a priori knowledge, photographic interpretation and image enhancements in order to best describe damage characteristics (Lo, 1986). In this study the damage syndrome is based on the change vector characteristics of the training sites, the differences in spectral radiances at these sites, and the identification and use of common mullein (dark blue areas on Fig. 3) as a bioindicator of ice damage. In order to place the validity of this classified image into perspective it is useful to discuss key components of the damage syndromes.

Figure 4 shows the spectral response pattern for four cover types (paper birch, sugar maple, white pine and common mullein) for the 1997-1999 period. White pine has also been included due to the severity of the damage to this species across the state. A spectral radiance curve indicates the amount of radiant energy received by the sensor at different wavelengths. The three overlapping wavelengths between the SPOT and Landsat ETM+ sensors are the green, red and near-infrared wavelengths. Vegetation tends to be characterized by chlorophyll absorption during photosynthesis at the blue (0.45-0.52μm Landsat) and red (0.61-0.68μm SPOT and 0.63-0.69μm Landsat) wavelengths. This results in low radiance values at these wavelengths, while the intervening green wavelengths (0.5-0.59μm SPOT, 0.52-0.6μm Landsat) are regions of high radiance for healthy vegetation. Species discrimination, while possible as the red wavelengths, is much better performed at the NIR ones (0.79-.89μm SPOT, 0.76-0.90μm Landsat) due to the high reflectance and scattering by vegetation. NIR wavelengths are also related to the amount of biomass present and are instrumental in the detection of stress in vegetation.

It can be observed that, whereas paper birch and sugar maple signatures are very similar at the (blue), green and red wavelengths, sugar maples are much more reflective in the NIR. Both species were at their healthiest in 1997. By July 1998, the amount of radiant energy being reflected by the chloroplasts (at the green wavelengths) had declined, although the overall level of photosynthetic activity (red wavelengths) was essentially unchanged. At the NIR wavelengths, however, there was at least a 50% decrease in radiance from 1997 to 1998, a decrease that was more pronounced in the sugar maples. This decline in the near-infrared was echoed in the NDVI values which indicated decreases in biomass among the deciduous and coniferous species alike.

This shift in the spectral radiance curves for both sugar maples and paper birches may have resulted from a combination of morphological changes and new growth. Many paper birches and sugar maples bent at varying degrees under the weight of the ice. Although straightening did occur in some cases (Burns, 1999), in others entire stands remained arched towards the ground in the fall of 1999 (Fig.5a). Another morphological change involved the varying percentages of crown loss. This was crucial given that at this spatial resolution it is the canopy's characteristics that are being sensed by the satellite. Epicormic branching is the final change to be considered, since these leaves are not spectrally the same as a full, mature canopy. Thus, overall photosynthetic activity remained virtually unchanged from 1997 to 1998 as a result of the epicormic shoots, other existing foliage and understory growth that was now able to thrive with the opening of the canopy. At the NIR wavelengths, however, one observes an overall decline in the standing biomass as well as evidence of stress symptoms, while the green wavelengths point to the physiological/phenological changes

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October 12, 2000

Ms. Sandy Wilmot
Vermont Department of Forests, Parks & Recreation
Vermont Monitoring Cooperative
111 West Street
Essex Junction, VT 05452

Dear Sandy

Please find enclosed the final report related to the Ice Storm Grant on the Use of Satellite Imagery to Develop a Classification Scheme to Detect Changes in Ice-affected Vegetation.

With the exception of the statewide map showing the extent of ice damage, the report is complete. This shall follow to be substituted for Figure 3 as soon as it becomes available.

Sincerely

LesleyAnn

Lesley-Ann Dupigny-Giroux, Ph.D.
Assistant Professor & VT State Climatologist

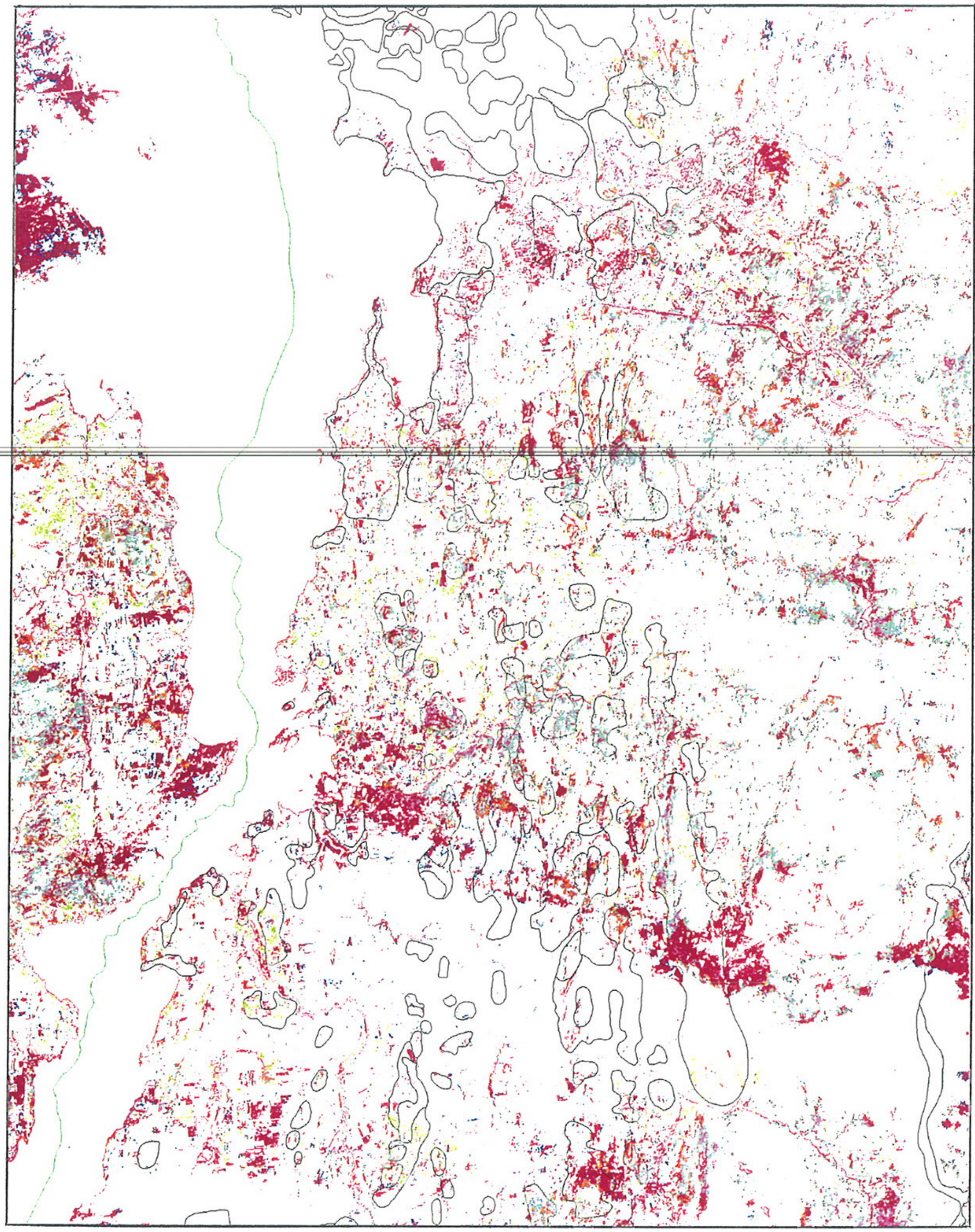

Figure 3 Ice-related damage to forest stands as derived from the July 1998 SPOTView image. The vector polygons shown on Figure 1 have been draped over these areas for visual comparison.

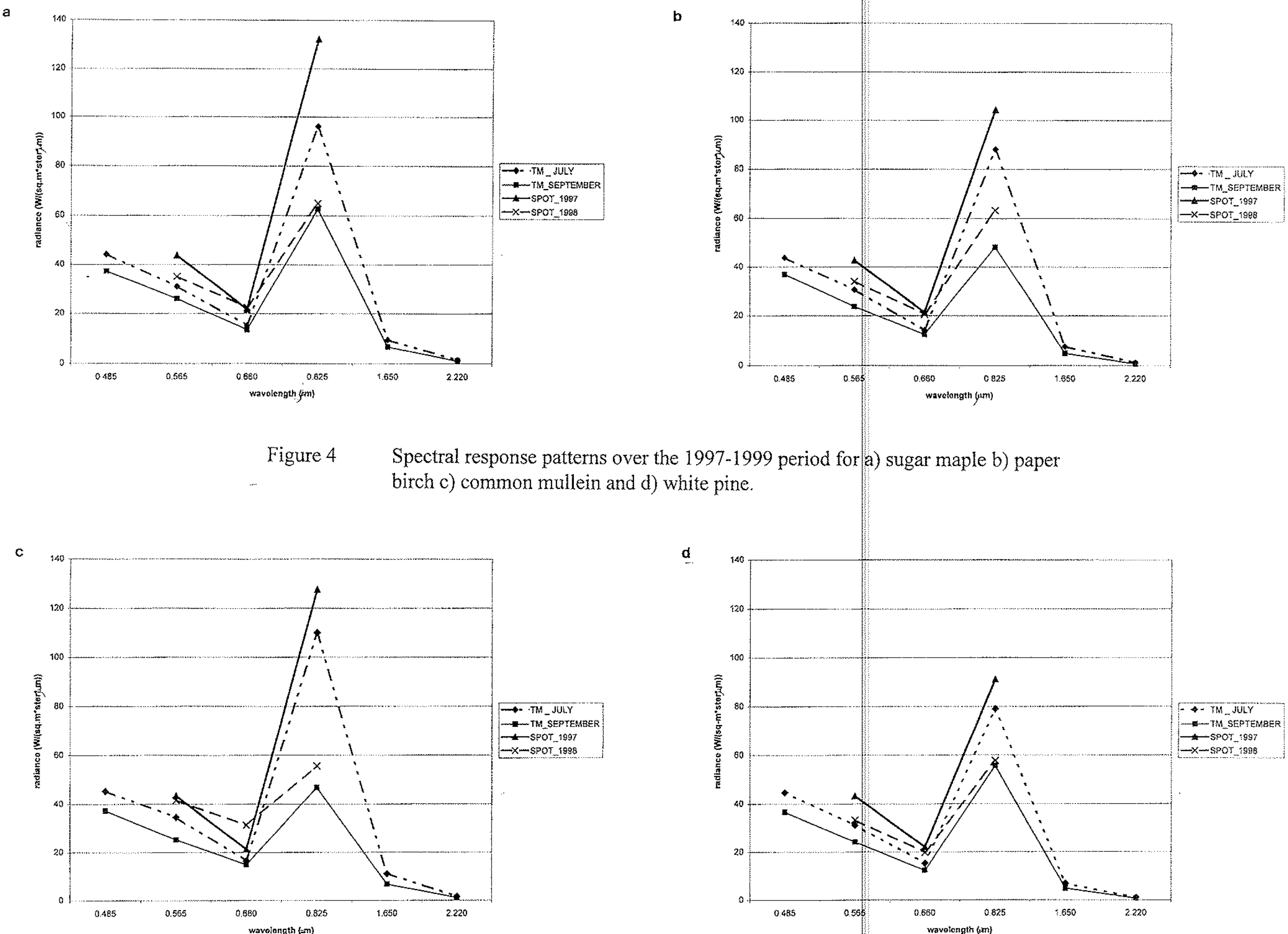

Figure 4 Spectral response patterns over the 1997-1999 period for a) sugar maple b) paper birch c) common mullein and d) white pine.

a

b

FIGURE 5

Photographs taken in October 1999 showing a) a stand of sugar maples on the northern face arched over to the ground and b) the infestation of common mullein also the northern face of Mount Philo.

the leaves present in 1998.

By 1999, the signs of recovery among the paper birches and sugar maples was mixed. Overall photosynthetic activity had increased, as had standing biomass back to levels that approached the non-stressed 1997 values. This was especially true for the birches. However, decreased reflection by chloroplasts at the green wavelengths points to other factors which complicated the recovery process. Many of the trees which survived 1998 with deficient crowns began 1999 with low root reserves (Burns, 1999). When this is combined with drought conditions which lasted into the fall of 1999, physiological and phenological adaptations may have occurred. Among these are leaf scorch which represents a reduction in the area from which transpiration takes place; leaf curling; and an acceleration in phenology. Given that vegetation phenology was three weeks ahead of schedule in 1998, it is unclear whether the 1998 and 1999 imagery truly captured comparative snapshots of the life cycles of these species.

On Mt. Philo common mullein (*Verbascum thapsus* L.) was primarily found on the north-facing regions that had been salvaged in 1998 to remove trees had either been blown-down or with at least 75% of their tops broken (Vile, 1998). These mullein-infested areas displayed quite dramatic changes in vegetation response over the 1997-1999 period. The 1997 spectral curve indicates that this region was initially dominated by sugar maples which did not afford a very dense canopy before the ice storm, as determined from the low NDVI values. Given the colonizing nature of common mullein which thrives in harsh conditions such as direct sun, thin soils, windswept locations, growth began quickly in this newly disturbed site. Apart from the increased light reaching the floor, the abundant moisture present after a wet spring and summer contributed the final factor necessary for the successful establishment and development of this plant (Gross, 1980).

Mullein is a biennial that flowers in the summer (late June with a peak in early August) of the second year. During the summer of 1998, these biennials of the *Scrophulariacese* family would have produced a tap root and a rosette of leaves (Hoshovsky, 1993). This low-lying, lateral growth would account for both the marked decline in photosynthesis at the red wavelengths as well as decreases in the standing biomass (relative to the predominantly sugar maple stands that were replaced). The relatively dry winter of 1998-1999 was ideal for the overwintering of these mother plants (Lovejoy, 1995) so that by July 1999, the plants were at least 180cm tall and ready to bloom (Fig.5b) (as inferred from plant structure and lack of flowers during field visits in October 1999). The prolific nature of this biennial would explain the resurgence in photosynthesis observed in 1999 as well as the increase in standing biomass. It is interesting to note that the rapidity of this infestation produced biomass amounts almost on the order of the original sugar maples. The decrease in chloroplast reflection is a function of the phenology of this plant. Gross (1984) measured the growth rate of mullein seedlings on bare vs. vegetated soils and found these rates to be 4-7 times faster on the former, yielding 2000 times more biomass. The presence of common mullein serves as a bio-indicator of areas of severe damage. Given that mullein is easily out-competed in regions of dense vegetative cover, its presence at similar stages in other parts of the state such as Shaw Mountain in Benson (Ruesink and Graves, 2000) and George Brook in the Granville/Ripton area (Faccio, 2000) lends strong evidence of ice storm related damage.

The final element of the damage syndrome are the change vectors for sugar maple, paper birch, common mullein and white pine on Mount Philo (Fig. 6). By plotting the mean radiances at the red, green and NIR wavelengths in three dimensional space, for each of the four images (August 7, 1997, July 14, 1998, July 21 1999 and September 23, 1999), the magnitude and direction of the change over time can be observed. While similar to the spectral response variations shown on Figure

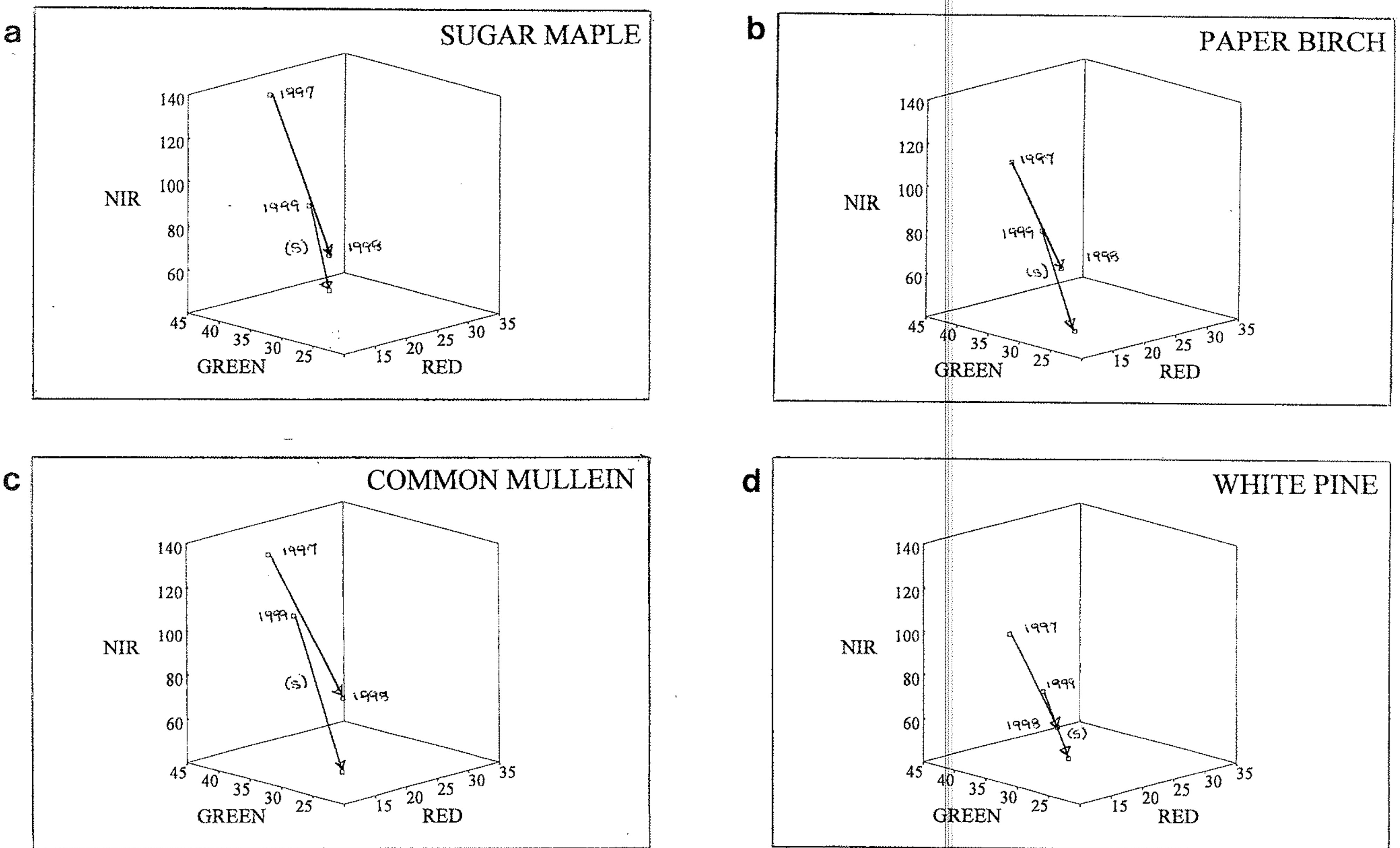

Figure 6 Change vector plots showing the variations in spectral response at the red, green and near infrared (NIR) wavelengths for a) sugar maple b) paper birch c) common mullein and d) white pine.

4, the change vector plots show much more clearly the differences in the response in the year after the ice storm. Also observed is the distinction between ice damage and senescence (s).

Validation of the classification

The validation of the final classified image involved verifying the areas labeled as damage against known damage. Model validation can be thought of as the confirmation that within its specified domain of applicability, the classification scheme possessed a satisfactory range of accuracy, consistent with the intended application of the scheme (after Schlesinger et al., 1979 in Tsang, 1991). This represents a hybrid of historical data validation and predictive validation. The former refers the use of a part of the image for calibration and the rest for validation, while the latter involves checking the classification's predictions against new images (Tsang, 1991).

Six sites were selected - Shaw Mountain, Pease Mountain, Snake Mountain, Mt. Fuller and East Woods in Vermont and the Bouquet River floodplain in New York. With the exception of the latter two, the other sites are also forested outcrops with species mixtures similar to those found on Mount Philo. In all cases ice damage was well captured. In addition, the presence of mullein on Shaw Mountain in the town of Benson (Ruesink and Graves, 2000) was also well captured.

The comparison between the classified image and the ice damage map of the Vermont Department of Forests, Parks and Recreation yielded interesting similarities and differences. In terms of similarities, both representations seemed to overlap most in areas of coniferous vegetation. One of the most striking differences was the orientation of the polygons/areas of damage. Many of the vector polygons ran north-south (a function of the flight path), while there was no real pattern on the image. Some of the mapped polygons do not coincide with classified areas, with one reason being the inability to locate polygons exactly even on-board an aircraft equipped with GPS capability. Another factor for the lack of coincidence was that some of the classified regions may be more related to species type rather than ice damage (Trial, 2000). The advantage of performing this classification using fairly coarse data (vs. aerial reconnaissance close to the ground) is that species like paper birch with their distinctive white barks are easy to locate visually and may be over represented in any method based solely on visual interpretation. This would apply to either aerial reconnaissance data or large scale aerial photography (e.g. DOQs). In contrast, species such as maples and ash which are single-stemmed may be overlooked from the air, but not if their spectral characteristics were examined.

Another difference was that riparian areas of damage (e.g. along Otter Creek) were not well captured by the original ice map. Conversely, there were several instances (e.g. north of the Greater Burlington area and south of Otter Creek) for which the scheme did not show damage but the ice map did.

Sources of error

There are five sources of error that need to be accounted for in this methodology. The first involves the use of the GPS. Although most points were obtained via triangulation with at least six satellites, there were two questionable points obtained within the forest canopy for which the line of sight was not as unimpeded as it should have been. These were discarded.

Secondly, there was a spatial mismatch between the accuracy of the GPS points and the corresponding pixels on the SPOTView or Landsat ETM+ imagery to which they were matched at either a 20m or 30m resolution. This inevitably overlapped with the third source of error - mixels. Mixels or mixed pixels occur wherever a pixel is made up of more than one feature type. Coniferous plantations tended to be more homogeneous than deciduous stands, although the spectra of the various evergreens were quite similar in some cases (e.g. Scotch pine and red pine). Thus, given that there were very few pure stands present at the study site, many of the ROIs used were actually combinations of at least two species.

The time lag among the event (January 5-9, 1998), initial reconnaissance (January 20, 1998), SPOT image acquisition (July 14, 1998) and field visits (October/November 1999) introduced differences in vegetation phenology, species removal, new species (mullein) and perhaps some initial recovery as compounding factors in separating out pre-storm vs. post-storm damage.

As aforementioned, the summer of 1998 was particularly wet making it difficult to acquire completely cloud-free imagery. The SPOTView image from July 14, 1998 showed the presence of high thin cirriform from west to east, south of the study area. This may have affected radiances biasing them to higher values.

SUMMARIZING REMARKS

This report has presented a means by which to update the 1998 aerial mapping of ice damage caused by the ice storm of January that year. Using a combination of SPOT and Landsat images from the 1997-1999 period, a damage syndrome related to this icing event was created. This was made up of change vectors for paper birch, sugar maple, white pine and the invasive species, common mullein; the spectral radiances of these and other species of interest and; locating mullein as a bioindicator of change from areas previously predominated by sugar maples. This damage syndrome formed the basis for the classified image of ice damage. Comparisons between the latter and the aerial mapping revealed good coincidence, as well as areas of damage along riparian reaches that were not well captured.

The ice storm of 1998 struck after a couple of years of adequate moisture, such that the vegetation of the area was not under undue stress. It was therefore relatively straightforward to determine the areas of damage based on physiological and morphological changes. However, the ongoing monitoring of the recovery of the ice-damaged forests may be complicated by post-ice storm moisture conditions. The particularly wet summer of 1998 helped to buffer some of the moisture-related stress that could have been detrimental to the forest recovery. However, by July 1999 the recovery signatures of the species examined were modified by the presence of eight months of drought conditions. Thus, given that it is difficult to adequately assess tree mortality/recovery within the first two years after the disturbance, ongoing efforts on this front should continue on a statewide basis. Indeed it has been noted that trees which appeared to be recovering in 1999 may actually decline in subsequent years (Burns, 1999). Although wet conditions in 2000 have allowed for a dramatic boost in forest health, close attention should be paid to the species growth/regrowth that is actually occurring in forests around Vermont.

ACKNOWLEDGMENTS

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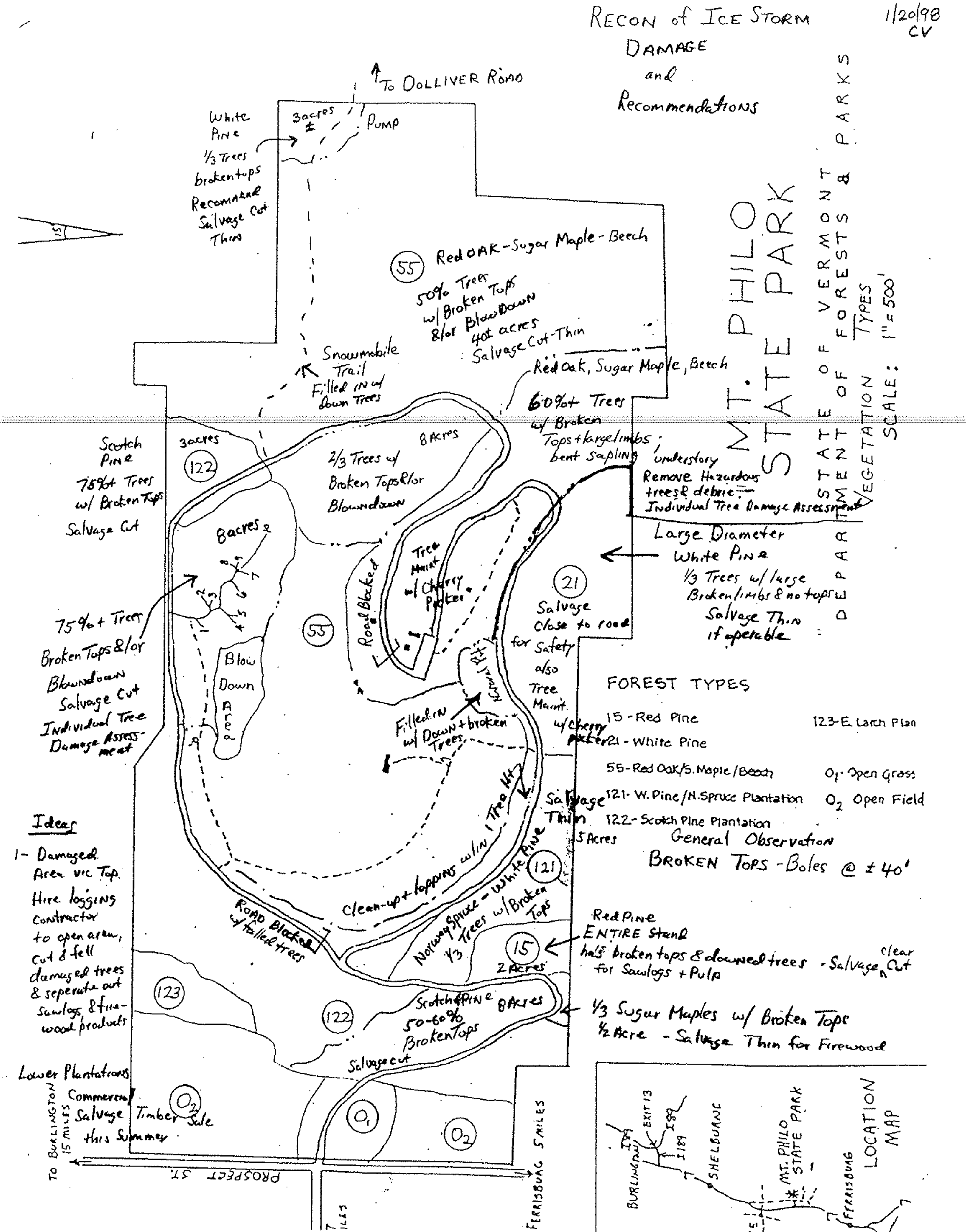
APPENDIX A

SKETCH MAP OF THE INITIAL RECONNAISSANCE OF THE ICE STORM DAMAGE ON MOUNT PHILO STATE FOREST PARK - JANUARY 20, 1998


RECON of ICE STORM
DAMAGE
and
Recommendations
1/20/98
CV
MT. PHILO
STATE PARK
STATE OF VERMONT
DEPARTMENT OF FORESTS & PARKS
VEGETATION TYPES
SCALE: 1" = 500'
To DOLLIVER ROAD
3acres ±
PUMP
White Pine
1/3 Trees
broken tops
Recommend
Salvage Cut
Thin
15
55
Red OAK - Sugar Maple - Beech
50% Trees
w/ Broken Tops
&/or BlowDown
40± acres
Salvage Cut-Thin
Snowmobile Trail
Filled in w/ Down Trees
Red Oak, Sugar Maple, Beech
60%± Trees
w/ Broken
Tops + large limbs;
bent sapling understory
Remove Hazardous
trees & debris.
Individual Tree Damage Assessment
Scotch Pine
75%± Trees
w/ Broken Tops
Salvage Cut
3acres
122
8 Acres
2/3 Trees w/
Broken Tops &/or
Blowdown
8acres
75%± Trees
Broken Tops &/or
Blowdown
Salvage Cut
Individual Tree
Damage Assessment
Blow Down Area
Road Blocked
Tree Maint.
w/ Cherry Picker
Large Diameter
White Pine
21
1/3 Trees w/ large
Broken limbs & no tops
Salvage Thin
if operable
Salvage
Close to road
for Safety
also
Tree Maint.
w/ cherry picker
Kennel Rd.
Filled in
w/ Down + broken
Trees
FOREST TYPES
15 - Red Pine
21 - White Pine
55 - Red Oak/S. Maple/Beech
121 - W. Pine/N. Spruce Plantation
122 - Scotch Pine Plantation
123 - E. Larch Plan
O1 - Open Grass
O2 Open Field
Salvage Thin
5 Acres
General Observation
BROKEN TOPS - Boles @ ± 40'
Clean-up + toppings w/in 1 Tree Ht
Norway Spruce - White Pine
1/3 Trees w/ Broken Tops
121
Road Blocked
w/ felled trees
Red Pine
ENTIRE Stand
has broken tops & downed trees - Salvage Clear Cut
for Sawlogs + Pulp
15
2 Acres
Ideas
1- Damaged Area vic Top.
Hire logging contractor
to open area,
cut & fell
damaged trees
& seperate out
sawlogs & fire-
wood products
123
122
Scotch Pine 8 Acres
50-60%
Broken Tops
1/3 Sugar Maples w/ Broken Tops
1/2 Acre - Salvage Thin for Firewood
Salvage cut
Lower Plantations
Commercial
Salvage Timber Sale
this Summer
O2
O1
O2
TO BURLINGTON 15 MILES
PROSPECT ST.
FERRISBURG 5 MILES
LOCATION MAP
EXIT 13
I-89
I-189
BURLINGTON
SHELBURNE
MT. PHILO STATE PARK
FERRISBURG

APPENDIX B

DATABASE OF THE LOCATIONS, SPECIES AND COMMENTS FROM FIELD OBSERVATIONS IN THE FALL OF 1999.

DATE	TIME	LAT	LONG	SPEICES	COMMMENTS
1-Oct	9:40am	44 16.771	73 13.186		flaky bark, ellipitcal leaves, alternate
1-Oct	9:46am	44 16.785	73 13.213	conifer, pine(white)	top broken, dead branchees
1-Oct	9:50am	44 16.799	73 13.170	white pine	top broken, dead branchees
1-Oct	9:55am	44 16.793	73 13.188	oak, red/white?	broken crown, bunched new growth(2 years) near top, smoot
1-Oct	10:00am	44 16.869	73 13.181	paper birch	good birch, 12-13 degrees, bow bent, 11 degrees
1-Oct	10:05am	44 16.842	73 13.167		
1-Oct	10:09am	44 16.855	73 13.090	paper birch	Severe damage to top
1-Oct	10:12am	44 16.825	73 13.420	american basswood	hugh leaves, 6-8 inches, top and middle broken
1-Oct	10:15am	44 16.762	73 13.092		big, leaf
1-Oct		44 16.640	73 13.109	maple(sugar)	4 inch diameter, 25 feet tall, 10-15 years
1-Oct	10:25am	44 16.681	13 13.109	hardwood	tiny leaves
1-Oct		44 16.810	13 13.109	paper birch, birch righ	top broken, broken in 2 places
1-Oct	10:32am	44 16.761	73 13.200	birch/cottonwood	smaller version, lily shaped leaves
22-Oct	9:05am	44 16.852	73 13.116		smaller tree up to 30 feet, upper branches broken, facing NW
22-Oct	9:14am	44 16.798	73 13.149	white ash	extreme top brakage, minimal leaf growth, norrow leaves
22-Oct	9:30am	44 16.824	73 12.852	paper birch(large)	broken @ top, near fork in road
22-Oct	9:32am	44 16.877	73 12.867	paper birch	broken@ top, up from fork in road
22-Oct	9:40am	44 16.796	73 12.782	paper brich	damage on east side
22-Oct	9:41am	44 16.813	73 12.788	paper birch	bent over top, forest thinning
22-Oct	9:42am	44 16.820	73 12.781	sweet birch	smooth bark , forest thinning
22-Oct	9:57am	44 16.840	73 12.753	paper birch	trunk about 1 foot diameter, whole tree bent NE
22-Oct	9:58am	44 16.839	73 12.728	paper birch	top broken, hanging down dead
22-Oct	10:06am	44 16.762	73 12.708	suger maple	lots of bich here with tops completely gone, yellow leaves, en
22-Oct		44 16.766	73 12.711	sugar maple	all facing east
22-Oct		44 16.777	73 12.693		all facing east
22-Oct	10:12am	44 16.769	73 12.704	birch	leaning over
22-Oct	10:24am	44 16.624	73 12.644		bent over toward the NW
22-Oct	10:25am	44 16.616	73 12.656	maple	brown bark, really thin, more moisture and wind, bent NE
22-Oct	10:37am	44 16.656	73 12.762	red oak	broken @ top
22-Oct		44 16.655	73 12.756		tree with tops off, tufts like PQ
22-Oct	10:45am	44 16.629	73 12.748	yellow maple	stand of yellow maple, slight breakage @ top, bent over
5-Nov	9:25am	44 16.724	73 13.316	paper birch	>75% crown damage
5-Nov		44 16.760	73 13.304	paper birch	<75%, broken .5 of tree, 50% damage
5-Nov		44 16.736	73 13.346	clump birch (7)	>75%, totally uprooted cluster
5-Nov		44 16.728	73 13.353	paper birch(stand)	cut up on ground
5-Nov		44 16.749	73 13.310	tamarack	top damage, 30-40% damage
5-Nov		44 16.705	73 13.302	yellow birch	bend over @ 90%
5-Nov	9:55am	44 16.792	73 13.300	white ash	crown gone, in midst of downed paper birched
5-Nov	10:15am	44 16.900	73 13.107	northern white cedar	clsuter of 4 with tops broken off (2 still attached), paper birch
5-Nov		44 16.841	73 12.980	shagbark hickory	3 part trunk, 2 bent and 1 split
5-Nov		44 16.802	73 12.760	mullein	mullein field
5-Nov	11:00am	44 16.830	73 12.774	paper birch	uprooted, top broken, 100% damage
5-Nov	11:02am	44 16.820	73 12.701	suger maple	bent @ 90 degree angle, tops and lower branches broken
5-Nov	11:04am	44 16.816	73 12.693	suger maple	total damage, splintered and broken in half, stand of maples
5-Nov	11:13am	44 16.873	73 12.663	sugar maple	top broken off
5-Nov	11:15am	44 16.874	73 12.660	suger maple	completely bent over to the ground
5-Nov	11;18am	44 16.856	73 12.664	suger maple	broken near base, splintered
5-Nov	11:30am	44 16.603	73.12.727	suger maple	broken middle trunk
5-Nov		44 16.600	73.12.732		broken branches close to top
5-Nov	11:40am	44 16.600	73.12.930		dumping ground