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ASSESSING FOREST DAMAGE AND TREE RESPONSE TO ICE STORM INJURY IN THINNED AND UNTHINNED HARDWOOD STANDS IN MAINE

By

Julie Lee Swisher

B.S. West Virginia University, 1999

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

(in Forestry)

The Graduate School

The University of Maine

December, 2001

Advisory Committee:

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ASSESSING FOREST DAMAGE AND TREE RESPONSE TO ICE STORM INJURY IN THINNED AND UNTHINNED HARDWOOD STANDS IN MAINE

By Julie Lee Swisher

Thesis Advisor: Dr. William D. Ostrofsky

An Abstract of the Thesis Presented
in Partial Fulfillment of the Requirements for the
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December, 2001

In January 1998, a severe ice storm struck the northeastern United States, causing severe injury to forested areas. Forest damage from ice storms is a result of glaze formation on twigs and branches. Ice storms are recognized as severe disturbances due to their highly destructive nature as a result of ice glaze.

Researchers and landowners have been concerned that thinned stands are more susceptible to ice injury than their unthinned counterparts. Thinned stands have fewer trees per area and thus less inter-tree support. In addition, the effects of wind maybe greater in thinned stands.

The objectives of this study were to investigate injury and recovery from the 1998 ice storm in thinned and unthinned hardwood stands. Four field sites were chosen and individuals in both thinned and unthinned areas were measured to determine damage and recovery values. Damage variables measured included pre- and post-storm crown class, percent crown loss and number and size of broken branches. Recovery variables

included transparency rating, tree height, number and location of sprouts as well as shigometer readings for each individual.

Aerial photography was used to determine ice injury using a computer-automated approach. This method consisted of rectifying and mosaicking four, digitally-scanned aerial photographs, performing an edge detection enhancement process, and using the results of this enhancement as a guide for creating computer training sites for an automatic detection of ice damage classes. The results of this method were compared to ice injury maps created from the same air photos that were analyzed using a traditional, manual approach.

Results indicate that thinned stands did not suffer the effects of the 1998 ice storm greater than the unthinned stands for all four study sites combined. However, at individual sites large differences between thinned and unthinned stands were detected. Percent crown loss at site 3, a heavily thinned area, was significantly different between the two treatments. While recovery variables suggested there was no significant difference in recovery between the treatments for the four sites combined, shigometer measurements at sites 3 and 4 suggested that the thinned stands are recovering better than unthinned stands. At site 1, the unthinned area was recovering better than the thinned areas. At site 2, the thinned area was more vigorous than the unthinned area, but a significant difference did not exist between the two. In addition, when data was analyzed according to site and species, the thinned stands were more vigorous than the unthinned stand. Core data suggests that trees were growing significantly better in the thinned stands after the ice storm, although for the two years prior to the storm, the thinned stands were doing significantly better as well.

The aerial approach for detecting ice injury was not comparable to the ice injury maps created using the more traditional manual approach. The overall accuracy of the new method correctly identifying the ice injury damage classes was 60%. Even if the overall accuracy met with accepted accuracy standards (85% accuracy), time and cost limitations would prevent the digital classification approach from becoming an appropriate method for using remotely sensed data to detect and assess ice injury.

DEDICATION

To my family-

my grandma: Dulcie Swisher

my mom and dad: Sandy and Gary Swisher,

my sister and niece, Jenny and Sydney Marshall,

and my soon-to-be husband and step-son, Bob Morris and Jed Kistner-Morris

ACKNOWLEDGEMENTS

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I was very fortunate to have the opportunity to create many friendships during my research. Thanks to all my fellow graduate students, especially Stephanie Phillips, who without them, I would not have been able to complete this degree.

Lastly, but most importantly, I would like to thank my family, and soon-to-be husband and step-son, for their encouragement and support. They truly made this possible. Not only did they instill in me an appreciation for the great outdoors, but gave me the strength to pursue it on my own. It is to them, that I dedicate this thesis.

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INTRODUCTION

Ice storms are frequent occurrences in the northeastern United States. These disturbances can have severe consequences on forest lands. The ice storm of 1998 affected a four state area including Maine, New Hampshire, Vermont and New York and affected 17 million acres in this region (Miller-Weeks et al. 1999). Natural resource losses were estimated to exceed 1 billion dollars (NEFA 1998).

The formation of ice storms occur when two air masses of differing temperatures and moistures meet. For example, when a cold air mass is stationed near the surface of the Earth, and a warm, moist air mass moves above or behind it, the precipitation from the warm air mass falls and freezes on contact to super-cooled objects on the Earth's surface (Bennett 1959; Lemon 1961; Geiger 1965; Baldwin 1973). Damage from ice storms is due to excessive ice loading or glaze. Glaze is defined as a "clear layer of ice formed by super-cooled water freezing on the surface of objects" (Smith 2000) and tends to form radially around forest objects such as twigs, branches, leaves, and boles (Lemon 1961). These disturbances are more frequent than other destructive disturbances of similar magnitude such as fires and windstorms.

Ice injury results when glaze adds excessive weight to the braches of trees (Warrillow and Mou 1999). Damage to trees includes broken branches in the canopy and in severe cases, bole breakage. Uprooted individuals and bent trees are also common. Damage tends to vary among species and sites. Injuries from ice storms could facilitate fungal infections, decay, and tree death (Melancon and Lechowicz 1987).

A number of factors in three broad categories- storm variables, tree level and stand level variables- determine storm severity and forest damage level for ice events.

Storm variables include ice load and wind direction/velocity. Tree level variables include species/branching pattern, position in canopy, tree size, and age/decay. Stand level variables include topography (aspect and percent slope), proximity to large water bodies, and previous management activities (Abell 1934; Lutz 1936; McCullough 1943; Lemon 1961; Cool et al. 1971; Whitney and Johnson 1984; Bruederle and Stearns 1985; Ostrofsky 1998a; Miller-Weeks et al. 1999; Smith 2000).

After the ice storm of 1998, natural resource managers, landowners, and researchers were concerned with the impact to the forest, especially areas that had been thinned in the recent past. It was generally accepted that thinned stands suffered more from the effects of wind due to fewer trees per acres than their unthinned counterparts. In addition, these less dense, thinned stands have less inter-tree support (Brender and Romancier 1965, Belanger and Brender 1968, Shephard 1975). During times of heavy ice accumulation on branches and twigs, support from neighboring trees can reduce the occurrence of breakage (Bennett 1959).

Nine studies have analyzed the effects of thinning on ice injury. Six of these studies have researched the effects of thinning on ice injury on coniferous species, while the other 3 analyzed the effect of thinning on hardwood species. The results of three of the hardwood studies indicated that thinned areas suffered greater damage than unthinned areas (Cool et al. 1971; Shepard 1975; Belanger et al. 1996). These studies are described below. In addition, the ice storm of 1998 affected hardwoods more than softwoods (Miller-Weeks et al. 1999) although no studies have been performed for the ice storm of 1998 in terms of ice injury and recovery in thinned and unthinned stands.

Yellow poplar (*Lirodendron tulipifera* L.) was found to recover quickly from a 1969 ice storm in western North Carolina. No clearly discernable relationship between crown damage and stocking or intensity of thinning was found. Dense stands suffered the least amount of damage, but heavily thinned stands did not suffer the most damage; rather, intermediately stocked stands suffered greatest by the ice accumulations (Della-Bianca and Beck 1977).

In a study conducted in New York, older second-growth stands that had been thinned were found to have suffered 15% more damage than the unthinned stands. The author noted that this was a very important finding because it raised "the question of possible increase in susceptibility to glaze damage" (Downs 1938). The study went on to conclude that a significant trend in basal area and ice injury was not noted (Downs 1938).

A 1957 study of an ice storm in the southern Appalachians suggested that thinned stands were more prone to ice injury than unthinned stands (Carvell et al. 1957). Crown thinning plots were `studied to determine the effects from various levels of thinning. Results indicated that as thinning intensity increased, injury increased. Hardwood stands which had less than 30% of the volume removed suffered much less than those stands that were thinned more heavily. The author also noted that even aged management is more desirable than uneven-aged management because trees in even-aged stands receive more support from neighboring trees and were less likely to be injured (Carvell et al. 1957).

Visual observations made by foresters and landowners following the 1998 disturbance suggested that thinned areas and areas near forest edges in Maine were damaged more than their unthinned counterparts (Ostrofsky 2000 pers. communication).

This study analyzed individuals in both thinned and unthinned stands and measured them for ice injury and recovery to find potential differences in the two treatments.

After the ice storm of 1998, aerial photos were taken of the affected areas in Maine. Traditional stereo-photo interpretation is performed by an analyst who locates and interprets the magnitude of ice injury. An alternative approach for detecting and mapping disturbance was revised and tested in this study. Rather than using an analyst to interpret the photos, a computer-generated image enhancement and digital classification approach was used to determine if results similar to the traditional approach could be achieved.

The three objectives for this research were:

(i) to compare tree damage at the species level between thinned and unthinned stands

(ii) to compare tree recovery at the species level between thinned and unthinned stands

(iii) to compare manual and digital approaches for detecting and classifying ice injury on aerial photography

These objectives were examined by testing the following null hypotheses:

$H_0$1: There is no significant difference in damage between thinned and unthinned forest stands.

$H_0$2: There is no significant difference in recovery between thinned and unthinned forest stands.

$H_0$3: There is no significant difference between manual and digital approaches for detecting and classifying ice injury on aerial photography

Chapter 1: ICE INJURY AND RECOVERY FROM ICE STORMS IN THINNED AND UNTHINNED TREATMENTS

LITERATURE REVIEW

Ice Storm of 1998

In January, 1998 a severe ice storm struck the northeastern United States and parts of southeastern Canada (Bangor Daily News 1998a). Witnesses described it as the worst storm on record for the northeast. The storm began in the northeast on January 5, 1998, when a stationary, low-pressure system in the area met with a warm, moist air mass that moved from the southeast into New England and eastern Canada. These two meteorological events, along with freezing ground temperatures, resulted in ice loading. Ice loading, a layered accumulation of ice, was caused by moisture from the air mass falling as rain and freezing on contact with supercooled objects on the earth's surface. Trees, roads, and power lines were covered with ice until January 10. On January 12, strong winds caused additional damage to trees still laden with ice. The weather did not moderate until January 23 (Miller-Weeks et al. 1999).

According to the North East State Foresters Association (NEFA), a total of 17 million acres of forestland in New York, Vermont, New Hampshire, and Maine were affected by the ice storm (Miller-Weeks et al. 1999). Natural resource losses were estimated to exceed $1 billion (NEFA 1998). In Maine alone, 11.3 million acres of forested lands located in the southern half of the state were affected and approximately 58 % (6.5 million acres) were classified as having moderate to severe damage (Bangor Daily News 1998b). While damage assessments noted that forest injury was patchy and highly

variable, estimated cost of standing timber losses without salvage operations was thought to exceed $300 million (Maine Forest Service 1998).

Unlike New Hampshire, Vermont, and New York, a banded pattern of damage occurred in Maine. Forest areas in York, Cumberland, and Lincoln counties had little to no damage, whereas counties to the north were moderately to severely damaged. These counties included Oxford, Sagadahoc, Kennebec, and Franklin. Moving further north, damage levels again became trace/light. Among the northern counties lightly affected were central Penobscot, Somerset, and southern Piscataquis.

The species most seriously damaged in Maine were American beech (*Fagus grandifolia* Ehrh.), yellow birch (*Betula alleghanienses* Britton), and paper birch (*Betula papyrifera* Marsh). The average crown loss for all species in Maine was 19%. Average crown loss in damaged areas in Maine was 46%. Seventeen percent of trees sampled were categorized as heavy to severely damaged (Miller-Weeks et al. 1999). Fifty percent of the trees surveyed were not damaged. Distribution of ice accumulation was between 100 and 1,200 feet elevation with some ice loading up to 2,400 feet, although the same study noted later that no elevation trend was apparent for Maine (Miller-Weeks et al. 1999). Irland (1998) suggested ice damage was greater in quantity and severity on higher elevations. Damage was heaviest on northeast to southeast slopes, as they received less sunlight following the storm (i.e. branches held ice loads longer) (Irland 1998).

General Ice Storm Characteristics

Ice storms are frequent occurrences in the eastern and north-central regions of the United States and commonly occur in the southeast. Formation occurs when a warm, moist air mass moves above or behind a cold air mass. Precipitation falls from the warm air mass, and freezes on the Earth's surface due to low temperatures resulting from the cold air mass (Bennett 1959, Lemon 1961, Geiger 1965, Baldwin 1973). Damage from ice storms is a result of ice loading or glaze. Glaze is defined as "a clear layer of ice formed by super-cooled water freezing on the surface of objects" (Smith 2000) and tends to form radially around forest objects such as twigs, branches, leaves, and boles (Lemon 1961). Thickness of glaze is dependent on drop size, temperature, and rate of fall of precipitation, as well as, temperature, humidity, and wind velocity of ambient air (Bennett 1959).

These disturbances are recognized as severe impacts to forest areas due to their highly destructive nature as a result of glaze. Generally, glaze load is minimal, from trace to 1 inch, but accumulations can reach 5 inches (Bruederle and Stearns 1985). Ice storms can increase canopy weight by 100-fold (Lemon 1961) and twig weight by 30-fold (Rogers 1923). Estimates have suggested that a tree 45 feet tall, with an average crown width of 18 feet, can accumulate 4.95 short tons of glaze during a severe ice storm (Oliver and Larson 1996). In 1900, Hermann von Schrenk noted that ice events only occurred at "very great intervals of time" in the mid-west. However, "Weather Bureau climatological data between 1900 to 1960 for the eastern United States indicate an average of two significant ice events per decade for northern New England, four for southern New England, seven for the mid-Atlantic, eight for the Midwest and one for the

southeast" (Irland 1998; Smith 2000). These disturbances have a frequency interval of 20 to 100 years, whereas other major disturbances such as fire and windstorms, have return intervals of 100 to 1000 years (Henry and Swan 1974; Lorimer 1977; Bormann and Likens 1979; Irland 1998). Therefore, ice storms occur more often and are more frequent than destructive forces of similar magnitude. Many small ice storms can go unreported or unrecognized, due to the absence of moderate to severe damage and/or small extent (Siccama et al. 1976).

While the ice storm of 1998 was characterized as a 100-year event (NEFA 1998), ice storms are very common in some areas. For example, from 1884 to 1959, a 75-year period, New York had 11 major ice events (Lemon 1961).

Ice Storm Injury

Injury to trees occurs when ice adds excessive weight to branches of individuals (Warrillow and Mou 1999). Damage includes branch and bole breakage involving all or part of the tree canopy. Uprooted individuals and bent trees are also common. Damage tends to vary among species and sites. Injuries from ice storms could facilitate fungal infections, decay, and tree death (Melancon and Lechowicz 1987). Individuals that lost less than 50% of their canopy were likely to survive the injury, whereas trees that lost 50 to 75% of their crowns can recover, but will likely experience recovery at a slower rate than trees which have less than 50% injury. In addition, the individuals in this injury class may have higher incidences of infestation of organisms that cause decay and discoloration. Individuals that lost more than 75% of their crown were not expected to recover (Cox 1998; Shortle et al. 1998; Miller-Weeks et al. 1999). This was the most

severe type of damage and usually resulted from broken tops or main branches. Larger, mature trees were prone to this damage type (Ostrofsky 1998b). Research suggests that trees with broken tops die within 4 years of damage (Steinman and O'Connell 1998). It should be noted that some living trees form scars from disrupted bark tissue. The disruptions are caused by tension or compression effects of the glaze accumulation, or by the cutting action of ice. In any event, these scars are not thought to create serious consequences to the tree (Lutz 1936).

Damage Variables

Smith (2000) recognized four situations of high risk for adverse forest health: exotic stress agents, exotic trees, human cultural activities, and climatic extremes. In the climatic extreme category lies "frosts, floods, high wind events, droughts, fires, wet snow, and hail, and includes ice (glaze)". A number of factors in three broad categories, storm level, tree level and stand level variables, determine storm severity and damage level for ice storms. Storm variables included ice load and wind direction/velocity. Tree level factors include species/branching pattern, position in canopy, tree size, age and pre-existing decay. Topography (aspect and percent slope), proximity to large water bodies, and previous management activities are included in the stand level category (Abell 1934; Lutz 1936; McCullough 1943; Lemon 1961; Cool et al. 1971; Whitney and Johnson 1984; Bruederle and Stearns 1985; Ostrofsky 1998a; Miller-Weeks et al. 1999; Smith 2000). Most studies showed no relationship between damage and wood specific gravity and modulus of rupture (MOR) (Lemon 1961; Bruederle and Stearns 1985; Warrilow and Mou 1999), although Cameron and Dunham (1999) found otherwise. A study conducted

by Cameron and Dunham (1999) found that overturned or snapped trees were bending more than undamaged trees due to their low modulus of elasticity (MOE). The capacity to accumulate ice until the branch or bole reaches its bearing capacity, is crucial however (Lemon 1961; Hauer et al. 1993). Wood strength also varies considerably with moisture, soil conditions, and growing space (Bruederle and Stearns 1985).

Storm Level Variables

Ice Load

As ice loads increase, damage tò forest areas increase. Several studies noted this relationship (Bruederle and Stearns 1985; Seischab 1993; Warrillow and Mou 1999). Trees are not able to bend and sway with heavy ice loads. This increases their susceptibility to damage. It should be noted that most literature on ice storms has been generated after catastrophic levels of damage occur. Therefore most, if not all articles were written about major storms and all reported relatively severe levels of damage.

Wind Direction/Velocity

Boerner et al. (1988) noted that the southwesterly winds probably created the heavy damage on southwestern aspects in a 1986 Ohio ice storm. Shephard (1975) noted that light winds were present during a 1973 North Carolina ice storm and heavier winds would have caused more damage. The 1976 ice storm of Wisconsin had wind speeds of 48 miles per hour and this factor was responsible for most of the damage (Bruederle and Stearns 1985).

Tree Level Variables

Species/Branching Patterns

Damage also varies according to species and branching pattern. The coniferous species tend to suffer less damage due to their canopy shape (Buttrick 1922; Abell 1934; Downs 1938; Deuber 1940; Bennett 1959). The excurrent (pyramidal) growth form is conducive of minimizing or eliminating branch breakage and ice accumulation (Smith 2000). Irland (1998) noted softwoods suffered less damage than hardwoods in the 1998 storm, although exceptions were recognized such as larch (*Larix laricina (*Du Roi) K. Koch), which suffered broken tops, branches and main stems. Red pine (*Pinus resinosa* Ait.) and eastern white pine (*Pinus strobus* L.) experienced light damage with a few instances of broken tops and bent boles. Paper birch was reported as severely damaged with bent tops and broken branches and was probably the species most affected by ice accumulations due to its fine branching pattern and limber stems (Irland 1998; Vicary 1998; Smith 2000). Aspen (*Populus* spp.) suffered similar damage as birch, though most of the individuals were characterized by broken branches and tops, rather than bending. Red maple *(Acer rubrum* L.) and sugar maple *(Acer saccharum* Marsh.) were severely damaged in some areas, while oak (*Quercus* spp.) sustained only light to moderate damage (Irland 1998; Smith 2000). Ash (*Fraxinus* spp.) suffered from broken branches and stems (Vicary 1998). While glaze may create severe damage in one species, it may induce slight damage in another (Campbell 1937). Researchers of other storms have noted damage differences among species (Campbell 1937; McKellar 1942; Siccama et al. 1976; Whitney and Johnson 1984; Melancon and Lechowicz 1986; Rebertus et al. 1997; Boerner et al. 1988; Warrillow and Mou 1999).

Position in Canopy

Trees species that are shade tolerant and grow under a previously established canopy are less vulnerable to damage from ice storms (Carvell et al. 1957; Rebertus et al. 1997). Boerner et al. (1988) noted understory trees suffered less damage than overstory trees. This is due to the protective canopy above the understory that intercepts the precipitation before it reaches the sub-canopy layers and decreased wind speed associated with a lower canopy position (Seischab 1993). Dominant and codominant species that grow in the upper canopy layer can be severely damaged. This is due to their increased exposure to ice loading and high winds. Warrillow and Mou (1999) found that dominant canopy individuals "generally had less ice damage than co-dominant and intermediate individuals".

Tree Size

The relationship between tree size and damage involving breakage is not always clear, although Boerner et al. (1988) did note that susceptibility was positively correlated with diameter at breast height (DBH). Downs (1938), Rebertus et al. (1997) and Seischab (1993) found similar results. Sapling- and pole-sized trees were prone to bending damage from heavy ice loads. This type of damage was noted in other ice storms as well (Abell 1934). Irland (1998) and Smith (2000) reported sapling-sized trees that undergo bending as a result of ice loading, may or may not recover. The amount of recovery depends on tree species and site. Trees that did not recover from this damage type, were more vulnerable to high winds, heavy snow loads, and uprooting. Many trees

lost smaller or secondary branches. This was the least damaging type of injury and usually did not result in loss of the individual, unless more than 75% of the tree canopy was removed (Ostrofsky 1998b). For larger, pole-sized trees, ice accumulations caused damage below the crown, which resulted in sprouting or even mortality. Again the result depends on the species, but generally larger trees suffer from broken branches and boles while smaller, pole-sized trees tend to bend rather than break.

Age/Decay

Wounds from broken branches often serve as a point of entry for decay, fungi and insects (Abell 1934; Irland 1998; Smith and Shortle 1998). For example, the three major hardwood species, sugar maple, yellow birch, and beech, could become infected with *Armillaria* root disease. Root diseases are secondary problems after the initial ice damage. Decay was more common in older trees and was a factor in degree of damage (Downs 1938, Smith 2000). Older, mature trees had a greater risk associated with injury (Hauer et al. 1994). Boerner et al. (1988) found direct damage was positively correlated with tree age. Potentially, older trees could lose larger branches. Studies suggest that injuries greater than 50 square inches have a high probability of developing decay (Ostrofsky 1998b). In addition to branch loss, other ports of entry for diseases and insects occurred, such as sunscald and branch lesions (Spaulding and Bratton 1946; Smith 2000). The spread of stain and decay is dependent upon species, size and position of wound, tree vigor, and local pathogens and insects (Shigo 1985). Decay of live trees was of special concern to landowners with future timber harvests in mind.

As the age of a tree increases, the susceptibility to ice damage increases (Bennett 1959; Boerner et al. 1988). Miller Weeks et al. (1999) found that trees with a larger DBH have a greater chance of incurring some type of damage than smaller trees. Two reasons may explain this: (1) heavier build-up of ice in large canopy trees or (2) branches in larger trees are more susceptible. This increase of susceptibility may be due to an increase in the numbers of unsound limbs as a tree ages (Seischab 1993). In addition, Campbell (1937) noted that decay was influenced by relative proportions of heartwood and sapwood present at the time of injury. In a live tree, heartwood is more susceptible to decay than sapwood. Therefore, older trees with greater amounts of heartwood are more susceptible than younger trees.

Stand Level Variables

Topography

Topography determines where the ice accumulations are greatest. Understanding climatic factors and related changes allowed researchers to explain subtle, yet important, differences in ice accumulations.

Aspect affects ice damage on trees (Downs 1938; Bennett 1959). However, this effect can vary greatly from site to site. Most studies however, conclude that individuals on east or northeast-facing aspects had greater damage then those on other aspects (Downs 1938; Seischab 1993; Rebertus et al. 1997; Irland 1998; Warrillow and Mou 1999). This pattern is undoubtedly associated with wind speed and direction. In addition, colder microclimates such as depressions, drainages, and higher elevations are associated with heavy damage (Abell 1934; Downs 1938; Boerner et al. 1988; Seischab

et al. 1993). Some studies did suggest otherwise. For example, Boerner et al. 1988 found that a study site in Ohio had more damage on SW slopes and valley bottoms, but it was not significant in predicting susceptibility. Damage patterns tended to occur on NE aspects more so than on other aspects, but this relationship was not pronounced.

As slope increases, damage to trees tends to increase (Warrillow and Mou 1999), although exceptions have been reported (Rebertus et al. 1997). Damage to trees on slopes, may present itself in several ways. First, trees living on slopes tend to have asymmetrical crowns, which allows for more ice loading on one side. In addition, the chances of uprooting and bending are greater on slopes (Downs 1938; Bruderle and Stearns 1985; Seischab et al. 1993).

Proximity to Large Water Bodies

Downs (1938) stated that sizable bodies of water may decrease glaze damage in their vicinity. The slight temperature change caused by a body of water warmer than the air temperature, can minimize or eliminate ice accumulations, but can also increase ice accumulations if the temperature of the water is near freezing and the ambient temperature is not.

Previous Management Activities

Improvement cuttings can reduce the amount and extent of damage on forest stands (Illick 1916). Cuttings that remove poor quality and diseased individuals, reduce the amount of trees that will be affected by ice accumulations and also reduce secondary damage within the stand.

Recovery

Tree recovery is dependent on the degree of damage. Mature trees will allocate carbon to dormant buds and new branches in order to increase foliage and canopy density (Irland 1998; Smith and Shortle 1998; Smith 2000). This will allow the tree to minimize loss in growth that is expected after the destruction of crown and major branches. However, the increase of nutrients to these sites will cause a decrease in carbon allocations to other areas such as roots and stems. With this reallocation of resources, comes increased susceptibility to soil moisture stress, insects and diseases (Irland 1998). If an individual that suffered from loss of branches or top, became infected with a pathogen, it will attempt to compartmentalize the affected area with a barrier zone, and prevent the spread of the pathogen (Smith and Shortle 1998). However, compartmentalization can be threatening to trees if the pathogen-affected area is large. Compartmentalization can reduce the storage space used for energy reserves. If the new storage space created after injury is greater than that compartmentalized, the tree can survive (Shigo 1985). Trees in thinned or edge location were thought to recover better than those in denser situations, as the allocation of resources was distributed among fewer trees.

Studies have shown that trees can recover from a severe ice storm (De Steven et al. 1991). Bruederle and Stearns (1985) found that a forest in southern Wisconsin, lost 35% of its canopy from an ice event, but 8.3% of the canopy loss was regained within one year of the ice storm.

Several reports of ice storms have occurred throughout the eastern United States. Research was conducted in the following states/countries: Canada (Melancon and Lechowicz 1986; Chabot et al. 1998), Maine, New Hampshire, Vermont (Irland 1998; Ostrofsky 1998a; Miller-Weeks et al. 1999), New York Downs 1938; Spaulding and Bratton 1946; Lemon 1961; Seischab et al 1993; Miller-Weeks et al. 1999), Connecticut (Siccama et al. 1976), Wisconsin (Rogers 1922; Bruederle and Stearns 1985), Michigan (Rogers 1923; Pennsylvania (Downs 1938; Lemon 1961), Missouri (Rebertus 1997), West Virginia (Carvell et al. 1957), Ohio (Spaulding and Bratton 1946; Boerner et al. 1988), Virginia (Whitney and Johnson 1984; Amateis and Burkhart 1996; Warrillow and Mou 1998;), North Carolina (Abell 1934; Della-Bianca and Beck 1977), Georgia (McKellar 1946; Belanger 1996) and Louisiana (Shephard 1975). Most were an initial assessment of short-term impacts such as injury types and species affected. Some noted storm characteristics and potential management options. These studies were invaluable in their findings, but focused on damage, rather than injury in terms of survival, recovery, vigor, and growth (Shortle et al. 1998). Nine studies (Downs 1938; Muntz 1947; Boggess and McMillan 1954; Carvell et al. 1957; Cool et al. 1971; Shepard 1975; Della-Bianca 1977; Amateis and Burkhart 1996; Belanger et al. 1996) have researched thinnings in relation to ice damage (six studied softwoods and three studied hardwoods), but none following the severe ice storm of 1998.

Thinnings

Research has suggested that some forest management practices such as thinnings and partial harvests, often create conditions that increase a stand's susceptibility to ice

damage (Downs 1938; Muntz 1947; Boggess and McMillan 1954; Carvell et al. 1957; Cool et al. 1971; Shepard 1975; Della- Bianca 1977; Amateis and Burkhart 1996; Belanger et al. 1996). Forest thinnings are a type of harvest operation called intermediate cuttings. Intermediate cuttings occur during the developmental stages of stand growth, with the purpose of improving the existing stand, regulating its growth, and allowing for early financial returns, without any effort directed towards stand reproduction. Thinnings are defined as intermediate cuttings aimed "at controlling the growth of stands by adjusting stand density" (Smith 1986). When a thinning occurs, the resources are allocated to fewer trees, thus improving conditions for growth.

In 1996 an ice storm study was conducted in central Georgia. Belanger et al. (1996) analyzed two loblolly pine plantations that were impacted by a 1983 ice storm. Each unthinned plantation contained areas that were thinned, so comparisons between trees in thinned and unthinned areas could be made. Results showed that damage was greatest in the thinned stands. Within the first year following the storm, marked reductions were noted in radial growth of damaged trees. Individuals that suffered severe damage did not totally recover during the five year period following the storm. Allocating resources to crown regrowth seemed to take priority over lower stem growth. Damage to thinned areas can offset the gains that occur after a thinning and "total mortality and top breakage were greatest in thinned plots". Also, no statistical differences in average DBH and stem taper for trees damaged or not damaged were noted. However, a significant relationship between tree height and damage was recognized. Taller trees, averaging 48.2 feet, were more damaged than shorter trees averaging 46.9 feet. Belanger et al. (1996) suggested these results were due to open,

thinned stands being "obviously more susceptible as ice forms on the crown". In addition, damaged trees were more sensitive to environmental stresses than undamaged trees.

As for management recommendations, the forest damage from ice storms associated with thinnings could be reduced if thinnings were light, frequent, and occur early in the life of the stand. Since the ice storm of 1983 was considered average (i.e. the windspeed, ice accumulation, etc. were similar to the averaged parameters of other storms), the author noted that severe ice storms may be impossible to manage for, but fortunately, were rare.

Of nine studies that researched thinning and spacing effects in thinned and unthinned treatments, only three focused on hardwood species. The following describes the size coniferous Amateis and Burkhart (1996) looked at four damage/forest relationships involving 1994 ice storm damage in a central Virginia loblolly pine spacing/density study. The four relationships were: (1) damage severity of stems and stand density, (2) damage severity of tops and stand density, (3) spacing intervals and damage, and (4) forked stems and damage severity. Results showed no significant differences in stem damage at various densities, top damage at various densities, and damage severity among several rectangular spacings. Since the paired t-test value for the fourth relationship studied was 6.5 the authors were able to reject their fourth Ho hypothesis that stated "trees with forked stems are not likely to suffer more top breakage than trees with single stems". Suggestions for management options included removing forked trees that are more vulnerable to ice damage.

Another interesting point mentioned in this paper involved the severity of the storm itself. It seems the authors felt that when a severe ice storm damages the forests in an area or region, much damage will occur over the area regardless of the stem density or spacing. However, the effects of a mild ice storm may allow for more predictable damage that follows certain relationships such as those studied.

Two studies conducted at the North Louisiana Hill Farm Experiment Station provided data on the relationship between ice damage and stand density. Shepard (1975) concluded that the number of damaged trees was greatest in heavily thinned plantations, but "trees in heavily thinned stands suffered light damage because they had sufficient time to respond to the thinnings before the storm struck". Average height loss and crown loss were greatest in the densest stands, and decreased as stand density decreased.

Studies of shortleaf and loblolly pine plantations in southern Illinois found that thinned stands were not damaged as severely as plantations that were unthinned. The thinning had removed weak and poor quality trees and the trees that remained were strong enough to withstand the storm. The authors mentioned that a heavy thinning may increase susceptibility, but were unsure of the exact spacing most effective for reducing damage (Boggess and McMillan 1954).

In 1944 and 1947, an ice event occurred in central Louisiana. Muntz (1947) studied the effects of the storm on three types of pine: loblolly, slash, and longleaf. Severe damage was noted in dense and open-grown stands, although the percentage of damaged trees was thought to be greater at higher densities. In addition, timber managers were advised to thin stands lightly and take the smaller trees. Commercial cuttings of

large trees in a plantation with large and small trees, may redirect damage from later ice storms to smaller trees.

South Carolina was affected by a severe ice storm in February 1969. Based on foresters' surveys and plot measurements, information was compiled by species and damage classes (Cool et al. 1971). Of the 24 surveys returned, nine respondents indicated that denser stands had less damage, while seven noted that higher densities produced greater damage. In addition, the study noted that "open grown trees showed good resistance" while "recently thinned stands of close-grown trees had maximum damage" (Cool et al. 1971).

The six aforementioned studies discussed damage in terms of conifers only. Most studies focus on this tree group rather than hardwoods. However, the ice storm of 1998, affected hardwoods more than softwoods (Miller-Weeks et al. 1999). Three studies have focused on ice damage and the effects on hardwood forests.

Yellow poplar was found to recover quickly from a 1969 ice event in western North Carolina (Della-Bianca and Beck 1977). No clearly discernable relationship between crown damage and stocking or intensity of thinning was found. Dense stands suffered the least amount of damage, but heavily thinned stands did not suffer the most damage; rather, intermediately stocked stands suffered greatest by the ice accumulations. Average annual radial growth for the damaged trees before the ice storm was 0.25 inches per year. Following the ice storm, growth in damaged trees slowed to 0.20 inches per year, for an approximately 21% decrease in growth due to damage. The incremental growth of undamaged individuals after the disturbance event was greater than before the event. For example, 30 trees were measured that had no apparent ice injuries. Their

growth rate was 114 % of the pre-storm rate. With the increase and decrease of growth rates, the average decrease for the stand was 35%.

Measurements of dry weights for leaves by plots were obtained before and after the storm. Weights taken one year after the storm were 90% of the pre-storm value and were 96% of weights taken two years after the storm. This recovery was thought to be a result of epicormic branching.

While most individuals formed new terminal leaders after they were lost due to heavy ice loads, most trees had not completely regained their previous height status. Most damaged trees were still five to ten feet short of pre-storm height measurements.

In a study conducted in New York, older, second-growth stands which had been thinned were found to have suffered 15% more damage than the unthinned stands. The author noted that this was a very important finding. The study went on to conclude that significant trends in basal area and ice injury were not noted in either young growth or second growth stands (Downs 1938).

A 1957 study of an ice storm in the southern Appalachians suggested that thinned stands were more prone to ice injury than unthinned stands. Crown thinning plots were studied to determine the effects from various levels of thinning. Results indicated that as thinning intensity increased, injury increased. Hardwood stands which had less than 30% of the volume removed suffered much less than those stands that were thinned more heavily. Carvell et al. (1957) also noted that even-aged management is more desirable than uneven-aged management because trees in even-aged stands receive more support from neighboring trees and were less likely to be injured.

Density of the forest stand played a large, though somewhat inconsistent, role in determining damage type and severity of the 1998 ice storm. Visual observations made by foresters and landowners following the 1998 disturbance suggested that thinned areas and areas near forest edges were damaged more than their unthinned counterparts. Thinned stands have less inter-tree support than unthinned, denser stands (Ostrofsky 2000).

However, these observations may incorporate a personal bias. For example, it seems likely that a managed forest will have more visits by people than unmanaged stands and during these visits the landowner would begin to develop an accurate description of the area including past damage, stand composition, and changes occurring within the stand. Characteristics of individual trees may even be recognized. Foresters and landowners may recognize damage in these stands, since more time and effort have been involved in their maintenance. Thinned stands are visited by landowners, whereas unmanaged stands may have little to no human interference. Therefore, it is plausible to say that damage in these areas would be more noticeable than the damage in unmanaged stands, thus creating personal bias (Ostrofsky 2000 pers. communication).

METHODS

Ice Injury and Recovery

Field Sites

In summer of 2000, four sites were chosen in western Maine for study. Each site was characterized as having moderate to severe injury as a result of the ice storm of 1998. Sites were chosen based on thinning history. Thinned areas located adjacent to unthinned areas was a requirement for all sites; therefore soil type, slope, aspect, and elevation were similar for thinned and unthinned areas for a particular site, but not across all sites. Only pre-storm dominant and co-dominant trees were measured because these individuals were severely affected by the ice storm.

Species Selection

Hardwood species for study were chosen based on availability at each site. Softwood species were not measured because they were not frequently injured as a result of the ice storm of 1998. Each site had two species measured except for site 1, where only one species was abundant. White ash (*Fraxinus americana* L.) was measured at site 1, paper birch, and red oak (*Quercus rubra* L.) at site 2, paper birch and red maple at site 3, and red maple and American beech at site 4. Twenty-five trees of one species were chosen in the thinned area at each site and 25 in the unthinned area for a total of 50 trees measured for each species; because two species were measured at each site, 100 trees were measured in total at each site. However, two exceptions existed. For example, because only one species was available at site 1, 84 trees were measured. Also, 106 trees

were sampled at site 2, instead of 100. Twenty-five trees were measured from each of the thinned and unthinned areas because this sample was considered high enough for statistical analysis but was low enough that all trees could be sampled within one field season.

Species Measurements

Several damage and recovery variables were measured and recorded for each tree, along with tree number, species, DBH, and height. Damage variables included pre- and post-storm crown class, percent crown loss, and number, size, and location of broken branches. It should be noted that broken branches above approximately 0.5 inches in diameter were recorded along with their location on the tree. Locations were recorded as 1 for a primary branch, 2 for a secondary branch and so on. Size and location of broken branches was recorded to ensure that the same types of branches were being measured in both thinned and unthinned stands. Pre- and post-storm crown classes were open, dominant, codominant, intermediate, and understory. Crown class data were analyzed by assigning a number to each class. For example, the open class was assigned a "1" and the dominant class was assigned a "2". By converting crown classes to numbers, the data could be analyzed statistically using t-tests. The data values reported for crown classes are not whole numbers, which seems to suggest that a tree could be in both classes. However this is not true. For instance, a crown class of 1.5 does not suggest that the trees in the treatment were half way between open and dominant canopy positions. Rather it suggests that about half the trees were in the open class and the other half were in the dominant class.

Broken branches were measured on all trees, but those individuals that had 96% to 100% of their crowns damaged were eliminated from the analysis. The actual number of broken branches could not be determined for these trees because their tops were removed. Including individuals with broken tops in the analysis would result in a lower estimate of broken branches.

Recovery variables included transparency rating (i.e. percent of crown that masked sunlight), number, height, and location of sprouts and a shigometer reading for each tree. The shigometer is an instrument that can give information about a tree's vigor. It delivers a pulsed electric current through the instrument's probe to the point of contact in the wood tissue (cambial layer) and measures the resistance of the layer in kohms. The median value for each species is determined and used as a baseline for comparing the remaining values. Trees with shigometer values below or at this baseline are considered vigorous; trees with shigometer values above this baseline are considered less vigorous (Osmose Wood Preserving Company 1980). In addition, increment borer samples were collected from each tree to examine recovery following the ice disturbance. Samples were not taken to the pith, but were to the most recent 10 to 20 years of growth. Each tree position was recorded using a Global Positioning System (GPS). Numbers were also written on all trees with a blue paint stick for later identification.

Global Positioning System

The position data collected was downloaded from the GPS receiver using Pathfinder software package. This data was exported as an ArcView shape file and imported into ArcView Version 3.0b (Environmental Systems Research Institute, Inc.

1997). The shapefiles were opened in ArcView as themes (i.e. a map associated with a database containing information about features located on the map) and several other files were automatically created by ArcView, one of which is called a .dbf file (database file). The .dbf files associated with the theme were opened in Excel, proofed and edited.

Statistical Analysis

Statistical analysis was performed on the data collected. Basic t-tests and two-way analysis of variance (ANOVAs) were performed in SYSTAT Version 9 software (SYSTAT, Inc. 1998) to compare averages of variables at each site, for each species and for all sites together.

The increment borer samples were measured using two methods. The cores that had easily distinguishable rings were read and distances between them measured with WinDendro ™ software. This method scans the image of the core tray and attempts to place markers between each year's ring of growth. The user adjusts the markers for a more precise measurement of each growth ring. The tray images can then be saved. In addition, the software package saves the distance measurements between growth rings into a spreadsheet. The Velmex measuring system, along with Measure J2X measuring software were used to determine distances between growth rings that were difficult to distinguish. SYSTAT was then used to analyze the data statistically.

RESULTS

Differences Between Stand Treatments

Specific site characteristics are given in Table 1.1. The results of t-tests for basal area, DBH, and height by treatment (thinned or unthinned) indicate that significant differences between thinned and unthinned stands exist (Table 1.2). These differences were necessary for this study. For example, basal areas between the two treatments were significantly different ($p<0.001$). In addition, basal area for thinned and unthinned areas at each site was different (Table 1.3). A difference in basal area was necessary to look at the specific effects of thinning. DBH was not significantly different between the two treatments ($p=0.714$); however, height was significantly different between the two treatments ($p=0.009$).

Overall Statistics

Figure 1.4 presents the overall means and standard deviations for all measured variables. The average crown class for the trees did not change as a result of the ice disturbance. Rather, the crown class after the storm, was the same as before the storm. However, it should be noted that the standard deviation increased from the pre-storm estimate of 0.601 to 0.994. Miller-Weeks et al. (1999) reports values for some of the same measurements, as well.

Most variables had large standard deviations including average percent crown loss, number of broken branches, transparency, number of sprouts, and the shigometer values.

Table 1.1. Characteristics for each field site.

Site	Location (ME)	County	Slope (%)	Aspect
1	Belgrade	Kennebec	10-15	east
2	West Sumner	Oxford	12	east
3	Greenwood	Oxford	15	south -southeast
4	Oakland	Kennebec	5	east -southeast

Site	Elevation (ft)	Age of Stand (years)	Year Thinned	Soil Type *
1	300	70 - 80	1996	SkB
2	920	35 - 40	1992-1993	LWD & LXC
3	800	app. 35 - 40	app 1996-1997	MXC & STD
4	425	app. 35 - 40	1997-1998	BkB

*see Appendix A for soil type descriptions

Treatment

Table 1.5 shows means and standard deviations by treatment for the four study sites combined, as well as p-values and significance. No significant differences occurred across treatments in terms of percent crown loss, numbers of broken branches, pre-and post-storm crown classes, percent transparency and shigometer values.

Table 1.2. T-tests for stand characteristics between thinned and unthinned stands.

Treatment	Statistics	Basal area (sq. ft./acre)	DBH (inches)	Height (feet)
Thinned	Mean	54.71	8.94	52.55
	St. Dev.	27.87	3.31	16.90
Unthinned	Mean	125.56	8.82	57.16
	St. Dev.	41.05	3.10	17.86
	p-value	0.000	0.714	0.009
	significant at alpha = .05	yes	no	yes

Table 1.3. Basal area for sites according to treatment.

Site	Treatment		Basal area (sq. ft./acre)	p-values	significance
1	Thinned	mean	83	0.694	no
		st. dev.	25		
	Unthinned	mean	93		
		st. dev.	32		
2	Thinned	mean	48	>0.000	yes
		st. dev.	18		
	Unthinned	mean	142		
		st. dev.	26		
3	Thinned	mean	35	>0.000	yes
		st. dev.	26		
	Unthinned	mean	146		
		st. dev.	25		
4	Thinned	mean	60	0.364	no
		st. dev.	29		
	Unthinned	mean	88		
		st. dev.	57		

Table 1.4. Means and standard deviations for all damage variables of the four study sites combined.

Statistic	Basal Area	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
mean	91.14	8.88	54.90	2.04	2.25
st. dev.	49.99	3.20	17.53	0.60	0.99

Statistic	Average Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer values (kohms)
mean	30.77	3.22	69.00	8.61	10
st. dev.	33.12	2.87	23.60	11.41	4

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Site

Variable means, standard deviations, p-values, and significance are shown in Table 1.6 for site 1. It should be noted that crown loss for site 1 was nearly identical for thinned and unthinned stands. Pre- and post-storm crown classes for thinned and unthinned areas were significantly different for site 2 (p=0.006 and p=0.006 respectively) (Table 1.7). For site 3, percent crown loss was significantly different between thinned and unthinned areas, but number of broken branches was not significant (p=0.048 and p=0.005 respectively) (Table 1.8). According to percent crown loss mean values, the thinned area had greater ice injury than the unthinned area. DBH and shigometer values were significantly different between the management areas at this site. In addition, the tree diameters were smaller in the thinned area, compared to the unthinned area. Shigometer values suggest that individuals in the thinned area were more vigorous than

trees in the unthinned area (i.e. the shigometer values were lower for trees in the thinned stands). Site 4 had two variables that were significantly different between management areas (Table 1.9). For example, the unthinned area had significantly more trees in the open crown class than the unthinned area for the pre-storm crown class variable ($p=0.047$). Also, the thinned area trees' were significantly more vigorous than the unthinned treatment as indicated by the shigometer values ($p=<0.001$).

Species

Based upon percent crown loss values, of the five species measured, paper birch sustained the most crown damage, whereas American beech sustained the least amount of damage (Table 1.10). Only heights were significantly different for white ash ($p=0.004$) (Table 1.11).

Pre-storm crown classes for paper birch were significantly different when comparing trees from thinned and unthinned areas ($p=0.035$) (Table 1.12). While both management treatments had the majority of their trees in the dominant class, the thinned stand had more trees in the open class. Percent crown loss was also significantly different between thinned and unthinned areas for paper birch. For example, average crown loss for the thinned area was 50.84%, while crown loss was 28.99% for the unthinned area. This created a significant difference between the two values ($p=0.007$). Numbers of broken branches between management treatments did not significantly differ. In addition, paper birch had significantly different shigometer values for thinned and unthinned areas with the thinned area being more vigorous ($p=0.011$).

Table 1.5. T-tests for all variables by treatment for all study sites.

Treatment	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
Thinned	mean	8.94	52.55	2.00	2.20
	st. dev.	3.31	16.90	0.70	1.13
Unthinned	mean	8.82	57.16	2.09	2.30
	st. dev.	3.10	17.86	0.48	0.84
	p-value	0.710	0.009	0.120	0.340
	significant at alpha = 0.05	no	yes	no	no

Treatment	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
Thinned	mean	52.00	3.29	67.00	8.58	10
	st. dev.	49.00	3.21	25.00	11.55	5
Unthinned	mean	45.00	3.16	71.00	8.65	11
	st. dev.	43.00	2.54	22.00	11.31	4
	p-value	0.116	0.697	0.130	0.960	0.103
	significant at alpha = 0.05	no	no	no	no	no

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Measurements of red oak at site 2 indicated that both pre- and post-storm crown classes significantly differed between the management treatments (p=0.028 and p=0.037 respectively) (Table 1.13). Both crown classes consisted mostly of dominant individuals, but the thinned stands had more "open" individuals than the unthinned areas.

Red maple had a significant difference of shigometer values between thinned and unthinned stands (p=0.015) (Table 1.14). The individuals in the thinned stand were more vigorous than the unthinned stand. The same was true for the American beech (p=0.007) (Table 1.15).

Site and Species

The height variable was significantly different at site 1 (p=0.004) (Table 1.16). T-tests for variables at site 2, using values for paper birch only, indicated that both thinned and unthinned areas contained individuals that were mostly in the dominant post-storm crown class (Table 1.17). However, the unthinned area had more individuals in the codominant class than the thinned area. Red oak at site 2 had significantly different crown classes before and after the ice disturbance (p=0.028 and p=0.0037) (Table 1.18). For both crown class variables, the thinned stands had more "open" individuals than the unthinned area. All other t-tests for red oak were not significantly different.

Red maple at site 3 had only one variable that was significantly different between the two management treatments (Table 1.19). The number of broken branches was significantly different with the thinned area having fewer broken branches per tree than the unthinned area (p=0.011). The paper birch at site 3 had several variables that were significantly different between the two management treatments (Table 1.20). For

example, DBH in the thinned area was on average smaller than in the unthinned area. This could be due to selection of larger trees during the thinning process or better site quality in the unthinned area. Post-storm crown classes were significantly different with the thinned area having more trees in the co-dominant class than the unthinned area ($p=0.004$). Percent crown loss was significantly different with 68% crown loss in the thinned stand, while only 34% crown loss was measured for the unthinned stand, although there was very little difference between the actual numbers of broken branches ($p<0.001$). Percent transparency supports the large difference in crown size between the two areas. The thinned area had 43% transparency while the unthinned area had 64%. However, the average shigometer value was significantly lower in the thinned stand (10), indicating more vigor than the unthinned area (12) ($p=0.013$).

For site 4, the red maple had two significantly different variables (Table 1.21). The tree diameters in the thinned stands were significantly larger than those in the unthinned stand ($p=0.016$). This could be due to the release effect that occurs after a stand is thinned or it could be due to better microsite conditions. Also, the shigometer values were significantly lower for the thinned stand, indicating a higher vigor ($p=0.010$). The American beech at site 4 had one significant variable- shigometer values (Table 1.22). Again, the shigometer values for the thinned area were lower than those on the unthinned area ($p=0.007$).

Table 1.6. T-tests for all variables for site 1, Belgrade.

Site	Treatment	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
1	Thinned	mean	11.93	64.29	2.29	1.84
		st. dev.	4.42	13.88	1.04	1.00
	Unthinned	mean	11.28	72.91	1.98	2.00
		st. dev.	2.91	11.83	0.62	0.98
		p-value	0.439	0.004	0.110	0.471
		significant at alpha = 0.05	no	yes	no	no

Site	Treatment	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
1	Thinned	mean	37.55	5.69	70.90	16.08	13
		st. dev.	27.78	4.02	18.40	17.79	8
	Unthinned	mean	37.53	4.68	76.10	14.89	10
		st. dev.	28.37	2.73	13.40	15.56	2
		p-value	0.998	0.208	0.152	0.749	0.066
		significant at alpha = 0.05	no	no	no	no	no

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.7. T-tests for all variables for site 2, West Sumner.

Site	Treatment	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
2	Thinned	mean	9.02	55.11	1.81	1.94
		st. dev.	2.90	13.49	0.52	0.91
	Unthinned	mean	8.45	53.15	2.04	2.42
		st. dev.	2.91	16.99	0.28	0.82
		p-value	0.320	0.512	0.006	0.006
		significant at alpha = 0.05	no	no	yes	yes

Site	Treatment	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
2	Thinned	mean	28.13	478.00	74.00	9.80	9
		st. dev.	32.52	3.00	22.00	9.98	3
	Unthinned	mean	27.48	3.14	71.00	10.77	10
		st. dev.	29.08	2.20	25.00	11.05	4
		p-value	0.910	0.534	0.560	0.630	0.320
		significant at alpha = 0.05	no	no	no	no	no

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.8. T-tests for all variables for site 3, Greenwood.

Site	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
3	Thinned	mean	8.49	49.68	1.94	2.68
		st. dev.	1.86	21.174	0.314	1.33
	Unthinned	mean	9.36	60.668	2.04	2.29
		st. dev.	2.47	16.919	0.283	0.76
		p-value	0.048	0.005	0.097	0.074
		significant at alpha = 0.05	yes	yes	no	no

Site	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
3	Thinned	mean	48.25	2.40	58.30	5.02	10
		st. dev.	43.62	2.11	32.50	7.59	2
	Unthinned	mean	23.50	3.16	66.60	5.46	11
		st. dev.	30.02	2.71	23.00	7.30	4
		p-value	0.001	0.181	0.145	0.768	0.021
		significant at alpha = 0.05	yes	no	no	no	yes

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.9. T-tests for all variables for site 4, Oakland.

Site	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
4	Thinned	mean	7.05	43.80	2.02	2.28
		st. dev.	2.14	10.94	0.80	1.07
	Unthinned	mean	6.47	43.35	2.30	2.47
		st. dev.	2.11	11.07	0.58	0.74
		p-value	0.176	0.978	0.047	0.307
		significant at alpha = 0.05	no	no	yes	no

Site	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
4	Thinned	mean	22.88	1.78	66.30	5.16	9
		st. dev.	29.85	1.99	20.60	6.68	3
	Unthinned	mean	23.46	1.77	69.90	3.96	12
		st. dev.	32.92	1.63	24.60	3.36	4
		p-value	0.930	0.979	0.430	0.360	<0.001
		significant at alpha = 0.05	no	no	no	no	yes

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.10. Overall means and standard deviations of tree characteristics by species.

Species	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
White Ash	mean	11.58	68.96	2.12	1.93
	st. dev.	3.67	13.45	0.85	0.99
Paper Birch	mean	7.72	48.38	1.99	2.66
	st. dev.	2.25	18.86	0.32	1.15
Red Oak	mean	10.02	60.22	77.60	1.86
	st. dev.	2.69	12.03	15.50	0.45
Red Maple	mean	8.20	53.14	2.11	2.29
	st. dev.	2.71	16.34	0.55	0.88
American Beech	mean	7.10	43.58	2.08	2.22
	st. dev.	2.25	9.49	0.75	0.86

Species	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
White Ash	mean	35.51	5.16	73.40	15.43	11
	st. dev.	27.98	3.41	16.00	16.52	6
Paper Birch	mean	37.69	2.56	59.80	5.94	11
	st. dev.	41.91	2.52	30.10	9.44	3
Red Oak	mean	17.44	3.56	80.40	13.38	7
	st. dev.	17.55	2.36	23.00	1.35	0
Red Maple	mean	25.16	2.46	68.50	6.20	10
	st. dev.	33.24	2.43	23.80	6.94	3
American Beech	mean	15.98	2.19	70.30	3.02	11
	st. dev.	23.65	2.07	16.70	5.78	3

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.11. T-tests for all variables for white ash.

Species	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
White Ash	Thinned	mean	11.93	64.29	2.29	1.84
		st. dev.	4.42	13.88	1.04	1.00
	Unthinned	mean	11.28	72.91	1.98	2.00
		st. dev.	2.91	11.83	0.62	0.98
		p-value	0.430	0.004	0.110	0.470
		significant at alpha = 0.05	no	yes	no	no

Species	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
White Ash	Thinned	mean	37.55	5.69	70.90	16.08	13
		st. dev.	27.78	4.02	18.40	17.79	8
	Unthinned	mean	37.53	4.68	76.10	14.89	10
		st. dev.	28.37	2.73	13.40	15.56	2
		p-value	0.990	0.196	0.152	0.750	0.066
		significant at alpha = 0.05	no	no	no	no	no

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.12. T-tests for all variables for paper birch.

Species	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
Paper Birch	Thinned	mean	7.47	56.09	1.93	2.74
		st. dev.	2.02	20.81	0.39	1.35
	Unthinned	mean	7.98	68.59	2.06	2.58
		st. dev.	2.45	26.08	0.23	0.92
		p-value	0.246	0.008	0.035	0.480
		significant at alpha = 0.05	no	yes	yes	no

Species	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
Paper Birch	Thinned	mean	50.84	2.45	55.40	4.54	11
		st. dev.	45.26	2.91	3.10	8.36	3
	Unthinned	mean	28.99	2.63	64.30	7.34	12
		st. dev.	35.04	2.27	26.20	10.31	3
		p-value	0.007	0.776	0.131	0.129	0.011
		significant at alpha = 0.05	yes	no	no	no	yes

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.13. T-tests for all variables for red oak.

Species	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
Red Oak	Thinned	mean	10.62	61.77	1.72	1.72
		st. dev.	2.55	7.32	0.54	0.61
	Unthinned	mean	9.42	58.67	2.00	2.08
		st. dev.	2.74	15.38	0.29	0.57
		p-value	0.115	0.369	0.028	0.037
		significant at alpha = 0.05	no	no	yes	yes

Species	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
Red Oak	Thinned	mean	20.14	4.20	82.40	13.56	7
		st. dev.	17.03	2.69	12.60	9.84	2
	Unthinned	mean	18.90	2.92	78.40	13.20	7
		st. dev.	18.24	1.80	19.50	9.45	2
		p-value	0.805	.0.55	0.393	0.896	0.603
		significant at alpha = 0.05	no	no	no	no	no

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.14. T-tests for all variables for red maple.

Species	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
Red Maple	Thinned	mean	8.37	53.19	2.04	2.22
		st. dev.	2.29	18.17	0.57	0.97
	Unthinned	mean	8.03	53.09	2.18	2.37
		st. dev.	3.09	14.48	0.52	0.76
		p-value	0.541	0.977	0.204	0.408
		significant at alpha = 0.05	no	no	no	no

Species	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
Red Maple	Thinned	mean	27.09	2.00	69.40	6.96	9
		st. dev.	33.19	1.92	22.60	6.70	3
	Unthinned	mean	27.62	2.91	67.60	5.44	11
		st. dev.	33.33	2.80	25.20	7.17	4
		p-value	0.937	0.080	0.709	0.276	0.015
		significant at alpha = 0.05	no	no	no	no	yes

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.15. T-tests for all variables for American beech.

Species	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
American Beech	Thinned	mean	7.01	43.36	1.88	2.08
		st. dev.	2.02	9.82	0.88	1.08
	Unthinned	mean	7.19	43.80	2.28	2.36
		st. dev.	2.50	9.34	0.54	0.57
		p-value	0.781	0.873	0.060	0.258
		significant at alpha = 0.05	no	no	no	no

Species	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
American Beech	Thinned	mean	19.80	2.08	67.00	4.00	10
		st. dev.	25.27	2.32	13.60	7.07	2
	Unthinned	mean	16.58	2.29	73.60	2.04	13
		st. dev.	22.00	1.83	19.10	4.03	4
		p-value	0.633	0.731	0.166	0.236	0.007
		significant at alpha = 0.05	no	no	no	no	yes

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.16. T-tests for all variables for white ash at site 1, Belgrade.

Species	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
White Ash	Thinned	mean	11.93	64.29	2.29	1.84
		st. dev.	4.42	13.88	1.04	1.00
	Unthinned	mean	11.28	72.91	1.98	2.00
		st. dev.	2.91	11.83	0.62	0.98
		p-value	0.439	0.004	0.110	0.471
		significant at alpha = 0.05	no	yes	no	no

Species	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
White Ash	Thinned	mean	37.55	5.69	70.90	16.08	13
		st. dev.	27.78	4.02	18.40	17.79	8
	Unthinned	mean	37.53	4.68	76.10	14.89	10
		st. dev.	28.37	2.73	13.40	15.56	2
		p-value	0.998	0.208	0.152	0.749	0.066
		significant at alpha = 0.05	no	no	no	no	no

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.17. T-tests for all variables for paper birch at site 2, West Sumner.

Site	Species	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
2	Paper Birch	Thinned	mean	7.59	49.17	1.89	2.14
			st. dev.	2.44	15.00	0.50	1.08
		Unthinned	mean	7.59	48.22	2.07	2.71
			st. dev.	2.83	17.09	0.26	0.90
			p-value	0.996	0.827	0.100	0.036
			significant at alpha = 0.05	no	no	no	yes

Site	Species	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
2	Paper Birch	Thinned	mean	35.27	2.62	66.00	6.43	11
			st. dev.	40.82	3.19	25.40	9.00	3
		Unthinned	mean	35.14	3.36	64.40	8.61	12
			st. dev.	34.69	2.56	27.90	12.06	3
			p-value	0.990	0.396	0.810	0.447	0.232
			significant at alpha = 0.05	no	no	no	no	no

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.18. T-tests for all variables for red oak at site 2, West Sumner.

Site	Species	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
2	Red Oak	Thinned	mean	10.62	61.70	1.72	1.72
			st. dev.	2.55	7.32	0.54	0.61
		Unthinned	mean	9.42	58.67	2.00	2.08
			st. dev.	2.74	15.38	0.29	0.57
			p-value	0.115	0.369	0.028	0.037
			significant at alpha = 0.05	no	no	yes	yes

Site	Species	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
2	Red Oak	Thinned	mean	20.14	4.20	82.40	13.56	7
			st. dev.	17.03	2.69	12.60	9.84	19
		Unthinned	mean	18.90	2.92	78.40	13.20	7
			st. dev.	18.24	1.80	19.50	9.45	2
			p-value	0.805	0.055	0.393	0.896	0.603
			significant at alpha = 0.05	no	no	no	no	no

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.19. T-tests for all variables for red maple at site 3, Greenwood.

Site	Species	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
3	Red Maple	Thinned	mean	9.64	62.14	1.92	1.96
			st. dev.	1.46	18.94	0.40	0.89
		Unthinned	mean	10.30	62.52	2.04	2.02
			st. dev.	2.64	8.96	0.35	0.55
			p-value	0.275	0.930	0.265	0.345
			significant at alpha = 0.05	no	no	no	no

Site	Species	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
3	Red Maple	Thinned	mean	28.22	2.55	73.20	7.60	10
			st. dev.	32.93	2.13	18.30	7.23	3
		Unthinned	mean	24.90	4.38	69.00	5.00	11
			st. dev.	24.97	2.96	21.20	6.77	4
			p-value	0.690	0.011	0.458	0.196	0.327
			significant at alpha = 0.05	no	yes	no	no	no

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.20. T-tests for all variables for paper birch at site 3, Greenwood.

Site	Species	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
3	Paper Birch	Thinned	mean	7.33	37.22	1.96	3.40
			st. dev.	1.48	15.26	0.20	1.32
		Unthinned	mean	8.41	58.82	2.04	2.42
			st. dev.	1.90	22.29	0.20	0.93
			p-value	0.029	0.000	0.164	0.004
			significant at alpha = 0.05	yes	yes	no	yes

Site	Species	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
3	Paper Birch	Thinned	mean	68.28	2.00	43.40	2.44	10
			st. dev.	44.32	2.14	36.90	7.18	2
		Unthinned	mean	22.10	1.76	64.10	5.92	12
			st. dev.	34.83	1.51	24.90	7.91	3
			p-value	0.000	0.779	0.025	0.110	0.013
			significant at alpha = 0.05	yes	no	yes	no	yes

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.21. T-tests for all variables for red maple at site 4, Oakland.

Site	Species	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
4	Red Maple	Thinned	mean	7.10	44.23	2.16	2.48
			st. dev.	2.28	12.16	0.69	1.05
		Unthinned	mean	5.76	43.67	2.32	2.58
			st. dev.	1.33	12.77	0.63	0.88
			p-value	0.016	0.875	0.394	0.710
			significant at alpha = 0.05	yes	no	no	no

Site	Species	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
4	Red Maple	Thinned	mean	25.96	1.46	65.60	6.32	8
			st. dev.	34.08	1.54	26.10	6.20	3
		Unthinned	mean	30.34	1.15	66.20	5.88	11
			st. dev.	40.37	1.09	29.10	7.66	3
			p-value	0.680	0.467	0.939	0.824	0.010
			significant at alpha = 0.05	no	no	no	no	yes

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Table 1.22. T-tests for all variables for American beech at site 4, Oakland.

Site	Species	Management Type	Statistic	DBH (inches)	Height (feet)	Pre-storm Crown Class [a]	Post-storm Crown Class [a]
4	American Beech	Thinned	mean	7.01	43.36	1.88	2.08
			st. dev.	2.02	9.82	0.88	1.08
		Unthinned	mean	7.19	43.80	2.28	2.36
			st. dev.	2.50	9.34	0.54	0.57
			p-value	0.781	0.873	0.060	0.258
			significant at alpha = 0.05	no	no	no	no

Site	Species	Management Type	Statistic	Crown Loss (%)	Broken Branches (per tree)	Transparency (%)	Sprouts (per tree)	Shigometer Values (kohms)
4	American Beech	Thinned	mean	19.80	2.08	67.00	4.00	10
			st. dev.	25.27	2.32	13.60	7.07	2
		Unthinned	mean	16.58	2.29	73.60	2.04	13
			st. dev.	22.00	1.83	19.10	4.03	4
			p-value	0.633	0.731	0.166	0.236	0.007
			significant at alpha = 0.05	no	no	no	no	yes

[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Significant Relationships Among Variables

Two-way Analyses of Variances (ANOVAs) were performed for all variables by site and treatment to determine significant relationships (Table 1.23). All assumptions for normality and constant variance were met.

The variables listed in Table 1.23 were used as the dependant variable and treatment and site were used as factors. An ANOVA was performed on each variable by both factors combined to check for interaction effects.

When percent crown loss was used as the dependant variable in the two-way ANOVA, with treatment and site as factors, a significant interaction existed (p=0.022). Therefore, site and treatment interact in their effect on percent crown loss. This interactive effect is different than the effects of treatment or site alone. A significant effect was present when percent crown loss and site was analyzed (p=0.001); however, this was not the case for treatment. When comparing means by treatment and percent crown loss for each site, it is obvious that site 3 was dramatically different in thinned and unthinned percent crown loss values. The grand mean for percent crown loss for all study sites combined was 48.9%. Figure 1.1 represents the average percent crown loss for each treatment by site.

A significant interaction existed between site and treatment when pre-storm crown class was used as the dependent variable in the two-way ANOVA (p=0.004). This suggests that crown classes prior to the storm are affected by the joint interaction of site and treatment. Again, a significant relationship existed for pre-storm crown class and site (p=0.018); however, treatment did not create a significant relationship with pre-storm

crown class. Figure 1.2 represents the average pre-storm crown class for each site. The grand mean for pre-storm crown class was 2.052.

Table 1.23. Results of 2-way ANOVAs performed with each variable as the dependent variable by treatment and site factors.

Variable	Significant Interaction Effects	P-values	Significance with treatment only	P-values	Significance with site only	P-values
Number of Broken Branches	no	0.600	no	0.221	yes	0.000
Number of Sprouts	no	0.847	no	0.955	yes	0.000
Crown Loss (%)	yes	0.022	no	0.103	yes	0.001
Transparency (%)	no	0.415	no	0.136	yes	0.002
Pre-storm Crown Class	yes	0.004	no	0.115	yes	0.018
Post-storm Crown Class	yes	0.015	no	0.339	yes	0.001
Shigometer Values	yes	0.000	no	0.101	yes	0.024

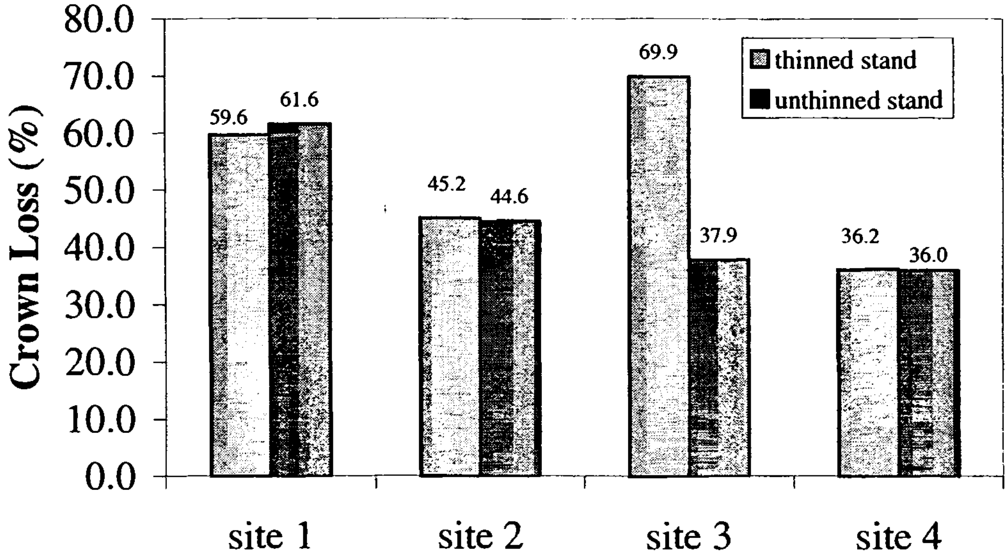
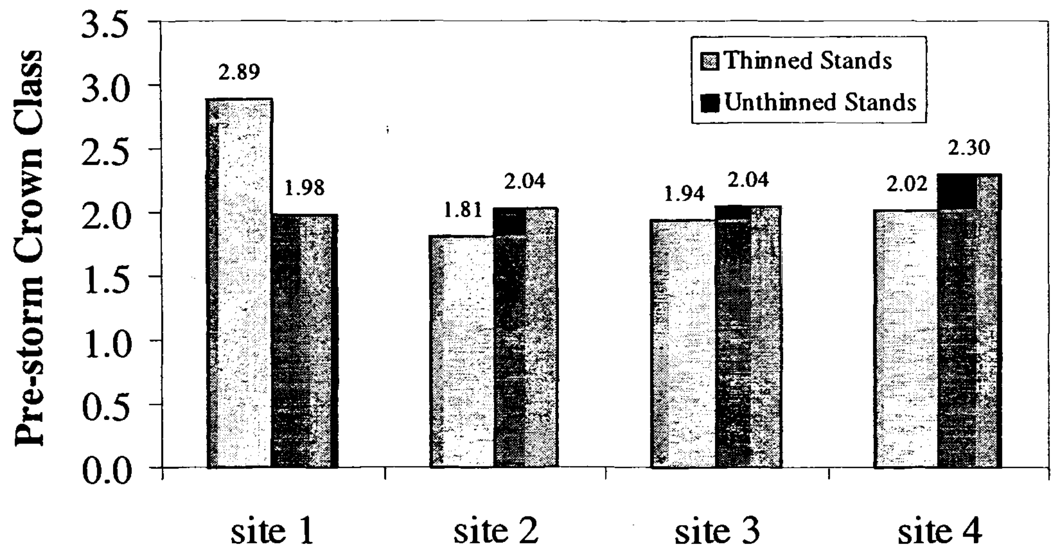


Figure 1.1. Percent crown loss by site for thinned and unthinned stands.

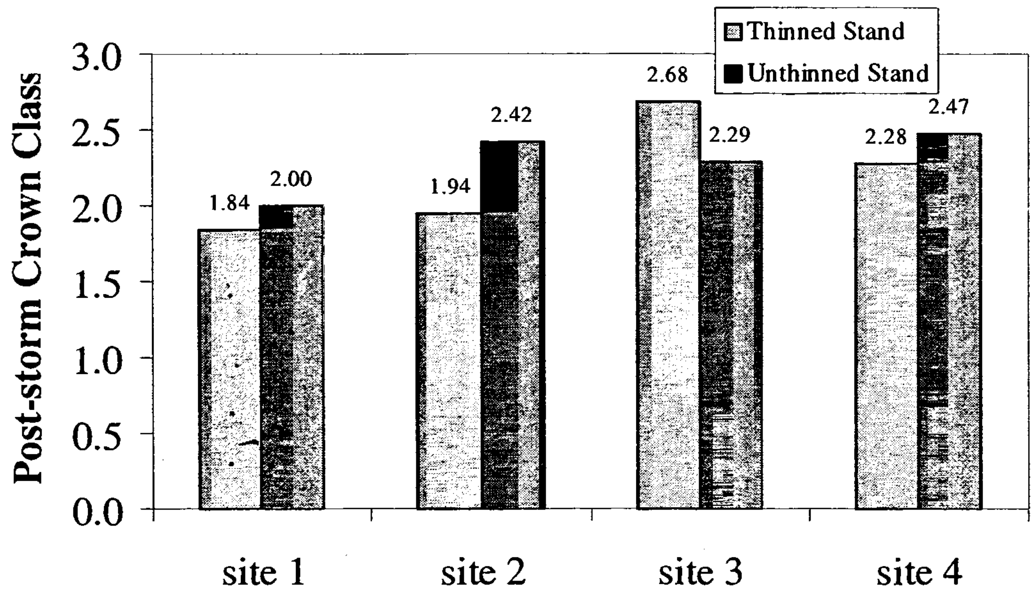
A significant interaction also existed between treatment and site factors when the ANOVA was performed using post-storm crown class as the dependant variable (p=0.015). This indicated that treatment and site combined have an effect on post-storm crown class. Figure 1.3 represents individual means for each treatment by site for post-storm crown class. In addition, when site alone was analyzed with post-storm crown class as the dependent variable, a significant relationship existed (p=0.001). The post-storm crown class grand mean for all sites combined was 2.240. The t-test that compared treatments for post-storm crown class showed that no significant difference existed between thinned and unthinned stands. However, the p-value was 0.074, close to the pre-determined significance value of 0.05.



[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Figure 1.2. Average pre-storm crown class by site for thinned and unthinned stands.

Regardless of significance of interactions, site was always a significant main effect and treatment was never a significant main effect. This again suggests that the four field sites were different from one another and that overall, treatment was not a significant factor in ice injury or recovery. However, while the sites were different, some general trends were still observed. For example, percent transparency, number of broken branches, and number of sprouts were not significant between thinned and unthinned stands for the four field sites combined or individually. Only when individual sites are analyzed does the significance of treatment become apparent.



[a] indicator variables used for statistical analysis of crown classes were 1 = open; 2 = dominant; 3 = codominant; 4 = intermediate; 5 = understory

Figure 1.3. Average post-storm crown class values by site for thinned and unthinned stands.

The results of two-way ANOVAs performed with shigometer values as the dependant variable and site and treatment as factors, showed that a significant interaction exists ($p<0.001$). In addition, a significant relationship existed for the site factor when site and shigometer values were compared ($p=0.021$). Figure 1.24 shows the mean shigometer values for thinned and unthinned stands for each site. When the t-tests for each individual site were analyzed, two of the four sites were significantly different in terms of their shigometer values, with the thinned stands having more vigorous trees ($p=0.013$, $p=0.010$, and $p=0.007$ respectively) (Tables 1.8 and

1.9, and Figure 1.4). Two-way ANOVAs performed on other recovery variables did not detect any significant interactions.

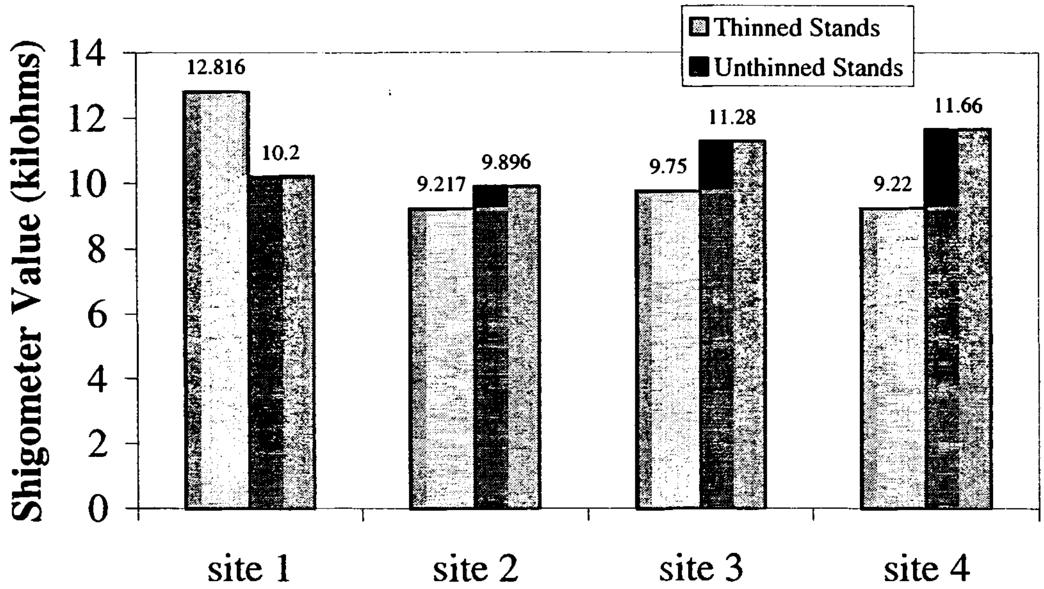


Figure 1.4. Mean shigometer values by site for thinned and unthinned stands.

Shigometer Analysis

Median shigometer values by species are listed in Table 1.24. Table 1.25 represents the median shigometer values for each species by site and indicates the number of individuals that are above and below the baseline median. Note that each species at each site had lower shigometer baselines in the thinned areas than in the unthinned area, except for site 1. Overall, thinned areas had individuals that were more vigorous than the unthinned areas. Also, the shigometer values for paper birch at site 3, and red maple and American beech at site 4 were significantly different between treatments (Tables 1.20, 1.21. and 1.22, respectively). It should be noted that shigometer

measurements can be compared within a species; for example, red maple shigometer measurements taken in thinned and unthinned areas can be compared. However, shigometer values cannot be compared between species, such as red maple and paper birch.

Table 1.24. Average shigometer values by species.

Species	Median Shigometer Values
White Ash	11
Red Oak	7
Paper Birch	11
Red Maple	9
American Beech	11

Table 1.25. Number of individuals above and below baseline shigometer values by site, species, and treatment

Site	Species	Type	Baseline Average (kohms)	Number of Individuals above	Number of Individuals Below
1	White Ash	Thinned	11	18	20
		Unthinned	10	22	23
2	Red Oak	Thinned	7	9	16
		Unthinned	8	8	17
	Paper Birch	Thinned	11	11	17
		Unthinned	12	11	17
3	Red Maple	Thinned	9	12	13
		Unthinned	10	9	16
	Paper Birch	Thinned	10	6	19
		Unthinned	13	8	17
4	Red Maple	Thinned	8	9	16
		Unthinned	11	9	16
	American Beech	Thinned	10	12	13
		Unthinned	13	10	15

Core Analysis

Of the 389 individuals measured for this study, 299 were used for core analysis. The lower number of cores used reflects some landowner's decision to allow only a few cores per species per damage class. In addition, some cores were removed from the analysis due to poor mounting or unreadable rings.

The average growth per season after the ice storm of 1998 was 1.54 mm (0.061 inches) (Table 1.26). This average does not incorporate the half-year of growth during the 2000 season; rather it includes 1998 and 1999 only. Before the ice storm, the average growth per year was 1.72 mm (0.068 inches). This later mean was obtained by averaging the distance between all rings before the ice storm back until 1975. Because some cores were measured back to 1940 while others were only measured back to the early 1990's, the pre-storm average includes a wide range of samples. The post-storm average was also compared to averages taken at 2- and 5-year intervals back to 1974 and 1973, respectively (Tables 1.26 and 1.27, respectively).

Figures 1.28 to Figure 1.37 show the growth averages for each species in two and five year intervals. White ash and paper birch growth slowed following the ice storm of 1998 (Figures 1.28 to Figure 1.31). According to Figure 1.32, red oak growth slowed following the ice storm, but the growth rate after the ice storm was not the slowest growth rate for red oak. For example, in 1992 and 1993, the growth rate was 2.28 mm, which increased to above 3.00 mm between 1994 and 1997. It then decreased following the storm to 2.74 mm. The number of samples for red oak cores was quite low, because the landowner was concerned that coring may reduce the timber value.

Red maple and American beech growth rates increased following the ice storm of 1998 (Figure 1.34 to Figure 1.37). Red maple growth had decreased from 1977 to 1997. then in 1998 and 1999 the growth rate increased from 1.39 mm to 1.41 mm (Figure 1.34). American beech had the largest increase following the ice storm of 1998. For example, growth had been well below 2 mm per year from 1974 to 1997. In 1998, the growth rate jumped to 2.23 mm (Figure 1.36).

Figure 1.38 shows averages per year by treatment for two years before and after the ice storm. This data indicates that while the thinned stands were growing significantly better than the unthinned stands following the ice storm, the unthinned stands were growing significantly better two years before the ice storm , as well.

Table 1.26. Core analysis averages for all species in 2-year intervals.

Total No. of Samples	Years	2-year Interval Averages (mm)
598	*1999 -1998**	*1.54*
597	1997 - 1996	1.52
591	1995 - 1994	1.45
582	1993 - 1992	2.64
573	1991 - 1990	1.61
553	1989 - 1988	1.65
528	1987 - 1986	1.65
483	1985 - 1984	1.66
425	1983 - 1982	1.70
363	1981 - 1980	1.72
320	1979 - 1978	1.72
251	1977 - 1976	1.66
209	1975 - 1974	1.61

*Years and ring width averages that appear in italics are post-storm data.

Table 1.27. Core analysis averages for all species in 5-year intervals.

Total No. of Samples	**Years**	**5-year Interval Averages (mm)**
598	*1999 - 1998**	*1.54*
1480	1997 - 1993	1.92
1396	1992 - 1988	1.63
1232	1987 - 1983	1.65
887	1982 - 1978	1.73
548	1977 - 1973	1.64

*Years and ring width averages that appear in italics are post-storm data.

Table 1.28. Average growth in 2-year intervals for white ash.

Total No. of Samples	Years	2-year Interval Averages (mm)
152	*1999 -1998**	*1.21*
152	1997 - 1996	1.39
152	1995 - 1994	1.41
152	1993 - 1992	1.68
150	1991 - 1990	1.92
143	1989 - 1988	1.89
132	1987 - 1986	1.84
116	1985 - 1984	1.84
93	1983 - 1982	2.00
71	1981 - 1980	1.93
56	1979 - 1978	1.93
32	1977 - 1976	1.73
18	1975 - 1974	1.61

*Years and ring width averages that appear in italics are post-storm data.

Table 1.29. Average growth in 5-year intervals for white ash.

Total No. of samples	Years	5-year Interval Averages (mm)
152	*1999 & 1998**	*1.21*
380	1997 - 1993	1.43
369	1992 - 1988	1.88
299	1987 - 1983	1.82
169	1982 - 1978	2.00
57	1977 - 1973	1.68

*Years and ring width averages that appear in italics are post-storm data.

Table 1.30. Average growth in 2-year intervals for paper birch.

Total No. of Samples	**Years**	**2-year Interval Averages (mm)**
124	*1999 -1998**	*1.39*
124	1997 - 1996	1.47
124	1995 - 1994	1.43
124	1993 - 1992	1.45
120	1991 - 1990	1.39
117	1989 - 1988	1.56
109	1987 - 1986	1.59
94	1985 - 1984	1.63
81	1983 - 1982	1.65
63	1981 - 1980	1.71
54	1979 - 1978	1.69
41	1977 - 1976	1.44
36	1975 - 1974	1.45

*Years and ring width averages that appear in italics are post-storm data.

Table 1.31. Average growth in 5-year intervals for paper birch.

Total No. of Samples	Years	5-year Interval Averages (mm)
124	*1999 - 1998**	*1.39*
310	1997 - 1993	1.45
299	1992 - 1988	1.47
245	1987 - 1983	1.63
156	1982 - 1978	1.67
91	1977 - 1973	1.47

*Years and ring width averages that appear in italics are post-storm data.

Table 1.32. Average growth in 2-year intervals for red oak.

Total No. of Samples	Years	2-year Interval Averages (mm)
22	*1999 -1998**	*2.74*
21	1997 - 1996	3.17
15	1995 - 1994	3.13
6	1993 - 1992	2.28

*Years and ring width averages that appear in italics are post-storm data.

Table 1.33. Average growth in 5-year intervals for red oak.

Total No. of Samples	Years	5-year Interval Averages (mm)
22	*1999 - 1998**	*2.74*
40	1997 - 1993	2.98

*Years and ring width averages that appear in italics are post-storm data.

Table 1.34. Average growth in 2-year intervals for red maple.

Total No. of Samples	Years	2-year Interval Averages (mm)
200	*1999 -1998**	*1.41*
200	1997 - 1996	1.39
200	1995 - 1994	1.30
200	1993 - 1992	1.43
199	1991 - 1990	1.45
195	1989 - 1988	1.56
189	1987 - 1986	1.51
179	1985 - 1984	1.52
165	1983 - 1982	1.57
150	1981 - 1980	1.63
140	1979 - 1978	1.66
118	1977 - 1976	1.69
105	1975 - 1974	1.57

*Years and ring width averages that appear in italics are post-storm data.

Table 1.35. Average growth in 5-year intervals for red maple.

Total No. of Samples	**Years**	**5-year Interval Averages (mm)**
200	*1999 - 1998**	*1.41*
500	1997 - 1993	1.35
494	1992 - 1988	1.50
452	1987 - 1983	1.52
371	1982 - 1978	1.63
267	1977 - 1973	1.60

*Years and ring width averages that appear in italics are post-storm data.

Table 1.36. Average growth in 2-year intervals for American beech.

Total No. of Samples	Years	2-year Interval Averages (mm)
100	*1999 -1998**	*2.23*
100	1997 - 1996	1.70
100	1995 - 1994	1.58
100	1993 - 1992	1.67
100	1991 - 1990	1.69
98	1989 - 1988	1.63
98	1987 - 1986	1.72
94	1985 - 1984	1.71
86	1983 - 1982	1.69
79	1981 - 1980	1.72
70	1979 - 1978	1.71
60	1977 - 1976	1.73
50	1975 - 1974	1.79

*Years and ring width averages that appear in italics are post-storm data.

Table 1.37. Average growth in 5-year intervals for American beech.

Total No. of Samples	Years	5-year Interval Averages (mm)
100	*1999 - 1998**	*2.23*
250	1997 - 1993	1.64
248	1992 - 1988	1.67
236	1987 - 1983	1.71
191	1982 - 1978	1.71
133	1977 - 1973	1.83

*Years and ring width averages that appear in italics are post-storm data.

Table 1.38. Core analysis averages for all species by treatment.

Treatment	Total No. of Samples	Year	Average Growth (mm)
Thinned	*146*	*1999*	*1.833*
Unthinned	*153*	*1999*	*1.261*
Thinned	*146*	*1998*	*1.186*
Unthinned	*153*	*1998*	*0.804*
Thinned	146	1997	1.056
Unthinned	153	1997	0.874
Thinned	146	1996	1.003
Unthinned	152	1996	0.846

*Years and ring width averages that appear in italics are post-storm data.

DISCUSSION

Damage Resulting From Ice Injury

Overall Damage

Data for the four study sites combined suggested that significant differences do not exist between thinned and unthinned areas as a result of ice injury (Table 1.5). There was no significant difference in percent crown loss or numbers of broken branches; nor was there a significant difference for pre- or post-crown classes. This is an especially important finding considering the four study sites were quite different. For example, site 1 was a pure ash stand and the only one of its type (Table 1.1). The other three study sites had similar species composition, but different soil types. In addition, sites 1 and 4 were similar topographically, as were sites 2 and 3. However, these two groups of sites were quite different. Sites 1 and 4 occurred at an elevation of approximately 300 to 400 feet whereas sites 2 and 3 occurred at an elevation ranging from 800 to 900 feet. Aspect and slope was similar for all four sites. Age of the stands was similar for all sites except site 1 which was considerably older than the other three sites. Therefore, the data is representative of other areas of the state, rather than just the four study sites (i.e. the four study sites incorporated different types of stands, not just pure ash stands or only stands with beech, birch, and maple).

Tree heights were significantly different between the two treatments (Table 1.5). This was probably due to height differences before the ice storm of 1998. Differences in height were probably not due to ice injury as percent crown loss between thinned and unthinned areas was not significantly different.

Ice Injury by Site

Height measurements for site 1 were significantly different (Table 1.6). These results could be due to the same reasons mentioned above. In addition, each stand may have had significant height differences before the thinning occurred. Ice injury does not seem to be the cause of this height difference because the two stands did not have significant differences in percent crown loss. Crown classes did change after the ice storm. For example, the thinned site had more codominant, intermediate, and understory individuals before the storm. The unthinned stand has similar crown class structure before and after the ice disturbance. In addition, white ash, the only species measured at this site had a high incidence of complete top removal.

Pre- and post-storm crown classes were significantly different at site 2; again, this difference is probably due to differences in the stands before the ice storm because other damage indicators showed no significant differences between thinned and unthinned stands (Table 1.7). Both thinned and unthinned stands had more individuals in the lower canopy classes after the ice storm.

The difference between the percent crown loss and number of broken branches at site 3 was probably due to the way each variable was measured (Table 1.8). For example, percent crown loss measured the percent of the crown lost due to ice injury. Number of broken branches did not take into account the total amount of crown as did percent crown loss. This could create the difference in significance noted in the t-test of site 3.

Site 3 also had several other variables that were significantly different between thinned and unthinned stands including DBH and height. One possible reason for the

significant differences in DBH between treatments may be due to differences in the stands before the ice storm took place. Height differences could also be due to differences that existed in the treatments prior to the storm. In addition, the DBH and height differences may be accounted to ice injury because crown loss was significantly different between the two treatments. Crown class changed dramatically after the ice storm. For example, more individuals in both treatments were in the lower canopy classes following the disturbance.

Site 4 measurements indicated that crown classes were significantly different before the ice storm, but were not significantly different after the ice storm (Table 1.9). The significance value was close to the pre-determined test value of 0.05 ($p=0.047$) for pre-storm values. In both thinned and unthinned stands, more individuals were in the lower canopy layers after the ice storm.

Ice Injury by Species

There was a significant relationship between species and percent crown loss (Table 1.10, $p<0.000$). This suggests that ice injury is species dependent. Of the species measured, data shows paper birch to have the greatest percent crown loss, followed by white ash, red maple, and red oak. The species that suffered the least amount of damage was American beech. Several other researchers have shown that ice injury is species dependant; however, there is no conclusive evidence to suggest that species are affected similarly by each ice storm (Carvell et al. 1957, Shepard 1975, Bruederle and Stearns 1985, Belanger et al. 1996). For example, Boerner et al. (1998) reported that red maple and white ash were rated from high to low ice injury susceptibility. American beech was

rated low to moderate in three separate studies (Siccama et al. 1976, Whintey and Johnson 1984, Boerner et al. 1988).

Paper birch showed the most significant differences between the thinned and unthinned areas (Table 1.12). For example, pre-storm crown classes for individuals in the thinned and unthinned areas were significantly different. However, after the ice storm, there was not a significant difference between crown classes. The ice injury "leveled out" the differences in crown class so that no significant difference existed after the ice storm.

Red oak, while losing 25% of its crown on average, was not greatly affected by ice injury in terms of its location in thinned or unthinned stands (Table 1.13). This species had two variables with significant differences between thinned and unthinned areas: pre- and post-storm crown classes. For both variables, the thinned treatments had trees that were significantly higher in the canopy than the unthinned treatment. Pre-storm crown classes were not altered as a result of the ice storm in the thinned stands. The unthinned stands' crown classes changed very little after the ice storm, as well.

Ice Injury by Site and Species

Numbers of trees in each crown class for paper birch at site 2 were altered as a result of the ice storm (Table 1.17). There was no significant difference between thinned and unthinned pre-storm crown classes, but post-storm crown classes were significantly different between stand treatments. However, in both treatments, the ice injury resulted in lowering tree canopy classes from dominant and co-dominant positions to sub-canopy positions. It was surprising that percent crown loss was not significantly different

between thinned and unthinned stands. The significant difference in post-storm crown classes seemed to indicate otherwise.

Red oak at site 2 showed basically no differences in pre- and post-storm crown classes for thinned and unthinned stands; however, when comparing the two treatments to each other, significant differences were revealed (Table 1.18). For example, individuals in the thinned stand did not change canopy positions after the ice storm, and neither did the individuals in the unthinned stands; however, when comparing thinned with unthinned areas, significant differences occurred. Data are interpreted to indicate that the two stand treatments were significantly different in terms of crown classes before the storm, but did not change as a result of the storm. These findings for red oak are different than those for paper birch at this same site. Data are interpreted to indicate that ice injury did create changes in canopy structure in both the thinned and unthinned areas for paper birch.

Red maple at site 3 showed a significant difference for the numbers of broken branches between thinned and unthinned stands (Table 1.19). The thinned stand had only an average of 2.48 branches broken per tree whereas the unthinned stand had on average 4.36 branches per tree broken.

The other species at site 3, paper birch, had six variables that were significantly different in thinnned and unthinned areas (Table 1.20). The paper birch at this site was the most severely affected in terms of the number of variables that were significantly different between the two sites. Both DBH and height were significantly different between the two management areas. The unthinned area had larger diameter trees, but these trees were shorter on average than individuals in the thinned area. Pre-storm crown

class averages were similar for both treatments, but were significantly different following the disturbance. The thinned stand suffered a shift from dominant canopy positions on average to co-dominant positions on average. The percent crown loss values reflect this shift. For example, crown loss for unthinned stands was 35%, but was 68% for thinned stands.

Damage Relationships Between Variables

The ANOVAs performed using damage variables as the dependant factor and treatment and site as factors resulted in three significant interactions. When an ANOVA was performed using percent crown loss as the dependant factor, an interaction existed with the site and treatment factors (Figure 1.1). This interaction was caused by the large difference in percent crown loss at site 3. The large difference in crown loss may be due to the heavy thinning that occurred.

A second significant interaction existed when pre-storm crown class was used as the dependant factor and site and treatment were used as factors. The significant interaction was a result of how site 1 responded to type (Figure 1.2). At site 1, the thinned stand was composed of trees primarily in the codominant, intermediate, and understory positions whereas the trees in the unthinned stands were mostly in the open and dominant positions. Analyzing the site and treatment factors alone indicated that treatment did not create a significant relationship with pre-storm crown class, but site did create a significant relationship with pre-storm crown class.

A third interaction existed when post-storm crown class was used as the dependant factor and site and treatment were used as factors. The significant interaction

was a result of how site 3 responded to type. The unthinned treatment at site 3 had more trees in the intermediate and understory classes than the thinned area. However, the opposite was true for the other three sites. When the site 3 values were removed from the analysis, the ANOVA could not be performed due to lack of variance. Analyzing factors alone indicated that the treatment was not a significant main effect; however, when site was analyzed with post-storm crown class alone, a significant relationship existed.

Recovery From Ice Injury

Overall Recovery

Data for the four field sites combined suggest that there is no significant difference in recovery between thinned and unthinned stands (Table 1.5). However, recovery measurements at individual sites and for individual species showed significant differences in the two treatments. The species that had the greatest amount of canopy in the summer of 2000 was red oak, followed by white ash, American beech, red maple, and paper birch (Table 1.10).

Recovery by Sites

At sites 3 and 4, significant differences occurred for the shigometer values (Tables 1.8 and 1.9, respectively). For both sites, the individuals in thinned areas were more vigorous than trees in unthinned areas. In addition, percent crown loss was significantly different for the two areas at site 3, but was not significantly different at site 4. For site 3, this indicates that while crown loss was significantly higher in the thinned stand, these individuals remained or became more vigorous than their unthinned counterparts.

Recovery by Species

For white ash specifically, heights between thinned and unthinned stands were significantly different (Table 1.11). Because no other variables were significantly different, including percent crown loss, the height differences probably existed prior to the 1998 ice storm.

Paper birch, being the species most devastated from ice injury, had several recovery variables that were significantly different between thinned and unthinned areas (Table 1.12). For example, although percent crown loss was significantly greater in the thinned stand, the thinned stand was more vigorous than the unthinned stand.

The shigometer values for red maple showed that the thinned areas had more vigorous trees than the unthinned areas (Table 1.14). This held true for American beech, as well (Table 1.15). However, the percent transparency and percent crown loss values for these cases did not show any significant difference between thinned and unthinned treatments. This indicates that tree vigor cannot be determined from crown size alone. Measurements that consider "internal" tree vigor are required to establish an accurate description of individual tree health.

Red oak's recovery variables were not significantly different between treatments (Table 1.13).

Recovery by Site and Species

In terms of recovery variables, paper birch and red oak at site 2 did not show any significant differences between thinned and unthinned stands (Tables 1.17 and 1.18, respectively), as did red maple at site 3 (Table 1.19).

Paper birch at site 3 showed a significant difference for percent transparency between thinned and unthinned stands (Figure 1.20). The thinned stand had a transparency value of 43%

whereas the unthinned stand had a transparency value of 64%. This was supported by percent crown loss values. Thinned stands had greater crown loss than the unthinned stands. In addition, vigor was significantly higher in the thinned stand, even though they suffered more injury and had crowns whose transparency values were lower than the unthinned stand, thus indicating that these individuals were recovering very well.

The thinned red maple at site 4 (Table 1.21), along with the thinned American beech at site 4 (Table 1.22), were significantly more vigorous than their unthinned counterparts, although the transparency values were similar for both treatments. Once again, amount of visible crown does not seem to indicate vigor of the tree.

Recovery Relationships Between Variables

A two-way ANOVA performed with shigometer values as the dependant factor and site and treatment as the factors indicated a significant interaction. The interaction was a result of how site 1 responded to treatment. For example, at site 1 the shigometer values were higher in the thinned stand rather than the unthinned stand. However, the opposite was true for the other three sites.

Shigometer Analysis

Median shigometer values suggest that individuals in the thinned stands were more vigorous than individuals in the unthinned stands. In Table 1.25, the stand medians were always more vigorous in the thinned than unthinned treatments, except for white ash at site 1; however, this exception was not significant (p=0.066) (Table 1.6).

Increment Cores

Average radial growth after the ice disturbance, 1.54 mm per year (0.061 inches), was lower than the average measured before the storm (1.72 mm or 0.068 inches) (Table 1.26). The post-storm value only used two years of growth data because only two full growing seasons had passed since the ice disturbance, whereas the pre-storm value used approximately 25 years. These data may suggest the trees were using resources to rebuild crowns, rather than adding growth radially.

Of all five hardwood species, two species' radial growth increased following the ice storm of 1998; red maple and American beech. Species and site characteristics may account for this phenomenon. First, red maple and American beech may have simply out competed other species at the site based upon their species characteristics. For example, American beech is a tolerant species and can remain in the subcanopy levels for many years. A disturbance such as an ice storm may eliminate enough of the dominant individuals in the canopy to allow American beech to receive more sunlight and therefore add radial growth. Why, then did American beech grow radially instead of rebuild its crown? The answer is that American beech was the least injured species and therefore didn't necessarily need to rebuild its crown. Rather it could use its resources to grow radially. Red maple is a very fast growing species. This same basic principal may have held true for red maple as well. While red maple is intermediate in tolerance it was still present in the understory, and with the ice storm removing part of the canopy, it was able to allocate its resources to growing radially. Red maple lost 25% of its crown to ice injury, but did not lose as much as paper birch and white ash. In addition, certain site characteristics could have promoted these species over others. For example, if red maple

and American beech happened to occupy sites that were heavily damaged, then more of the site resources were allocated to those trees that survived the disturbance. Other species such as white ash, red oak, and paper birch incremental growth decreased following the ice storm. One explanation for this observation could be that these species may not have occupied sites that received as much damage as the sites that American beech and red maple occupied. In addition, these species may have been outcompeted.

Core data indicated that white ash and paper birch had the least amount of relative radial growth compared to each species average growth rates prior to the ice storm of 1998. White ash was a severely affected species with an average of nearly 36% crown loss. Many individuals were completely topped and rebuilt large crowns of epicormic branches. White ash probably allocated its resources to rebuilding crowns, rather than growing radially.

This same reasoning can be applied to paper birch, as well. Paper birch suffered the most crown injury with almost 38% crown loss. Therefore, paper birch, like the white ash allocated its resources to rebuild crowns, rather than growing. Another plausible reason why paper birch radial growth was slowed after the ice storm is due to this species high percentage of trees that were permanently bent by the weight of ice. These trees were so severely stressed due to their new position, that resources could not be allocated to radial growth.

Management Implications of Ice Storms

The results of this study suggest that landowners should not be concerned with continuing to thin their hardwood stands. A thinned stand is not at greater risk for ice

injury. In addition, the thinning may actually accelerate the recovery process by creating individuals that are more vigorous than their unthinned counterparts.

However, it should be noted that heavily thinned stands may be at a greater risk to ice injury. For example, site 3 in Greenwood, ME was heavily thinned (i.e. had 35 square feet of basal area per acre remaining after the thinning operation). Site 3 was the only study site that had a significant difference in percent crown loss between thinned and unthinned stands. This fact may be due to the heavy thinning that took place at site 3. Determining a basal area threshold, above which ice injury greatly increases, would be ideal.

The amount of time after a thinning may also be crucial to the amount of ice injury. For example, the four field sites researched in this study had at least two growing seasons pass since the thinning occurred. This time allowed the sites to respond to the thinning (i.e. fill in crown openings) and regain inter-tree support. If a newly thinned area was used in this study, this inter-tree support may not be re-established and more injury could have occurred.

CONCLUSIONS

Overall, no significant differences existed between thinned and unthinned stands in terms of damage and recovery variables; however, at individual sites, significant differences did exist. For example, sites 1 and 3 had significant differences between thinned and unthinned stands for pre-storm crown classes, site 2 had a significant difference between thinned and unthinned treatments for post-storm crown class, and site 3 had significantly different percent crown loss values. None of the four research sites had significant differences between treatments for numbers of broken branches, percent transparency, and number of sprouts. Sites 3 and 4 had significant differences between treatments for shigometer values. These results suggest that damage was patchy and highly variable and that extrapolation of damage and recovery data from this study to the entire state of Maine, are not valid unless exceptions to general trends are noted. For the small, private landowner, this fact is crucial. The significant differences at the site level were the catalyst for the concern of those affected. The small landowner may be concerned with overall averages, but should realize that averages are just that- averages- and that their forest property may greatly deviate from the reported means. Therefore, the null hypothesis ($H_0 1$) " There is no significant difference in damage between thinned and unthinned forest stands" is not rejected.

Of the five species studied, paper birch, red maple, and American beech all showed higher vigor in the thinned stands, suggesting that individuals in the thinned stands may have a better chance of recovery than individuals in unthinned stands. In addition, the transparency ratings for these three species were not significantly different across the two treatments, thus suggesting that visible live crown alone is not an

appropriate indicator of tree vigor. Therefore the null hypothesis ($H_0 2$) "There is no significant difference in recovery between thinned and unthinned forest stands" is not rejected because while thinned stands appear to be doing better, the recovery differences in thinned and unthinned stands were not significant.

Chapter 2: COMPARISON OF MANUAL AND DIGITAL APPRAOCHES FOR CLASSIFICATION OF ICE INJURY FROM AERIAL PHOTOGRAPHY

LITERATURE REVIEW

Remote Sensing Applications

Gathering data without direct contact with objects under investigation is called remote sensing and includes aerial photography and satellite imagery. Satellite imagery has been used to map natural disturbances such as hurricanes, floods, and fires in order to direct emergency personal to the most devastated areas for immediate relief. In addition, this imagery has been used following disturbance events to evaluate recovery and changes in systems (Cohen et al. 1998). Air photos have been used to "prepare forest type maps, locate access roads and property boundaries, determine bearings and distances, and measure areas" (Avery and Berlin 1992). Disease- and insect-infested areas can be determined and evaluated over time to determine changes in extent and severity of these problems. Other related fields, such as recreation and wildlife have used aerial photography to aid in management efforts (Avery and Berlin 1992).

Research shows that remotely sensed data has proven to be an appropriate tool to assess and monitor large-area forest attributes (Hudak and Wessman 1998; Hyyppa et al. 2000). Remote sensing is often less expensive and less time consuming than traditional ground surveys. While remote sensing does not eliminate the need for ground measurements, it does reduce the amount of ground data required to measure accurately forest attributes (Hyyppa et al. 2000; Holmstrom et al. 2001).

Digital Image Processing

In order to use remotely sensed data, several operations must be performed before the actual analysis of the data can begin. The first step is to correct the data radiometrically and geometrically. Radiometric corrections include removing noise introduced by the sensor system or atmosphere.

Geometric Corrections

Geometric corrections involve removing geometric distortion from an image (Jensen 1998). For example, when an image or photo is taken, it is an irregular representation of the Earth's surface. In order for this image or photo to be positioned on a flat surface it must be rectified. Several types of rectification are possible including image-to-image and image-to-map rectification. This study focuses on rectification using a polynomial transformation and nearest neighbor resampling technique. Image-to-map rectification is appropriate when accurate area, direction, and distance measurements are required, but it may not remove all distortion caused by topographic relief displacement in images (Jensen 1998).

Rectification involves transforming images to the same coordinate system using ground control points (GCPs). GCPs are specific points that can be located in both the source and reference images. Useful GCPs include road intersections and airport runways. The reference image, which has map coordinates and a projection, is used to rectify another image, the source image, which does not contain map coordinates or a projection. When a linear transformation is used, 3 GPS are required to create a transformation matrix. A transformation matrix consists of coefficients that are used in a

polynomial equation to convert reference coordinates to source coordinates. When coefficients for the matrix are calculated, the goal is to create polynomial equations for which there is the least amount of error when they are used during the transformation process. Error is the distance between the GCP source coordinates and the transformed GCP source coordinate. This error is called the root mean square (RMS) error. Acceptable levels of RMS error depend upon reference data accuracy, accuracy of the GCP, and use of the final product (Lillesand and Kiefer 1994, ERDAS Field Guide 1999).

Once an acceptable RMS has been achieved and the transformation performed, the source image is then resampled to calculate new data file values for the output image. There are three types of resampling support by ERDAS Imagine: nearest neighbor, bilinear interpolation, and cubic convolution. The nearest neighbor method retransforms the newly rectified coordinates back to the source file coordinates. The pixel closest to the retransformed coordinates is the nearest neighbor and is used as the new pixel value. With the nearest neighbor method, the original data values are transferred without averaging them as do the other two methods, but pixels in the output image may be offset by up to one-half pixel (Lillesand and Kiefer 1994). In addition, nearest neighbor is suitable for use before classification (ERDAS Field Guide 1999). Results of the rectification can be checked for accuracy by overlaying a vector layer for comparison. Once images are rectified and their accuracy is checked, they can be mosaicked. Mosaicking involves combining several images into one large image. Images must be rectified for this operation (Lillesand and Kiefer 1994, ERDAS Field Guide 1999).

Manual Photo Interpretation

Manual interpretation of remotely sensed data involves several steps, most of which include the user. After air photos are taken and printed, the user will identify the areas for study, which for this case would include ice damaged forest areas. The areas are identified by the user, who then draws polygons around the area of interest. Next, the polygons are digitized for computer recognition and maps are generated based upon the digitized areas.

Image Classification

"Image classification is an information extraction process that involves the application of pattern recognition theory to multispectral images" (Avery and Berlin 1992). This type of classification uses the pixel brightness values of the image to classify features. Pixel brightness values, also called digital numbers, are numbers that quantify the spectral reflectance of each pixel related to features found within the ground resolution. A computer uses these values to classify pixels into clusters of similar brightness values.

Usually, this method is used in conjunction with satellite imagery. However, certain applications, such as classifying disturbance from ice storms, requires a higher resolution than commonly used satellite imagery (i.e. Landsat TM) can provide for forestry applications. While some high-resolution satellite images are now available (i.e. IKONOS), they are extremely expensive to purchase.

Reasons for Digital Classification

Digital classification of aerial photographs was chosen as the method for this study for a number of reasons. First, because manual interpretation of aerial photography has proven to be an efficient method for classifying ice injury at varying injury levels, I wanted to attempt a different approach using aerial photography and determine if it was a valid method for detection of ice injury. Secondly, 15,500 aerial photos were taken of injured areas in southern Maine. It seems logical with such a large amount of data that a digital approach would be more efficient than a manual approach.

Texture Analysis

Digital aerial photographs lack true spectral reflectance values. They do, however, have an attribute that can be used in place of the digital numbers and absolute reflectance called texture. Texture is a property of variability in image tone or color (Avery and Berlin 1992). Several methods are available for describing the texture of an image including statistical, structural, and spectral. Statistical analysis of texture involves characterizations of texture as smooth or rough based on statistical measurements such as mean and variance (Gonzalez and Woods 1993). Smooth textures are associated with croplands, bare fields, and calm bodies of water. Rough textures are associated with forests (Avery and Berlin 1992). Texture analysis aids in the development in spectrally distinct classes based not on spectral differences, but rather their tone or texture differences. Essentially, texture analysis is a type of image enhancement (i.e. filter) which uses a mathematical algorithm to alter the pixel values. Pixel values from a pre-

defined moving window are used in the algorithm and the result is a change in the pixel value (ERDAS Field Guide 1999).

Texture analysis filters can be categorized under a larger heading of spatial enhancements and among its counterparts include edge detection and edge enhancement. Spatial enhancements modify pixel values based on the value of neighboring pixels. Edge detection is a type of convolution that enhances linear features. In the case of ice injury, edge detection could be used to enhance downed or bent trees. Edge detection can amplify an edge, line, or a spot. Edge enhancement is similar to the edge detection, but edge enhancement essentially is a high pass filter that is used to sharpen the image (ERDAS Field Guide 1999).

Supervised Classification

Edge enhancements can be used in conjunction with supervised classification to identify particular areas or differences in feature types. Supervised classification is an important type of classification because it is closely controlled by the image analyst. The analyst has the ability to develop training sites that are used when the classification algorithm is performed. Training sites are areas of pixels that represent a pattern or land cover feature that is known to the analyst either through reference data or general knowledge of the area. Signatures are the result of training and each signature corresponds to a class. The computer uses an algorithm to determine the numerical signatures for each training class, such as parametric or non-parametric decision rules. Parametric rules assume a normal distribution, whereas non-parametric decisions can be used for data that has a bimodal distribution. Several non-parametric decision rules exist

including parallelepiped. Parallelepiped uses the standard deviation of the digital number, which is then added and subtracted from the mean of the class to establish upper and lower boundaries for each class (ERDAS Field Guide 1999).

Once the computer has determined the signatures for each class, each pixel in the remainder of the image is compared to the signatures and assigned to the class it most closely "resembles" spectrally. These pixel groups are used to instruct the computer system to identify pixels with similar spectral characteristics. Reference data can include aerial photography ground truth data, or maps. Each training site is then recoded to the pre-established classification scheme.

Five basic steps are used to classify images using the supervised approach. They are as follows (Avery and Berlin 1992):

1) Choose training sites. Training sites are groups of pixels that represent a specific group of information, such as a specific spectral signature.
2) Generate statistical parameters. Statistical algorithms are used to define the specific spectral characteristics of the training site. These statistics are used to train the computer to classify according to the training sites.
3) Classify the data. The remaining areas of the imagery are classified based upon the training sites. Each pixel is classified into one of the training site types.
4) Determine accuracy of classification. If the classification is shown to be inaccurate, steps 1-3 are repeated.
5) Document the results. Once an accurate classification is achieved, the results are documented as maps and tabular data.

Accuracy Assessment

Accuracy assessments report on the accuracy of the classification by comparing the results to reference data in a matrix format. Reference data is assumed to be true and is placed in the columns of the matrix. Reference pixels or areas are randomly selected and are points on the classified image for which actual data are known. These reference areas are not the same areas as the training sites. The rows of the error matrix are made up of the classification values. Results of the accuracy assessment indicate the reliability of the classification. The overall accuracy, producer's accuracy, user's accuracy and the kappa statistic are all reported from the accuracy assessment results. The overall accuracy is calculated by dividing the total number of correctly classified pixels (the sum of the major diagonal) by the number of pixels in the error matrix. The producer's accuracy is the probability of a reference pixel being correctly classified and is a measure of omission error (exclusion). The user's accuracy is the probability that an area on the map actually represents that class on the ground and is a measure of commission (inclusion). The kappa statistic incorporates the off-diagonal matrix values as a product of the row and column marginals. The kappa statistic and the overall accuracy values may not be the same, depending upon the amount of error in the accuracy assessment matrix. An overall accuracy of 85% has been proposed as the cut-off between acceptable and unacceptable classifications. This value is the recommended level of minimum accuracy to accept, although there is nothing inherently absolute about this value (Congalton and Green 1999).

While textural analysis has not been previously used for determining ice injury from aerial photography, it has been used for other forestry applications. Hudak and Wessman (1998) used this method for determining woody plant encroachment on the South African savanna. They found that image texture analysis of aerial photography was well correlated with forestry parameters found in the horizontal place such as a woody stem count and woody stem density. However, forestry parameters in the vertical plane such as canopy height, varied considerably and were not well correlated with image texture. The researchers also found that coarsened grain sizes decreased the sensitivity of image texture to canopy structural variation. Hyyppa et al. (2000) compared the accuracy of several remote sensing data sources and found that aerial photography was accurate in estimating forest measurements and suggested that texture analysis methods may improve the estimation accuracy.

METHODS

Aerial Photography Acquisition and Scanning

Remotely sensed data were used to locate and assess position and severity of damage from the 1998 ice storm at site 2 in West Sumner, Maine. Four, true color aerial photos, in a 2 by 2 configuration, were purchased from the James W. Sewall Company. The flight and photo numbers for each photo were as follows: 20-168, 20-169, 20-94, and 20-95. These photos were flown on 10 April, 1998 (leaf-off) and had a representative fraction of 1:9,000. Each photo was scanned at 750 dots per inch (1 foot resolution) using a Horizon Ultra scanner and FotoLook 32 B3.6006 software and covered an area of 1045 acres (1.63 sq miles). These digital photos were saved as files and later converted to .img files in ERDAS Imagine.

Photo Rectification and Mosaicking

Three layers of data, roads, rivers, and streams, were downloaded from the Maine Office of GIS (ME OGIS) website and saved as tiff files. These layers were digitized from the West Sumner USGS 7.5 min quad by the ME OGIS. Hard copy United States Geological Survey (USGS) 7.5 minute quads have a horizontal accuracy of 20 meters (60 feet). Once digitized, their accuracy decreases, with an additional 12 meters (36 feet) of horizontal accuracy. A single layer consisting of streams, roads, and rivers was created using the append command in ArcInfo. Once the new layer was cleaned and built, it was converted from its vector format to a raster format and used as a reference image to rectify the first air photo. The photo was rectified using a first order polynomial equation

and then resampled using the nearest neighbor resampling technique. The RMS error of the photo was 32 meters (96 feet). Next, the adjacent photo in the east-west flight line was rectified to the first photo. A third air photo was rectified to the combination layer of rivers, roads, and streams and the fourth photo was rectified to the third photo. Each rectified photo was subset to remove the flight date, flight number and photo number so that this information would not appear on the photo mosaic. The photos were mosaicked using ERDAS Imagine remote sensing software (ERDAS, Inc. 1999). Total area of the mosaicked photos was 3280 acres (5.13 sq. miles). Areas of interest were drawn around non-forestry features such as fields, roads, and rivers and "filled" with a value of 0 because the analysis should only examine ice injury to forest areas.

Digital Analysis and Damage Classifications

Three texture analyses were performed using various window sizes including 3x3, 7x7, and 15x15 configurations. In addition, three other types of image enhancements were performed including a 3x3 edge detect, a 3x3 edge enhancement, and a non-directional edge enhancement. The third layer of the 3x3 edge detect was used along with two layers, the visible green and visible red bands, from the air photo mosaic to create a stack image. The stack image included the most appropriate layers to use for classification. Appropriate layers were chosen by visually comparing the results of all possible band combinations and color guns.

Classification rules used in the traditional, manual approach were used for the alternative, digital classification approach. Classification rules were obtained from the James W. Sewall Company and were as follows:

- crown areas that were less than 20% damaged were placed into the light damage category
- crown areas that were between 20% and 50% damaged were placed into the moderate damage class
- crown areas that were greater than 50% damaged were placed into the heavy damage class.

Selection of Training Areas for Supervised Classification

Training sites were developed from the stacked image. Ice injury labels were assigned to each training site based upon the damage category classification scheme from the James W. Sewall Company. Forty-five training sites were created, fifteen for each of the three ice injury classes. Each of the training classes was approximately 4 acres. Many training sites were created to account for the variation within each ice injury class. The supervised classification was then performed using the training sites. A non-parametric decision rule called parallelepiped was used for the classification due to the variability in seemingly homogeneous areas. For example, a training site containing only hardwood trees, still includes a "background" signature of the forest floor. Therefore a bimodal spectral distribution was present. However, even though a non-parametric decision rule is chosen, the classification also used parametric methods (i.e. maximum likelihood) to aid in the classification of the entire image. Maximum likelihood classification rule is based on the probability that a pixel belongs to a specific class. It assumes that probabilities are equal for all classes and that the inputs bands have normal distributions. For example, if a pixel falls into an overlap region between two or more

parallelepipeds, it will be tested against the overlapping signatures only. If neither of the signatures is parametric, the pixel will not be classified. Pixels that are left unclassified are tested against all parametric signatures. If none of the signatures are parametric, then the pixel will remain unclassified. Once the photo mosaic image was classified, the 45 training signatures were recoded into the three ice injury classes.

The results of the supervised classification suggested that distorted data at the edge of the air photo mosaic was creating a misclassification of data. The distortion is a result of relief displacement in the photo. Relief displacement is caused by the perspective of the camera, which radiates from the nadir point. For example, for trees near the center of the photo, only the crown can be seen. However, trees near the edge of the photo appear to be lying down and therefore the entire tree can be seen. The classification placed the edge areas into the heavily damage class because the trees appear to be lying down, when in actuality they were not damaged. Therefore, the outer 200 meters (600 feet) was trimmed from the edge to remove the displacement area from the mosaic and the supervised classification was performed again following the same procedure. As a result of the trim, the ground area of the mosaic was reduced by 720 acres (22%) to 2560 acres (4 sq. miles).

Accuracy Assessment

An accuracy assessment comparing the results of the supervised classification to the manual interpretation was performed to determine if both methods came to the same conclusion about damage levels from the ice storm of 1998. It should be noted that the training sites were masked from the image by filling the areas of interest with a "0" value

and therefore, these areas were not used in the accuracy assessment. The number of sample units was 180. Congalton and Green (1999) suggest 50 sample units per class as a rule of thumb, but recommend using the multinomial distribution to obtain a better estimate of sample units. This formula, however, requires knowing the approximate distribution of the three levels of ice injury. This distribution was not known prior to classification and therefore the rule of thumb was used, but 10 sample units were added to each class for a total of 180 sample units. The 30 extra sample units were added in case the random points were located on areas that had been masked out. However, none of the sample units needed to be removed for this reason and the total sample units used for the accuracy assessment was 180. The pixel sample points were stratified randomly meaning each ice injury class received 60 sample units each. The reference data was an ice injury digital map created by the James W. Sewall Company for the Maine State Forest Service. This map was created by manual photo interpretation of the same four air photos and was used in the supervised classification of air photos. It should be noted that some areas of the reference layer created by the James W. Sewall Company were not classified because they did not contain damage. Accuracy assessment points located in these areas on the reference map were therefore labeled as "light".

RESULTS

Image Enhancements

Figures 2.1 and 2.2 represent the photo mosaic and a subset portion of the mosaic, respectively. The three texture analyses performed on the photo mosaic did not produce the desired results (i.e. the damaged trees were not more distinguishable from the background). The 3x3 texture analysis performed on the photo mosaic is shown in Figures 2.3 and 2.4. Visual inspection of the images indicated that while the ice injury was enhanced, other individual trees without ice injury were enhanced as well. When the texture images were compared to the original photo mosaic, it was clear that ice injury was in no way visually enhanced or easier to detect. Note that the dark polygons are areas that were non-forested and masked out. Similar results occurred for the 7x7 texture analysis (Figures 2.5 and 2.6) and the 15x15 texture analysis only these results were more "blurred" as the window size increased. Ice injury was not visually detectable or enhanced for all three texture analyses. The results of the edge enhancement were virtually the same as the input photo mosaic and are therefore not included as a figure. The enhanced image was nearly identical to the original photo mosaic. The results of the non-directional enhancement is shown in Figures 2.7 and 2.8. These images were similar to the texture analyses in that the ice injury was not visually enhanced. Figures 2.9 and 2.10 represents the 3x3 edge detect. Edge detection proved to be the best enhancement technique because the other techniques only smoothed the mosaic and did not enhance the ice damaged trees. A layer stack consisting of layer 3 of the edge detect along with layers 2 and 3 from the photo mosaic are shown in Figures 2.11 and 2.12. This was the image used in the supervised classification after the edge trim was performed to remove

the photo distortion. Figure 2.13 shows the ice injury reference data from the Maine Forest Service. The overall accuracy of the supervised classification was 60%. The producer's and user's accuracy, as well as the error matrix and kappa statistics are show in Table 2.1.

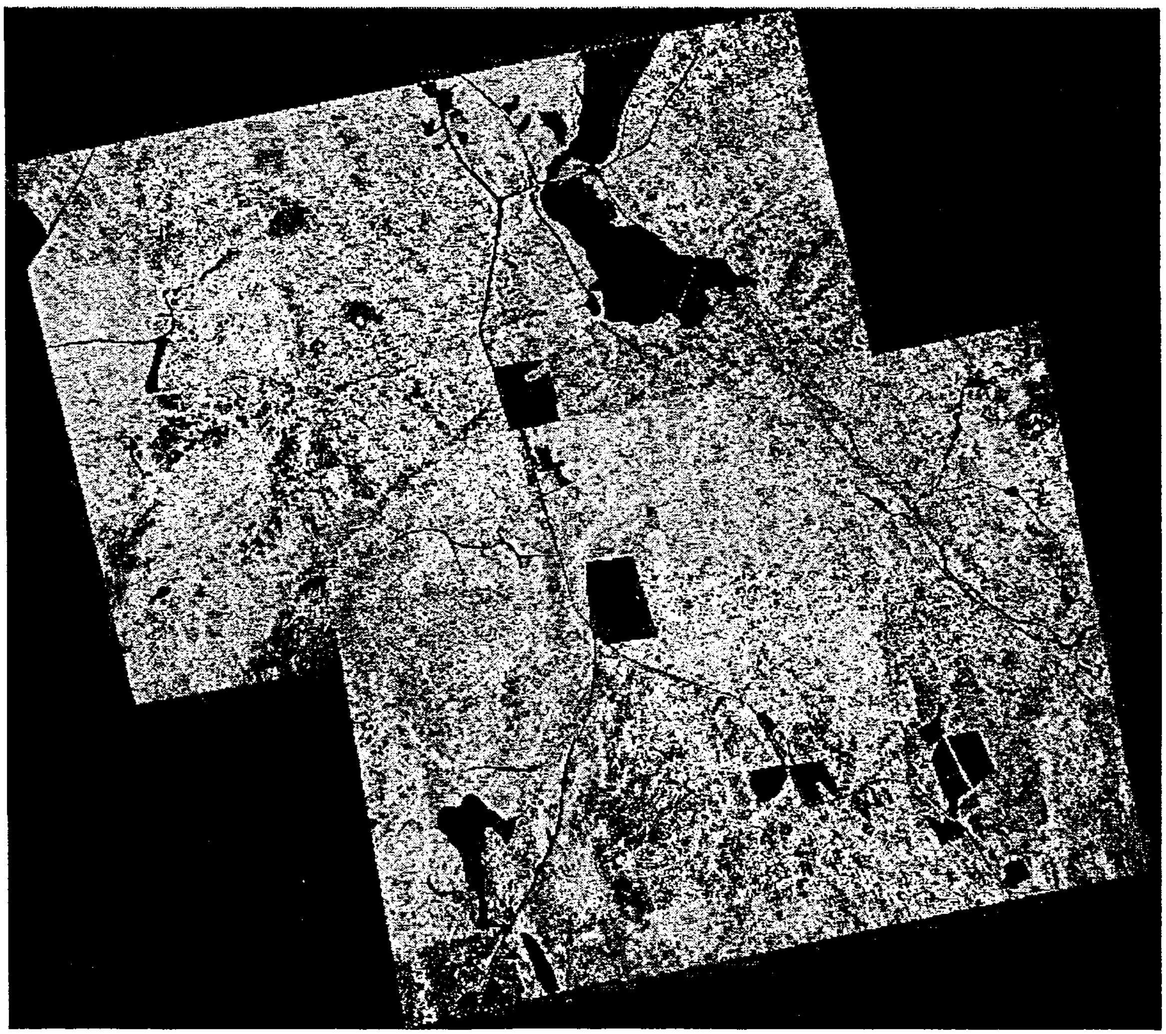


Figure 2.1. Mosaic of four air photos with non-forested areas masked out.

Figure 2.2. Subset of photo mosaic.

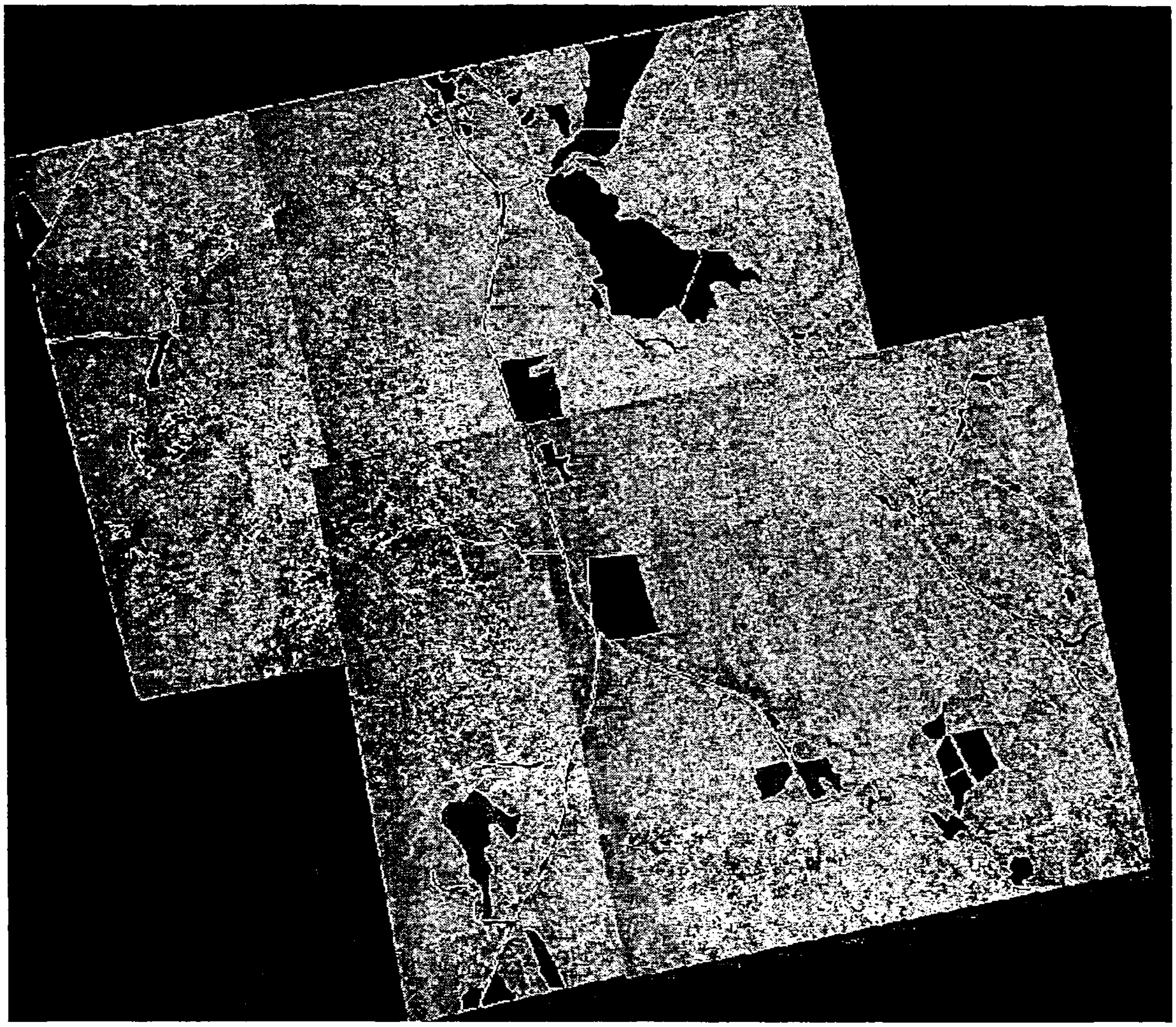


Figure 2.3. Photo mosaic of 3x3 texture analysis.

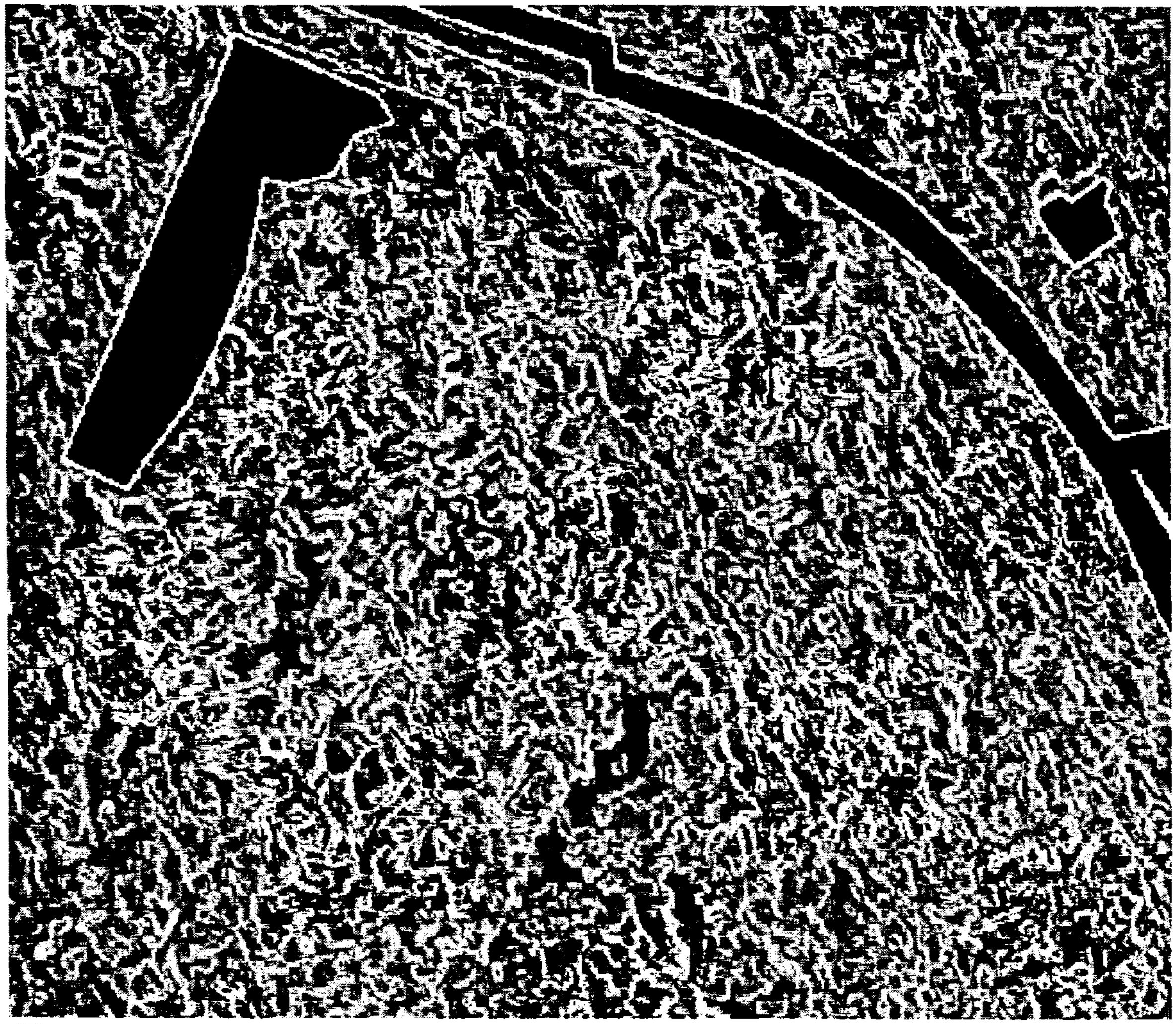


Figure 2.4. Subset of 3x3 texture analysis mosaic.

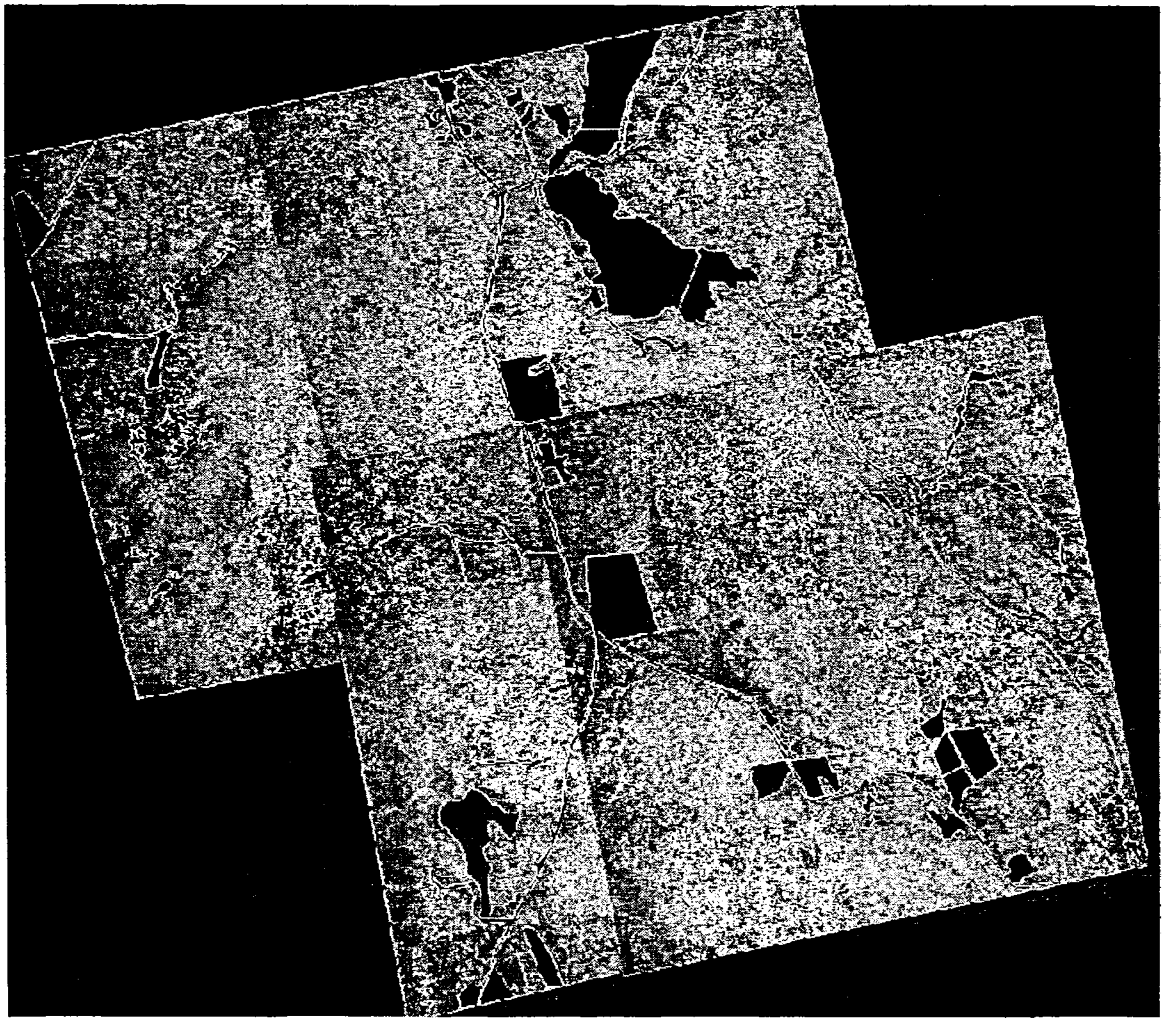


Figure 2.5. Photo mosaic of 7x7 texture analysis.

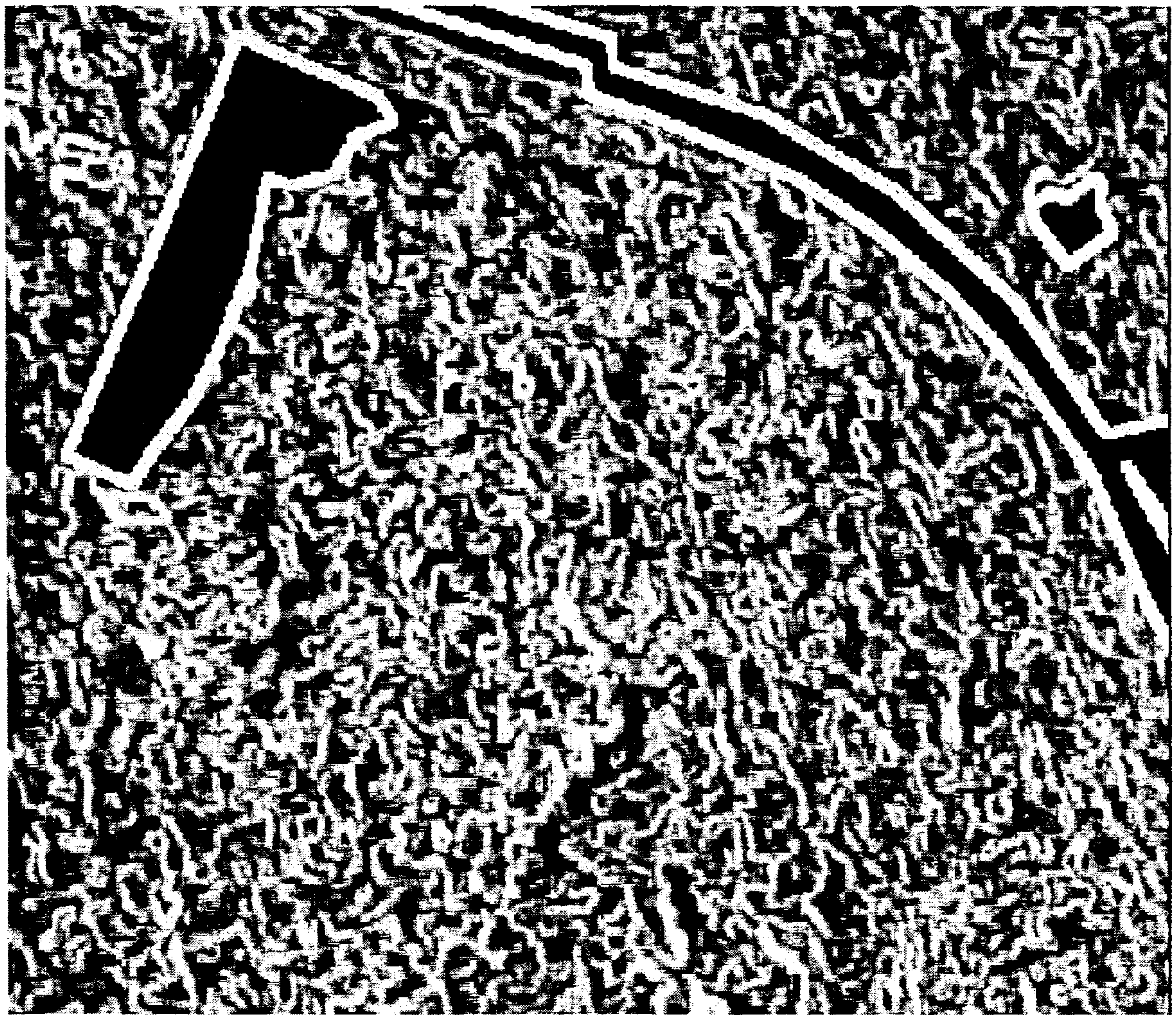


Figure 2.6. Subset of 7x7 texture analysis mosaic.

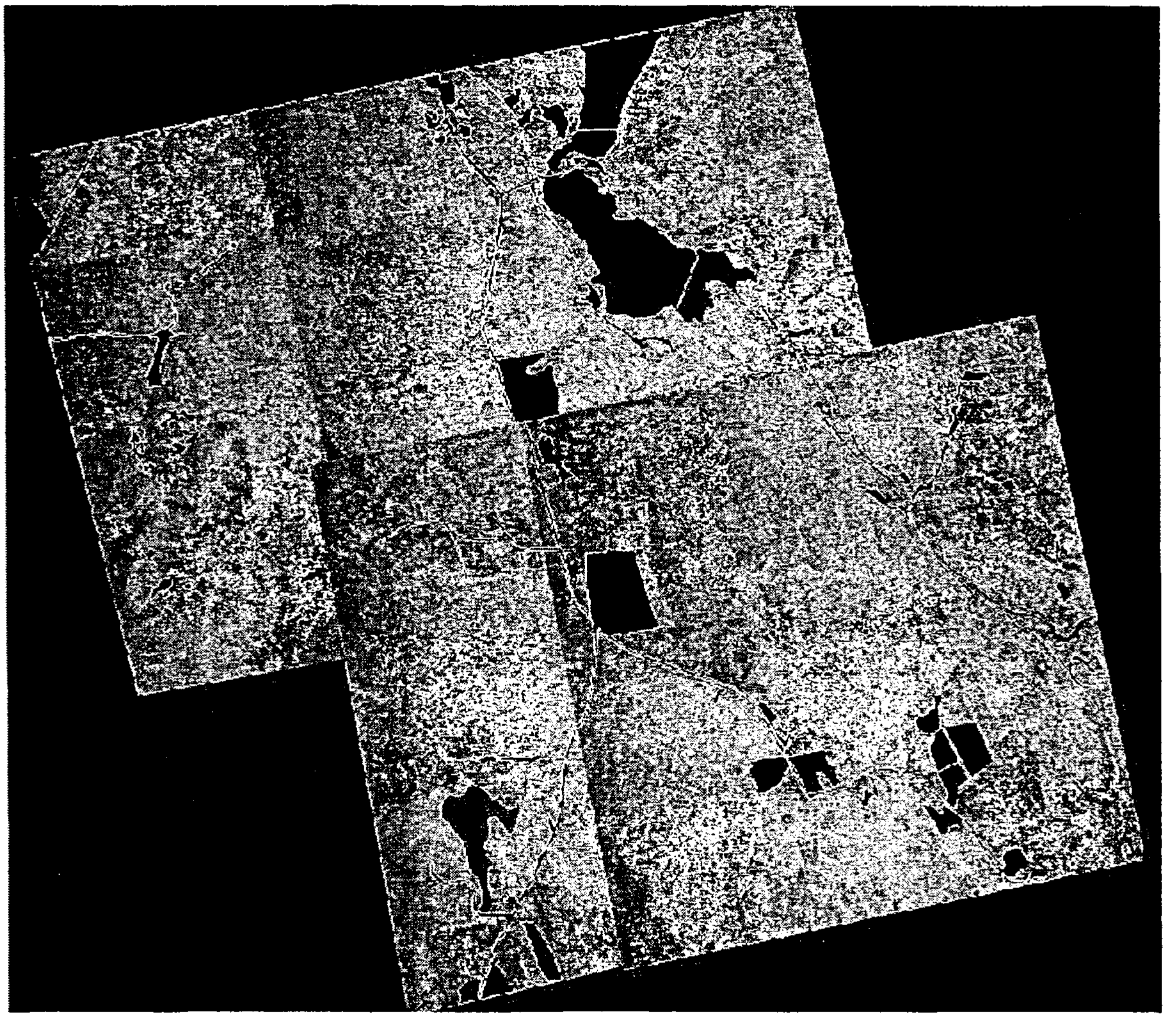


Figure 2.7. Photo mosaic of the non-directional enhancement.

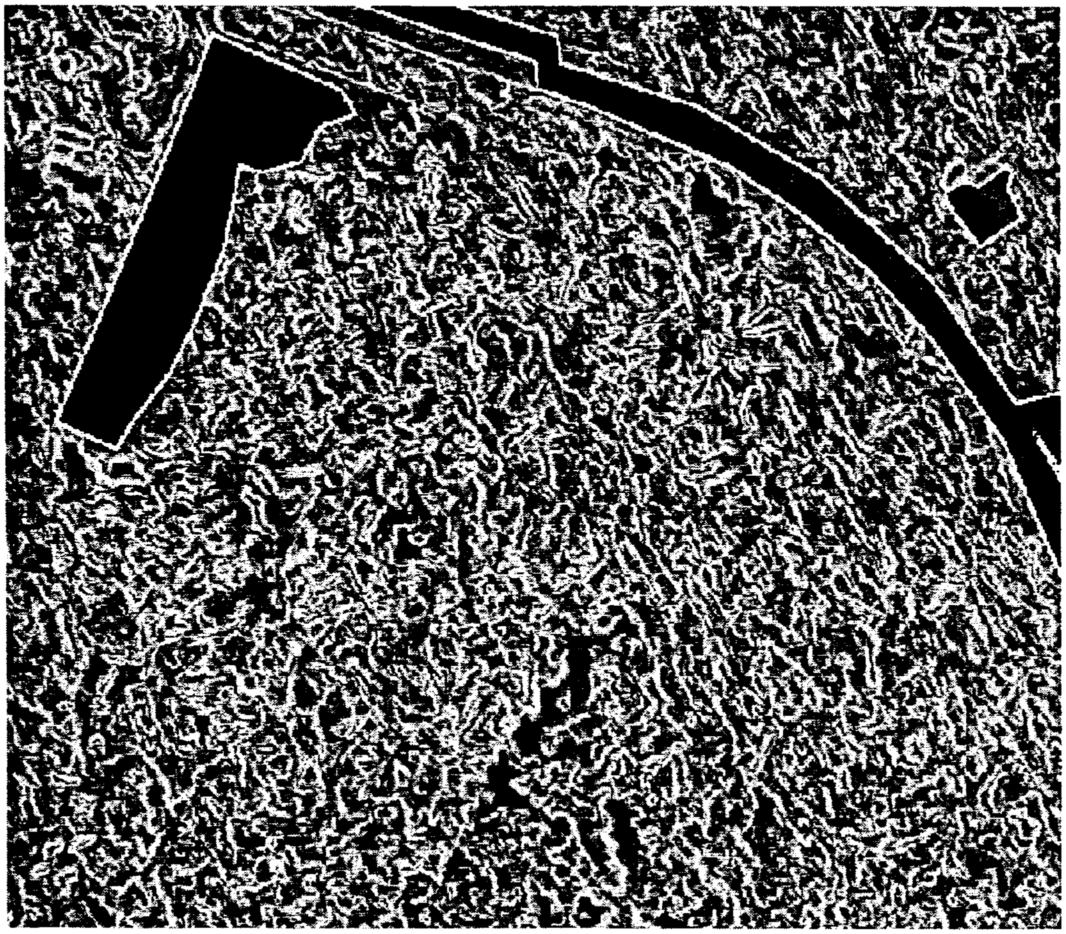


Figure 2.8. Subset of the non-directional enhancement.

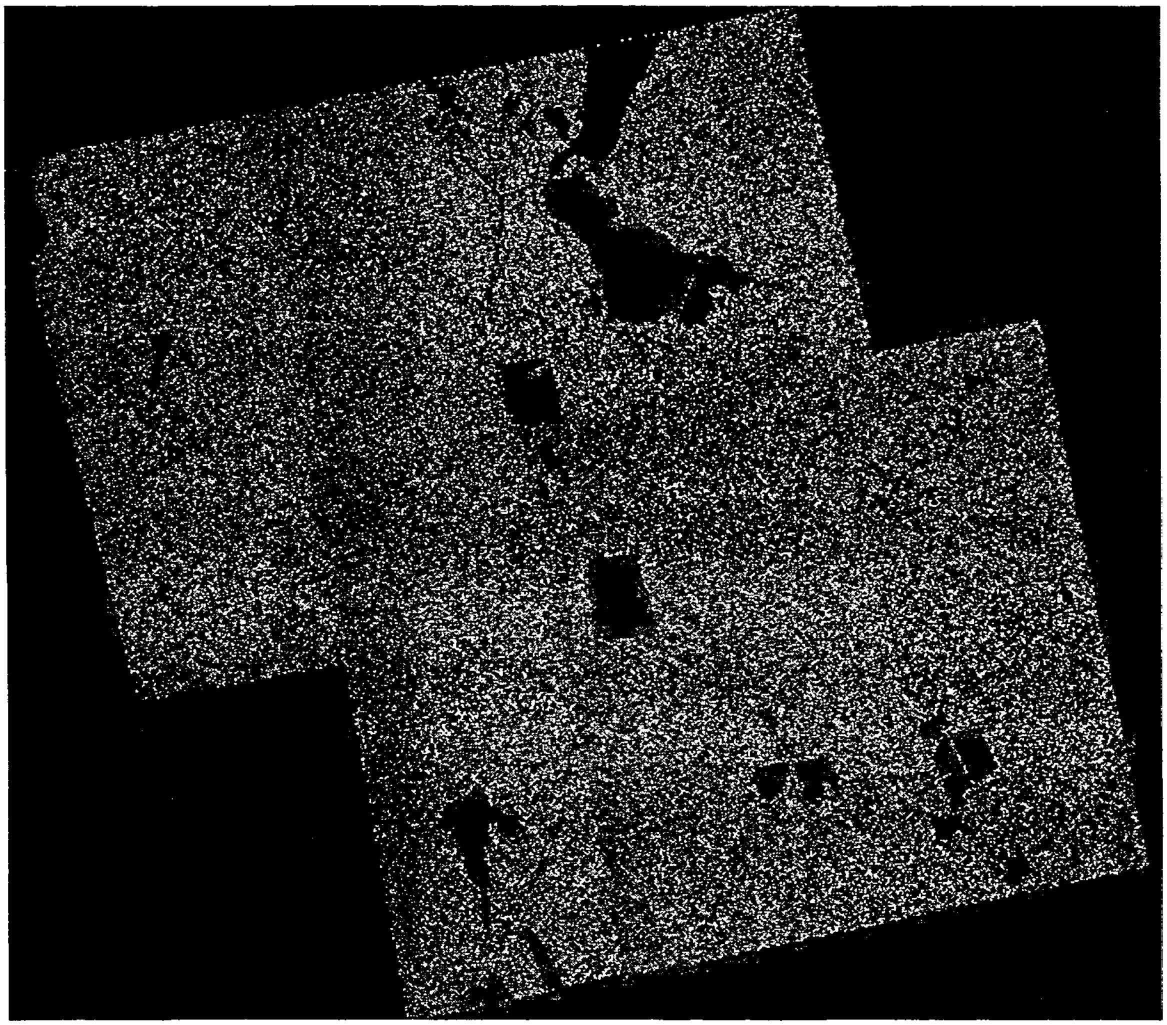


Figure 2.9. Photo mosaic of 3x3 edge detect enhancement.

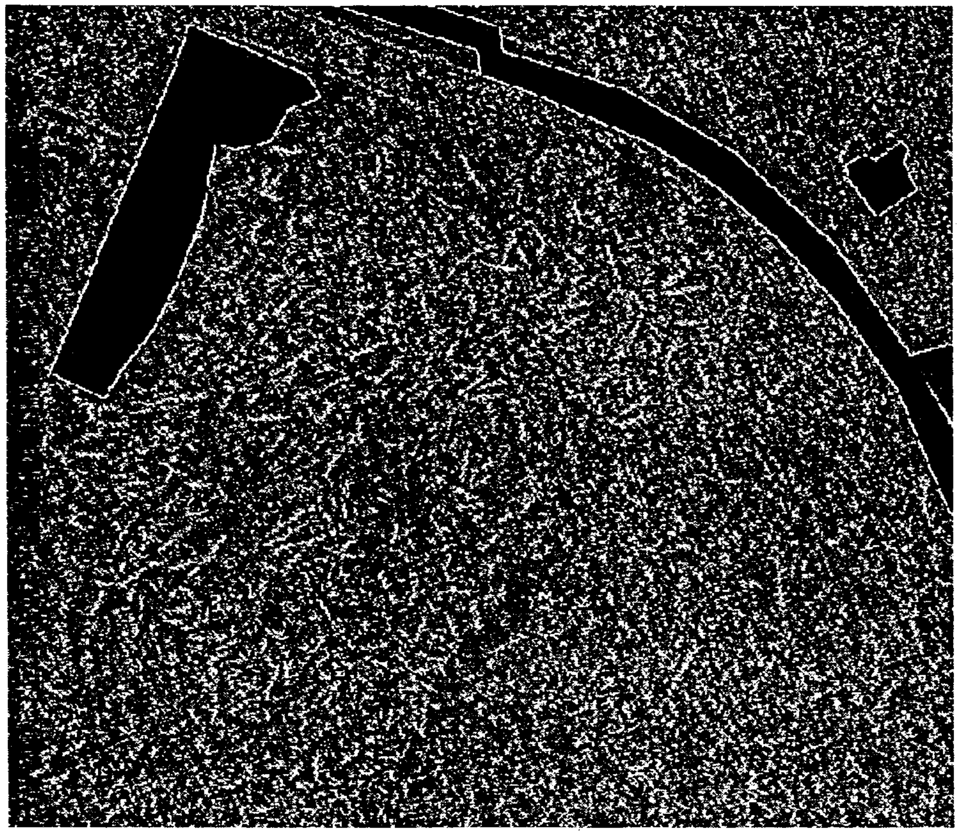


Figure 2.10. Subset of 3x3 edge detection enhancement mosaic.

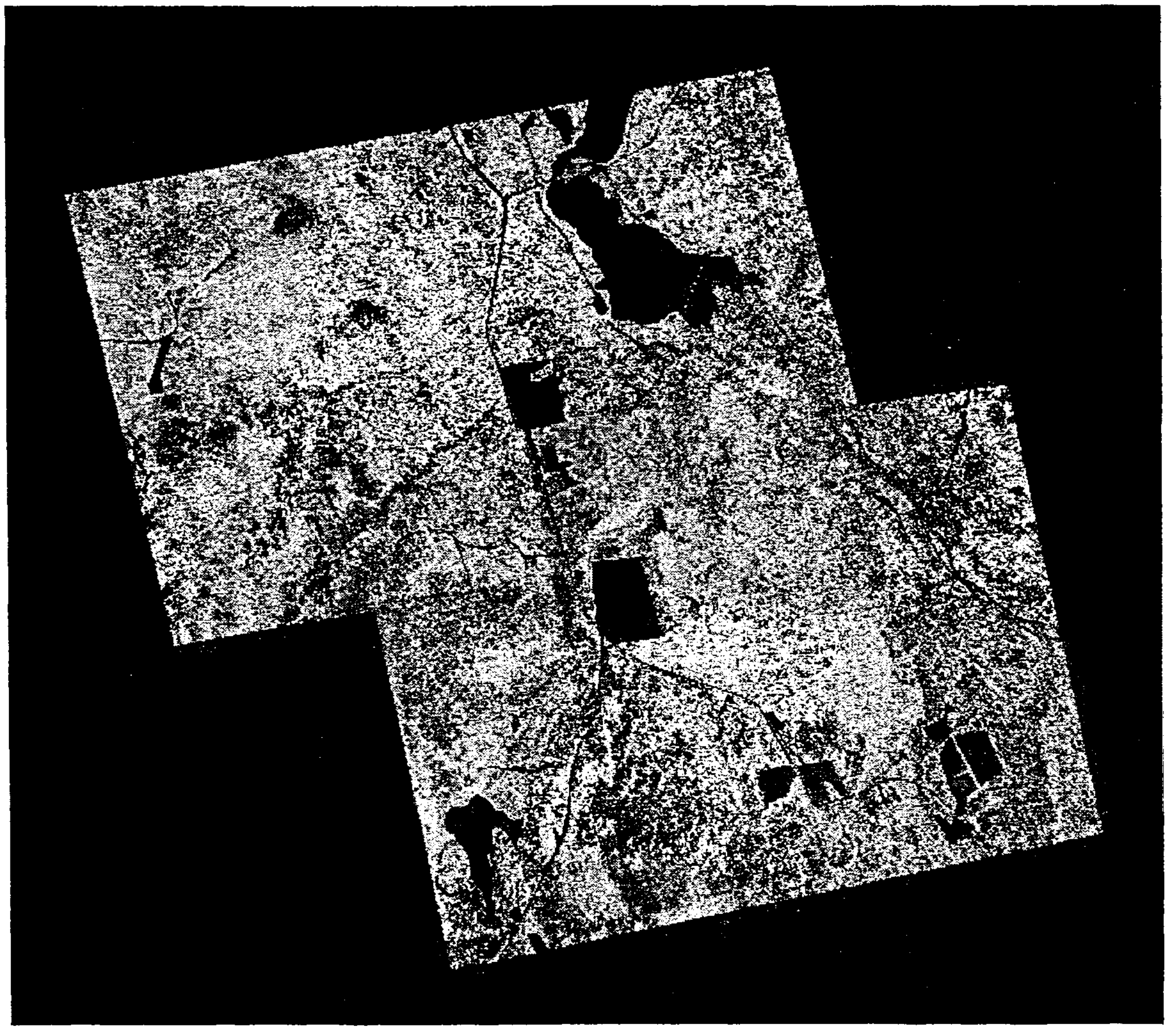


Figure 2.11. Trimmed photo mosaic of 3x3 edge detect stack. Two layers in this image are bands 2 and 3 from the original photo mosaic. The third layer is band 3 from the edge detect.

Figure 2.12. Subset of photo mosaic of 3x3 edge detect stack. Two layers in this image are bands 2 and 3 from the original photo mosaic. The third layer is band 3 from the edge detect.

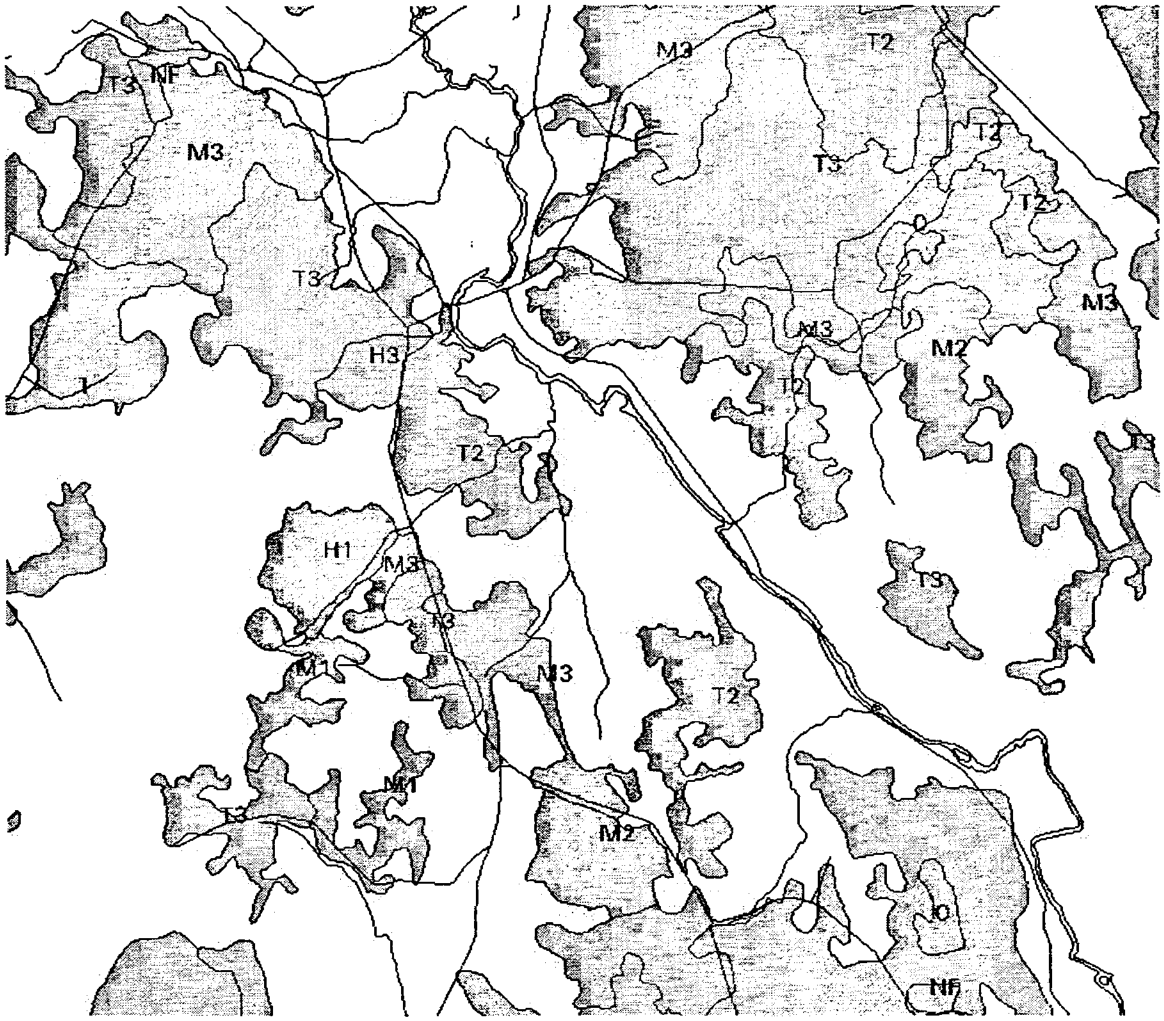


Figure 2.13. Reference layer from the Maine Forest Service. T1, T2, and T3 represent areas that were lightly damaged. M1, M2, and M3 represent area that were moderately damaged. H1, H2, and H3 indicate areas that were heavily damaged. Areas that were not classified were not damaged.

Table 2.1. Accuracy assessment error matrix, user's and producer's accuracy, and kappa statistics.

		Reference Data			
		Light Injury	**Moderate Injury**	**Heavy Injury**	row total
Classified Data	**Light Injury**	103	5	8	116
	Moderate Injury	22	5	2	29
	Heavy Injury	33	2	0	35
	column total	158	12	10	180

Producer's Accuracy		**User's Accuracy**	
light injury =	103/158 = 65%	light injury =	103/116 = 89%
mod. injury =	5/12 = 42%	mod. injury =	5/29 = 17%
heavy injury =	0/10 = 0%	heavy injury =	0/35 = 0%

Kappa Statistics

overall kappa = 0.0310

DISCUSSION

The overall accuracy of 60% indicates that this particular supervised classification was not acceptable for use as the accuracy was below acceptable standards. While the methodology tested does shed some light on a possible new approach for detecting ice injury, other issues prevent this technique from being plausible. For example, the cost in digitally processing each photo would be enormous, especially if all 15,500 photos were used. Costs incurred in the process include paying analysts to perform the digital processing plus a large start-up cost to obtain the required software and hardware. In addition, large amounts of data storage are needed to process such high-resolution aerial photography. The time needed to perform these operations on four photos took several months. Clearly some of this time was spent on finding the best enhancement technique, but even if the best technique was known before processing began, the length of time to complete a project involving 15,500 photos would be lengthy. Obviously, the methods tested would not have met the criteria for an efficient and timely procedure as was needed immediately following the ice storm of 1998 to quickly obtain an estimate of ice injury.

However, two issues could have accounted for the automated classification's low overall and kappa accuracies. First, the registration accuracy of the photo mosaic along with the inaccuracy of the digital USGS 7.5 minute quads used to rectify the photos could have created enough differences between the reference layer the mosaic registration to mislabel areas in the accuracy assessment that were classified correctly. USGS 7.5 minute quadrangle maps have an accuracy of ±20 meters (±60 feet). A digital USGS 7.5 minute quadrangle had an additional inaccuracy of ±12 meters (±36 feet). Once the first air photo was rectified, it had an RMS error of 32 meters (±96 feet). Error such as this

becomes magnified and introduces more and more inaccuracy as image processing continues. Therefore, there were inaccuracies in the registration of the photo mosaic and these differences between the reference and automated classification could have been great enough to mislabel areas in the accuracy assessment. It should also be noted that it was difficult to rectify photos in western Maine where roads and other features required for rectification were not plentiful. In addition, the heavy and moderated damage classes were under represented in the photo mosaic (twelve and ten areas respectively versus 158 for the light damage class), which could lead to the computer having difficulty classifying these areas.

It is interesting to note that a majority of the area classified by the reference classification (i.e. manual classification) was classified in the light class; however, site 2 was located in the band of damage in the state of Maine characterized as severe. In addition, if the methodology tested here was not able to detect ice injury in this area, it seems likely that it would not have been able to detect ice injury in other less damaged areas.

The minimum mapping unit of the reference layer was 25 acres; however, the minimum mapping unit of the supervised classification was approximately four acres. According to Congalton and Green (1999), "reference data should be collected at the same minimum mapping unit as was applied to the map generated from the remotely sensed data. Failure to consider this issue can cause huge problems". This problem could not be avoided as the reference data was created before the supervised classification was performed, and thus the minimum mapping unit of the reference was not able to be altered. The informed reader then asks, "Why not simply change the

minimum mapping unit of the supervised classification"? This was not possible using only four air photos; a 25 minimum mapping unit on the mosaic would only have allowed for 100 accuracy assessment areas. However, even with this problem, the minimum mapping units are similar enough to allow the accuracy assessment to indicate on a general level the ability of this method to estimate ice injury.

The results of mosaicking photos creates "seams" where the edges of two photos meet. The "seams" are noticeable in the photo mosaic because each photo has differences due to sun angle and atmospheric conditions. Even though stereo-photos are taken at approximately the same time and of approximately the same area, the sun angle and atmospheric differences from one camera angle to the next are apparent in the mosaic. Therefore, correction procedures to eliminate these differences would have been helpful. However, training sites were located on each photo of each injury class and therefore, most of the variability between photos was accounted for.

The trim of the outer 200 meters to eliminate the relief displacement distortion occurred after the four photos were mosaicked; however, it should have been performed before mosaicking occurred because relief displacement alone the edges of each photo were not trimmed, only the sides that were on the outer edge of the mosaic were trimmed. In other words, only two sides of each photo were trimmed when all four sides should have been.

In addition, the variability between photos was accounted for by using 45 training sites. For example, "light" injury is one class, but comes in several forms or signatures depending upon the variability of the class and the photos. Therefore, 15 "forms" of this one class were created using the training sites to enable the classification to account for

the variability in the class itself and among the photos. It should be noted that each training site was as homogeneous as possible, but the non-parametric rule was chosen because there were often significant spectral differences between background (forest floor) and forest areas.

Methodologies between traditional and supervised classification are difficult to compare, even if methodologies are as similar as possible. For example, digital methods, albeit supervised or unsupervised classifications, allow for the classification of all areas of the photos regardless of damage class. However, the producer's of the manual classification did not necessarily classify the area if it did not contain damage.

The scale of the two methods created some differences, as well. The supervised approach used only four of the possible 15,500 photos that were used in the manual classification. This alone creates differences in the two methodologies. In terms of time and money constraints it is easier to classify four photos, rather than 15,500 photos and it is easier to "become familiar" with four photos and get the classification as close to accurate as possible. This is not the case when dealing with thousands of photos.

CONCLUSIONS

Based upon the findings of this study, the digital approach on scanned aerial photos is not an acceptable method for classifying ice injury due to accuracy, cost, and time issues. Therefore, the null hypothesis (Ho3) "There is no significant difference between manual and digital approaches for detecting and classifying ice injury using aerial photographs" is rejected. However, the methodology presented here does lay a foundation for future work of this type.

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APPENDIX A: Soil Descriptions for Four Field Sites.

Site 1 soil type is Scio very fine sandy loam (SkB). It is characterized by very fine sandy loam on 3 to 8% slopes found along natural drainage ways and streams. This type is used primarily for hay and pasture, but is also suited to cultivated crops and forests. These soils have a high potential for woodland growth and the limitations and restrictions are insignificant. This soil is tied for the highest potential productivity, a value of 10, of the four sites. The other soil, STD, at site 3 also has a pontential productivity value of 10.

The soil types at site 2 are Lyman-Tunbridge-Monadnock complex (LWD) and Lyman-Tunbridge-Skerry complex (LXC). LWD is a soil found in hilly, stony areas and is primarily used as woodlands. The erosion hazard and equipment limitations are moderate while the seedling mortality and plant competition hazards are slight. Productivity is rated as an 8.

LXC is a soil primarily used as a woodland and its main limitations are due to its rockiness, often, making reforestation difficult. It has a potential productivity rating of 7. While the erosion hazard and equipment hazard limitations are slight, the seedling mortality, windthrow hazard and plant competition are moderate to severe.

Site 3 had two soil types present, as well. The first soil type, Monadnock-Skerry association (MXC), consists of strongly sloping hills and is mainly used as woodland. Its productivity potential is 8 and erosion hazard, equipment hazard, seedling mortality, and windthrow are slight soil limitations, while plant competition is moderate.

The other soil type at site 3 is Skerry-Colonel association (STD). Most areas with this soil type are used as forests. In addition, they tend to have a seasonal high water

table and reforestation can be impeded due to rocks in the soil. Its potential productivity is a 10 and has moderate limitations for erosion hazard, equipment, windthrow hazard, and plant competition. The seedling mortality has a slight soil limitation.

Berkshire very fine stony loam is the soil type at site 4. It is characterized 3% of its surface area covered with stones. Its primary purpose is woodlands and is well suited for this purpose. It has a potential productivity value of 9 and has slight limitations in terms of erosion, equipment, and seedling mortality. Windthrow hazard and plant competition have moderate limitations.

APPENDIX B: Metadata for Layers used in Remote Sensing Aspect of Study.

Ice storm air photos-

Purchased from the James W. Sewall Company
Old Town, ME

True color
Representative fraction: 1:9,000
Flown on: April 10, 1998
Flight line and photos numbers: 20-168
20-169
20-95
20-94
Photos were scanned at 650 dpi to obtain 1 foot resolution
Pixel size: 1 foot
Coverage area: West Sumner, Maine
Accuracy: first photo has an RMS of 32 meters

Aerial photography was commissioned by the 1998 Ice Storm Recovery Project, an interagency program led by the Maine Forest Service in cooperation with the U.S. Forest Service.

Projection: Universal Transverse Mercator (UTM)
Datum: NAD83
Spheroid: GRS1980
Units: meters

Rectification reference layers-

Rivers, roads, and streams layer was obtained from the Maine Office of GIS website (http://apollo.ogis.state.me.us/catalog/catalog.htm) as digital vector layers. The layers were appended in Arc and convert to a raster in ERDAS Imagine.
Pixel size: 1 meter
Coverage area: West Sumner, Maine

Projection: Universal Transverse Mercator (UTM)
Datum: NAD83
Spheroid: GRS1980
Units: meters

Ice injury layer-

Obtained from the Maine State Forest Service, Augusta, Maine.
Files were obtained as .e00 files and convert to arc coverages using Import71
(ADD MORE LATER)
Minimum mapping unit: 25 acres
Coverage area: West Sumner, Maine

Projection: Universal Transverse Mercator (UTM)
Datum: NAD83
Spheroid: GRS1980
Units: meters

BIOGRAPHY OF THE AUTHOR

Julie Lee Swisher was born on March 22, 1975 to Sandy and Gary Swisher in Parkersburg, West Virginia. She was raised in Parkersburg, where she graduated from Parkersburg High School in 1993. She graduated from West Virginia University in 1999 with two Bachelor of Science degrees: Forest Resources and Wildlife Resources with an emphasis in Fisheries Management. As an undergraduate, Julie worked for West Virginia University as a forestry field technician for two summers and worked at the Natural Resource Analysis Lab as a GIS technician. She is a member of the Society of American Foresters (SAF) and Xi Sigma Pi. Julie entered the Department of Forest Management at The University of Maine in August of 1999. Julie is a candidate for the Master of Science degree in Forestry from the University of Maine, December 2001.