The Effects of Ice Damage on Management Decisions for Loblolly Pine Plantations located in the Piedmont Region of Virginia

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Abstract

The effect of ice damage on loblolly pine (*Pinus taeda*) plantations in the Piedmont region of Virginia was examined to discover if management decisions can minimize net present value losses. A simulation approach was used for the analysis. Loblolly pine plantations were simulated using the growth and yield model, Trulob. Ice damage was factored into the model using prediction equations from a previous study. A decision tree framework was used to determine which management plans resulted in the highest net present value.

The results show that ice storms can cause significant losses to the net present value of loblolly plantations. In most instances changing management plans could not minimize losses. In situations where altering management plans can result in higher net present values if ice occurs, landowners should also be aware of the suboptimal net present value they will be returned if these plans are followed and no ice storms occur.

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Chapter I. Introduction and Objectives

I. 1. Introduction

Pine plantations in the southeastern United States are susceptible to damage from ice glaze caused by freezing precipitation. The effects of the glaze can vary greatly, from beneficial pruning to the total destruction of any viable, commercially profitable timber. Ice storms in the recent past have caused significant losses. In February of 1994 an unusually destructive ice storm hit the southeastern United States from northeastern Texas to Virginia (Lott and Ross 1994, Lott and Sittel 1994). This storm caused over 3 billion dollars worth of damage over the area, including significant destruction to standing timber. In January of 1998 an ice storm struck the northeastern United States, affecting an estimated 25 million acres through the United States and Canada (Irland 1998). The economic losses resulting from severe ice damage can jeopardize private landowner investments and restrict their ability to reinvest in forestlands. The meteorology of the southeast, along with its large number of pine plantations, makes ice damage an increasingly important topic for forest management.

To effectively manage a pine plantation under the risk of ice damage, certain factors must be included in the decision making process. A general recognition must be made of the frequency and severity of ice storms in a region to make estimates of a stand's risk to damage. Likewise, the stand and individual tree characteristics that increase susceptibility to damage must also be recognized. Finally, the effects ice damage has on the dynamics of the thinning regime, rotation length of a stand, and total merchantable volume need to be understood. All of these elements must be understood in order for the goals of the landowners to be accomplished. The focus of this research is to better understand the dynamic effect of ice damage to management plans, timber volume output and net present value.

I. 2. Objectives

The main objective of this study will be to assist small private landowners that currently have or are planning to invest in loblolly pine plantations. This study will provide small private forest landowners with examples of the losses that can occur from ice damage, and the impact of different management activities on the magnitude of losses. This study will focus on landowners with loblolly pine plantations in the Piedmont region of Virginia. The specific goals of the study are as follows:

1. Review the literature on ice storms and timber management. This will be accomplished by summarizing past studies in the area dealing with the frequency, history, and effects of ice storms on timber management.

2. Determine the effects that ice damage can have on the value of a stand with empirical examples. From these examples, document how the effects change among stands with different characteristics (site index, planting density, and thinning regime) and with the age of the stands.

3. Formulate management plans that account for ice damage and compare those to management plans that do not consider ice damage. From these differences in management plans, discover the cost of following one management schedule while the other scenario occurs. Example: how much value would a landowner lose if they followed the optimal schedule for a stand that will get hit by ice, but does not sustain any damage?

4. From the costs analysis, derive the probabilities of ice storm occurrence necessary to justify following the management regime for ice damage over the management regime that does not take ice storms into account.

Chapter II. Literature Review

II. 1. Meteorology

Freezing precipitation is a common form of winter weather in the southeastern United States. The eastern side of the Appalachian Mountains has been cited as one of the most common areas for ice storms (Forbes et al. 1987). From Louisiana to North Carolina, between 20 to 40% of all winter weather is in the form of freezing precipitation (Robbins and Cortinas 1996). The Piedmont region on the eastern side of the Appalachian Mountains often incurs heavy ice storms. In a climatology of the contiguous United States, Robbins and Cortinas (1996) found that one of the higher zones of freezing rain occurrences is located on the eastern side of the Appalachian Mountains, from northeast Georgia to Virginia, with Greensboro, North Carolina in the center of the zone. McKellar (1942) reported that severe ice storms occur on average once every five years in a region in the southern Appalachian Piedmont around Athens, Georgia. Travis and Meentemeyer (1991) found comparable results for an ice storm chronology for the same area. After studying data over an eight-year period, Bennett (1959) reported that the majority of Virginia fell in the range of 9-17 storms for the period between 1929-1937. In a more recent county-scale study, the state of Virginia was found to experience between 1 to 5 icing events over the period from 1984-1991 (U.S. Environmental Protection Agency 1994). Despite these data it is important to remember that glaze storms are not recorded regularly by any central agency, and the reports by the National Climatic Data Center (NCDC) are not uniform (Bendel and Paton 1982; Shan et al. 1998; U.S. Environmental Protection Agency 1994). Due to the nature of the collected data, a dependable frequency rate of major ice storms is currently unattainable (Lott and Sittel 1994).

Glaze storms in the southeast often are a result of precipitation that is formed in or falls through a layer of air that is above the freezing point. The precipitation that falls from this warm layer of air enters a layer that is below freezing and then freezes upon impact with the ground (Forbes et al. 1987). An average storm is between 120-360km in length (Bendel and Paton 1982). The southeastern region is especially susceptible to this type of precipitation, because of a phenomenon that is known as cold-air damming. Cold-air damming is the process of cold air becoming trapped along the sides of mountain range slopes (Richwein 1980). This trapped cold air forms a U-shaped dome, and when this dome is overrun by a moist a warm front, freezing precipitation is produced (Bell and Bosart 1988). In the southeastern region below Maryland, and between the Appalachian Mountains and the Atlantic Coast, a climatology performed by Bell and Bosart (1988) found that three to five damming events per month could be expected during the winter months, with the highest occurrences in December and March.

II. 2. Effects of Ice Damage

One of the most detrimental effects that glaze has upon the trees is the increased weight. The weight of glaze is the storm characteristic most strongly correlated to the degree of damage (Bruederle and Sterns 1985). The ice forming on tree branches and needles can increase the weight by as much as 30 times, and the size as much as 10 times (Baxter 1952). Oliver and Larson (1996) estimated that an additional five tons of weight could be added to a 50-foot tall conifer with a 20-foot average crown width. This increased weight can lead to the tree holding between 15 and 30 times its original weight (Abell 1934, Bennett 1959, Lemon 1961). The ice accumulation necessary to cause considerable damage has been reported by Lemon (1961) as ½ to 1-inch thick. During the 1994 storm in the southeast United States, melted precipitation amounts exceeding 7 inches were reported (Lott and Ross 1994).

In addition to the added weight, glaze storms are often accompanied by wind, which can magnify damage to the timber (Carvell et al. 1957; Bendel and Paton 1982). Amateis and Burkhart (1996) stated that a combination of a heavy loading and only moderate winds could cause substantial damage. Wind damage can vary from complete uprooting to the breakage of the topstems. Wind also contributes to tree damage by causing the accumulation of the precipitation on the windward side of the tree (Bennett 1959). This causes an imbalance in the tree’s crowns, which could lead to severe crown breakage. The severity of damage can vary greatly depending on the differences in local climate and topography (Peltola et al. 1999). This can be due in part to the fact that the icing event itself is affected greatly by the local climate and topography, and can vary widely in a small area.

Variables directly related to the icing event itself are not the only factors important in estimating the damage that standing timber will incur. The susceptibility of a stand can vary greatly, and is not solely dependent on a single characteristic. Stand characteristics such as topographical location, species composition, and age all have been identified as determining the extent of damage (Lemon 1961; Bruederle and Sterns 1985; DeSteven et al 1991; Rebertus et al. 1997). The way glaze affects standing timber is a complex issue, and because of the multiple factors that control the damage, no single method of determining a stand's susceptibility has been developed.

There is wide variation in the ability to withstand ice damage among different species. Lemon (1961) and Whitney and Johnson (1984) found that late succession species were often more resistant than early succession species. There are differences in reports on the hardiness of conifer versus deciduous trees. Many studies have stated that evergreen conifers were at a disadvantage because of the presence of foliage during the ice storm season (Lemon 1961; Whitney and Johnson 1984; Boener et al. 1988; Illick 1916). However, others have stated that conifers had adapted to handle ice damage through their symmetrical narrow crown shape, branching patterns, flexibility and other adaptations (Downs 1938; Carvell et al. 1957; Bennett 1959). The difference in these conclusions seems to be another result of the erratic nature of ice storms and their damaging effects.

In three separate studies, loblolly pine (*Pinus taeda*) was shown to be one of the more resistant southern yellow pine species. In a study in the vicinity of Athens, Georgia by McKellar (1942), loblolly pine was the least affected species out of whole and mixed stands of loblolly, slash (*Pinus elliottii*), and longleaf pine (*Pinus palustris*). Loblolly pine trees had the least amount of broken stems, broken limbs, badly bent, slightly bent, and uprooted trees (McKellar 1942). Williston (1974) reiterated this point when he reported that loblolly pine was second only to shortleaf pine (*Pinus echinata*) as the least damaged, when shortleaf, longleaf, and slash pine were compared in storms occurring in Louisiana and Mississippi. Hebb (1971) found that loblolly was more resistant than sand pine, slash pine, and longleaf when he studied damage after an ice storm in South

Carolina. Hebb (1971) concluded that loblolly's resistance is enhanced by good survival and growth when compared to other southern yellow pines. Loblolly pine’s resistance could further be explained by sparse foliage when compared to other pines, which results in less ice accumulation (Bennett 1959).

The size and age of a tree also plays a role in determining both the extent and the type of damage incurred. Shepard (1978) reported that smaller trees were more likely to bend, be uprooted or rootsprung, whereas larger trees were more likely to break. Muntz (1947) found that smaller trees usually recover whereas taller trees are more likely to develop sweep. Muntz (1947) also found that loblolly pine would tend to bend rather than break. The measurements of size most useful in predicting damage are a subject of debate. Amateis and Burkhart (1996) developed equations estimating damage classes based on a combined variable using diameter and height, the two attributes they found to have the highest correlation with damage classes. However, Valinger et al. (1993) found that both damaged and undamaged trees had similar distributions of diameters and heights. In the Valinger et al. (1993) study, trees with lower clear bole heights and higher numbers of neighboring trees were at a higher risk of damage. These differences in significant attributes explaining the ice damage show the unpredictability inherent in predicting a stand’s susceptibility.

The shape of the trees also helps determine what type of damage may occur. Amateis and Burkhart (1996) reported that thicker, stout trees were more likely to resist stem bending and rootspringing and instead suffer top breakage. Trees with little stem taper were found to be the most susceptible to breakage (Petty and Worrell 1981). Trees that had an irregular shape, such as an asymmetrical crown also suffered more damage (Williston 1974).

It is also notable that in a study conducted by Belanger et al. (1996) the trees that showed the greatest potential for growth were also the most susceptible to damage. The trees that had the highest rate of growth before the storm often had the most severe reductions after the storm event (Belanger et al. 1996).

Damage caused by icing events may not only be immediate. Stands weakened by ice damage are more susceptible to damage from fire, pest infestations, and more ice damage (Bennett 1959, Williston 1974). Shepard (1978) found that in two storms occurring in successive years, the second did more damage, due to the weakened nature of the stand, although the storm was less severe.

An important point regarding ice damage to timber stands is the effect that thinning has on the stands. In the study by Amateis and Burkhart (1996), no correlation was found between the density of the stand and damage incurred. Amateis and Burkhart (1996) also hypothesized that thinned stands may be better suited to handle ice damage because it would cull forked trees, and produce more stout trees that are well spaced with heavy boles. The thinning may increase top breakage, but these trees have a better chance of a survival. However, there are also studies that suggest thinning may increase susceptibility. Belanger et al. (1996) found that recently thinned stands were more susceptible to damage that would result in death of the trees. Shepard (1978) also found that thinned stands were more susceptible. Shepard (1978) found that stands that were row thinned incurred more than six times the damage that stands thinned from below incurred, which tended to maintain a healthy viable tree stock. When reporting on ice damage in pine plantations, Muntz (1947) suggested that thinnings should be light, and should focus on taking smaller trees. This suggestion is supported by findings that the size of the opening in the forest affects the stability of a stand (Gardiner et al. 1997) and that the exposed surface area is important in determining the damage (Croxton 1939).

II. 3. Ice Damage Risk and Timber Management

With the effects that ice damage can have on forest stands, it is advisable to consider the risk of ice damage in forest management planning. Decisions such as when to harvest, and whether to reinvest are affected by this risk, and if this risk is not considered in the analysis, the management plan could fall short of meeting the goals for which it was designed. In recent years there have been many studies that have examined the effects that the risk of catastrophic events can have on management plans. These studies have found that inclusion of risk into management planning can cause significant changes to management plans.

The major focus of previous studies has been how the optimal rotation of a forest stand is modified under the risk of catastrophe. The Faustmann model is a leading formulation for modeling rotation length decisions (Newman 1985). The Faustmann model maximizes the discounted net revenues from an infinite series of like rotations and recognizes the costs associated with using the land for forest production. The model holds that the optimal rotation length occurs when the increase in stand value by allowing one more period of growth is equal to the costs of delaying the harvest one year plus the costs of delaying future harvests on the land one period. This framework has been modified in studies to reflect the effects of catastrophic risk into management planning.

Martell (1980) incorporated risk into the Faustmann model by including an term to represent the probability of a catastrophic event, in this case fire, occurring into the formulation, and by doing so found deterministic rotation ages in the presence of risk. The risk assumed that the fire damaged the entire stand but revenue was still possible from salvage harvesting. He used this modified formulation in a dynamic programming model with empirical data and found that as the probability of damage increased, the optimum rotation length and the value of the investment decreased.

Routledge (1980) also extended the Faustmann formula to include risk from catastrophic events by including a probability of damage. He assumed that the risk of catastrophe was the only source of risk in the model and that a proportion of the stand could be salvaged after the catastrophe occurred. Routledge accomplished this by adding a factor to Faustmann's model to represent the potential damage. This caused the optimal length to occur when the increase in value from allowing the stand to grow one more period was equal to both the costs of interest in delaying the harvest and the potential losses from a catastrophic event. Routledge's (1980) primary finding was that when risk is incorporated into management planning, the optimal rotation length decreases as the risk is increased.

The method in which risk can be included in management planning was examined by Reed (1984). He found that when adding fire as a time independent risk that resulted in total destruction, the effect could be represented by adding the occurrence rate of catastrophic events to the discount rate in the Faustmann formulation.

The effect the type of risk could have on management formulations was investigated by Thorsen and Helles (1998). They examined the effects of endogenous risk of windthrow on stand management. In their study, Thorsen and Helles (1998) included thinnings as a management option that directly affected the level of risk faced by stands. Their findings show that when risk is examined as endogenous in relation to management activities, the optimal management plans still had the overall effect of shortening rotation length, but not as severely as past studies where risk is considered exogenous to management actions.

The risk of catastrophic events has also been factored into forest-level management. Gassmann (1989) explored the effects of risk in the form of stochastic modeling. He looked at the effect stochastic modeling had on harvest sequences developed to maximize the total wood volume. Gassmann (1989) showed that stochastic models generate more conservative harvesting policies than deterministic models. Boychuk and Martell (1996) developed optimization models that used both deterministic average and stochastic fire loss and found that in order to maintain a stable timber supply, harvests must be reduced in the short term in order to create a buffer stock of timber for the long term.

Another area in which risk has been incorporated into management decisions is whether or not to invest in timberlands in the presence of risk. Yin and Newman (1996) examined this question at the forest level by integrating risk into a profit function, and then calculating the willingness to invest. Two type of investors were examined, those who had the opportunity to invest in perpetuity after the catastrophe and those who did not. While both types of investors would need higher prices to enter the market in the presence of risk, it was shown that those who did not have the opportunity to invest after a catastrophe would require a higher selling price. Yin and Newman (1996) concluded that due to this, small landowners could be forced out of the markets if risk is present.

All of the previous research has examined the effect of including risk on the optimal rotation length of a forest resource. However, they do not provide landowners clear examples of what losses associated with risk they could incur. Also they do not consider what level of risk is necessary to justify changing harvesting strategies. This research seeks to give non-industrial private landowners facing risk of ice damage an idea of what losses are possible and what risk is necessary to make changing harvesting strategy profitable.

Chapter III. Methods

III. 1. Introduction

The main objective of this research is to give non-industrial private landowners a framework to judge when it is in their best interest to modify existing management plans to reflect risk in the form of damage from an ice storm. In the review of previous literature dealing with the inclusion of risk on forest management decisions, it has been shown that risk can cause changes to management decisions. However, the amount these changes affect profit and management plans has not been explored. There is no context in which landowners can judge what level of risk is necessary to make changing management decisions economically profitable. The aim of this study is to find how management decisions are affected, and find the level of risk that makes changing management decisions profitable in the presence of risk of ice damage.

To accomplish this we utilize simulation modeling with empirical data to replicate the effects of ice damage to various management regimes. After the effects have been found, we use a decision tree analysis and an expected value function to discover at what point is the risk of damage is great enough to justify changing management plans. We have assumed that the landowners' objective is to maximize the net present value of their investment. We also assume that the landowners make decisions on the planting density, thinning intensity, and the time of thinnings and harvests to maximize their returns.

For the model, pine plantation growth simulations were conducted using a growth and yield program. Twelve scenarios were examined. The twelve scenarios consist of three site indices that are common for the Piedmont of Virginia and four different ice damage situations, including the case of no ice storms. The ice scenarios simulated ice storms at three different times during the stands growth, ages 10, 15, and 20. For each scenario, 180 management regimes were simulated. The management plans consisted of different planting densities, thinning intensities, thinning ages, and harvesting ages. From the 180 regimes, the management plan that resulted in the highest net present value was selected as the optimal management option for each scenario. The net present values were calculated from a formula that valued both the timber and land. For the scenarios simulated with an ice storm, trees were removed from the growing stock to represent the effect of ice damage. The volumes removed were determined by a set of prediction equations based on empirical data. A flow chart detailing the process is presented in Figure 3.1.

Comparisons were made between scenarios that had no damage and damaged stands, in terms of volumes, net present value, and optimal management options. Simulations were compared to determine which plantation characteristics resulted in the highest damage and losses. Using a decision tree framework and an expected value function, determinations of the probability of ice damage necessary to follow the ice damage adjusted management plans were calculated.

III. 2. Growth and Yield Calculations: TRULOB

All growth and yield projections for the research were performed with the model TRULOB. TRULOB is a density-independent individual tree growth and yield model for managed loblolly pine plantations developed by Zhang et al. (2001). The model was developed to simulate loblolly pine plantations managed using various silvicultural treatments and located in the natural range of the species.

TRULOB was selected as the model for the research for two reasons. First, the model provides reliable estimates of loblolly pine plantation growth for various stand conditions and management actions (Zhang et al. 2001). This allowed the analysis to include various site indices, planting densities, and thinning regimes. Second, the model's method of growth projection allowed the effects of ice damage to be applied on a tree level. This allowed the ice damage to be applied according to individual tree characteristics, but its effects to be examined on an aggregate per acre basis. This aspect is important because of the method used to model the amount of ice damage a pine plantation would sustain.

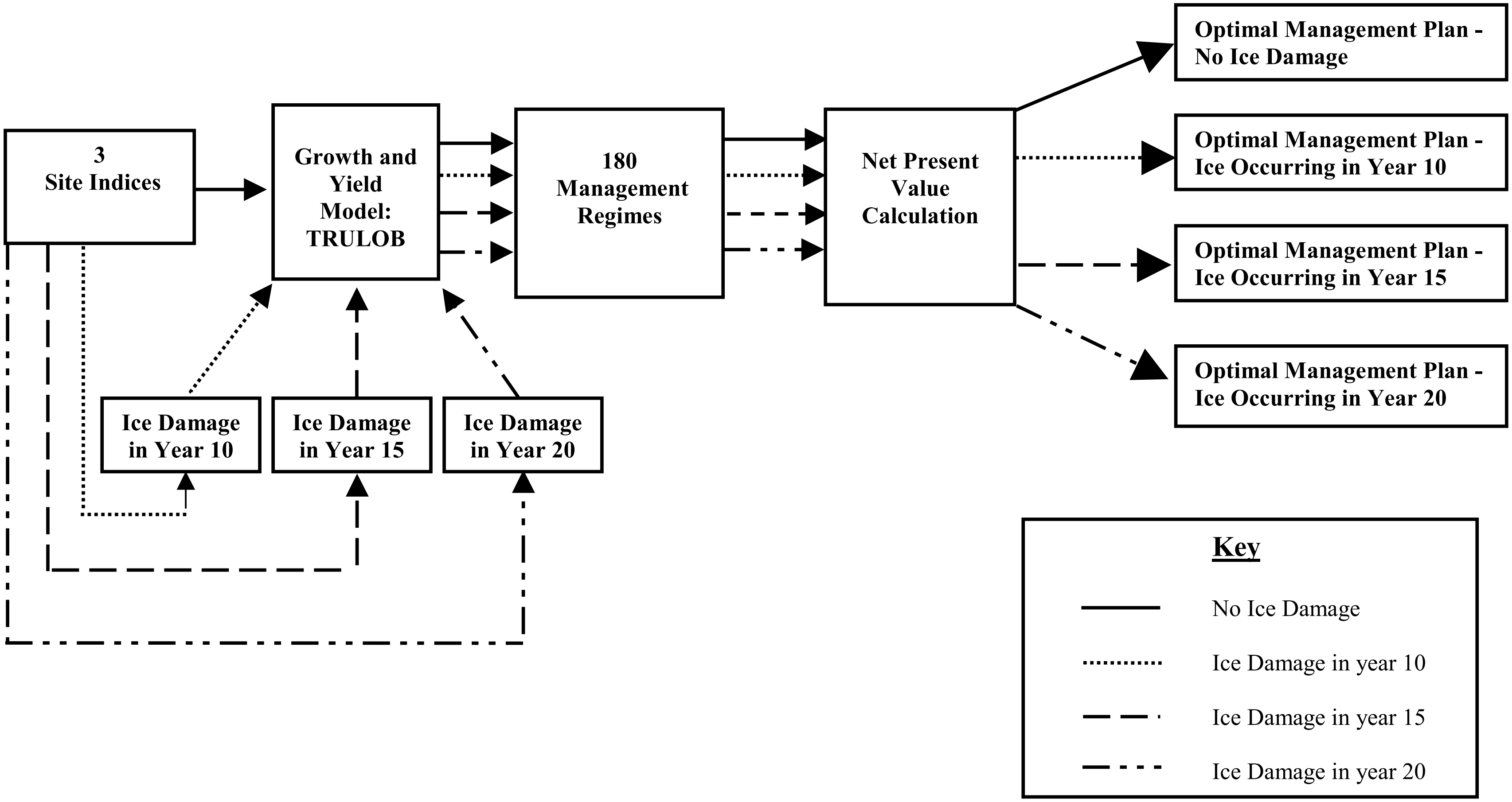


Figure 3.1. Flow chart summarizing the method of determining how ice damage affects the management of loblolly pine plantations.

The original version of TRULOB was modified for the research. A new application was developed that enabled the tree list to be modified at any point in the stand's growth. This application allowed a list containing the trees per acre and their respective heights and diameter to be exported and modified in a spreadsheet program. The modified list could then be imported back into TRULOB, reflecting the mortality due to ice damage. The details of how ice damage was simulated in the TRULOB model are discussed in a later section.

III. 3. Scenarios

Twelve scenarios were examined for the analysis. These scenarios were selected to represent different site conditions and ice damage situations that landowners in the Piedmont of Virginia may encounter. The different scenarios were composed of three different site indices, each examined with four different ice storm situations, for a total of twelve individual scenarios.

The productivity of a site is an important characteristic of pine plantations, and is a main factor in determining a plantation's management. Three site productivity levels were selected to represent the tree producing ability of sites in the region. Low, medium, and high productivity levels were represented by the site indices 55, 65, and 75 for loblolly pine at base age 25, respectively. These site indices were chosen after consultation with silviculturists familiar with the area and consulting literature descriptions of loblolly growth in the region (Burns and Honkala 1990). These indices show the natural variation in the region and give landowners examples they can apply to their own circumstances. Also by examining three different site indices, differences in how sites are affected by ice and what their best management options in the event of ice damage can be compared.

The timing of the ice events were selected to explore the effects ice storms can have on stands at different points in the stands rotation. By modeling ice storms at different times during the stands growth, the sensitivity of management decisions as the stand matures can be investigated. The ages of 10, 15, and 20, were used because they represent different stages in the plantation's maturity. Specifically they correspond to the periods before, during, and after the times at which intermediate thinnings are typically applied. The twelve scenarios are detailed in Figure 3.2.

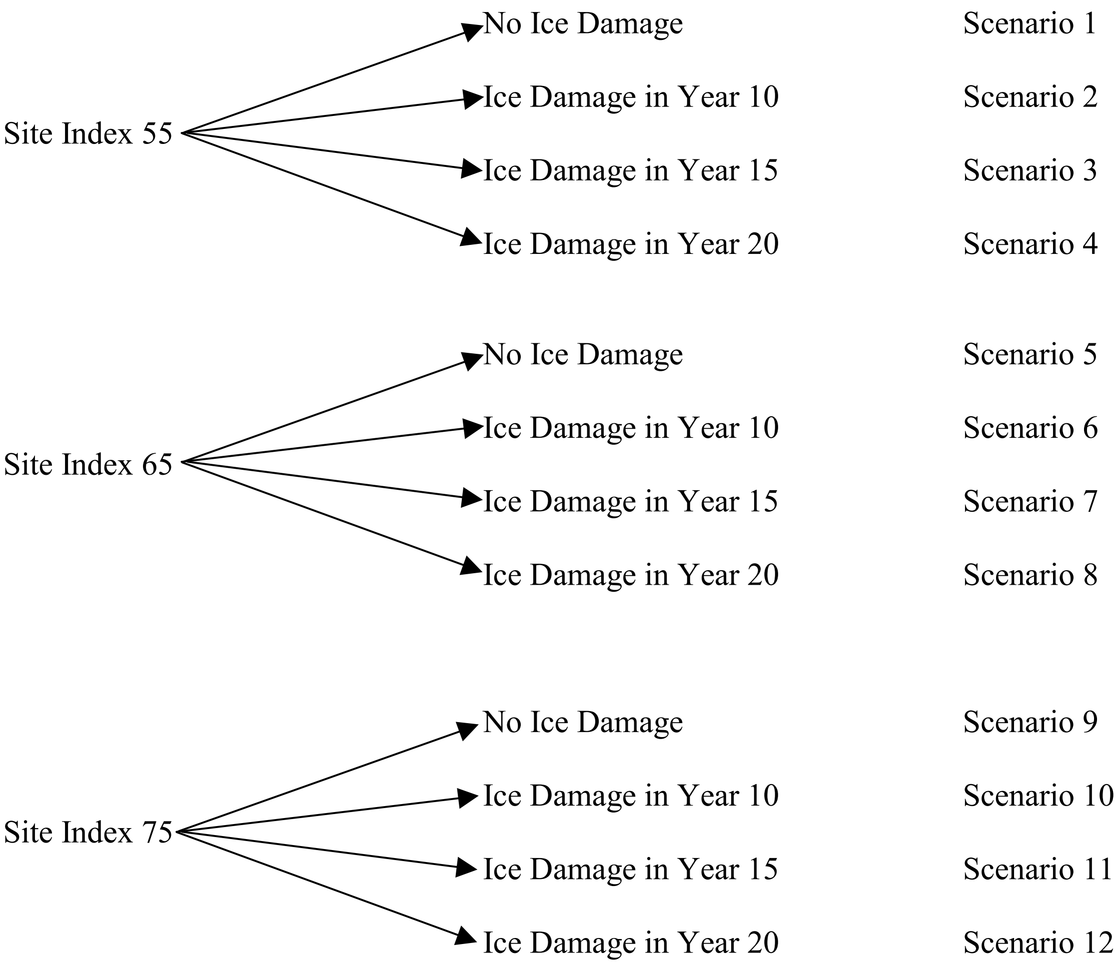


Figure 3.2. The twelve different plantation scenarios examined in the research.

III. 4. Management Plans

A set of 180 different management plans were simulated for each scenario. These management plans consisted of different planting densities, thinning intensities, thinning ages, and harvest ages. All characteristics of the management plan elements represent common silvicultural practices of the Piedmont region.

The planting densities of 300, 500, and 700 trees per acre were selected as the initial densities for the simulated plantations. These planting densities were chosen to show the range of common planting practices in the area. The planting densities were selected after discussions with silvilculturist familiar with practices in the region and with previous studies conducted in the area (Conrad et al. 1992). By including three separate planting densities, the dynamic between stand density and ice damage could be examined.

The practice of thinning is a common management technique for loblolly pine plantations in the Piedmont of Virginia. Thinnings provide intermediate income to landowners and increase the overall growth rates of the remaining trees. For this research two thinning intensities were examined. Both a high intensity and a low intensity thinning were modeled in which 50% or 33% of the standing basal area was removed, respectively. The two thinning levels were examined to determine if the intensity of thinning treatments had an effect on the amount of damage ice could have on plantations. All thinnings were modeled by using a row and low thinning function in TRULOB. A row and low thinning operation first removes a predetermined number of rows. Additional volume is removed by harvesting the smaller trees in the remaining rows. This method most accurately depicts common thinning practices in the Virginia Piedmont region. A fifth row thinning was selected, in which every fifth row was harvested, removing approximately 20% of the basal area. The remaining basal area was taken by selecting smaller stems in the stand to remove for a total of either 33% or 50% of the basal area removed, depending on the intensity.

The intermediate thinnings were considered at different years in order to select which timing produced the best results. Intermediate thinnings were considered at the stand ages of 13, 15, 17, or 19. A no thin option was also examined.

All harvests were simulated as silvicultural clearcuts, in which all stems were cut for timber production. Final harvests were considered in years 25, 27, 29, 31, 33 and 35. This age range was selected because it reflected common rotation lengths in the region. Harvests were only considered every two years in order to keep the number of simulations manageable.

The combinations of three planting densities, two thinning intensities, five thinning options and six harvest ages as possible management options resulted in a total of 162 unique management plans for the analysis. All 162 regimes were simulated for all twelve scenarios, and from these the optimal management option was selected. The elements of the management regimes are in Table 3.1.

Table 3.1 Components of management regimes examined in research.

Planting Density	**Thinning Intensities**	**Thinning Options**	**Harvest Ages**
300	33	No Thinning	Clearcut at Age 25
		Thin at Age 13	Clearcut at Age 27
500		Thin at Age 15	Clearcut at Age 29
	50	Thin at Age 17	Clearcut at Age 31
700		Thin at Age 19	Clearcut at Age 33
			Clearcut at Age 35

III. 5. Product Merchantability and Pricing

The dollar values of volumes harvested during thinning and clearcut operations were determined according to product class. Only stems over 5 inches in diameter at breast height (dbh) were considered merchantable. Stems measuring below 5 inches in dbh were not considered in the valuation process. All timber cut was classified into product classes based on the operation in which the stem was harvested or the size of the stem when cut.

All stems cut during intermediate thinning operations were classified and valued as pulpwood regardless of size. During final harvests, stems were classified according to merchandising specifications from Timber-Mart South (Timber-Mart South Quarterly Report 1990-2000). All stems measuring between 6 to 12 inches dbh were classified as pulpwood. All stems over 12 inches dbh were classified as sawtimber. Original volumes from TRULOB were reported in volumes and converted into pulpwood or sawtimber units based on their dbh at time of harvest. The conversion factors used can be seen in Table 3.2. Pulpwood volumes are reported in standard cords. Sawtimber volumes are reported in board feet, Scribner rule.

Table 3.2. Conversion factors used to convert cubic volume into cords and board feet.

Dbh Class	Cubic ft./cd	Scribner board-ft /cu.ft.ob
5	84	0
6	85	0
7	87	0
8	90	2.47
9	91	3.07
10	92	3.49
11	93	3.78
12	94	3.97
13	95	4.09
14	95	4.17
15	95	4.22
16	95	4.27
17+	95	4.29

Prices used for the analysis were ten-year statewide averages for Virginia. The averages were found using price data from Timber-Mart South (Timber-Mart South Quarterly Reports 1990-2000). Using these averages, pulpwood was valued at $16.42 per cord, and sawtimber was valued at $174.63 per thousand board feet for the analysis. All prices used for the analysis represent the stumpage value, or the price the landowner would receive for the standing timber.

Three different discount rates were used to examine the dynamics between ice damage and discount rates and to see what the effect of increasing the time value money would have on the selection of the optimal management plans. Discount rates of 5%, 7.5%, and 10% were considered. By examining three different discount rates we allow for variation in the value individual landowners place on their investments and their expected returns.

Using the calculated volumes and the ten-year price average, the values for all scenarios were calculated. The total values were discounted using the three different discount rates. The total discounted timber values were added to a discounted land value to calculate the net present value (NPV). All income from the timber was discounted back from the year in which the income is expected. All land was valued at \$500 per acre. This land value was developed from discussion with Revenue Assessors of local governments in the Piedmont of Virginia and by consulting various studies on forest land values (Pleasonton 1974, de Steiguer 1982, and Klemperer 1996).

Costs were factored into the analysis in the form of planting costs. Costs were subtracted from the NPV to account for the planting costs associated with the initiation of the stands. A cost of \$0.056 per seedling planted was applied to the analysis (Dubois et al. 1999). This led to an overall costs ranging from \$16.80 to \$39.20 dollars per acre, depending on initial planting density. No other costs were considered for the analysis. The formula used to calculate the net present values of the management plans is as follows:

$$NPV=(P_{pulp}*C_{thin})/(1+i)^{Yt}+[(P_{pulp}*C_{cc})+(P_{saw}*ST_{cc})/(1+i)^{Ycc}]+LV/(1+i)^{Ycc} - PC \quad \{Eqn.3.1\}$$

Where:
P_{pulp} = Price of Pulp(per std cord)
P_{saw} = Price of Sawtimber (per MBF Scribner rule)
C_{thin} = Cords harvested during thinning (std cord)
Yt = Year of thinning operation
i = Discount rate
C_{cc} = Cords harvested during clearcut
ST_{cc} = Sawtimber harvested during clearcut
Ycc = Year of clearcut operation
LV = Bare land value
PC = Planting Costs

III. 6. Ice Damage Modeling

Ice damage was modeled in the research by using prediction equations developed by Amateis and Burkhart (1996). The damage prediction equations were developed from empirical data collected on loblolly pine stands located in the Piedmont of Virginia. The stands were damaged by a severe ice storm that struck central Virginia in March of 1994. The study discovered that a tree's diameter and height could be correlated to the level of damage a single tree would incur in the event of an ice storm. A set of equations were developed that predicted the extent a tree is damaged by either top breakage or stem lean. The equations determine the probability that a tree will be in one of five condition classes representing different levels of damage.

For this study, we use the probabilities of damage classes to represent the amount of tree volume affected by the ice storm. We assume that trees found to have either greater than 45% stem lean or greater than 50% top damage were considered damaged beyond merchantability and have no value. The formulas used to predict the probability that a tree would be classified as damaged beyond merchantability can be written as follows:

$$P_{td} = 1 - \{[e^{(4.6128 + -0.00392 * d2h)}] / [1+ e^{(4.6128 + -0.00392 * d2h)}]\} \quad \{\text{Eqn. 3.2}\}$$

$$P_{sl} = 1 - \{[e^{(1.6318 + 0.00517 *d2h)}] / [1+e^{(1.6318 + 0.00517 *d2h)}]\} \quad \{\text{Eqn. 3.3}\}$$

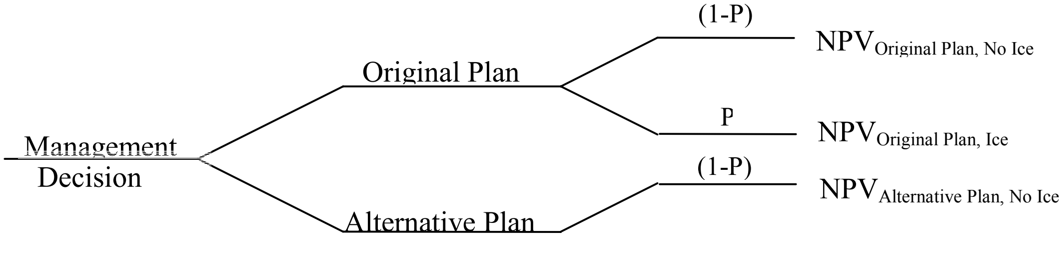
Where:
P_{td} = Probability of 50% or greater top damage
P_{sl} = Probability of 45% or greater stem lean
d = Diameter at breast height of tree
h = Height of tree

At the ages of 10, 15 and 20, current stand data from each scenario was exported into a Microsoft Excel spreadsheet program. The spreadsheet was used to calculate the total probability of ice damage that each size class of trees in the stand would incur. This probability was then assumed to be the percentage of trees damaged, and this percentage was removed from the growing stock. For example, if the prediction equations calculated that trees in a specific size class had a severe damage probability of 0.25, then 25% of the trees in the size class were removed to represent the damage. All trees were removed without costs or compensation. If an intermediate thinning was scheduled in year 15, the thinning was simulated before the ice damage was modeled. An example of the spreadsheet setup used to calculate the total probability can be seen in Appendix 1. After the trees had been removed for ice damage, the stands were simulated to continue growth as normal.

III. 7. Ice Storm Probability

For each site index, the optimal management plans were compared and contrasted to see the effects ice damage had on management plan determination and net present values. Management plans were compared to see if changing management decisions could produce greater net present values in the event of an ice storm. In instances where the alternative optimal management plans selected were the same as the original optimal management plans, only the loss in net present value was examined. However, in cases where optimal management plans changed when ice was factored into the model, the difference in management plans were also examined. If management plans differed, then the amount a landowner could lose by choosing the wrong plan is reported. For example, if a landowner chooses the optimal management plan with the risk of ice factored into the analysis, but no ice occurs, then the difference in the net present value of the two plans is examined. This indicates the amount that a landowner stands to lose if they manage for the wrong assumption of ice damage. Also if a change in management plans could improve landowner returns, the probability of an ice storm necessary to make changing management plans beneficial was calculated, similar to Sullivan's (1987) application of this method to wildfire rehabilitation options.

A decision tree was used to analyze the various outcomes. Each management plan had two net present values, one if no ice storm occurred, and one if an ice storm did occur. The decision tree used for the analysis is diagrammed in Figure 3.3.



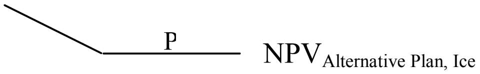


Figure 3.3. Decision tree diagram detailing the different outcomes of the two management plans, where P represents the probability of an ice storm occurring.

The probability of an ice storm necessary to change management plans represents the rate of risk that makes selecting the alternative management plan a better decision. This determination is based on expected values of the two management plans. The expected value function provides an expected net present value. This expected net present value is the sum of the two net present values, with no ice damage and one with ice damage, multiplied by their probability of occurring. At the necessary probability the expected values of the two management plans are equal. This is represented in Equation 4. Any risk greater than this, and it is in the landowners best interest to follow the alternative management plan that was selected when ice damage was included. If the risk is lower than this probability, then the landowner should follow the plan that was selected when ice damage was not factored into the decision.

The values from the different management decisions were plugged into Equation 3.4b, derived from Equation 3.4a to determine the necessary probability.

$$NPV_{ON}(P) + NPV_{OI}(1-P) = NPV_{AN}(P) + NPV_{AI}(1-P) \qquad \{Eqn.3.4a\}$$

$$P_{\text{ice storm}} = (NPV_{AI} - NPV_{OI}) / (NPV_{ON} - NPV_{OI} - NPV_{AN} + NPV_{AI}) \qquad \{Eqn.3.4b\}$$

Where:
$P_{\text{ice storm}}$ = Ice storm probability that results in a higher expected value for alternative plan
NPV_{ON} = Net present value of original plan if ice storm does not occur
NPV_{OI} = Net present value of original plan if ice storm does occur
NPV_{AN} = Net present value of alternative plan if ice storm does not occur
NPV_{AI} = Net present value of alternative plan if ice storm does occur

This probability is the necessary risk that would have to be present to justify changing plans. If the risk is lower than the calculated probability, following the original management plan would yield a higher expected value. If it is higher, then it would be better to change management regimes to the alternative plan.

III. 8. Sensitivity Analysis

A sensitivity analysis was performed to determine the sensitivity of the selection of optimal management plans is to fluctuations in product prices and land values. This was examined by decreasing and increasing the parameters of product prices and land values in the model and observing how many management plans changed as a result. Both sawtimber and pulpwood prices were altered 20% from the ten year average prices. The land value was decreased by half and also doubled from the original value of $500 per acre to see how changes to land value affected the model. Each parameter was altered separately to find which elements of the model were most sensitive to fluctuations. The values used to test the sensitivity of the model are summarized in Table 3.3. The number of management plan changes as a result of changes in parameters was counted for each scenario in order to gauge sensitivity.

Table 3.3. Modified parameter values used in sensitivity analysis.

Parameters	Initial Value	Reduced Value	Increased Value
Sawtimber Prices / mbf (scribner)	$174.63	$139.70	$212.44
Pulpwood Prices / std.cord	$16.42	$13.13	$19.71
Land Value / acre	$500.00	$250.00	$1,000.00

III. 9. Assumptions and Limitations

In this research certain assumptions were made in order to clearly define the model. These assumptions create limits to applying the model to actual situations. Among the limitations is that the research assumes detrimental effects of ice damage only occur at the time of the storm. The volumes affected by the ice were simply removed from the growth and yield model. There was no factor to model how the other trees, damaged below the non-merchantability point, were affected. The remaining trees are assumed to resume the normal growth. This does not take into account the change in growth rates because of the damage. Ice damage could possibly cause growth rates to increase from the thinning effect or decrease as a result of the damage. Also there is no factor for the increased risk that the remaining trees are under after the storm. Trees damaged by ice are more prone future damage from fire, pest infestations, and more ice damage (Bennett 1959, Williston 1974). Also, it is assumed that an ice storm can only occur once in a rotation. Multiple ice storms occurring during the rotation were not considered.

A second assumption of the model is that the damaged trees are removed from the site without cost or compensation. This ignores the cost a landowner might incur to clean up the damaged timber or any possible income the landowner may receive from salvage cut. Finally use of the prediction equations from the Amateis and Burkhart (1996) study implies that these results are only valid for storms of similar magnitude. Storms of lesser or greater magnitude may produce different results.

Chapter IV. Results

The results will be discussed in three sections. First, the damages that the stands in all the simulations incurred when ice damage was modeled into the analysis will be summarized. Specifically, the extent of damage and how it varied over different site indices, planting densities, and thinning intensities will be examined. The second section will detail how the optimal management options changed between scenarios with no damage and those with ice damage. The net present value losses associated with ice damage will be examined and how the management plans changed to mitigate these losses will be discussed. The costs to the landowner for following the wrong management plan for the ice storm situation along with the probability necessary to warrant changing management plans due to ice damage will also be reported. The third section will present the results of the sensitivity analysis. The effects of price fluctuations on the selection of the optimal management plans will be discussed.

IV. 1. Ice Damage

When ice damage was included into the model, 13% to 30% of the trees per acre were damaged beyond merchantability. The removal of these damaged trees had significant effects on all the simulations. However, these effects were not uniform throughout. Certain characteristics of the simulations, management plans, or ice storms showed definite influence on the amount of damage suffered. The results in this section are derived from all the simulations performed in the research. Therefore, the results include but are not limited to the simulations from the selected optimal management plans.

The age of the stand when the ice storm occurred had the greatest impact on the amount of damage the plantations sustained. The ice storms that were modeled in year 10 of the stands growth had a significantly greater impact than later storms. There was at least a 7% increase in losses in the ice storm at year 10 than the ice storm in year 15. The ice storm occurring in year 20 was slightly less damaging than the storm in year 15. Percent losses of trees per acre, basal area, and volume can be seen in Table 4.1.

Table 4.1. The average percentage of losses due to ice damage for all scenarios, summarized by the stand age when the ice storm occurred.

	TPA Losses (%)	Basal Area Losses (%)	Volume Losses (%)
Year 10	25.9%	24.1%	23.0%
Year 15	17.2%	16.3%	16.0%
Year 20	15.1%	15.2%	15.1%

The productivity of the plantation's site showed some impact on the amount of damage incurred. Plantations grown on poorer sites suffered the highest percentages of losses. As site productivity improved, the resistance to damage also showed improvement. The percentages of loss can be seen in Table 4.2.

Table 4.2. The percentages of losses due to ice damage for all scenarios, summarized by site index.

	TPA Losses (%)	Basal Area Losses (%)	Volume Losses (%)
Low Site Productivity	21.1%	20.0%	19.3%
Medium Site Productivity	19.1%	18.1%	17.7%
High Site Productivity	18.0%	17.4%	17.1%

The characteristics of planting density and thinning intensity had much smaller effects on the amount of damage a stand would sustain. All categories examined varied by no more than 1.1%. The percentages of losses summarized by planting density and thinning intensity are reported in Tables 4.3 and 4.4, respectively.

Table 4.3. The percentages of losses due to ice damage for all scenarios, summarized by planting density.

	TPA Losses (%)	Basal Area Losses (%)	Volume Losses (%)
300 tpa Planting Density	18.7%	18.0%	17.6%
500 tpa Planting Density	19.6%	18.7%	18.3%
700 tpa Planting Density	19.8%	18.9%	18.2%

Table 4.4. The percentages of losses due to ice damage for all scenarios, summarized by thinning intensity.

	TPA Losses (%)	Basal Area Losses (%)	Volume Losses (%)
33% Thinning Intensity	19.4%	18.5%	18.0%
50% Thinning Intensity	19.3%	18.5%	18.1%

The major trend seen in the ice damage is that stands composed of smaller diameter trees tend to be damaged more than stands with larger diameter trees. The earliest occurrence of ice damage, the lowest site productivity, and the highest planting density all have higher percentages of damage. All of these conditions are characterized by smaller diameter trees. These results suggest that smaller trees are more easily affected by ice storms, and having a larger diameter growing stock could decrease the amount of losses. A possible reason of higher damage to smaller diameter trees is that these trees are not as sturdy as larger trees and cannot withstand the added weight from ice.

IV. 2. Net Present Values Losses from Ice Damage

The net present values of all the simulations declined between 8.5% to over 16% when ice damage occurred. When ice damage was modeled in year 10 of the plantations growth, the largest losses of net present values occurred. The percentages of net present value losses declined when ice damage was modeled into the scenario in the years 15 and then rose slightly when ice damage occurred in year 20. The net present value losses are highest when ice occurs in year 10 because of the higher percentages of damage that storms occurring at this age cause. The slight increase in the losses of net present value when ice occurs in year 20 could be attributed to a shift in product classes during this time period from age 15 to age 20. A higher percentage of trees damaged in year 20 would be in the more valuable sawtimber product class, resulting in a higher percentage loss of net present value. These percentages are reported in Table 4.5.

Table 4.5. Net present value losses in all three damage years and discount rates.

	10 Year	15 Years	20 Years
5% Discount Rate	16.2%	9.9%	10.4%
7.5% Discount Rate	15.3%	9.1%	9.2%
10% Discount Rate	14.8%	8.5%	8.7%

IV. 3. Optimal Management Plans

The optimal management plans selected when the scenario were modeled without ice damage are reported in Table 4.6. All optimal management plans recommend either

500 or 700 trees per acre original planting density, and a high intensity intermediate thinning at age 13 or 15. All three site indices recommend higher planting density and longer rotation lengths at lower discount rates and lowered the final harvest age as discount rates increased. These are the management plans that represent the best possible management regimes for their respective stands if no ice damage affects the stand throughout its rotation.

Table 4.6. Optimal management plans for all site productivity levels and discount rates when no ice damage is included in the model.

Site Index	Discount Rate	Planting Density	Thinning Intensity	Thinning Age	Harvest Age	NPV
55 (Scenario 1)	5%	700	50	13	35	$271.23
	7.5%	500	50	13	25	$135.18
	10%	500	50	15	25	$66.52
65 (Scenario 5)	5%	700	50	13	35	$528.01
	7.5%	500	50	13	27	$239.51
	10%	500	50	13	25	$123.29
75 (Scenario 9)	5%	700	50	13	33	$874.19
	7.5%	700	50	13	29	$414.62
	10%	500	50	13	25	$213.82

IV. 4. Low Productivity Sites (Site Index = 55)

When ice damage was factored into the model, the stands simulated on the least productive sites had a considerable number of the optimal management plans change. When the two lowest discount rates were applied, all scenarios with ice damage changed from the original optimal management plan. At the highest discount rate, one of the management plans changed.

IV. 4. A. 5% Discount

When the 5% discount rate is applied, management plans recommend a lower planting density and earlier harvest when ice storms occur. Planting densities are reduced from 700 trees per acre to 500 trees per acre for all ice storm events. The recommended final harvest for all ice storm events occur at age 29. The percent of net present values loss following these plans range from 9.4 % to almost 18%. These management plans and their net present values are shown in Table 4.7.

Table 4.7. The optimal management plans for the least productive sites when ice damage is included in the analysis, discounted with a 5% rate.

	Planting Index	Thinning Intensity	Thinning Age	Harvest Age	NPV	% NPV Loss
Scenario 1 - No ice storm	700	50	13	35	$271.23	
Scenario 2 - Ice storm at age 10	500	50	13	29	$222.70	17.9%
Scenario 3 - Ice storm at age 15	500	50	13	29	$240.37	11.4%
Scenario 4 - Ice Storm at age 20	500	50	13	29	$245.66	9.4%

IV. 4. B. 7.5% Discount Rate

All the optimal management plans also change when a discount rate of 7.5% is applied. All of the plans recommend a later intermediate thinning age as a method of mitigating losses over the original management plan. The net present value percentage losses ranged from 6.6% to over 16%. These management plans and their net present values are reported in Table 4.8.

Table 4.8. The optimal management plans for the least productive sites when ice damage is included in the analysis, discounted with a 7.5% rate.

	Planting Index	Thinning Intensity	Thinning Age	Harvest Age	NPV	% NPV Loss
Scenario 1 - No ice storm	500	50	13	25	$135.18	
Scenario 2 - Ice storm at age 10	500	50	15	25	$113.24	16.2%
Scenario 3 - Ice storm at age 15	500	50	15	25	$124.52	7.9%
Scenario 4 - Ice Storm at age 20	500	50	15	25	$126.21	6.6%

IV. 4. C. 10% Discount Rate

When a 10% discount rate is applied, only one management plan changes from the optimal management plan selected with no ice damage. The management plan for when an ice storm occurs in year ten of the stands growth recommends that a lower planting density, along with a later and less intense intermediate thinning could lessen the losses from ice damage. The management plans for the other ice storm events are the exact same as the management plan recommended when no ice damage occurs. The management plans and net present values are summarized in Table 4.9.

Table 4.9. The optimal management plans for the least productive sites when ice damage is included in the analysis, discounted with a 10% rate.

	Planting Index	Thinning Intensity	Thinning Age	Harvest Age	NPV	% NPV Loss
Scenario 1 - No ice storm	500	50	15	25	$66.52	
Scenario 2 - Ice storm at age 10	300	33	19	25	$56.00	15.8%
Scenario 3 - Ice storm at age 15	500	50	15	25	$61.21	8.0%
Scenario 4 - Ice Storm at age 20	500	50	15	25	$62.17	6.5%

IV. 4. D. Necessary Probabilities of Ice Damage

When the scenarios that take ice damage into account have different management plans than the scenario that does not, their management plans represent alternative plans that could return a higher net present value in the event of an ice storm. This return would be higher than if the scenario that did not take ice damage into account, or original plan, was followed. In the event of an ice storm, the amount that this return is higher than the original plan would be the benefits from following the alternative plan. However, if no ice storm occurs, and the alternative management plans were followed, less than optimal net present values would be returned. The amount these plans are lower than the original plans are the costs of following the alternative management plan when no ice storm occurs. These values represent the amount a landowner stands to gain or lose by choosing to follow the alternative plan. All of the alternative management plans have a necessary probability of an ice storm that makes following them return a higher expected value than following the original management plan. These probabilities provide insight into how much risk a landowner should be facing in order to make choosing the alternative management plans a wise decision. The benefits and costs of following the alternative plans, along with the necessary probabilities of ice damage are summarized in Table 4.10.

Table 4.10. Possible benefits and costs of following the alternative management plans along with their necessary probabilities for the least productive sites.

Discount Rate	Scenario	Possible Benefits of choosing Alternative plans	Possible Costs of choosing Alternative Plans	Necessary Probability of Ice Storm
5%	Scenario 2 - Ice storm at age 10	$9.60	$4.93	0.34

	Scenario 3 - Ice storm at age 15	$4.55	$4.93	0.52
	Scenario 4 - Ice Storm at age 20	$1.89	$4.93	0.72
7.5%	Scenario 2 - Ice storm at age 10	$1.71	$1.23	0.42
	Scenario 3 - Ice storm at age 15	$4.26	$1.23	0.22
	Scenario 4 - Ice Storm at age 20	$0.22	$1.23	0.85
10%	Scenario 2 - Ice storm at age 10	$1.97	$1.79	0.48
	Scenario 3 - Ice storm at age 15	NA	NA	NA
	Scenario 4 - Ice Storm at age 20	NA	NA	NA

The benefits in choosing the alternative plans generally are higher than the costs when ice occurs at age 10, represented by scenario 2. Generally, as the age when the ice storms affect the stand increase, the costs begin to outweigh the benefits. This is reflected in the higher necessary probabilities of ice damage in year 20 of the first two discount rates.

The low necessary probability in scenario three with a 7.5% discount rate is a reflection of the substantially higher benefits that the landowner stands to gain by following the alternative plan. This large benefit may be due to the fact that in this scenario, the intermediate thinning is performed in the same year as the ice damage. In scenario one, the optimal management plan without ice damage, the intermediate thinning is recommended at age 13. By delaying the thinning to occur directly before an ice storm, the smaller trees that would have been damaged are now harvested for revenue, and the stand is stocked with larger trees that can withstand an ice storm better.

IV. 5. Medium Productivity Sites (Site Index = 65)

The management plans for the medium productive sites changed few times in comparison with the least productive sites. In only two cases did the optimal management plan for the scenarios with ice differ from the management plan selected for the scenario without ice damage. In most cases, the management plans were the same, regardless if ice occurred or not.

IV. 5. A. 5% Discount Rate

When the 5% discount rate is applied to the medium productivity scenarios, only one management plan differs from the original management plan. If an ice storm occurred at age 10, a higher net present value could be returned if the stand was harvested two years earlier than the original recommendation. If an ice storm occurred at age 15 or 20, the landowner should follow the same management plan as if no ice storm occurred in order to receive the highest possible net present value. The management plans and their net present values are reported in Table 4.11.

Table 4.11. The optimal management plans for the medium productive sites when ice damage is included in the analysis, discounted with a 5% rate.

	Planting Index	**Thinning Intensity**	**Thinning Age**	**Harvest Age**	**NPV**	**% NPV Loss**
Scenario 5 - No ice storm	700	50	13	35	$528.01	
Scenario 6 - Ice storm at age 10	700	50	13	33	$409.36	22.5%
Scenario 7 - Ice storm at age 15	700	50	13	35	$463.01	12.3%
Scenario 8 - Ice Storm at age 20	700	50	13	35	$466.60	11.6%

IV. 5. B. 7.5% Discount Rate

When a 7.5% discount rate was applied to the scenarios, changes similar to those when a 5% discount rate was applied occurred. Only one change in management plans could produce a higher net present return. Like the 5% discount rate, when an ice storm occurs at age 10, by shortening the harvest age by two years, a higher net present value is possible. The management plans and net present values for the medium productivity sites with a discount rate of 7.5% are summarized in Table 4.12.

Table 4.12. The optimal management plans for the medium productive sites when ice damage is included in the analysis, discounted with a 7.5% rate.

	Planting Index	**Thinning Intensity**	**Thinning Age**	**Harvest Age**	**NPV**	**% NPV Loss**
Scenario 5 - No ice storm	500	50	13	27	$239.51	
Scenario 6 - Ice storm at age 10	500	50	13	25	$190.90	20.3%
Scenario 7 - Ice storm at age 15	500	50	13	27	$215.92	9.8%
Scenario 8 - Ice Storm at age 20	500	50	13	27	$214.87	10.3%

IV. 5. C. 10% Discount Rate

When a 10% discount rate is applied to the medium productivity sites, the same management plan returns the highest net present value, regardless of the occurrence of an ice storm. The management plans and the resulting net present values are reported in Table 4.13.

Table 4.13. The optimal management plans for the medium productive sites when ice damage is included in the analysis, discounted with a 10% rate.

	Planting Index	**Thinning Intensity**	**Thinning Age**	**Harvest Age**	**NPV**	**% NPV Loss**
Scenario 5 - No ice storm	500	50	13	25	$123.29	
Scenario 6 - Ice storm at age 10	500	50	13	25	$99.58	19.2%
Scenario 7 - Ice storm at age 15	500	50	13	25	$111.60	9.5%
Scenario 8 - Ice Storm at age 20	500	50	13	25	$110.92	10.0%

IV. 5. D. Necessary Probabilities of Ice Damage

For the majority of the scenarios in the medium site productivity class, changing management plans would not increase the net present value of the stand. Although the two occasions of alternative management plans both occurred in scenario 6, when ice damage occurred at age 10, the amount they improved the net present value were different. In the first alternative management plan, when the discount rate is 5%, the possible benefits from choosing the alternative plan outweigh the costs. A 41% chance of an ice storm occurring would make this management plan yield a higher expected value than the original plan. However, in the second alternative plan, the costs outweigh the benefits. A 63% chance of an ice storm is necessary to make choosing the alternative plan a prudent financial decision. The benefits and costs of the two alternative management plans along with the necessary probabilities are reported in Table 4.14.

Table 4.14. Costs and benefits of following the two possible alternative management plans along with their necessary probabilities for the medium productivity sites.

Discount Rate	**Scenario**	**Possible Benefits of choosing Alternative plans**	**Possible Costs of choosing Alternative Plans**	**Necessary Probability of Ice Storm**
5%	Scenario 6 - Ice storm at age 10	$17.10	$11.85	0.41
7.5%	Scenario 6 - Ice storm at age 10	$5.23	$8.83	0.63

IV. 6. High Productivity Sites (Site Index = 75)

The majority of the scenarios simulated on the highest productivity sites did not change management plans. Similar to the medium productivity sites, in only two occurrences of ice damage were alternative management plans possible.

IV. 6. A. 5% Discount Rate

When the 5% discount rate was applied to the valuation of high productivity sites, one possible alternative plan occurred. If an ice storm damaged a stand at age 10, the net present value could be increased by harvesting two years earlier. If an ice storm occurs at the other ages of the stand, the optimal management plan is the same as if no ice damage occurs. The management plans and the net present values of the high productivity scenarios valued with a 5% discount rate are reported in Table 4.15.

Table 4.15. The optimal management plans for the highest productivity sites when ice damage is included in the analysis, discounted with a 5% rate.

	Planting Index	**Thinning Intensity**	**Thinning Age**	**Harvest Age**	**NPV**	**% NPV Loss**
Scenario 9 - No ice storm	700	50	13	33	$874.19	
Scenario 10 - Ice storm at age 10	700	50	13	35	$676.56	29.2%
Scenario 11 - Ice storm at age 15	700	50	13	33	$773.19	14.9%
Scenario 12 - Ice Storm at age 20	700	50	13	33	$745.55	19.0%

IV. 6. B. 7.5% Discount Rate

One alternative management plan is possible when a 7.5% discount rate is used. Like the alternative management plan when a 5% discount rate is used, the alternative management plan occurs when an ice storm occurs at age 10. This alternative management plan recommends that a lower planting density be applied to increase the net present value in the event of an ice storm. All other management plans are the same as the original. These management plans and their net present values can be seen in Table 4.16.

Table 4.16. The optimal management plans for the highest productivity sites when ice damage is included in the analysis, discounted with a 7.5% rate.

	Planting Index	**Thinning Intensity**	**Thinning Age**	**Harvest Age**	**NPV**	**% NPV Loss**
Scenario 9 - No ice storm	700	50	13	29	$414.62	
Scenario 10 - Ice storm at age 10	500	50	13	29	$324.13	21.8%
Scenario 11 - Ice storm at age 15	700	50	13	29	$368.69	11.1%
Scenario 12 - Ice Storm at age 20	700	50	13	29	$354.35	14.5%

IV. 6. C. 10% Discount Rate

As with the medium site productivity levels, when the 10% discount rate is applied to the valuation of the scenarios, no alternative management plans exists. The optimal net present values are obtained by following the same management plan. The occurrences of ice storms have no effect on the determination of the management plans. These management plans and net present values are summarized in Table 4.17.

Table 4.17. The optimal management plans for the highest productivity sites when ice damage is included in the analysis, discounted with a 10% rate.

	Planting Index	**Thinning Intensity**	**Thinning Age**	**Harvest Age**	**NPV**	**% NPV Loss**
Scenario 9 - No ice storm	500	50	13	25	$213.82	
Scenario 10 - Ice storm at age 10	500	50	13	25	$174.90	18.2%
Scenario 11 - Ice storm at age 15	500	50	13	25	$192.77	9.8%
Scenario 12 - Ice Storm at age 20	500	50	13	25	$181.73	15.0%

IV. 6. D. Necessary Probabilities of Ice Damage

The two alternative plans for the high productivity levels are both characterized by high costs of choosing the alternative management plan. In each case, the costs exceed the benefits, resulting in high necessary probabilities of ice storms. These results can be seen in Table 4.18.

Table 4.18. Costs and benefits of following the two possible alternative management plans along with their necessary probabilities for the high productivity sites.

Discount Rate	Scenario	Possible Benefits of choosing Alternative plans	Possible Costs of choosing Alternative Plans	Necessary Probability of Ice Storm
5%	Scenario 10 - Ice storm at age 10	$8.18	$28.73	0.78
7.5%	Scenario 10 - Ice storm at age 10	$9.30	$18.00	0.66

IV. 7. Sensitivity Analysis

The parameters of price and land value were change to see how they would affect the optimal management plan determination. The results from the sensitivity analysis indicate that the selection of management plans is most sensitive to price changes when simulating low quality sites. The strongest trend was viewed in simulations involving low quality sites. The management plans on these sites changed 44 % when the parameters were altered. All of the price and land value fluctuations caused management plans to change. However, the selection of management plans is slightly more sensitive to decreases in pulpwood prices and lower land values than other parameter changes. Both of these parameters caused 33% of the management plans to change, compared to 22% for the other parameters. The instances when different management plans were selected due to parameter deviation are summarized in Table 4.19.

Table 4.19. Summarization of sensitivity analysis. X denotes when the respective parameter change caused a new optimal management plan to be selected.

Discount Rate	5%			7.5%			10%		
Site Index	Low (SI=55)	Medium (SI=65)	High (SI=75)	Low (SI=55)	Medium (SI=65)	High (SI=75)	Low (SI=55)	Medium (SI=65)	High (SI=75)
No Ice Damage									
Decreased Sawtimber Price	X			X					
Increased Sawtimber Price							X	X	
Decreased Pulpwood Price	X						X	X	
Increased Pulpwood Price				X					X
$250 Land Value				X	X			X	
$1000 Land Value	X				X				
Ice at Age 10									

Decreased Sawtimber Price	X			X	X		X		
Increased Sawtimber Price	X				X				
Decreased Pulpwood Price	X								
Increased Pulpwood Price				X			X		
$250 Land Value	X				X				
$1000 Land Value		X	X	X			X	X	
Ice at Age 15									
Decreased Sawtimber Price		X							
Increased Sawtimber Price			X			X			
Decreased Pulpwood Price			X			X			
Increased Pulpwood Price		X							
$250 Land Value			X						
$1000 Land Value		X	X		X			X	
Ice at Age 20									
Decreased Sawtimber Price					X			X	
Increased Sawtimber Price					X			X	X
Decreased Pulpwood Price									
Increased Pulpwood Price					X			X	
$250 Land Value			X		X	X		X	X
$1000 Land Value									

Chapter V. Discussions and Conclusions

Ice storms can have detrimental effects on the volumes and net present values of managed forest stands. These damaging effects can cause management plans for forest loblolly pine plantations to fall short of their objectives. However, what is not understood about ice damage and its affect on management plans is how sensitive it is to management decisions and whether or not changing management strategies can reduce the harmful effects.

Our research showed that the timing of an ice storm and the site productivity have the largest role in determining the number of trees affected by ice damage. Ice storms that occur early in a stands rotation can have higher damage rates than later occurring storms, leading to decreases in net present values. Stands grown on low productivity sites also suffer more damage and have larger decreases in the net present values. These results suggest that stands dominated by smaller trees are more susceptible to damage from an ice storm.

In some situations management decisions can lessen the negative effects of ice damage. This is most evident when making decisions involving stands located on low quality sites, where net present values can be increased by changing management plans. In the majority of low quality sites, choosing a lower planting density, or increasing the age when intermediate thinnings were performed could reduce the value loss. However, the results also show that the decision to change management plans should be made with the possible costs and benefits in mind. Although alternative management plans may exist that would yield a higher net present value, the costs resulting from following the alternative plan and no ice occurring may outweigh the benefits.

On the majority of medium and high productivity sites, reducing the losses of net present value from ice damage was not possible. The optimal management plan for these sites did not change when an ice storm occurred, and therefore changing management plans would only further reduce the net present value. In the few cases where reduced losses were possible, most of the new management plans recommended changing the age of the final harvest. This element of the management plan can be altered after the ice storm has occurred. Therefore, landowners do not incur costs associated with choosing other alternative management plans, such as planting density, which must be decided when the occurrence of ice is still uncertain. This characteristic of managing plantations on medium and high productive sites reduces the impact ice damage can have on makes the inclusion of ice damage risk into management decisions less important.

The different effects ice damage can have on management decisions depending on site quality causes the implications of our research for the management of loblolly pine plantations to also change with the site productivity. Landowners with loblolly pine plantations on lower quality sites should be aware of the risk of ice damage because of the increase in losses they may incur. Management activities to grow larger trees quicker may mitigate losses from ice damage. However landowners that change management plans to account for ice damage should be aware of the lower net present value they may receive if no ice storms occur. Landowners with loblolly pine plantations on medium or high productivity sites should not factor ice damage into management decisions. On these higher quality sites, changes in management decisions either had no beneficial effect on the net present value, or could be made after the ice storm had occurred.

Further research is needed to better understand the dynamic between ice damage and loblolly pine plantation characteristics. Although our research provides some insight into what characteristics can affect damage and net present value, further research into the amount these characteristics affect the amount of damage loblolly pine plantations will incur would help to better prepare a landowner to manage for ice damage. Also a reliable estimate of the frequency of ice damage is desirable to give landowners a better understanding of the risk they face.

Chapter VI. Literature Cited

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Appendix 1.

Example of spreadsheet used to model ice damage.

Beginning Tree List					**Top Damage**		**Stem Lean**				***Ending Tree List***		
Diameter	**Height**	**Live Frequency**	**Thin Frequency**	**D^2H**	**Pr of class 4**	**Pr of class 5**	**Pr of class 4**	**Pr of class 5**	**Sum of 4&5 Probabilities**	**% of Surviving Trees**	**Diameter**	**Height**	**Live Frequency**
11.51	48.15	0.01	0.00	554.21	0.02	0.08	0.03	0.01	0.14	0.86	11.51	48.15	0.01
11.36	48.04	0.02	0.00	545.73	0.02	0.08	0.03	0.01	0.14	0.86	11.36	48.04	0.02
11.21	47.94	0.04	0.00	537.41	0.02	0.08	0.03	0.01	0.13	0.87	11.21	47.94	0.03
11.07	47.82	0.07	0.00	529.37	0.02	0.07	0.03	0.01	0.13	0.87	11.07	47.82	0.06
10.92	47.71	0.11	0.00	520.99	0.02	0.07	0.03	0.01	0.13	0.87	10.92	47.71	0.10
10.77	47.59	0.17	0.00	512.54	0.02	0.07	0.03	0.01	0.13	0.87	10.77	47.59	0.15
10.62	47.47	0.25	0.00	504.13	0.02	0.07	0.03	0.01	0.13	0.87	10.62	47.47	0.22
10.47	47.34	0.37	0.00	495.65	0.02	0.06	0.03	0.01	0.13	0.87	10.47	47.34	0.32
10.32	47.21	0.54	0.00	487.21	0.02	0.06	0.04	0.02	0.13	0.87	10.32	47.21	0.47
10.17	47.08	0.76	0.00	478.80	0.02	0.06	0.04	0.02	0.13	0.87	10.17	47.08	0.66
10.02	46.94	1.04	0.00	470.34	0.02	0.06	0.04	0.02	0.13	0.87	10.02	46.94	0.90
9.87	46.80	1.40	0.00	461.92	0.02	0.06	0.04	0.02	0.13	0.87	9.87	46.80	1.22
9.72	46.65	1.85	0.00	453.44	0.01	0.06	0.04	0.02	0.13	0.87	9.72	46.65	1.61
9.56	46.50	2.39	0.00	444.54	0.01	0.05	0.04	0.02	0.13	0.87	9.56	46.50	2.08
9.41	46.34	3.03	0.00	436.06	0.01	0.05	0.05	0.02	0.13	0.87	9.41	46.34	2.63
9.26	46.18	3.76	0.00	427.63	0.01	0.05	0.05	0.02	0.13	0.87	9.26	46.18	3.26
9.10	46.01	4.60	0.00	418.69	0.01	0.05	0.05	0.02	0.13	0.87	9.10	46.01	3.99
8.94	45.84	5.52	0.00	409.81	0.01	0.05	0.05	0.02	0.13	0.87	8.94	45.84	4.78
8.79	45.66	6.52	0.00	401.35	0.01	0.05	0.05	0.02	0.14	0.86	8.79	45.66	5.64
8.63	45.47	7.58	0.00	392.41	0.01	0.04	0.06	0.03	0.14	0.86	8.63	45.47	6.54
8.47	45.28	8.68	0.00	383.52	0.01	0.04	0.06	0.03	0.14	0.86	8.47	45.28	7.47

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