The economic impact of the 1998 ice storm on eastern Ontario woodlots: Case studies of red pine and white cedar

by Jeremy Heigh[1], Glenn Fox[1], Daniel McKenney[2] and Kimberly Rollins[1]

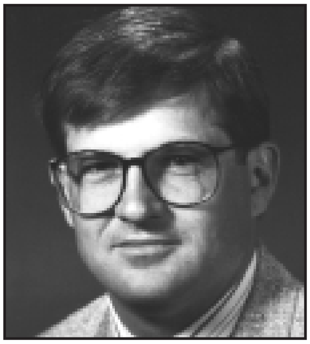
This paper reports estimates of the economic costs of the 1998 ice storm at the enterprise and regional levels for owners of red pine (*Pinus resinosa Ait.*) and white cedar (*Thuja occidentalis L.*) woodlots. The results are based on alternative management regimes and response strategies and illustrates the broader issues currently discussed in forestry such as intensive silviculture and harvest practices. A partial capital budget approach was used to estimate representative per hectare losses for red pine and white cedar. Stochastic simulations and sensitivity analyses were used to examine the robustness of the estimates of economic damages. Per hectare losses for red pine ranged from $560 per hectare for minimal damage for a 25-year-old stand being managed under a target harvest regime to $13,236 per hectare for a 55-year-old stand subjected to severe damage and being managed under a Faustmann harvest regime. Total economic loss for red pine plantations is estimated to be between $21.2 and $32.5 million (1999 constant dollars) at the regional level. This estimate varies with the harvest regime being used. Per hectare losses for white cedar ranged from $307 per hectare for a 70-year-old stand suffering minimal damage and being harvested under a mean annual increment rule on site index 12 land to $1721 per hectare for a 70-year-old stand suffering severe damage and being managed under a mean annual increment rule on site index 10 land. The range of estimated aggregate losses for white cedar is larger than the range for red pine, extending from $3.56 million to $39.6 million with a mean estimate of $22 million (1999 constant dollars) for the mean annual increment harvest regime.

Key Words: partial capital budget, stochastic simulation, sensitivity analysis, natural disaster policy

Cet article fait état des estimés des coûts économiques reliés à la tempête de verglas de 1998 au niveau des entreprises et des régions pour les propriétaires de boisés de pin rouge (*Pinus resinosa Ait.*) et de cèdre occidental (*Thuja occidentalis L.*). Les résultats reposent sur des régimes alternatifs d'aménagement et de stratégies de réaction et illustrent les thèmes généraux discutés actuellement en foresterie comme la sylviculture intensive et les pratiques de récolte. Une approche selon un budget de capitaux partiels a été utilisée pour estimer les pertes représentatives par hectare pour le pin rouge et cèdre occidental. Des simulations stochastiques et des analyses de sensibilité ont été utilisées pour examiner la résistance des estimés des dégâts économiques. Les pertes par hectare pour le pin rouge variaient de 560 $ l'hectare dans le cas de dégâts minimes pour un peuplement de 25 ans aménagé selon un régime de récolte ciblé à 13 236 $ l'hectare pour un peuplement de 55 ans ayant subi des dommages sévères et aménagé selon un régime de récolte Faustmannn. Les pertes économiques totales pour les plantations de pin rouge sont estimées entre 21,2 millions $ et 32,5 millions $ (en dollars constants de 1999) au niveau de la région. Cet estimé varie en fonction du régime de récolte utilisé. Les pertes par hectare pour le cèdre occidental variaient de 307 $ l'hectare pour un peuplement de 70 ans ayant subi des dégâts minimes et étant récolté selon la règle de l'accroissement annuel moyen pour une station d'indice 12 à 1 721 $ l'hectare pour un peuplement de 70 ans ayant subi des dommages sévères et aménagé selon la règle de l'accroissement annuel moyen pour une station d'indice 10. L'écart pour les pertes cumulatives estimées pour le cèdre occidental est plus important que dans le cas du pin rouge, passant de 3,56 millions $ à 39,6 millions $ avec un estimé moyen de 22 millions $ (en dollars constants de 1999) selon un régime de récolte basé sur l'accroissement annuel moyen.

Mots-clés : budget de capitaux partiels, simulation stochastique, analyse de sensibilité, politique de désastre naturel

Jeremy Heigh



Glenn Fox

Daniel McKenney

Kimberly Rollins

Introduction

On the morning of January 5, 1998 residents of eastern Ontario awoke to the devastating beauty of one of the region's worst ice storms in recorded history. The storm continued for six days, affecting an area of over 600 000 hectares and coating the landscape with between 40 and 100 millimetres of ice. The destruction of forested lands directly affected private and public woodlots as well as forest product producers who depend on tree harvest from those woodlots. This paper reports estimates of the direct economic damage to red pine (*Pinus*

[1]Department of Agricultural Economics and Business, University of Guelph, Guelph, Ontario N1G 2W1.
[2]Canadian Forest Service, Sault Ste. Marie, Ontario P6A 5M7.

resinosa Ait.) and white cedar (*Thuja occidentalis* L.) woodlots in eastern Ontario as a result of the storm. Compiling these estimates represents the first phase in the economic analysis of the effects of the storm on woodlot owners. Ultimately, additional research should compare these estimated damages to the levels of compensation and assistance received by woodlot owners in the aftermath of the storm. The distribution of losses as well as assistance and compensation between government-owned and privately owned red pine and white cedar stands as well as between small woodlot owners and industrial forest production firms should be examined as part of a more comprehensive economic analysis of the effectiveness of policy response to the storm. This paper, however, is limited to the characterization of losses. The approach that we develop could potentially be applied to other species and types of forest stands in the region and elsewhere.

Johnson (1998) has estimated that mills in eastern Ontario purchase 93% of sawlogs from private lands. Of those sawlogs, 1% are red pine and 53% are white cedar. Johnson also states that red pine and white cedar are among the most highly storm-damaged species. Approximately 8000 hectares of red pine plantations and 35 000 hectares of white cedar woodlots are located within the area impacted by the storm (Richardson *et al.* 1994, Williams 1995).

For red pine, we compared the results of using the Mean Annual Increment, the Faustmann or Net Present Value Maximization and the Target harvest regimes. For white cedar, we compare the Mean Annual Increment and the Faustmann harvest regimes. The red pine analysis is based on the volume and composition of wood output per representative hectare under different growing conditions. The white cedar analysis is based essentially on per-stem calculations of volume and form, aggregated to a per representative hectare level.

We present details of the derivation of the harvest ages for the various harvest regimes later in the paper. The Mean Annual Increment harvest regime identifies the year that the mean annual increment of the stand is the greatest. For a red pine plantation on a site index of 18 or 22, this maximum is achieved when the stand is approximately 65 years old (Ontario Ministry of Natural Resources 1986). For white cedar, the mean annual increment rule indicates a harvest age of 90 years. The Faustmann harvest regime identifies the harvest age at which the net present value of the silvicultural enterprise is maximized (Bowes and Krutilla 1989). Given a thinning regime at years 25 and 30, the optimal harvest age for a Faustmann rule for red pine on site index 18 is 65 years and for site index 22 is 60 years. For white cedar, the Faustmann model indicates a harvest age of 50 years. A Target harvest regime identifies the age at which the most of the stems in a stand have reached a specific size. Using relationships between site index, tree spacing and tree growth, the most rapid path to the target crop can be identified. We follow Johnson *et al.* (1999) and set the target for red pine as sawlogs of 24 metres in length. This target is achieved for red pine when the stand is 75 and 64 years old for site index 18 and 22 respectively.

Thinning has an important influence on costs and revenues. However, the economics of thinning in Canada are not well understood. We considered two thinning regimes for red pine. Under the Mean Annual Increment and Faustmann harvest regimes, thinning occurs at years 25 and 30 as this is the most common practice in eastern Ontario. At those ages, the average tree has the right dimensions for sale as pulpwood and possibly small poles and sawlogs. Truly optimizing the thinning regime, which would depend on prices, thinning costs, site productivity and harvest regime, is outside the scope of this study. However, we do consider a thinning regime for the Target harvest case that has been optimized using a Density Management Diagram (Smith and Woods 1997). This is possible because the target is predefined. For this reason, our net present values for the Target harvest regime are actually higher than those that we report for the Faustmann harvest regime in the red pine model, where thinning is not optimized.

Methods

A capital budget was developed for red pine plantations and white cedar woodlots. Capital budgeting involves the estimating the magnitudes and the timing of costs and benefits from, in this case, the ice storm and associated remedial actions and the intertemporal comparison of these costs and benefits through discounting and compounding. Several combinations of damage levels, management regimes and production situations were examined in order to explore the range of possible damage estimates. This procedure was necessary due to the limited data available on the type of management regime being followed in different stands throughout the region and also on the level of damage specific to these two species in the study area.

The capital budgeting approach used in this study was conducted in a similar fashion to the enterprise level analysis of the economic impact of the storm on eastern Ontario maple syrup producers described by Kidon *et al* (2002) . The capital budget included the costs and revenues associated with the production of these species at the time of the storm. Point and interval estimates of net present values and of damages were derived using Monte Carlo simulation with Palisade RISK® software. Our baseline assumptions included a real discount rate[3] of 5% and constant future stumpage values. This rate of time preference is based on Kula (1984) and on standard practice in cost-benefit analysis undertaken in the Canadian context. The use of the real discount rate estimated by Kula implies that our capital budgeting is conducted from what is usually called a "social perspective" in cost-benefit analysis. Among other things, this perspective attempts to measures costs and benefits without regard to the distribution of either costs or benefits within a society. This has important implications for the interpretation of the net present values that we report for representative hectares of red pine stands. Sensitivity analysis was conducted to examine the effects of a higher real discount rate and also to explore the effect of future real stumpage prices rising at a rate of 1% per year on our damage estimates. For red pine, the net present value of a single rotation can be expressed as;

$$PV_S = (R_h + R_{t1}(1+i)^{A-t1} + R_{t2}(1+i)^{A-t2} - C_o(1+i)^A - \sum_{k=1}^{5} C_b(1+i)^{A-k} - \left(C_r + C_p\right)(1+i)^{A-t1})/(1+i)^A \qquad (1)$$

[3]The real discount rate represents a rate of time preference that has been adjusted for the effects of inflation. Observed rates of time preference, say, in the form of market interest rates, include the effects of inflation. A market interest rate of 8% when the rate of inflation is 3% would amount to a real discount rate of 5%.

where PV_S = the net present value per hectare;
R_h = the net revenue received at harvest;
A = the age of the stand at harvest;
R_{t1}, R_{t2} = the net revenues from thinnings at years t_1 and t_2, compounded forward to the harvest year
i = the real discount rate;
C_o, C_b, C_r, C_p = stand establishment costs (including site preparation and purchasing and planting stock), the cost of brushing in each of the first five years and the costs of developing roads pruning in year t_1, respectively, compounded forward to the harvest date;

The numerator of the ratio in Equation (1) represents revenues and costs, all compounded forward to the harvest year. The denominator expresses those compounded revenues and costs as a present value.

Since white cedar is not intensively managed in the region, the net present value equation for a single rotation is the following,

$$PV_s = \frac{R_h}{(1+i)^A} \tag{2}$$

However, since red pine is intensively managed in the region, we used a multiple rotation model to calculate net present values for this species. Equation (3) shows how the net present value of an infinite series of rotations is calculated. The assumption is that existing red pine stands will be artificially regenerated to red pine in perpetuity. The net present value of this sequence of stands is calculated as;

$$PV_M = (R_h + R_{t1}(1+i)^{A-t1} + R_{t2}(1+i)^{A-t2} - C_o(1+i)^A - \sum_{k=1}^{5} C_b(1+i)^{A-k} - \left(C_r + C_p\right)(1+i)^{A-t1}) / (1+i)^A - 1 \tag{3}$$

where PV_M = the net present value of an infinite series of red pine rotations.

Since regeneration of white cedar in eastern Ontario is poorly documented, only a single rotation model is considered in our analysis. In both the red pine and white cedar results, the opportunity cost of land is omitted from the analysis. One reason for this omission is that land on which white cedar is grown in the region often has limited use for other purposes. In the case of red pine, we have assumed, by using the multiple rotation net present value formula, that land currently used to grow red pine will be used this way in perpetuity. Of course, we are not in a position to know with certainty how land will be used in this region in the future.

Partial capital budgeting is used to estimate the costs of the storm for various combinations of harvest regime, site productivity conditions and age of the stand at the date that the storm occurred. The net present value of a particular representative hectare was calculated for the situation that would have been expected if the storm had not occurred. The net present value for that same representative hectare was then calculated when the storm did occur. Damages were calculated as the difference between these two net present values. Storm damage was unique for each species due to the characteristics of the trees themselves and the stands. For this reason, the physical damage per hectare for minimal, moderate and severe damage levels was different for the two species. For example, in red pine plantations, 20%, 40% and 100% of the stand were damaged in the minimal, moderate, and severe damage categories respectively. For white cedar, these percentages were 15%, 30% and 50%. We assumed that all of the damaged trees were removed, sold at salvage value, and therefore not included in final harvest costs and revenues. Appendix Table A summarizes the partial budget information used for red pine and Appendix Tables B and C do the same for white cedar. The difference in the net present value of the silvicultural enterprise for that capital budget with the storm and if the storm had not occurred is the direct economic loss from the storm.

The estimated per hectare losses are aggregated to produce a regional loss estimate for each species for the region. To construct these aggregate estimates we projected the approximate land area for each species in each district at the time that the storm occurred from the most recent Forest Resource Inventory (Williams 1995). We combined this information with an estimate of the land area in each district subjected to each of the three levels of damage, based on the Natural Resources Canada (1998) ice storm damage map. The map was developed based on damage to hardwood species, which depends on site productivity, location and topography (C. Nielsen, personal communication), attributes that also influence damage to conifers. We used the ice storm damage map to estimated the land area subject to each of the three levels of damage in each district. It should be kept in mind that limitations on both location and incidence of damage data specific to red pine and white cedar need to be appreciated in interpreting our aggregate damage estimates, which should be viewed as preliminary.

Red Pine: Background, Methods, Data Sources and Important Assumptions

Starting around 1915, red pine stands were established in eastern Ontario to rehabilitate and consolidate blowsand that resulted from abandoned agricultural fields. Fig. 1 illustrates the typical timing and relative magnitude of costs and revenue components for red pine production. These activities can include establishing the stand (site preparation and planting), building roads and ditches, brushing, pruning, thinning and harvesting.

The harvest regimes depend on growth data, product proportions and price information. The growth data used in all three red pine harvest regimes were based on the combined data of Plonski (1971) and Beckwith and Roebbelen (1983). The lack of a single and complete source for growth data suggests that further data are required to more accurately describe red pine growth. One of the artifacts of our approach, splicing together two different growth and age profiles for red pine, is that the growth and yield relationship that results is not concave. This results, in one case (Site index 18), in the Faustmann harvest regime giving identical harvest ages as the Mean Annual Increment harvest regime. This is clearly an unexpected outcome and underscores the need for additional biometric research on growth and yield relationships.

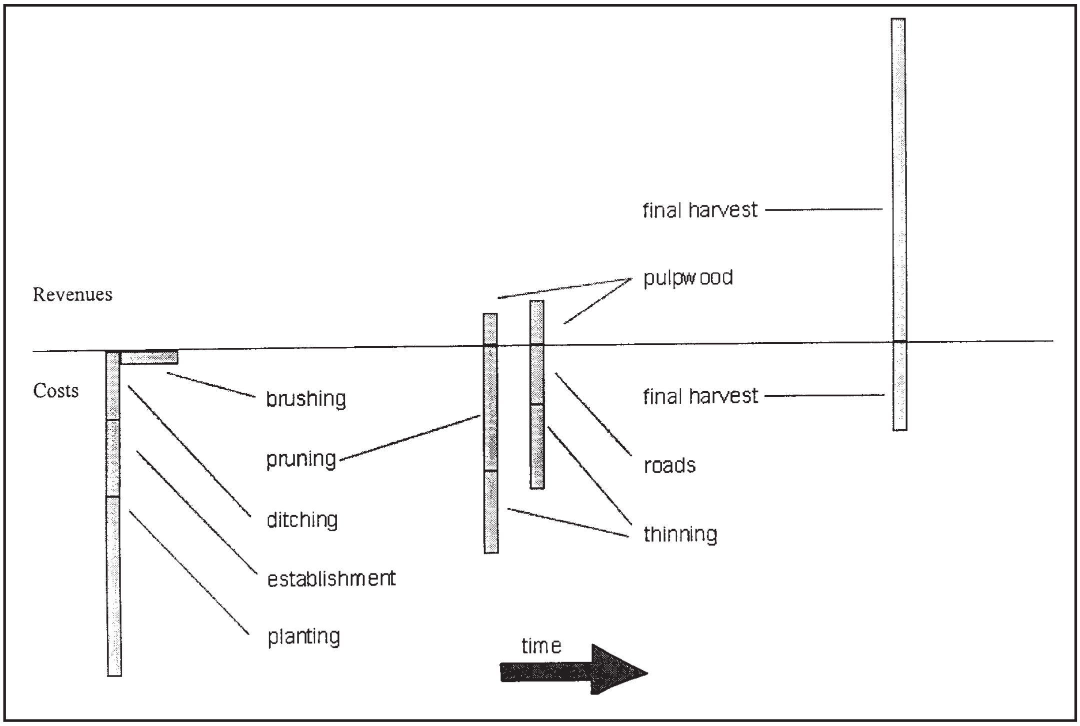


Fig. 1. The timing of revenues and costs in the red pine capital budget.

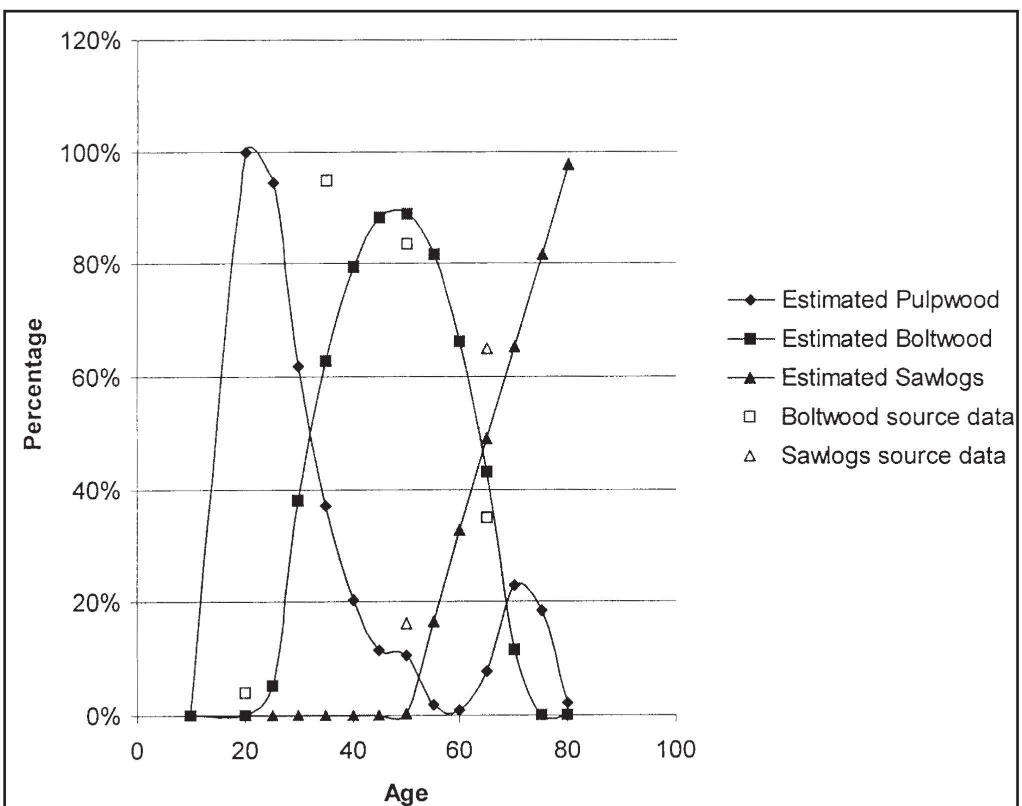


Fig. 2. Estimated product proportions for red pine.

Determining the maximum net present value and identifying the optimal target crop required that the stand products, their associated values and the product proportions at each harvest date be estimated. Following Johnson *et al.* (1999) we have included three red pine products: sawlogs, boltwood and pulpwood. We assume that pulpwood is the residual product and any merchantable volume not in sawlogs or boltwood will be sold as pulpwood. To calculate the value of a hectare of red pine at any point in its production cycle, the proportions of merchantable volume in each of the three product categories was estimated. Based on Steill (1964) and Johnson *et al.* (1999) we fitted a regression equation to their data to estimate product proportions

Table 1. Costs and key assumptions included in the red pine production capital budget

Activity	Units	Cost	Timing
Site Preparation[1]	$/ha	$225.00	Date of establishment (Year 0)
Purchasing Stock and Planting Costs[1]	$/ha	$650.00	Date of establishment (Year 0)
Ditching Costs[2]	$/ha	$8.80	Date of establishment (Year 0)
Brushing Costs[3]	$/ha/year	$49.77	Years 1 through 5
Pruning Costs[4]	$/ha	$555.00	Year of first thinning -Under Mean Annual Increment and Net Present Value Harvest Regimes ~ Year 25 -Under Target Harvest Regime ~ Year 36
Road Building Costs[5]	$/ha	$160.00	Tear of second thinning -Under Mean Annual Increment and Net Present Value Harvest Regimes ~ Year 30 -Under Target Harvest Regime ~ Year 49
Harvesting Costs[3]	$/ha	$400.00	Year of final harvest -Under Mean Annual Increment Regime ~ Year 55 -Under Net Present Harvest Regime ~ Year 60 -Under Target Harvest Regime ~ Year 64
Thinning Costs[6]	$/ha	$400.00	Second year of thinning for Target Harvest Regime (year 49)
Products	**Units**	**Price**	
Sawlogs[1]	$/m^3	$19.32	
Boltwood[1]	$/m^3	$4.55	
Pulpwood[1]	$/m^3	$1.36	
Thinning Revenue[3]	$/metric ton	$7.00	
Biological Assumptions			
Index Classification	18 & 22		
Initial trees per hectare	2000[1]		
Target Height	24m[1]		
Financial Assumptions			
Real Interest Rate	5%		

Source: 1. Johnson et al. (1999); 2. Shepley Excavation and Brenning, Personal correspondence; 3. Fowler, Personal correspondence; 4. Berry (1964); 5. Brenning, Personal correspondence; 6. Scott and Scott, Personal correspondence.

(Fig. 2). Details of the estimation procedure are reported in Heigh (2001).

Table 1 indicates the assumptions we have made on prices, costs, biological conditions, and the real discount rate for red pine. Prices and costs are allowed to vary using @RISK analytical software. The coefficient of variation on prices is 11% and on costs it is 20%, based on historical price and cost data (See Heigh 2001 for details). Site indexing is a measure of site productivity. Based on the latest Forest Resource Inventory data (Williams 1995), we assume that red pine plantations are growing on a site index of 18 or 22. We assume that red pine plantations are initially stocked at 2000 trees per hectare (Johnson *et al.* 1999). Finally, following Kula (1984), we assume a real discount rate is 5% for the base scenario results. A 7% real rate is considered as part of our sensitivity analysis.

Damage to red pine stands depended on tree size, age at the time the storm occurred and spacing. Younger trees may recover if pruned after incurring damage, however mature trees will remain unmerchantable (Downs 1943, Cayford and Haig 1961, Williston 1974, Borzon *et al.* 1978, Barry *et al.* 1993, Van Dyke, 1999). Since there is a high risk of compression failure in storm damaged trees we assume salvaged trees are only used for pulpwood (Mergen and Winer 1952, Meating *et al.* 2000). We assume that as storm damage increases that a greater percentage of the stand is salvaged as pulpwood and that the cost to reestablish roads and ditches increases as well. If thinnings have not been completed at the time of the storm, we assume that thinning will still be done. However, the costs and revenues associated with thinning will be reduced by the portion damaged by the storm.

Red Pine: Model Results

Table 2 illustrates the changes in the net present value of a representative hectare of red pine for various ages on site indexes 18 and 22 for the three harvest regimes. The importance of optimizing the thinning regime is illustrated by the highest net present value being observed in the Target harvest regime, since it is the only regime of the alternatives to be optimized for thinning. The negative net present values for all harvest regimes

Table 2: Net present value of a representative hectare of red pine under various assumptions

	Site Index 18		
	Harvest Regime		
Age and Sensitivity Conditions	Mean Annual Increment[a]	Target[b]	Faustmann (Net Present Value)[c]
Baseline net present value at age 25[d]	–$2,612	–$3,112	–$2,612
	(–$1,688, –$3,536)	*(–$2,190, –$4,017)*	*(–$1,688, –$3,536)*
% change when real interest rate = 7%	–133%	–103%	–133%
% change when future prices rise[e]	23%	16%	23%
Baseline net present value at age 45[d]	–$6,951	–$8,282	–$6,951
	(–$4,350, –$9,505)	*(–$5,836, –$10,721)*	*(–$4,350, –$9,505)*
% change when real interest rate = 7%	–239%	–195%	–239%
% change when future prices rise[e]	20%	12%	20%
Baseline net present value at age 55[d]	–$11,134	–$13,314	–$11,134
	(–$7,192, –$15,507)	*(–$9,531, –$17,545)*	*(–$7,192, –$15,507)*
% change when real interest rate = 7%	–316%	–261%	–316%
% change when future prices rise[e]	8%	7%	8%

	Site Index 22		
	Harvest Regime		
Age and Sensitivity Conditions	Mean Annual Increment[a]	Target[b]	Faustmann (Net Present Value)[c]
Baseline net present value at age 25[d]	–$2,464	–$1,778	–$2,286
	($1,514, –$3,406)	*(–$734, –$2,751)*	*(–$1,314,–$3,232)*
% change when real interest rate = 7%	–146%	–136%	–98%
% change when future prices rise[e]	21%	43%	26%
Baseline net present value at age 45[d]	–$6,672	–$4,873	–$6,209
	(–$3,984, –$9,464)	*(–$2,157, –$7,709)*	*(–$3,526, –$8,973)*
% change when real interest rate = 7%	–254%	–241%	–189%
% change when future prices rise[e]	23%	32%	21%
Baseline net present value at age 55[d]	–$10,726	–$7,749	–$9,966
	(–$6,439, –$14,950)	*(–$3,462, –$12,232)*	*(–$5,743, –$14,301)*
% change when real interest rate = 7%	–329%	–443%	–348%
% change when future prices rise[e]	9%	11%	6%

Note: [a] Harvest under Mean Annual Increment rule at year 55.
[b] Harvest under Target rule at year 75 for site index 18 and year 64 for site index 22.
[c] Harvest under Net Present Value rule at year 60.
[d] Baseline results are derived for a real discount rate of 5% and constant future real stumpage values. The 95% confidence interval is reported in parentheses.
[e] Stumpage prices were assumed to increase by 1% per year in real terms.

show that compounded establishment costs of red pine production outweigh the present value of anticipated harvest revenues[4].

[4]The negative net present values that we report for red pine stand beg the question of why a rational land owner would invest in establishing a red pine woodlot. Recall that our analysis adopts the convention of cost- benefit analysis that recognizes costs and benefits regardless of the distribution of those benefits and costs. Generally, private land owners have not personally paid the establishment costs and even many of the early tending costs associated with red pine stands. These costs were paid by taxpayers. So while, from an overall cost-benefit perspective, the compounded costs of establishing and maintaining a red pine stand may be substantially less than the value of the wood at harvest, if the private land owner receives the harvest revenue and the taxpayers incurred the costs, red pine may be an attractive enterprise from the private land owners point of view. In addition, one of the elements of the rationale for establishing red pine stands was to control erosion. We have not attempted to estimate the erosion benefits from red pine in this study. Finally, other so-called "amenity benefits" may be associated with forested landscapes, in the form of recreation benefits, wildlife habitat and other non-fibre related values. To the extent that amenity benefits were generated from establishing red pine stands in eastern Ontario, the compounded value of those benefits might offset the negative net present values that we report.

Table 3: Breakeven analysis for red pine production

	Site Index 18	Site Index 22
Harvest Regime	Decrease in all Production Costs	
Mean Annual Increment	52%	50%
Target	61%	44%
Faustmann (Net Present Value)	52%	45%
	Decrease in Establishment Costs[a]	
Mean Annual Increment	84%	80%
Target	100%	58%
Faustmann (Net Present Value)	84%	73%

Notes: [a] Establishment costs include site preparation, purchasing and planting stock.

Given these negative net present values, we conducted a break-even analysis to illustrate the importance of production costs in red pine production. Table 3 indicates the percentage reductions in costs that would be necessary for red pine production to break even, that is, to generate a net present value of zero. On a site index of 22, production costs would need to

Table 4. Estimated damage from the 1998 ice storm for a representative hectare of red pine in eastern Ontario: mean annual increment harvest regime[a]

	Site Index 18		
	Damage Class		
Age at the Time of the Storm	**Minimal**	**Moderate**	**Severe**
Baseline damage at age 25[b]	$961	$2,127	$4,411
	($837, $1,079)	*($1,923, $2,323)*	*($3,896, $4,919)*
% change when real interest rate = 7%	–37%	–19%	–17%
% change when future prices rise [c]	14%	8%	9%
Baseline damage at age 45[b]	$2,021	$3,890	$8,280
	($1,676, $2,364)	*($3,466, $4,318)*	*($7,342, $9,215)*
% change when real interest rate = 7%	–29%	–19%	–17%
% change when future prices rise[c]	16%	13%	14%
Baseline damage at age 55[b]	$3,085	$5,642	$12,108
	($2,539, $3,625)	*($4,951, $6,323)*	*($10,351, $13,657)*
% change when real interest rate = 7%	–20%	–13%	–11%
% change when future prices rise[c]	9%	7%	7%
	Site Index 22		
	Damage Class		
Age at the Time of the Storm	**Minimal**	**Moderate**	**Severe**
Baseline damage at age 25[b]	$985	$2,157	$4,487
	($861, $1,114)	*($1,950, $2,385)*	*($3,976, $5,011)*
% change when real interest rate = 7%	–37%	–19%	–18%
% change when future prices rise[c]	13%	8%	10%
Baseline damage at age 45[b]	$2,088	$4,001	$8,542
	($1,717, $2,439)	*($3,520, $4,504)*	*($7,425, $9,691)*
% change when real interest rate = 7%	–29%	–19%	–17%
% change when future prices rise[c]	16%	13%	15%
Baseline damage at age 55[b]	$3,178	$5,813	$12,530
	($2,586, $3,779)	*($5,008, $6,587)*	*($10,729, $14,261)*
% change when real interest rate = 7%	–19%	–13%	–11%
% change when future prices rise[c]	10%	8%	8%

Notes: [a] Harvested at year 55.
[b] Damage per hectare when the real interest rate = 5% and future real stumpage values are constant. The 95% confidence intervals are reported in parentheses.
[c] Stumpage prices were assumed to increase by 1% per year in real terms.

fall by as much as 50% under the Mean Annual Increment harvest regime. Under the Target harvest regime (the regime with the least negative net present value) production costs must fall by 44%[5].

Tables 4, 5 and 6 report our estimates of ice storm damages for the three harvest regimes, for two site productivities and for various ages of the stand at the date that the storm occurred. Appendix A summarizes the changes and costs and revenues included in the partial capital budget calculations. Fig. 3 illustrates the relationship between the age of the stand at the time of the storm and the cost per hectare for minimal and severe damage. For all harvest regimes, the cost of the storm increases as the stand ages and, not surprisingly, as the level of damage increases. Damage estimates are slightly higher on the more productive site (index 22). Increasing the real discount rate to 7% decreases the estimated cost of the storm, since the future wood harvest that is lost as a result of the storm is worth less as a present value with the higher discount rate. Conversely, if real stumpage prices were to increase by 1% per year, in real terms, the cost of the storm increases. Overall, the magnitude of the damages from the storm are not trivial. For example, for a stand that was 55 years of age when the storm occurred, that experienced a severe level of damage and was being managed under a Faustmann harvest regime, the estimated per hectare loss exceeded $13,000 on Site Index 22 (Table 6). Losses for younger trees for minimal damage levels were estimated in the $500 to $1000 per hectare range.

Red Pine: Estimation of Aggregate Damages

Kidon *et al.* (2001) estimated aggregate damages to the eastern Ontario maple syrup industry. In an effort to produce an aggregate estimate to compare to their results, we have compiled a provisional aggregate estimate of damages for red pine stands. Damage to red pine in eastern Ontario was specific to regions and geographical characteristics (C. Nielsen, personal correspondence). However, direct incorporation of the spatial variation in damage was impossible because such data were not available in a form that could be readily accessed for our analysis.

The procedure that we used to prepare an aggregate damage estimate is detailed in Heigh (2001). Data from the most recent Forest Resource Inventory for the region (Williams 1995), based on data collected in 1980, were used as the basis of projecting stand ages at inventory locations on the date that the storm began.

[5]Amenity values have not been included. If these values were included, the production costs may not need to decrease as much to break even.
[6]The saw-toothed pattern illustrated in Fig. 4 reflects the effects of trees reaching higher value threshold categories as they get older. This is, by construction, not a continuous smooth process.

Table 5. Estimated damage from the 1998 ice storm for a representative hectare of red pine in eastern Ontario: target harvest regime[a]

	Site Index 18		
	Damage Class		
Age at the Time of the Storm	Minimal	Moderate	Severe
Baseline damage at age 25[b]	$560	$1,776	$4,052
	($495, $624)	*($1,582, $1,962)*	*($3,546, $4,547)*
% change when real interest rate = 7%	–27%	–13%	–14%
% change when future prices rise[c]	19%	8%	8%
Baseline damage at age 45[b]	$919	$2,779	$6,839
	($745, $1,107)	*($2,470, $3,091)*	*($6,040, $7,651)*
% change when real interest rate = 7%	–33%	–17%	–17%
% change when future prices rise[c]	23%	12%	12%
Baseline damage at age 55[b]	$910	$2,659	$6,628
	($673, $1,153)	*($2,266, $3,066)*	*($5,646, $7,681)*
% change when real interest rate = 7%	–48%	–22%	–18%
% change when future prices rise[c]	27%	15%	14%
	Site Index 22		
	Damage Class		
Age at the Time of the Storm	Minimal	Moderate	Severe
Baseline damage at age 25[b]	$894	$2,250	$5,152
	($782, $1,010)	*($2,027, $2,473)*	*($4,582, $5,730)*
% change when real interest rate = 7%	–35%	–16%	–16%
% change when future prices rise[c]	16%	10%	11%
Baseline damage at age 45[b]	$1,653	$4,033	$9,757
	($1,329, $1,979)	*($3,516, $4,528)*	*($8,486, $11,005)*
% change when real interest rate = 7%	–34%	–16%	–13%
% change when future prices rise[c]	20%	12%	11%
Baseline damage at age 55[b]	$1,977	$4,320	$10,319
	($1,533, $2,406)	*($3,603, $5,008)*	*($8,657, $11,939)*
% change when real interest rate = 7%	–39%	–18%	–11%
% change when future prices rise[c]	16%	9%	7%

Notes: [a] Harvested at year 75 on a site index of 18 and harvested at year 64 on a site index of 22.
[b] Damage per hectare when the real interest rate = 5% and future real prices are constant. The 95% confidence interval is reported in parentheses.
[c] Stumpage prices were assumed to increase by 1% per year in real terms.

Severity of damage by age category was estimated on the basis of spatial ice deposition data. Location data on red pine stands were only available at the district level. We assumed an even distribution of red pine within each district. Following Richardson *et al.* (1994), we assumed that 80% of red pine in the region was located on site index 18 and 20% on site index 22. For each township in the region, the land area experiencing ice deposition consistent with minimal, moderate and severe damage was determined from the spatial ice deposition map (Natural Resources Canada 1998). These proportions were applied to the estimated land area in red pine in that township.

The aggregate cost of the ice storm was greatest under the Faustmann harvest regime, since, generally speaking, the per hectare damages under the Faustmann harvest regime were larger. The 95% confidence interval for aggregate damage extended from $26.5 million to $33.1 million. The interval for the Mean Annual Increment regime was from $25.8 million to $32.5 million and for the Target harvest regime it was from $21.2 million to $27.4 million. We were not in a position to assess which, if any, of the three harvest regimes is being followed with respect to red pine in the region. We are not able to choose one of these aggregate estimates as more applicable than the others. In any case, the ranges are reasonably consistent. Kidon *et al.* (2001) reported an aggregate estimate of losses to the maple syrup industry in the region of $7.1 (± 0.4) million.

White Cedar: Background, Methods, Data and Important Assumptions

Northern white cedar is a common and commercially important species in eastern Ontario (Schaffer 1996). White cedar is valued for its durability (Behr and Meyers 1975), which makes it ideal for uses as lumber, fencing, building material in houses, shingles and lawn furniture (Ward 1989). White cedar often grows in a pure even-aged stand (Lanark Cedar, personal correspondence; Paquette, personal correspondence; Johnston 1977). Living longer than 400 years and able to survive in shade (Johnston, 1977), it often outlives other competing species and is thereby able to capitalize on forest disturbances (Heitzman *et al.* 1997, Johnston 1977).

Pure white cedar stands naturally occur in eastern Ontario. Unlike red pine, there are few expenses incurred during production and most of these occur at harvest. The slow growth of the trees, relatively low prices and the naturally dense growth of the species have discouraged investment in management practices (Miller Cedar Posts, personal correspondence; Ward 1989). Since white cedar can be managed extensively and is commercially valuable, regeneration of the species could be worthwhile. However, short-term regeneration (within 200 years of harvest) is not well understood (Armstrong Cedar, personal correspondence; Verme and Johnston 1986, Heitzman *et al.*

Table 6. Estimated damage from the 1998 ice storm for a representative hectare of red pine in eastern Ontario: Faustmann (Net Present Value) harvest regime[a]

	Site Index 18		
	Damage Class		
Age at the Time of the Storm	**Minimal**	**Moderate**	**Severe**
Baseline damage at age 25[b]	$961	$2,127	$4,411
	($837, $1,079)	*($1,923, $2,323)*	*($3,896, $4,919)*
% change when real interest rate = 7%	–37%	–19%	–17%
% change when future prices rise[c]	14%	8%	9%
Baseline damage at age 45[b]	$2,021	$3,890	$8,280
	($1,676, $2,364)	*($3,466 , $4,318)*	*($7,342, $9,215)*
% change when real interest rate = 7%	–29%	–19%	–17%
% change when future prices rise[c]	16%	13%	14%
Baseline damage at age 55[b]	$3,085	$5,642	$12,108
	($2,539, $3,625)	*($4,951, $6,323)*	*($10,651, $13,657)*
% change when real interest rate = 7%	–20%	–13%	–11%
% change when future prices rise[c]	9%	7%	7%
	Site Index 22		
	Damage Class		
Age at the Time of the Storm	**Minimal**	**Moderate**	**Severe**
Baseline damage at age 25[b]	$1,047	$2,224	$4,610
	($915, $1,184)	*($2,024, $2,447)*	*($4,113, $5,135)*
% change when real interest rate = 7%	–36%	–18%	–16%
% change when future prices rise[c]	14%	9%	10%
Baseline damage at age 45[b]	$2,236	$4,205	$8,951
	($1,850, $2,628)	*($3,736, $4,668)*	*($7,912, $10,010)*
% change when real interest rate = 7%	–26%	–16%	–13%
% change when future prices rise[c]	14%	11%	11%
Baseline damage at age 55[b]	$3,414	$6,158	$13,236
	($2,797, $4,046)	*($5,372, $6,903)*	*($11,499, $14,857)*
% change when real interest rate = 7%	–14%	–8%	–5%
% change when future prices rise[c]	8%	5%	4%

Notes: [a] Harvested at year 60.
[b] Damage per hectare when the real interest rate = 5% and future real prices are constant. The 95% confidence interval is reported in parentheses.
[c] Stumpage prices were assumed to increase by 1% per year in real terms.

1997, Davis *et al.* 1998, Heitzman *et al.* 1999). In general, white cedar woodlots in eastern Ontario are clearcut and allowed to regenerate naturally (Lanark Cedar, personal correspondence; Paquette, personal correspondence) and are predominantly found on site indexes 10 and 12 [Forest Resource Inventory (Williams 1995)].

In the capital budget for white cedar, revenue per hectare is determined by the number of stems per hectare and the price of the products that can be produced from those stems. Price per stem is determined by tree height, diameter and quality. Therefore, to calculate the per hectare value of a white cedar stand it was necessary to estimate the number of trees per hectare, average diameter of the stems and the dominant tree height for each age and site index. It was also necessary to estimate how many of the stems per hectare would be of merchantable quality. Only trees of suitable dimensions and merchantable quality are included in the per hectare value. As a general rule, 70% of the white cedar trees in a stand will be of dominant height (Wensink, personal correspondence). We used this rule to estimate the merchantable volume per hectare.

We incorporated variation in prices, costs and yields for white cedar with @Risk, in a similar fashion as was done for red pine. The coefficient of variation for prices was assumed to be 24%, for costs 20%, based on interviews that indicated that nominal prices for cedar had exhibited little variation in recent years, so that variations in real prices reflected variations in the rate of inflation. Yields were assumed to vary by by ± 0.14 trees per hectare, based on procedures described in Heigh (2001). The prices we used were based on the price list that Lanark Cedar provides to their foresters and prices on this list vary across lengths and dimensions. The costs in the model are road construction ($350/ha), marking costs ($80/ha), harvesting costs ($34/metric ton) and hauling costs ($12/metric ton) (Wensink, personal correspondence).

Since white cedar grows in dense stands and is a relatively branchy species with thick foliage, ice accumulation from the storm caused the trees to either snap just below the crown (Paquette, personal correspondence) or bend down to the ground (Turtle 1998). Those trees that snapped were often fractured throughout the remaining stem and those that bent would never regain any commercial value (Lanark Cedar, personal correspondence). Also, due to the resistance of white cedar to decay, damaged stands must be salvaged in order to promote regeneration. In the partial capital budget for white cedar, damaged trees are removed from the stand. Only 50% of the salvaged trees are assumed to be merchantable (Armstrong Cedar, personal correspondence; Paquette, personal correspondence; Miller Cedar Posts, personal correspondence).

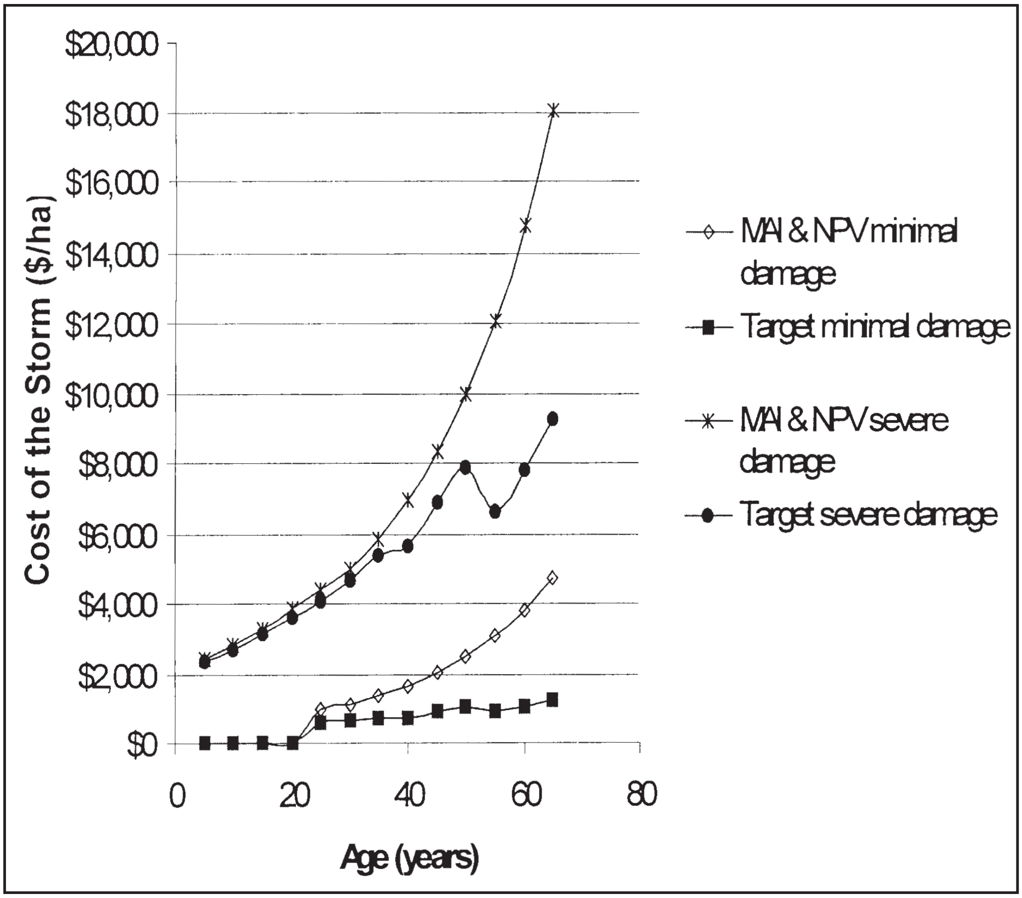


Fig. 3. Red pine representative hectare damage estimates – Site index 18.

White Cedar: Model Results

Unlike red pine, our capital budget results for white cedar generate positive net present values (Table 7). This occurs because white cedar does not incur the substantial establishment costs typical of red pine production. For a stand that is currently 25 years old, growing on site index 10 and that will be harvested under a Mean Annual Increment regime, the net present value per hectare is $479. This increases to $1,114 per hectare if a Faustmann regime is used, indicating substantial gains to following the economist's preferred harvest decision rule. Older stands are worth more, since there is less time that will elapse before revenues will be received.

Tables 8 and 9 report our estimates of the magnitude of losses from the ice storm for different combinations of incidence of damage, stand age and harvest regime for site indexes 10 and 12. The relationship between the cost of the storm and the age of the stand for site index 10 is illustrated in Fig. 4[6]. As the trees grow, the value of the stem increases by steps since prices only increase as the stem grows through progressive size thresholds. This creates the irregular path that the storm cost follows. Cost of damage in the Faustmann harvest regime is highest because the harvest cycle is shorter which results in less discount of the harvest revenue. Mean estimated damages range from a low of $307/ha for 70-year-old stands suffering minimal damage on site index 12 to $1721/ha for 70-year-old stands suffering severe damage on site index 10 for the Mean Annual Increment harvest regime (Table 8). Comparable losses are generally higher for the Faustmann harvest regime (Table 9) since the profitability of fibre production is higher under this rule.

We have indicated that the economically optimal harvest age is 50 years. As the stand ages beyond this date, the economic benefit of harvesting increases more rapidly than the economic cost of harvesting, especially on more productive sites such as site index 12. In fact, as we can see in Table 8, for trees 70 years old, the benefit to harvesting can be so great as to make the storm damage and corresponding salvage operation economically profitable (note the negative costs, and therefore revenues, for the minimum confidence interval). The woodlot owner is made better off by being forced to harvest earlier than he or she would otherwise have been done under the Mean Annual Increment harvest regime.

White Cedar: Estimation of Aggregate Damages

Aggregation of our representative hectare damage estimates for white cedar confronted similar data limitations as those that we faced with red pine. Here, we also constructed projections of land area under white cedar in the region at the time that the storm occurred from the Forest Resource Inventory (Williams 1995) data. We assumed that, at the time of the storm, 20% of the trees were between ages 40 and 60 and 80% were between 60 and 80 years (Heigh 2001). Like red pine, we used ice deposition maps to estimate the proportion of each township that fell into each damage category. We then multiplied the estimated per hectare loss for each damage, age and site class category by our estimate of the land area in each township in that category. Our aggregate estimate of damage is the sum of those products.

Table 7. Net present value of a representative hectare of white cedar under various harvest assumptions

	Site Index 10	
	Harvest Regime	
Age and Sensitivity Conditions	**Mean Annual Increment**[a]	**Faustmann (Net Present Value)**[b]
Baseline net present value at age 25[c]	$766	$1,699
	($569, $1,192)	*($1,207, $2,748)*
% change when real interest rate = 7%	–71%	–39%
% change when future prices rise[d]	99%	31%
Baseline net present value at age 45[c]	$2,034	$4,410
	($1,497, $3,069)	*($3,221, $6,964)*
% change when real interest rate = 7%	–58%	–7%
% change when future prices rise[d]	61%	5%
Baseline net present value at age 55[c]	$3,272	
	($2,433, $4,937)	
% change when real interest rate = 7%	–48%	
% change when future prices rise[d]	47%	
Baseline net present value at age 70[c]	$6,803	
	($5,088, $10,205)	
% change when real interest rate = 7%	–31%	
% change when future prices rise[d]	24%	
	Site Index 12	
	Harvest Regime	
Age and Sensitivity Conditions	**Mean Annual Increment**[a]	**Faustmann (Net Present Value)**[b]
Baseline net present value at age 25[c]	$372	$1,707
	($266, $597)	*($1,205, $2,672)*
% change when real interest rate = 7%	–71%	–39%
% change when future prices rise[d]	114%	34%
Baseline net present value at age 45[c]	$983	$4,423
	($705, $1,516)	*($3,155, $6,949)*
% change when real interest rate = 7%	–57%	–7%
% change when future prices rise[d]	71%	9%
Baseline net present value at age 55[c]	$1,582	
	($1,144, $2,511)	
% change when real interest rate = 7%	–48%	
% change when future prices rise[d]	52%	
Baseline net present value at age 70[c]	$3,402	
	($2,384, $5,475)	
% change when real interest rate = 7%	–31%	
% change when future prices rise[d]	25%	

Notes: [a] Harvest under Mean Annual Increment rule at year 90.
[b] Harvest under Faustmann (Net Present Value) rule at year 50.
[c] Damage per hectare if the real interest rate = 5% and future real prices are constant. The 95% confidence interval is reported in parentheses.
[d] Stumpage prices were assumed to increase by 1% per year in real terms.

Since the Faustmann harvest regime indicates that white cedar is optimally harvested at age 45 we concluded that this harvest regime is not being generally applied in eastern Ontario. This conclusion is also supported by the general lack of interest in intensive management of white cedar in the region. We therefore calculated aggregate loss estimates for the Mean Annual Increment harvest regime only. The total aggregate cost of the storm for white cedar was between $3.56 million and $39.6 million.

As was mentioned when discussing Table 8, it is uneconomical in terms of net present value maximization to leave stands unharvested beyond age 50. However, the Forest Resource Inventory (Williams 1995) data indicate that 80% of stands in eastern Ontario are between 60 and 80 years old and we therefore assume that they are being harvested under a harvest regime something like the Mean Annual Increment harvest regime. Storm damage across this 80% of the inventory would force an economically advantageous harvest and therefore reduce the cost of the storm. Compared to red pine, white cedar is being harvested much further past the economically optimal harvest age. Another comparison is the coefficient of variation used in the models to represent prices. The variation in white cedar prices is more than twice that of red pine. This contributes to the wider confidence intervals around aggregate damages.

Discussion

Our results indicate that the per hectare losses experienced by owners of red pine and white cedar stands in eastern

Table 8. Estimated damage from the 1998 ice storm for a representative hectare of white cedar in eastern Ontario: mean annual increment harvest regime[a]

	Site Index 10		
	Damage Class		
Age and Sensitivity Conditions	**Minimal**	**Moderate**	**Severe**
Baseline damage at age 25[b]	$362	$388	$423
	($226, $508)	*($180, $581)*	*($103, $711)*
% change when real interest rate = 7%	–25%	–67%	–174%
% change when future prices rise[c]	25%	38%	48%
Baseline damage at age 45[b]	$484	$743	$880
	($328, $647)	*($433, $1,083)*	*($478, $1,328)*
% change when real interest rate = 7%	–26%	–61%	–76%
% change when future prices rise[c]	20%	29%	32%
Baseline damage at age 55[b]	$520	$871	$1058
	($304, $727)	*($374, $1,384)*	*($394, $1,730)*
% change when real interest rate = 7%	–32%	–71%	–86%
% change when future prices rise[c]	23%	31%	33%
Baseline damage at age 70[b]	$674	$1,357	$1,721
	($344, $1,078)	*($520,* $2,349)	*($601, $3,022)*
% change when real interest rate = 7%	–31%	–52%	–57%
% change when future prices rise[c]	19%	22%	23%

	Site Index 12		
	Damage Class		
Age and Sensitivity Conditions	**Minimal**	**Moderate**	**Severe**
Baseline damage at age 25[b]	$380	$428	$491
	($255, $505)	*($264, $589)*	*($253, $709)*
% change when real interest rate = 7%	–7%	–18%	–32%
% change when future prices rise[c]	16%	24%	31%
Baseline damage at age 45[b]	$424	$595	$687
	($266, $564)	*($281, $860)*	*($292, $1,022)*
% change when real interest rate = 7%	–9%	–26%	–32%
% change when future prices rise[c]	15%	23%	26%
Baseline damage at age 55[b]	$400	$565	$653
	($211, $569)	*($134, $921)*	*($95, $1,112)*
% change when real interest rate = 7%	–18%	–53%	–70%
% change when future prices rise[c]	15%	25%	28%
Baseline damage at age 70[b]	$307	$441	$512
	(–$46, $588)	*(–$127, $1,106)*	*(–$630, $1,372)*
% change when real interest rate = 7%	–36%	–155%	–254%
% change when future prices risec	23%	34%	37%

Notes: [a] Mean Annual Increment harvest regime is harvested at year 90.
[b] Damage per hectare when the real interest rate = 5% and future real prices are constant. The 95% confidence intervals are reported in parentheses.
[c] Stumpage prices were assumed to increase by 1% per year in real terms.

Ontario as a result of the 1998 ice storm were substantial. Kidon *et al*. (2001, 2002) were able to compare their loss estimates to the level of assistance provided for maple syrup producers in the aftermath of the storm. They concluded that there was a reasonable correspondence between the losses suffered and the assistance provided. Data on assistance for owners of red pine and white cedar stands were not available in a form to enable us to make this sort of comparison, but this is clearly a policy research question that needs to be addressed.

Our estimates of aggregate losses for the region for these two species also indicate that the damage from the storm was substantial, economically. As we indicated earlier, however, there were important data limitations in aggregating our per hectare results to the regional level. Further work on aggregation procedures beyond the preliminary estimates that we prepared is needed. It was beyond the scope of this study to undertake long-term wood supply implications from the damage done by the storm, but if the data problems that confronted our aggregate analysis can be overcome, wood supply projections could be developed to help better characterize the long term impact of the storm on the wood products industry in the region.

Although this was not our primary purpose with this project, our results also shed additional light on several issues related to the economics of silviculture in eastern Ontario. For example, it may surprise some readers to see the comparison between net present values per hectare for red pine, which is relatively intensively managed in Ontario, and white cedar, which is much more extensively managed. In addition, comparison of both the net present values per hectare and the size of the damages from the 1998 ice storm under different harvest regimes

Table 9. Estimated damage from the 1998 ice storm for a representative hectare of white cedar in eastern Ontario: Faustmann (Net Present Value) harvest regime[a]

	Site Index 10		
	Damage Class		
Age and Sensitivity Conditions	**Minimal**	**Moderate**	**Severe**
Baseline damage at age 25[b]	$429	$612	$855
	($281, $611)	*($359, $945)*	*($454, $1,378)*
% change when real interest rate = 7%	–18%	–39%	–58%
% change when future prices rise[c]	16%	21%	24%
Baseline damage at age 45[b]	$515	$1,173	$1,525
	($345, $775)	*($753, $1,820)*	*($966, $2,376)*
% change when real interest rate = 7%	–2%	–6%	–7%
% change when future prices rise[c]	4%	5%	5%
	Site Index 12		
	Damage Class		
Age and Sensitivity Conditions	**Minimal**	**Moderate**	**Severe**
Baseline damage at age 25[b]	$509	$773	$1,125
	($374, $676)	*($548, $1,086)*	*($772, $1,632)*
% change when real interest rate = 7%	–14%	–27%	–37%
% change when future prices rise[c]	15%	19%	21%
Baseline damage at age 45[b]	$562	$1,293	$1,683
	($386, $832)	*($866, $1,971)*	*($1,114, $2,583)*
% change when real interest rate = 7%	–1%	–5%	–37%
% change when future prices rise[c]	7%	8%	8%

Notes: [a] Faustmann harvest regime is harvested at year 50.
[b] Damage per hectare when the real interest rate = 5% and future real prices are constant. The 95% confidence intervals are reported in parenthesis.
[c] Stumpage prices were assumed to increase by 1% per year in real terms.

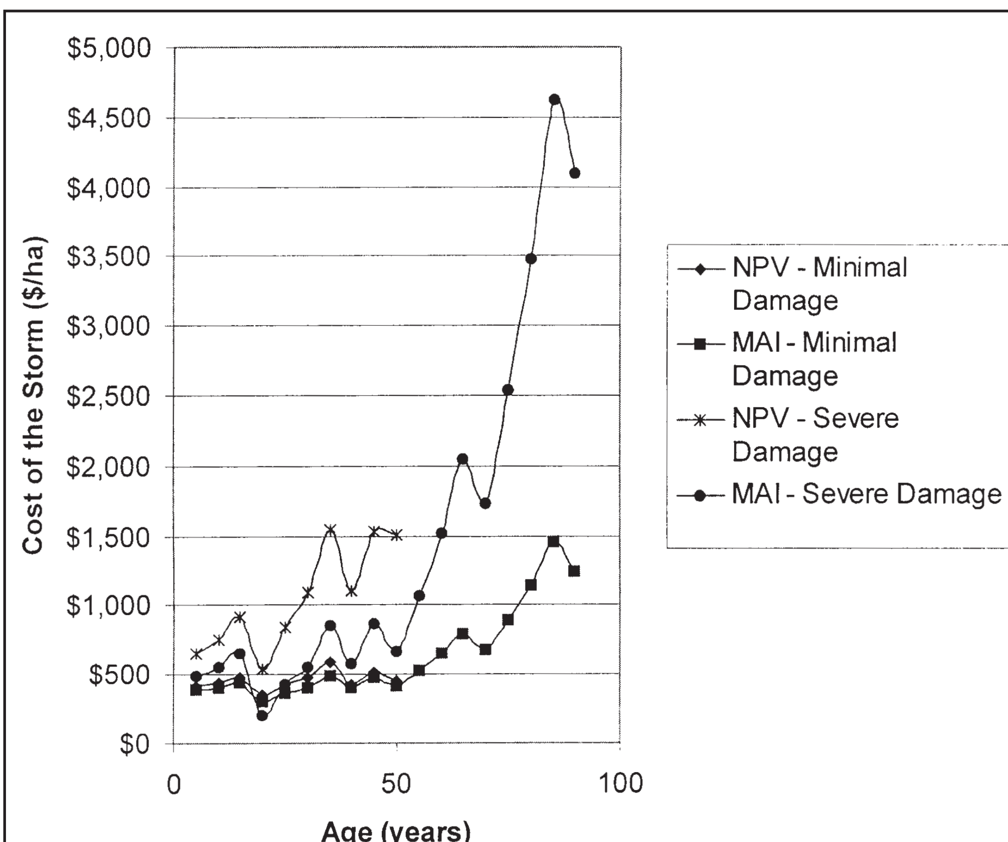


Fig. 4. White cedar representative hectare damage estimates – Site index 10

illustrates the importance of differences in those regimes for the economic performance of forestry. In some cases, the differences in net present values between a Mean Annual Increment harvest regime and a Faustmann model were substantial.

Our findings also illustrate the need for improved information on the economics of thinning and demonstrate the importance of assessing revenues on the basis of product yields rather than simple volume-based revenue calculations in the economics of silviculture.

Acknowledgements

Funding for this project was provided under the *Canada-Ontario agreement for the Ice Storm Economic Recovery Assistance Program, Annex A, Assistance for the Agricultural Sector and Rural Communities in Eastern Ontario*. This program is jointly funded by the Government of Canada and the Government of Ontario. The authors would like to thank Cathy Nielsen, R.A. Lautenschlager and Anthony Hopkin for capable assistance in conducting this research.

References

Barry, P.J., R.L. Dogget and K.M. Swain. 1993. Management Bulletin: How to evaluate and manage storm-damaged forest areas. Southern Region: USDA Forest Service. Forest Health, R8-MB (63). Atlanta, GA.

Behr, E.A. and W. Meyers. 1975. Natural durability of northern white cedar from five sites. Natural Resources. Michigan State University Agricultural Experiment Station East Lansing, Michigan.

Beckwith, A.F. and P. Roebbelen. 1983. Red pine growth and yield tables. Ontario Ministry of Natural Resources. Forest research report no. 18. Maple, Ontario.

Berry, A.B. 1964. A time study in pruning plantation white spruce and red pine. For. Chron. 40(1): 122–128.

Borzon, E.L., A.F. Beckwith and W.G. Irwin. 1978. Ice and snow damage to coniferous plantations in Northumberland forest. Ontario Ministry of Natural Resources. Maple, Ontario.

Bowes, M.D. and J.V. Krutilla. 1989. Multiple-Use Management: The economics of public forestlands. Resources for the Future. Washington, D.C. 186 p.

Cayford, J.H. and R.A. Haig. 1961. Glaze damage in Red and Scots pine plantations in southeastern Manitoba. For. Chron. 37(1):16–21.

Davis, A., K. Puettman and D. Perala. 1998. Site preparation treatments and browse protection affect establishment and growth of northern white-cedar. North Central Forest Experiment Station, United States Department of Agriculture Forest Service. Grand Rapids, MN.

Downs, A.A. 1943. Minimizing glaze damage in pine. Appalachian Forest Experimental Station. USDA Forest Service; Technical Report no. 55. Asheville, NC.

Heigh, J., 2001. Estimating the cost of the 1998 ice storm for woodlot owners in eastern Ontario: Case studies of red pine and white cedar. M.Sc. Thesis. University of Guelph, Guelph, Ontario.

Heitzman, E., K.S. Pregitzer and R.O. Miller. 1997. Origin and early development of northern white cedar stands in northern Michigan. Can. J. For. Res. 27: 1953–1961.

Heitzman, E., K.S. Pregitzer, R.O. Miller, M. Lanasa and M. Zuidema. 1999. Establishment and development of northern white cedar following strip clearcutting. Forest Ecology and Management 123: 97–104.

Johnson, L. 1998. An assessment of the wood market impacts of the 1998 ice storm and program implications for the forest recovery assistance project. Unpublished report. Ontario Ministry of Natural Resources. Kemptville, Ontario.

Johnson, L., J. Williams, L. McIntyre, E. Boysen, L. Dool, D. Downey and B. Wells. 1999. Financial aspects of property management: Understanding the financial costs and benefits of private woodlot management. Land Owner Resource Center. Vol. 2. Manotick, Ontario.

Johnston, W.F. 1977. Manager's Handbook for: Northern White Cedar in the North Central States. North Central Forest Experiment Station, U.S. Department of Agriculture. St. Paul, MN.

Kidon, J., G. Fox, D. McKenney and K. Rollins. 2001. Economic Impact of the 1998 Ice Storm on the Eastern Ontario Maple Syrup Industry. For. Chron. 77(4): 667–675.

Kidon, J., G. Fox, D. McKenney and K. Rollins. 2002. An Enterprise Level Economic Analysis of the Effects of the 1998 Ice Storm on Maple Syrup Producers in Eastern Ontario. Forest Policy and Economics 4: 210–211.

Kula, E. 1984. Derivation of social time preference rates for the United States and Canada. Quarterly Journal of Economics 98: 873–882.

Meating, J., O. Van Dyke, A. Boyd and K. Wright. 2000. Management of ice storm damaged woodlots and plantations. Ontario Ministry of Natural Resources, Southcentral Sciences Section, Science Development and Transfer.

Mergen, F. and H.I. Winer. 1952. Compression failures in the boles of living conifers. J. For. 50(9): 677–679.

Ontario Ministry of Natural Resources. 1986. Managing red pine plantations. Ontario Ministry of Natural Resources. Kemptville, Ontario.

Natural Resources Canada. 1998. Damage to the Hardwood Forests of Eastern Ontario by the 1998 Ice Storm Map. Natural Resources Canada. Great Lakes Forestry Centre. Sault Ste. Marie, Ontario.

Plonski, W.L. 1971. Normal yield tables for red pine for Ontario. Ontario Department of Lands and Forests. Toronto, Ontario.

Richardson, T., C. Nielsen and B. Matson. 1994. Management and marketing of red pine plantations: eastern region. Eastern Ontario Model Forest. Kemptville, Ontario.

Schaffer, W.W. 1996. Silvicultural Guidelines for the Eastern White Cedar. Edited by Eric Boysen. Southern Region Science and Technology Transfer Unit, Ontario Ministry of Natural Resources. Brockville, Ontario.

Smith, D.J. and M.F. Woods. 1997. Red pine and white pine density management diagrams for Ontario. Ontario Ministry of Natural Resources. Southcentral Sciences Section. Technical report no. 48. North Bay, Ontario.

Stiell, W.M. 1964. Twenty-year growth of red pine planted at three spacings. Forest Research Branch, Department of Forestry. 1045. Ottawa, Ontario.

Turtle, R. 1998. Ice damage appraisal underway in Ontario and western Quebec. Logging and Sawmill Journal. 29: 9–10.

Van Dyke, O. 1999. A literature review of ice storm impacts on forests in Eastern North America. Ontario Ministry of Natural Resources, Southcentral Sciences Section. Pembroke, Ontario. Technical Report no. 112.

Verme, L.J. and W.F. Johnston. 1986. Regeneration of northern white cedar deeryards in upper Michigan. Journal of Wildlife Management. 50: 307–313.

Ward, D.B. 1989. Commercial utilization of Atlantic white cedar. Economic Botany 43: 386–415.

Williams, J. 1995. Summary of eastern Ontario: Model forest wood supply by county, township and forest stratum. Eastern Ontario Model Forest. Kemptville, Ontario. Information report no. 27.

Williston, H. L. 1974. Managing pines in the ice-storm belt. J. For. 72(9): 580 Kemptville, Ontario.582.

Personal Correspondence

Armstrong Cedar. Damage to white cedar and price changes, Ottawa, Ontario.

Brenning, H. Excavation company owner, Ottawa, Ontario.

Fowler, G. Woodlot and plantation owner, Iroquois, Ontario.

Lough, S. Lanark Cedar, Damage to white cedar and prices, Carleton Place, Ontario.

Miller, J. Miller Cedar Posts, Damage to white cedar and prices, McDonald's Corners, Ontario.

Nielsen, C. Forest Biodiversity Specialist, Ontario Ministry of Natural Resources, Southcentral Science and Information, Kemptville, Ontario.

Paquette, R.M. Forest biologist. Ontario Ministry of Natural Resources, Kemptville, Ontario.

Scott, J. and D. Scott. Woodlot and plantation owner, Ontario.
Shepley Excavation. Excavation company, Essex, Ontario.
Wensink, P. Managing white cedar stands, Domtar, Cornwall, Ontario.

APPENDIX TABLE A: Partial budget information for red pine

	Increase	Decrease
	Minimal Damage	
Revenues	- sell 20% of the hectare as pulpwood from salvage operation	- loss of 20% of revenue from future thinnings - loss of 20% of revenue from final harvest
Costs	- pay to salvage 20% of hectare - pay to reestablish roads and ditches ($300/ha)[1]	- 20% less harvesting costs at the final harvest
	Moderate Damage	
Revenues	- sell 40% of the hectare as pulpwood from salvage operation - increased revenue, 40% of net present value for multiple rotations of a hectare established today (replanted portion)	- loss of 40% of revenue from future thinnings - loss of 40% of revenue form final harvest - loss of 40% of future rotation revenue from current production cycle
Costs	- pay to salvage 40% of hectare - pay to reestablish roads and ditches ($420/ha)[1]	- 40% less harvesting costs at the final harvest
	Severe Damage	
Revenues	- sell entire hectare as pulpwood from salvage operation - increased revenue, 100% of net present value for multiple rotations of a hectare established today (replanted) portion)	- loss of revenue from future thinnings - loss of all revenue from final harvest - loss of 100% of future rotation revenue from current production cycle
Costs	- pay to salvage entire hectare - pay to reestablish roads and ditches ($530/ha)[1]	- no harvesting costs at the final harvest of current production cycle

APPENDIX TABLE B: Partial budget information for white cedar less than 40 years old

	Increase	Decrease
	Minimal Damage	
Revenues	- 15% of the stand is salvage but only 50% of those trees are merchantable	- final harvest is reduced by 15% due to salvage operations
Costs	- pay to salvage 15% of the stand - pay to haul 50% of the salvaged trees to mill - pay to establish roads early	- decrease final harvest costs since 15% of volume has been salvaged - decrease final hauling costs since 7.5% of volume has been salvaged - no longer pay for roads prior to final harvest
	Moderate Damage	
Revenues	- 30% of the stand is salvage but only 50% of those trees are merchantable	- final harvest is reduced by 30% due to salvage operations
Costs	- pay to salvage 30% of the stand - pay to haul 50% of the salvaged trees to mill - pay to establish roads early	- decrease final harvest costs since 30% of volume has been salvaged -decrease final hauling costs since 15% of volume has been salvaged - no longer pay for roads prior to final harvest
	Severe Damage	
Revenues	- 50% of the stand is salvage but only 50% of those trees are merchantable	- final harvest is reduced by 50% due to salvage operations
Costs	- pay to salvage 50% of the stand - pay to haul 50% of the salvaged trees - pay to establish roads early	- decrease final harvest costs since 50% of volume has been salvaged - decrease final hauling costs since 25% of volume has been salvaged - no longer pay for roads prior to final harvest

APPENDIX TABLE C: Partial budget information for white cedar more than 40 years old

	Increase	Decrease
	Minimal Damage	
Revenues	- 10% of the stand is salvage but only 50% of those trees are merchantable	- final harvest is reduced by 10% due to salvage operations
Costs	- pay to salvage 10% of the stand - pay to haul 50% of the salvaged trees to - pay to establish roads early	- decrease final harvest costs since 10% of volume has been salvaged - decrease final hauling costs since 10% of volume has been salvaged - no longer pay for roads prior to final harvest
	Moderate Damage	
Revenues	- 25% of the stand is salvage but only 50% of those trees are merchantable	- final harvest is reduced by 25% due to salvage operations
Costs	- pay to salvage 25% of the stand - pay to haul 50% of the salvaged trees - pay to establish roads early	- decrease final harvest costs since 25% of volume has been salvaged -decrease final hauling costs since 25% of volume has been salvaged - no longer pay for roads prior to final harvest
	Severe Damage	
Revenues	- 33% of the stand is salvage but only 50% of those trees are merchantable	- final harvest is reduced by 33% due to salvage operations
Costs	- pay to salvage 33% of the stand - pay to haul 50% of the salvaged trees - pay to establish roads early	- decrease final harvest costs since 33% of volume has been salvaged - decrease final hauling costs since 33% of volume has been salvaged - no longer pay for roads prior to final harvest