Cutting versus herbicides: Tenth-year volume and release cost-effectiveness of sub-boreal conifer plantations

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ABSTRACT

Few cost-effectiveness studies of vegetation management in conifer plantations are reported in the literature. This study provides follow-up cost-effectiveness analysis from research conducted at the Fallingsnow Ecosystem Project in northwestern Ontario, Canada with the objective of determining the relationship between release treatment costs and planted white spruce (*Picea glauca* [Moench] Voss) stem volume ($ m^{-3}) ten years after alternative release treatments. Treatment cost estimates for 2003 were calculated by applying 1993 time-study data to estimated 2003 market costs for each treatment component. Untreated control plots had no treatment costs and were not included in the analysis. Including them will always suggest that doing nothing will be the most cost-effective, regardless how limited spruce volume is. The most cost-effective treatment was the aerial application of herbicide Vision ($12.16 m^{-3}), followed by the aerial application of herbicide Release ($12.18 m^{-3}), cutting with brushsaw ($38.38 m^{-3}) and mechanical tending by Silvana Selective ($42.65 m^{-3}). No cost differences were found between the herbicide treatments ($p = 0.998$) or between the cutting treatments ($p = 0.559$). The herbicide treatments were three-fold more cost-effective than the cutting treatments ($p = 0.001$). This analysis only considered the planted conifer component of these young stands.

Key words: clearing saws, competition, forest vegetation management, glyphosate, Great Lakes – St. Lawrence Forest, herbicide alternatives, mixedwood, pesticide, release treatment, triclopyr, weed

RÉSUMÉ

Il y a peu de références sur les études de la rentabilité du contrôle de la végétation dans les plantations de conifères. Cette étude présente le suivi d'une analyse de la rentabilité des travaux de recherche effectués au sein du projet de l'écosystème de Fallingsnow dans le nord-ouest de l'Ontario au Canada ayant pour but de déterminer la relation entre les coûts des traitements et le volume ($ m^{-3}) des tiges d'épinette blanche (*Picea glauca* [Moench] Voss) en plantation, 10 ans après différents traitements de dégagement. Les coûts estimés des traitements en 2003 ont été calculés en utilisant les données d'études de temps de 1993 par rapport aux coûts du marché de 2003 pour chacune des composantes des traitements. Les parcelles témoins non traitées ne se sont pas vu attribuer de coûts et non pas été incluses dans l'analyse. Leur inclusion laissera toujours entendre que ne rien faire sera le traitement le plus rentable, peu importe le volume des tiges d'épinette retrouvé. Le traitement le plus rentable a été la pulvérisation aérienne d'herbicide Vision (12.16$ m^{-3}) suivi de la pulvérisation aérienne de l'herbicide Release (12.18$ m^{-3}), de la coupe au moyen de débroussailleuse (38.88$ m^{-3}) et le dégagement mécanique au moyen du Sylvana Selective (42.65$ m^{-3}). Aucune différence de coût n'a été relevée entre les traitements herbicides ($p = 0.998$) ou entre les traitements de coupe ($p = 0.559$). Les traitements herbicides ont été trois fois plus rentables que les traitements de coupe ($p = 0.001$). Cette étude porte seulement sur la partie plantation de conifères de ces jeunes peuplements.

Mots clés : débroussailleuses, compétition, contrôle de la végétation forestière, glyphosate, Forêt des Grands-Lacs et du St-Laurent, alternatives aux herbicides, forêts mélangées, pesticide, traitement de dégagement, triclopyr, mauvaises herbes

Introduction

Economic efficiency is becoming increasingly important in the Canadian forest sector, largely due to tough international competition (NRCan 2002). For example, since 1990 Canada has become less competitive in global markets, due to successes in Scandinavian and Southern Hemisphere countries (NRCan 2003). Other countries have shown major gains in forest productivity resulting from more intensive silviculture (including major investments in regeneration, release treatments and other stand tending) (NRCan 2003). This international competition as well as uncertain local wood supplies are causing members of the forest industry in Canada to consider broader use of more intensive silviculture (NRCan 2002) both to maintain Canada's international economic competitiveness and to meet global demand for Canadian wood products (NRCan 2002, NRCan 2003).

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Long-term economic forest research in Canada is very important (McKenney *et al.* 1997). Although many studies provide economic insight into plantation silviculture (McKenney *et al.* 1992, Richardson 1993, Biblis *et al.* 1998, Holgen *et al.* 2000, George and Brennan 2002, Ahtikoski and Pulkkinen 2003, Huang and Kronrad 2004, Kimberley *et al.* 2004), only one such North American boreal study investigates vegetation release treatment (controlling weed species with herbicide and non-herbicide options) cost-effectiveness (Bell *et al.* 1997a). This is corroborated by the review paper by Thompson and Pitt (2003). Of the 1256 scientific publications that directly related to forest vegetation management (NRCan 2004) only 18 publications (1.4%) were related to forest vegetation management treatment economics across all Canadian forest types, with only the above-mentioned study in the boreal conifer context.

Work presented here is important due to the dearth of published vegetation management treatment cost data for North American boreal conifer plantations. Furthermore, longer-term growth data are needed for cost and economic analysis of vegetation management options (Pitt *et al.* 1999). This study is a follow-up cost-effectiveness analysis (CEA) to work by Bell *et al.* (1997a) at Fallingsnow Ecosystem Project. The objective is to determine the relationship between release treatment costs and juvenile white spruce stem volume growth (\$ m^{-3}) (Willcocks *et al.* 1990) in a plantation ten years after alternative release treatments to provide baseline release treatment costing information to those considering more intensive forest management.

Methods

Short- and long-term ecological consequences of alternative conifer release treatments are being evaluated in the Fallingsnow Ecosystem Project, which was established as a randomized complete block design. The research site (48°8′–13′N, 89°49′–53′) is approximately 60 km southwest of Thunder Bay, Ontario, and is located in the transition between the boreal and the Great Lakes — St. Lawrence forests (Rowe 1972). From 1986 to 1988, three 75- to 101-year-old stands, which are now research areas, were clearcut. Each stand formed one block that is 20 ha or larger. Within each block, each treatment covers a minimum of 4 ha.

Harvested blocks were planted with 82-cm tall bareroot white spruce (*Picea glauca* [Moench] Voss) stock (2+2) between 1986 and 1989, with 2- to 2.5-metre spacing. Planting was followed by alternative release treatments in 1993, that included: (1) motor-manual cutting by human-operated brushsaws (18 cm above the ground line in mid- to late-October), (2) mechanical cutting by a Ford tractor mounted with a parallelogram boom attached to a Silvana Selective cutting head (33 cm above ground line in late October to early November), (3) glyphosate herbicide (Vision) applied at 1.5-kg acid equivalent per hectare (kg-a.e. ha^{-1}) delivered aerially by a Bell 206 helicopter in August, (4) triclopyr herbicide (Release) applied at 1.9-kg a.e. ha^{-1} delivered aerially by a Bell 206 helicopter in August, and (5) untreated control (Bell *et al.* 1997a).

Treatment Productivity

Release treatment productive machine hours (PMH) or time that brushsaw, Silvana Selective, or helicopter were working was recorded for each block during detailed time studies (Bell *et al.* 1997a). Only costs associated with treatment and field supervision were included in the cost calculations. Non-field costs such as treatment planning, reconnaissance, layout, monitoring, and public meetings were not included in the analysis because these costs are common to all treatments and are not likely to significantly change the results. Obtaining a pesticide permit for the Vision and Release treatments was not included in the analysis because there is no fee for obtaining a pesticide permit and time spent applying for the permit will likely be negligible. The costs incurred by a company forester or pesticide applicator to possess and maintain a valid pesticide applicators' license in Ontario are also negligible and not included.

Tree Stem Volume and Density

Sampling of tenth-year growth characteristics (stem diameter, height, density) in early September 2003 were used to calculate tree volume for each treatment area (experimental unit). Six, 10-m * 2-m sampling transects were randomly laid out, in each treatment area. For each white spruce stem falling within the sample plot boundaries, diameter at 130 cm above ground (DBH, nearest 0.1 cm, diameter tape) and height (nearest 0.1 m, height poles) were recorded. These two metrics were used to calculate individual-tree gross total volumes (GTV) using Honer's Standard Volume Equation (eq. 1) (Honer *et al.* 1983).

[1] $GTV = (0.0043891 * D^2 (1 - 0.04365 * 0.176)^2) / 1.440 + 1.3048 * 342.175 / H)$

where *GTV* is gross total volume; *D* is diameter at breast height measured in centimetres; and *H* is total height measured in metres.

Tree counts were used to generate an average stem density for each experimental unit and expressed as stems ha^{-1} (sph). Stem densities were multiplied by the average GTV for each experimental unit to generate an estimate of gross volume per hectare (GTV ha^{-1}).

2003 Cost Estimates

Treatment cost estimates for 2003 were calculated by applying 1993 time-study data (Bell *et al.* 1997a) to estimated 2003 market costs for each treatment component. Brushsaw and Silvana Selective treatment costs were estimated based on 2003 cost assumptions (Tables 1 and 2). Total costs for brushsaw treatments in 1993 were \$173.91 per day; \$21.74 per Scheduled Machine Hour (\$ SMH^{-1}) and \$30.62 per PMH (\$ PMH^{-1}). Total costs for Silvana Selective in 1993 were \$63.07 SMH^{-1} and \$74.20 PMH^{-1} (Bell *et al.* 1997a).

Estimated aerial spray treatment costs for 2003 were based on the selling price of Release and the manufacturer's suggested retail price (MSRP) of Vision, using label mixing ratios and actual 1993 application rates. In 2003, the selling price of Release was \$30.00 per litre (\$ L^{-1}) (Darren Dillenbeck, Dow AgroSciences INC, Sault Ste. Marie, ON, personal communication) and the MSRP of Vision was \$14.50 L^{-1} (Roy Maki, Monsanto Canada INC, Thunder Bay, ON, personal communication) (Table 3).

Many factors influence aerial herbicide application pricing, such as the total size of program in hectares, spray block locations and size, total application volume, and contractor supplied resources. A rotary wing spray program will vary

Table 1. Actual 1993 and estimated 2003 costs for one brushsaw operator working on a conifer release treatment.

Direct labor cost ($ day^{-1})	$109.61	$200.00
Fringe benefits (%)	20.0%	25.6%
Fringe benefits cost ($ day^{-1})	$21.92	$51.26
Labour cost for operator ($ day^{-1})	$131.53	$251.26
Saw cost (incl. depreciation, gaz blades, files and repairs)	$19.70	$25.00
Other costs (transport and supervision @15% of labour and saw)	$22.68	$41.44
Utilization (%)	71%	71%
Total cost		
per day	$173.91	$317.70
per productive machine hour	$30.62	$55.93
per scheduled machine hour	$21.74	$39.71

depending upon the abovementioned factors from approximately $45.00 ha^{-1} to $70.00 ha^{-1} (Paul Zimmer, Zimmer Air Services INC., Thunder Bay, ON, personal communication). The estimated aerial spray contract rate used for this study was $65.00 ha^{-1}, which includes helicopter, pilot, mixer crew, and two block security workers (James Harrison, Greenmantle Forestry INC., personal communication). Sensitivity analysis was conducted over the range of helicopter rates.

Since no vegetation release treatment cost is associated with the untreated control (i.e., doing nothing; $0.00 ha^{-1} and a resultant cost-effectiveness value of $0.00 m^{-3}), it was not included in the analysis. If we were to include untreated control in a cost-effectiveness analysis, it would suggest that untreated control would always be the most cost-effective treatment, even if spruce GTV production was *very* low. Furthermore, untreated control was also not included in the analysis because conifer planting costs are high, necessitating the need to protect the planting investment from deleterious plants through vegetation release. For example, in 2003 approximate planting costs for container stock in northwestern Ontario ranged from about $425 ha^{-1} to $525 ha^{-1}, based on a planting density of 2500 sph (A. Dorland, Haveman Brothers Forestry Services, Thunder Bay, ON, personal communication).

The treatment cost estimates ($ ha^{-1}) were then applied to the volume per area measurements (m^3 ha^{-1}) to determine cost-effectiveness expressed as treatment cost to planted conifer volume growth ($ m^{-3}) for each experimental unit (which is the response variable used in the ANOVA).

Table 2. Cost analysis for a cleaning machine used in forestry release operations in 2003.

Scheduling	
Hours/day	16
Days/week	5
Weeks/year	25
Scheduled hours/year (SMH)	2000
Estimated life of machine (years)	5
Estimated life of machine (SMH)	10000
Scheduled hours/year (SMH)	2000
Purchase price ($)	$400,000.00
Salvage value ($)	$60,000.00
License ($ year^{-1})	$0.00
Insurance ($ year^{-1})	$8,000.00
Interest rate (%)	8%
Utilization (%)	80%
Estimated life of machine (PMH)	$8,000.00
Lifetime repair cost ($)	$300,000.00
Fuel consumption (PMH^{-1})	$7.50
Fuel cost ($ $^{-1}$)	$0.45
Oil & lubrication ($ PMH^{-1})	$0.25
Operator wages ($ SMH^{-1})	$20.00
Fringe benefits (%)	25%
Administration and profit (%)	10%
Fixed costs	
Annual capital cost	$89,955.19
Annual other costs	$8,000.00
Annual total	$97,955.19
Cost per PMH	$61.22
Cost per SMH	$48.98
Variable costs	
Cost per year	$67,250.00
Cost per PMH	$34.53
Cost per SMH	$33.63
Labour costs	
Cost per year	$50,000.00
Cost per PMH	$31.25
Cost per SMH	$25.00
Administration and profit	
Cost per year	$21,520.52
Cost per PMH	$13.45
Cost per SMH	$10.76
Total costs[a]	
Total per year	$236,725.71
Total per PMH	$147.95
Total per SMH	$118.36

[a]Total costs would likely be higher because supervision and overhead were not accounted for.

Analysis of Variance (ANOVA)

Analysis of variance was conducted using SAS® (SAS Institute Inc. 1989) following the linear model (Steel and Torrie 1980):

$$[2] \quad Y_{ij} = \mu + B_i + T_j + \epsilon_{ij} \qquad i = 1, 2, 3; j = 1, 2, 3, 4$$

where Y_{ij} is the measured response from the ith block and the jth treatment; μ is the overall mean; B_i is the random effect of the ith block; T_j is the fixed effect of the jth release treatment; ϵ_{ij} is the interaction effect of the ith block with the jth release treatment (the error term for testing the fixed treatment effects).

Planned orthogonal contrasts (Wine 1964, Wendorf 2004) were conducted using the SAS® Proc GLM (SAS Institute Inc. 1989). Comparisons included brushsaw vs. Silvana Selective; Release vs. Vision; and herbicide vs. cutting. The untreated plots were not included in the ANOVA because there is no cost associated with the treatment. Diagnostic normal proba-

Table 3. Manufacturers' suggested retail price (2003), product concentration, application rate (Bell et al. 1997a) and herbicide cost per ha based on application rate

	2003 MSRP ($ L^{-1} concentrate)	Product concentrate (kg a.i. L^{-1})	Application rate (kg a.i. ha^{-1})	Cost ($ ha^{-1})
Release ®	$30.00	0.480	1.9	$118.75
Vision ®	$14.50	0.356	1.5	$61.10

bility plots of model residuals and side-by-side dot plots of residuals were used to verify that the assumptions of normality and homogeneity of variance were met.

Results

Averaging across all blocks, the Release treatment produced the greatest white spruce volume, followed by Silvana Selective, Vision, brushsaw and untreated control (Table 4). The Vision treatment was most cost-effective, followed by Release, brushsaw, and Silvana Selective.

Sensitivity analysis was conducted over the entire range of helicopter contractor rates ($45.00 ha^{-1} to $70.00 ha^{-1}). Over this range, aerial spray of herbicide remained the most cost-effective relative to other treatments. For example, cost-effectiveness for the Release and Vision treatments at the contractor rate of $45 ha^{-1} were estimated to be $10.86 m^{-3} and $10.23 m^{-3} respectively; at the contractor rate of $65 ha^{-1} (the rate used in this study), they were estimated to be $12.18 m^{-3} and 12.16 m^{-3} respectively; and at the contractor rate of $70 ha^{-1}, they were estimated to be $12.52 m^{-3} and $12.65 m^{-3}, respectively. The value of $45 ha^{-1} doesn't capture *all* the associated aerial spray costs (i.e., helicopter, pilot, mixer crew, and two block security workers) because this rate is based on the assumption that some resources are supplied by the forest manager (i.e., block security workers, etc.). The estimated aerial spray contract rate used for this study was $65.00 ha^{-1}, because this value closely reflects the 2003 rate for contractor provided services.

Overall, the two herbicide treatments were found to be three-fold more cost-effective than the two cutting treatments (least dollars invested to gross total volume produced [$ m^{-3}]) (Fig. 1). ANOVA and orthogonal contrasts performed on the cost per volume data (Table 5) indicate no difference exists between the two herbicide treatments (p = 0.998) nor between the two cutting treatments (p = 0.559). A highly significant difference was detected when the herbicide and cutting treatments were compared (p = 0.001).

Discussion

Cost-effectiveness analysis and other analyses that attempt to link biological responses to silviculture treatment costs (and other economic indicators) are important but appear infrequently in the literature. Forest companies, however, usually keep detailed records of treatment costs and resultant crop tree response over time. This study provides information that can be used to augment company records and influence future silviculture decision-making.

Admittedly, benefit cost analysis (BCA) is superior (Pearse 1990) to a CEA in that the former compares financial returns (value) on release treatment investment, while the latter only compares release treatment cost-effectiveness (dollars invested to spruce volume produced) among treatments with no regard for potential product value. After only ten years of growth post-vegetation release, these stands have virtually no current market value. The stands in this study will likely need to grow for at least another twenty years to reach harvestable volumes, at which time market value for the product may have changed substantially. A BCA was therefore not pursued in this paper because many ecological and economic uncertainties exist until the time when stands will likely be harvested. Consider Pearse's (1990) comment:

> "Future costs and revenues associated with forestry projects are often highly uncertain, especially when they are based on predictions spanning several decades. Knowledge about how stands grow and respond to treatments is always limited. Expectations about future harvests can be upset by unpredictable events such as fire and other natural catastrophes. And the technology, product prices, and production costs assumed in making predictions are likely to change in unforeseeable ways."

Aerial herbicide applications were most cost-effective mainly due to a very low application cost per hectare and a relatively high planted conifer volume growth response. The aerial application of Release herbicide produced a high average GTV per hectare (16.58 m^3 ha^{-1}, Table 4) because it allowed for some post-treatment competition, which encouraged white spruce to shift biomass allocation from branch to stem (Jobidon 2000, Pitt and Bell 2004). This change in allocation may have the secondary benefit of potentially increasing future wood quality. Future sampling will need to assess for wood quality and other indicators that could be indicative of potential products and value. Furthermore, Legare *et al.* (2004) suggests that 5% to 15% aspen (*Populus spp.*) basal area in black spruce (*Picea mariana* [Mill.] BSP) stands could increase economic value per hectare. In and of itself, hardwood fibre has the potential to increase the economic worth of so-called "lower grade" forests as new products and processes (i.e., biofuels, engineered wood products) have been developed, and will likely develop in the future.

Assessment of surviving trembling aspen (*Populus tremuloides* Michx.) in the Release treatment during field data collection showed that some individuals were not killed (Greifenhagen *et al.* 2005). These individuals possess telltale "crooks" in their stems indicating Release induced rapid cell growth but not death. Reduced efficacy is likely due to application timing. Release herbicide is most effective in controlling broadleaf competitors (with minimal effect to conifers and monocots) when applied during active competitor growth, i.e., early to mid-summer (Dow AgroSciences 2002). The Release treatment may have also been less effective biologically, due to relatively low herbicide deposit rates (Thompson *et al.* 1997).

Unlike Release, Vision applied in late summer was very effective in controlling competing vegetation while protecting conifers. Since leaf litter from competing vegetation can enrich the soil, it is possible that good spruce growth rates in Release can be due to the beneficial effects of some competing vegetation's litter, such as encouraging nutrient cycling, enriching the soil, and reducing soil acidification (Cote and

Table 4. White spruce volume and density, release treatment productivity, cost to treatment area (1993 and 2003), and treatment cost per tenth-year volume (cost-effectiveness, 2003) by treatment-block (experimental unit) and average.

	Treatment				
	Brushsaw	Silvana	Release	Vision	Control
Block I*					
Gross Total Volume (m^3 ha^{-1})	9.24	10.79	11.29	8.06	5.85
Density (sph)	2500	2583	2500	2583	2417
Productive machine hours (h ha^{-1})	10.20	3.73	na	na	na
1999 cost per area ($ ha^{-1})	312.32	276.77	152.51	151.93	na
2003 cost per area ($ ha^{-1})	570.49	551.85	183.75	126.10	na
2003 cost per volume ($ m^{-3})	61.77	51.13	16.27	15.65	na
Block II					
Gross Total Volume (m^3 ha^{-1})	12.80	13.46	23.83	11.56	6.77
Density (sph)	2667	2750	2750	2750	2667
Productive machine hours (h ha^{-1})	6.53	3.85	na	0.01	na
1999 cost per area ($ ha^{-1})	201.48	285.67	152.51	151.93	na
2003 cost per area ($ ha^{-1})	365.22	569.61	183.75	126.10	na
2003 cost per volume ($ m^{-3})	28.53	42.31	7.71	10.91	na
Block III					
Gross Total Volume (m^3 ha^{-1})	6.71	12.21	14.62	12.69	9.30
Density (sph)	2750	2833	2833	2917	2833
Productive machine hours (h ha^{-1})	2.98	2.85	0.01	0.01	na
1999 cost per area ($ ha^{-1})	91.25	211.47	152.51	151.93	na
2003 cost per area ($ ha^{-1})	166.67	421.66	183.75	126.10	na
2003 cost per volume ($ m^{-3})	24.84	34.53	12.57	9.93	na
Average					
Gross Total Volume (m^3 ha^{-1})	9.58	12.16	16.58	10.77	7.31
Density (sph)	2639	2722	2694	2750	2639
Productive machine hours (h ha^{-1})	6.57	3.48	0.01	0.01	na
1993 cost per area ($ ha^{-1})	201.68	257.97	152.51	151.93	na
2003 cost per area ($ ha^{-1})	367.46	514.37	183.75	126.10	na
2003 cost per volume ($ m^{-3})	38.38	42.65	12.18	12.16	na
Standard Error	4.89	4.89	4.89	4.89	na

[a]Since block one was destroyed (c.f. Bell *et al.* 1997a), blocks were renumbered in this study as follows: Block I = Block 2; Block II = Block 3; and Block III = Block 4.

Table 5. Analysis of variance results with orthogonal contrasts for cost per volume ($ m^{-3}) for vegetation release treatments in a white spruce plantation.

Source	df	SS	MS	F-ratio	F-crit (0.05)	F-crit (0.01)	Prob
Constant	1	8329.77	8329.77				
Block	2	590.279	295.139				
Treatment	3	2437.79	812.595	11.322	4.76	9.78	0.007
Vison vs. Release	1	0.000519828	0.000519828	7.24E-06	5.99	13.7	0.998
Brushsaw vs. Silvana	1	27.36058661	27.36058661	0.381	5.99	13.7	0.559
Herbicide[a] vs. Cutting[b]	1	2410.423963	2410.423963	33.585	5.99	13.7	0.001
Error (Block*Treatment)	6	430.621	71.7702				
Total	11	3458.69					

[a]Vision and Release
[b]Brushsaw and Silvana Selective

Fyles 1994, Krause 1998, Perie and Munson 2000). The benefits of leaf litter were not realized in the Vision treatment where competition was low relative to Release. These differences in stem volume influenced the CEA. Treatments that were moderately efficacious (*c.f.* Pitt and Bell 2005) in controlling competition (Release and Silvana Selective) produced more spruce stem volume (Table 4).

The MSRP for Vision in 2003 was \$14.50 L^{-1}, however, it generally sells for less (Roy Maki, personal communication). Since Release is sold through agents with set pricing, the product was sold for \$30.00 L^{-1} across Canada in 2003, with no variation in purchase price (Darren Dillenbeck, *per. comm.*). Since Vision can be purchased for less than the MSRP (the price used in this study), Vision treatments can be more cost-effective than reported here. Aerial spray costs (Vision and Release) in typical management operations will likely be lower than the values reported in this study (Table 3,4) because operational sites differ from the small, irregularly shaped treatment blocks and rolling terrain at the Fallingsnow Ecosystem Project. Furthermore, aerial spray cost-effectiveness in the study may have been skewed because any aerial application that does not have GPS-assisted guidance (either on-ground or in the air) will compromise application uniformity. As a result, some "green striping" or missed slivers occurred (Bell *et al.* 1997b). Release and Vision treatments had similar cost-effectiveness values (p = 0.998) which likely had more to do with differences in herbicide purchase prices in 2003 (Table 4) than with growth responses.

Brushsaw and Silvana Selective cutting treatments had similar cost per volume values (p = 0.559). This can be partially attributed to similar post-treatment responses. In the cut treatments, sprouting and suckering of trembling aspen and other competitive species was evident. Brushsaw and Silvana Selective treatments can be optimized through proper treatment timing and technique. There seems to be an ideal level of aspen (not too high, nor too low) that encourages white spruce production and overall productivity (Man and Lieffers 1999). Cutting competing vegetation in June or July rather than October may provide maximum stem mortality (while still allowing for low levels of competing vegetation) thus reducing the number of post-treatment sprouts and suckers (Bell *et al.* 1999). The ideal balance between the spruce and aspen can lead to increased crop tree volume growth response. Furthermore, the cost of both cutting treatments increased at similar rates from 1993 to 2003 (brushsaw = 82.5%; Silvana Selective = 99.4%), probably due to commensurate increases in labour and equipment costs. Brushsaw cutting effectiveness is highly dependent on pre-treatment stem density; mechanical and herbicide treatment are not affected by this factor. Our CEA is based on average stem density and does not explicitly take this cost factor into account.

Cutting is often seen as a good alternative to herbicides but limitations such as availability of labour force and equipment can exist. Similar cost-effectiveness of the two cutting treatments suggest that the Silvana Selective or other mechanical plantation cleaning machines (Ryans and Lirette 2003) may be more suited to geographic areas where worker shortages exist. Forestry field worker shortages have been attributed to poor work conditions including high physical stress, risk of accidents, and seasonal nature of work (Dubeau *et al.* 2003).

Availability of mechanical plantation cleaning machines is another issue. The Silvana Selective is not presently available to Canadian markets and few alternative mechanical plantation cleaning machines exist. The mechanical plantation cleaning machine estimate (Table 2) is based on what one might expect to pay to purchase, operate and maintain a machine similar to the Silvana Selective. If market pressures encourage Canadian mechanical plantation cleaning machine distributors to supply this equipment, it could become available in the future.

Opportunity costs should also be considered when deciding upon a vegetation release treatment. Opportunity costs measure the real costs to society and can be defined as, "the value of output sacrificed by not directing [resources] to their best alternative use (*c.f.* Pearse 1990)." Within the context of this study, the cost to society as a whole would be the difference in value of forest resource output forgone between the best vegetation release alternative and the actual alternative employed; it measures the real cost to society of using a resource in a particular way (Pearse 1990). In order to capture the opportunity costs between alternative treatments in this study, all forest values (such as hardwoods, non-timber forest products, etc.) would need to be captured for each alternative. Then alternative treatments would be compared to the best alternative to determine forgone value.

Treatments that provide the greatest cost-effectiveness may not necessarily be the most socially acceptable. When managing public forests, the broader social context must also be considered. Based on surveys, the general public in Ontario deems herbicide use on publicly owned forests unacceptable (Buse *et al.* 1995, Wagner *et al.* 1998). Furthermore, in the province of Quebec, most pesticides have been banned (Reuters News Service 2002).

Although the general trend in Ontario is to plant densities of around 2500 sph, results from this project suggest that white spruce plantations might benefit from higher initial stocking levels. These densities could be achieved through both conifer and hardwood crop tree species. Higher initial crop tree densities are particularly important if broadcast vegetation management treatments are to be applied. Day and Bell (1988) recommended white spruce crop plans based on established densities of 1900 sph. This estimate, made at a time when empirical data were limited, influenced initial stocking of the Fallingsnow Ecosystem Project.

Final Remarks

The CEA of conifer release treatments relies on good initial time study data and good treatment cost estimates through time. This study is one of only a few North American CEAs of northern conifer plantation release treatments reported in the literature; therefore, results must be confirmed by other studies. Results from this study can be used to supplement existing industry documentation, but forest managers must continue to maintain detailed costing records to determine cost-effectiveness for their own situation. Future research needs include growth and vegetation release cost analysis for other conifer species. Furthermore, cost analysis data gaps exist because broadleaf trees were previously considered undesirable and possessed limited value (i.e., trembling aspen). Future studies and future sampling at Fallingsnow Ecosystem Project should develop field techniques that capture potential stand values (i.e., sampling for quality, not just volume) in order to facilitate a BCA. Field sampling could include destructive sampling to test for wood properties which can be linked to values.

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