Effects of precommercial thinning on the forest value chain in northwestern New Brunswick:

Part 6 – Estimating the economic benefits

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ABSTRACT

The Green River precommercial thinning (PCT) trials were established between 1959 and 1961 in naturally regenerating balsam fir (*Abies balsamea* [L.] Mill.)-dominated stands an average of eight years after overstory removal. Following clearcut harvest of three of the study's six replicates in the fall of 2008, the rotation-length effects of PCT and vegetation management (VM; deciduous tree and brush suppression) on the forest value chain were integrated into a spreadsheet-based model that estimates the net present value (NPV) of these silvicultural treatments. Assuming costs and prices near recent values, both PCT and VM were observed to support positive landowner NPVs through discount rates in excess of 6%. At a discount rate of 4% and an age where sawlog production was maximized, PCT and VM offered similar NPV (>\$550/ha). Landowners that can attract buyers willing to pay a premium for wood from thinned stands (equal to the sum of reduced operational overhead charges, harvesting and sawmilling costs and increased pulping costs) could see the value of their stands double. Sensitivity analyses revealed that these results are dependent on site productivity, silvicultural costs and a strong premium on sawlog stumpage rates. Depending on economic circumstances, PCT and VM could be attractive investments on high quality sites that are situated in close proximity to wood processing infrastructure.

Keywords: silviculture, precommercial thinning, vegetation management, balsam fir (*Abies balsamea*), net present value (NPV)

RÉSUMÉ

Les essais d'éclaircie précommerciale de Green River ont été réalisés entre 1959 et 1961 dans des peuplements naturellement régénérés de sapin baumier (*Abies balsamea* [L.] Mill.) et dominés par cette espèce, huit années en moyenne après le retrait de l'étage dominant. Au cours de l'automne 2008, trois des six répétitions ont été coupées à blanc, les effets de l'éclaircie précommerciale tout au long de la révolution et le contrôle de la végétation (CV; suppression des feuillus et des broussailles) sur la chaîne de valeur forestière ont été intégrés dans un modèle de calcul prédéfini qui estime la valeur actuelle nette (VAN) de ces traitements sylvicoles. En estimant que les coûts et les prix offerts sont proches de leur valeur actuelle, tant l'éclaircie précommerciale que le CV ont engendré une VAN positive pour les propriétaires sous forme de taux d'escompte de plus de 6%. Dans le cas d'un taux d'escompte de 4 % et d'un âge où la production de billes de sciage est maximisée, l'éclaircie précommerciale et le CV ont présenté une VAN similaire (> 550 \$/ha). Les propriétaires qui peuvent attirer des acheteurs prêts à payer une prime pour du bois provenant de peuplements éclaircis (égale à la somme des réductions des frais de gestion des opérations, des coûts d'exploitation et de sciage et des frais accrus de mise en pâte) pourraient voir doubler la valeur de leurs peuplements. Les analyses de sensibilité indiquent que ces résultats dépendent de la productivité du site, des coûts des travaux sylvicoles et d'une prime élevée sur les droits de coupe de bois de sciage. Selon les conditions économiques, l'éclaircie précommerciale et le CV pourraient être des investissements intéressants sur les sites de qualité supérieure qui sont situés à proximité des infrastructures de transformation du bois.

Mots clés : sylviculture, éclaircie précommerciale, contrôle de la végétation, sapin baumier (*Abies balsamea*), valeur actuelle nette (VAN)

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Introduction

Precommercial thinning (PCT) is a silvicultural tool that is used to reduce the density of young stands that have developed from prolific natural regeneration or artificial seeding. While PCT may be used in a variety of forest types (Murray and Cameron 1987), its primary application in eastern Canada has been in conifer-dominated forests, where more than 2.7 million hectares have been thinned during the past 20 years and efforts continue at a rate exceeding 100 000 ha per year (CCFM 2012).

The intent of PCT is to redistribute available growing resources, including sunlight, soil moisture and nutrients, to selected stems during juvenile stand development, when felled trees are below merchantable size limits (Smith 1986). A variety of well-understood and accepted stand-level management objectives can be achieved with PCT, including control over species composition, increasing the proportion of trees with desirable characteristics, preparation of stand structure for subsequent commercial thinning, and increased tree growth and health (Piene 1982, Smith 1986, Karsh *et al.* 1994, Smith *et al.* 1997, Anonymous 2008).

Less understood and accepted by decision-makers are the product yield implications and associated financial returns of PCT; factors that affect forest-level management objectives and decisions over the long term. In the absence of empirical data, managers have been forced to use model projections to conduct optimization and financial analyses of silvicultural inputs including PCT (e.g., Daggett 2003, Olson *et al.* 2012, Bataineh *et al.* 2013) and vegetation management (VM) (e.g., Homagrain *et al.* 2011). The outputs of these analyses are necessarily highly dependent on a variety of assumptions, and the absence of rotation-length validation data has contributed to protracted uncertainty and skepticism about the real economic benefits of such silvicultural investments. As we enter an era where slow-grown, natural-origin, conifer-dominated forests account for an increasingly smaller portion of our wood supply, continued lack of clarity about the financial benefits of silviculture may impede sound decision-making around investment in forest renewal and, ultimately, may threaten sustainability of both the forest and the forest industry (Reed 1986).

The Green River PCT trials, established by Dr. Gordon Baskerville in northwestern New Brunswick between 1959 and 1961, offer a statistically rigorous, rotation-length view of the effects of thinning on the growth and yield of balsam fir (*Abies balsamea* [L.] Mill.)-dominated stands (Baskerville 1959, 1961; Akerley 1961; Pitt and Lanteigne 2008; Pitt *et al.* 2013a). We used harvest data collected some 50 years after thinning to document the component effects of PCT on the forest value chain, including roundwood product yield (Pitt *et al.* 2013b), harvesting and wood handling efficiencies (Plamondon and Pitt 2013), disease losses (Warren *et al.* 2013), lumber product yield (Duchesne *et al.* 2013) and pulp and paper production (Bicho *et al.* 2013). In the sixth paper of this series, we introduce a spreadsheet-based model (available

from the authors upon request) that quantitatively integrates the findings outlined in the previous papers and permits comparisons of the treatment alternatives, given user-defined inputs related to costs and prices. Herein we test the sensitivity of the influence of these inputs on the net present value (NPV) of standing timber, illustrating the use of the rotation-length Green River data in value chain optimization. It is our hope that these data will contribute to a better foundation of understanding about the financial returns available from silvicultural treatments such as PCT in northeastern Canada and the United States, thus promoting sound decision-making around sustainability and investments in forest renewal.

Methods

Stand response data

A detailed description of the Green River experiment can be found in Pitt *et al.* (2013a). Between 1959 and 1961, three nominal PCT spacings (4 ft [1.2 m], 6 ft [1.8 m] and 8 ft [2.4 m]) were replicated six times within six naturally regenerated balsam fir-dominated stands, an average of eight years following harvest. Treatment plots were at least 1 ha in size and each contained two 0.081-ha permanent sample plots (PSPs). Each of the six replicate blocks also contained a similarly quantified unthinned control plot. Stands had originated from advanced regeneration that averaged eight years of age at the time of harvest; thus, trees were approximately 16 years old, on average, at the time of thinning (see Table 1 of Pitt *et al.* 2013b). Site index (dominant tree height at breast-height age 50) ranged between 19 and 21 m for the replicates encompassed by this study (Pitt and Lanteigne 2008).

In September 2008, following the ninth sequential measurement of the study's PSPs, three of the six replicate blocks were clearcut harvested using a cut-to-length system. Harvester instrumentation permitted the spatial quantification of product volume (studwood, random-length sawlogs, pulpwood and unmerchantable discard for excessive rot or other defect) for each of more than 13 000 harvested stems (Plamondon and Pitt 2013). This large data set was used to construct functions predicting product volumes from tree diameter at breast height

Table 1. Model input values for baseline economic comparison of silvicultural scenarios

Cost factors	Baseline	Units	Sensitivity range tested
Vegetation management (VM, or "brush control")	120	\$/ha	±50%
Age of vegetation management	4	years	not varied
Precommercial Thinning (PCT)	650	\$/ha	±50%
Age of PCT	8 ^a	years	not varied
Discount rate (<i>i</i>), net of inflation	4.0	%	0% through 11%
Operational overheads	5	\$/m ³	not varied
Haul distance	100	km	not varied
Change in site productivity (0 = observed Green River GMV)	0	%	-30% to +10%
Revenue factors			
Stumpage (standing timber) – Sawlog	20.59 ^b	\$/m ³	±50%
– Softwood pulpwood	11.83 ^b	\$/m ³	±50%

^a Our spreadsheet model includes simple modifiers that increase stem decay losses with stand age at the time of thinning and stand age at the time of harvest. Specific details can be found in the model documentation.

^b New Brunswick rate, averaged between April 1, 2000 to March 31, 2010 (Office of the Attorney General 2009).

(DBH) (Pitt *et al.* 2013b), which were subsequently used to estimate roundwood products across the study's 48 PSP measurement sets through time, under the assumption that these functions, based on tree size, are generally independent of tree age.

During harvest, detailed sampling was conducted to assess the incidence and severity of root and butt rot. Rot volumes were quantified and equations generated to estimate these values as a function of PCT treatment and tree DBH (Warren *et al.* 2013). These functions were used to quantify per-hectare losses, based on the treatment-specific diameter distributions present.

To quantify product volume and quality, 150 trees were selected from the three harvest blocks, representing the range of stem diameters present in each treatment plot (Duchesne *et al.* 2013). These trees produced 479 sawlogs that were converted to dimensional lumber in a manner that allowed the tracking of each tree and the treatment plot from which it originated. Lumber production values were modeled as a function of DBH and expressed on a per-hectare basis using the treatment-specific diameter distributions present. The resulting chips and stem tops were subjected to pulping trials for the production of Northern Bleached Softwood Kraft (NBSK)¹ pulp, based on the underlying experimental design (4 treatments $\times$ 3 blocks; Bicho *et al.* 2013). Pulp values were expanded to a per-hectare basis from treatment-specific estimates of slab-wood chip and top-log volumes.

The above relationships were then integrated into a spreadsheet-based model that describes stand growth and the availability of studwood, random-length sawlogs, pulpwood, and the resultant lumber and NBSK products as a function of stand age. Of the three PCT spacings tested at Green River, we limited this effort to the nominal spacing of 6 ft (1600 merchantable stems per ha by stand age 30), consistent with recommendations of Pitt *et al.* (2013b), Duchesne *et al.* (2013), Bicho *et al.* (2013) and Warren *et al.* (2013) that this spacing was near optimal for maximizing individual stem size without compromising per-hectare production or product quality. Herein, we subsequently refer to this treatment as "PCT".

Additionally, it must be recognized that the relatively fully stocked, pure conifer state of the "unthinned" stands in the Green River study would seldom be achieved on such productive sites without some VM to reduce the competitive influence of deciduous tree and shrub species (Pitt *et al.* 2013b). Indeed, early establishment reports for this study refer to the "brush control" that was undertaken in the unthinned plots for this purpose (Baskerville 1959, 1961; Akerley 1961). Had some plots at Green River been left fully untended (i.e., without any VM or PCT), one might expect these stands to have developed with substantially reduced conifer stocking, very likely in exchange for intolerant hardwoods (Pitt *et al.* 2004). At a nearby study site, for example, where neither VM nor PCT were carried out, age-40 conifer abundance was reduced to less than half in favor of intolerant hardwoods (Olson *et al.* 2012). In keeping with the recognition that the unthinned stands at Green River were subjected to vegetation management (as opposed to being "untended"), we subsequently refer to this treatment herein as "VM".

¹Thermomechanical pulp numbers were generated and included in the model, but not used in these analyses since greater value is currently generated with NBSK than newsprint.

Cost factors considered

In our spreadsheet model, only those silvicultural costs associated with stand establishment—PCT or VM—are considered directly in the valuation of standing timber (Fig. 1). A natural regeneration scenario is assumed, typical of the succession that takes place in balsam fir-dominated stands of the Northeast region (Pitt *et al.* 2013a). For a baseline scenario, we initialized silvicultural rates at \$120/ha for VM, incurred at stand age 4, and \$650/ha for PCT, incurred at stand age 8 (Table 1). We also assumed that undesirable species would be removed during PCT, negating the additional cost of VM in these stands (note that if VM were to be applied to a stand destined for thinning, doing so would likely reduce PCT costs by an equivalent amount, retaining total input costs at around \$650/ha for the thinned stands).

Costs such as operational overheads, harvesting (felling and forwarding), lumber conversion and pulping are considered insofar as their potential to influence a buyer's willingness to pay (WTP) a premium for standing timber originating from PCT. For each of these costs, we calculated the cost difference observed between VM and PCT stands, on a per-cubic-metre basis, and then ascribed the net decrease (or increase) in costs to the PCT volume produced (Fig. 1).

Specifically, overheads (road construction and maintenance related to harvest [excluding permanent road infrastructure], and supervision [but not forest management planning]) are typically levied on the basis of the volume harvested (\$/m³). We initialized these overhead charges at \$5/m³ for VM stands. Because PCT stands produce more merchantable volume per unit area than VM stands (Fig. 2), the associated costs may be spread over larger volumes. For example, if 20% more volume is produced in a PCT stand than a VM stand (Pitt *et al.* 2013b), then the construction costs of harvest-block roads will be 20% lower per m³ of wood harvested than they would in a VM stand (alternatively, to harvest a fixed volume, one would have to build 20% less road in a PCT stand). To account for this cost differential, we used:

$$[1] \quad \Delta OH_r = OH_{VM} - OH_{VM} \times (GMV_{VM,r} / GMV_{PCT,r}),$$

where ΔOH_r is the estimated overhead cost differential for PCT stands per m³ of gross merchantable volume (GMV) harvested at stand age r years. For example, at a harvest age of 45 years, overhead charges in PCT stands would be \$0.97/m³ lower than in an equivalent unthinned stand.

Similarly, the harvest cost functions generated from detailed timing studies on all three Green River blocks (Plamondon and Pitt 2013) indicated the following:

$$[2] \quad \Delta HC_r = 64.79 \times \exp(-0.0298 \times r) - 51.96 \times \exp(-0.0317 \times r),$$

where ΔHC_r is the estimated harvesting cost differential for PCT stands per m³ of gross merchantable volume harvested at stand age r years. For example, at a harvest age of 45 years, wood in PCT stands was observed to be nearly \$4.50/m³ less expensive to harvest than that in an equivalent unthinned stand.

External 3-D laser scans (Comact Equipment Inc.) of the 150 trees harvested for lumber conversion analysis in the Green River Study (Duchesne *et al.* 2013) were used within

Fig. 1. Schematic diagram of the costs and revenues considered in the calculation of landowner Net Present Value (NPV) over the length of a rotation [*r*].

Fig. 2. Yield curves used as the foundation for economic analyses. The x-axis (Stand age) reflects years post harvest; since trees existed as advanced regeneration prior to harvest, actual tree ages averaged eight years older than *x*. Curves for precommercial thinning (PCT) and vegetation management (VM) scenarios are from model [A3] of Pitt *et al.* 2013b, formerly referred to as “6-ft spacing” and “unthinned”, respectively. Arrows reflect the ages of maximum sawlog production (MAI) and the point at which the two scenarios are compared in the text.

FPOptitek to simulate the sawmilling process and estimate generic lumber conversion costs, which included variable costs related to sawing, drying and planning, but excluded fixed costs). We assumed a typical stud mill equipped

with two sawing lines, having a consumption factor of 3.48 m³/Mfbm (Pierre Bédard, FPInnovations, personal communication, January 16, 2013). Simulations were run for each tree and the estimated lumber conversion costs per m³ of sawlog volume were plotted over tree size (*DBH*). The resulting data were subjected to non-linear regression to estimate the cost functions for logs from brushed-unthinned and 6-ft spaced trees. Although there was no statistical difference between the milling costs (*MC*) of trees coming from the two groups (*p* = 0.20), *MC* per m³ were slightly higher for thinned trees of the same *DBH*, consistent with their slightly increased taper (Pitt and Lanteigne 2008). However, since tree sizes were consistently larger in thinned stands, the cost differential could be expressed as:

$$[3] \Delta MC_r = 211.2 \times qDBH_{VM}^{-0.7314} - 282.4 \times qDBH_{PCT}^{-0.8150},$$

where ΔMC_r is the estimated sawmilling cost differential for PCT stands, per m³ of total sawlog volume harvested at stand age *r* years, and *qDBH* is the quadratic mean *DBH* of the stands at age *r*. For example, at a harvest age of 45 years, saw timber from PCT stands was estimated to be nearly \$1.70/m³ less expensive to mill than that from an equivalent unthinned stand, given differences observed in average tree size (Pitt *et al.* 2013 b).

Finally, pulping of the sawmill residues (slab-wood) and pulpwood (top-logs) emanating from the sawmilling trials generated treatment-specific data that permitted costing of the production of NBSK. The differential in profit margins for the production of NBSK from PCT stands was calculated as -\$6.27/tonne for tops and +\$0.84/tonne for slabs (Bicho *et al.* 2013). Translating the observed m³ per ha production of top-log and slab-wood chips to NBSK product allowed valuation of this differential on a per-hectare basis. For example, by stand age 45, PCT'd stands produced 43.4 m³/ha of top-log wood and 120.4 m³/ha of slab-wood, each producing 5.6 tonnes/ha and 15.0 tonnes/ha of NBSK product, respectively. Given the differential profit margins identified, this suggests that, from a pulp production perspective, PCT stands might be valued as much as \$22.51/ha less than unthinned stands of the same age.

While the distance between standing timber and a processing facility may significantly affect the value of standing timber through a buyer's willingness to pay, we assumed that transportation costs apply to wood from thinned and unthinned stands in an equitable fashion. In the model, transportation costs (*TC*) per m³ are estimated as a linear function of haul distance (*HD*,

km) and *GMV* (m³), irrespective of treatment (“Log Truck Costing Model”, Jan.Michaelsen@fpinnovations.ca):

$$[4] \quad TC = [2.958 + 0.0728 \times HD] \times GMV.$$

Accordingly, our spreadsheet allows the user to estimate wood costs under different haul distances, but for the purposes herein, we have fixed this distance at 100 km.

Benefit values considered

Timber Royalties (a.k.a. Crown Dues) are the “values” that we ascribed to standing timber resulting from the treatments tested at Green River. As a baseline, the averaged rates published for New Brunswick for the period April 1, 2000, to March 31, 2010 (Office of the Attorney General 2009) were used: \$11.83/m³ for pulpwood; \$20.59/m³ for studwood and random-length sawlogs (Table 1). For example, a stand thinned to 6-ft spacing was observed to contain a total of 311 m³/ha, distributed as 268 m³ of sawlogs and 43 m³ of pulpwood per ha at stand age 45 (Pitt *et al.* 2013b), generating a total stumpage value of just over \$6000/ha.

Additionally, we calculated the theoretical premium that a buyer might pay for standing timber that has originated from a PCT treatment (Fig. 1) by adding the cost differentials (VM – PCT; calculated above through [1], [2], and [3]) for overhead charges, harvesting, sawmilling and pulping. Continuing with the above example, the value of a 45-year-old PCT stand might then be \$6000/ha, plus a willingness-to-pay valued at (\$0.97 [311 m³/ha] + \$4.50 [311 m³/ha] + \$1.70 [268 m³/ha] - \$22.51/ha) = \$2134/ha.

Economic analyses

The costs and benefits identified above were then contrasted in discounted form using:

$$[5] \quad NPV = \frac{\sum_{t=0}^r R_t(1+i)^{r-t} - \sum_{t=0}^r C_t(1+i)^{r-t}}{(1+i)^r},$$

where *NPV* is the Net Present Value (\$/ha), *t* is the time (years) when a cost or revenue is incurred (*t* = 0 is the present), *r* is the rotation age (years), *R_t* is revenue incurred at time *t*; *C_t* is cost incurred at time *t*, and *i* is the discount rate, net of inflation (Gregory 1972). In the analyses reported herein, we used costs and prices in relatively recent dollar values (as described above) to calculate net worth, with *i* being initialized at 4% (intended to be a real interest rate, net of inflation) (Table 1). The internal rate of return (IRR) was calculated for VM, PCT, and PCT+WTP scenarios, as the value of *i* for which discounted costs equal discounted revenues.

As a baseline, the NPV analysis was conducted with the initial inputs outlined above and detailed in Table 1. The sensitivity of this outcome was then observed in response to our varying certain key parameters. Specifically, discount rate was varied from 0% through 11%. The effects of site productivity were observed by suppressing the Green River yield curves (Fig. 2) by as much as 30%, and inflating them by as much as 10%. The costs of VM and PCT were simultaneously varied through ±50% of the baseline values. Timber royalties for sawlogs and pulpwood were each varied through ±50% of the baseline values. Parameter interactions were not studied.

Results and Discussion

In an economic analysis of long-term investments, such as those in silviculture, selection of an appropriate age at which to compare alternatives can be difficult. A key conclusion of the work of Duchesne *et al.* (2013) and Bicho *et al.* (2013) was that there were no substantive differences between PCT and VM in terms of end-product quality. Any economic comparisons made using the data from this experiment should take place at stand ages that reasonably support this conclusion, or they may not be valid. In addition, foresters often have the forest-level mandate to “maximize production” to meet sustainability objectives. As a means of addressing both of these criteria, we selected the age of maximum sawlog volume mean annual increment (MAI), which occurred at stand ages 45 (5.9 m³/ha/yr) and 50 (4.3 m³/ha/yr) for the PCT and VM treatments, respectively (Pitt *et al.* 2013b; illustrated on the gross merchantable volume curves of Fig. 2). Unless otherwise specified, all subsequent comparisons of silvicultural scenarios herein have been made at these ages.

Given the initial inputs summarized in Table 1, the Green River data suggest that PCT treatment would generate a landowner NPV of \$560/ha at the point of maximum sawlog MAI (Fig. 3), with an IRR of 6.2%. Contrasted with a NPV of \$600/ha (IRR = 8.5%) for VM, the results suggest that both treatments would lead to stands of approximately similar value in terms of timber royalties. Both PCT and VM results closely match the financial analyses conducted on growth projections for a similar study in fir–spruce stands of central Maine (Daggett 2003, Bataineh *et al.* 2013). For VM, our IRR is higher than the 4.3% estimated on growth projections by Homagain *et al.* (2011) for a variety of boreal species in Ontario, possibly due to the wide range of site conditions that they considered.

Fig. 3. Net present value (NPV) for silvicultural scenarios involving precommercial thinning (PCT) and vegetation management (VM), as a function of stand age, given the baseline context outlined in Table 1. Value propositions based on timber royalties are shown as solid lines; the dashed line reflects the theoretical value of standing timber based on buyer's willingness to pay (WTP) a premium for wood from thinned stands. Arrows reflect the ages of maximum sawlog production (MAI) and the point at which the scenarios are compared in the text.

Fig. 4. Net present value (NPV) for silvicultural scenarios involving precommercial thinning (PCT) and vegetation management (VM), as a function of (a) discount rate (i) and (b) changes in site productivity, given all other conditions held constant at the baseline outlined in Table 1. Value propositions based on timber royalties are shown as solid lines; the dashed line reflects the theoretical value of standing timber based on buyer's willingness to pay (WTP) a premium for wood from thinned stands.

If buyers are willing to pay a premium for the increased efficiencies of harvesting and milling wood from PCT stands, potentially greater stand values might be realized (\$930/ha; IRR=7.1%) through PCT (despite these stands being slightly less attractive for pulping) (Fig. 3). Under such market conditions, landowners may expect to realize as much as 53% more value for stands that have been subjected to PCT, as opposed to VM alone. It is important to note, however, that the slopes of these NPV curves suggest that the greater the silvicultural investment, the more narrow the window of opportunity for harvest prior to reaching the economic "best-before" date. In other words, stands with high silviculture investment have a more narrow "optimum rotation age" than those with low silvicultural investment.

Discount rate

Time preference for money (discount rate) has a profound effect on the NPV of silvicultural options. As discount rates

are increased, the age of financial maturity (maximum NPV) will fall, regardless of the silvicultural scenario being considered. For example, if one had very low time preference for money ($i \sim 1\%$), maximum landowner NPV would occur at stand ages near 50 and 55 for the PCT and VM treatments, respectively. At a discount rate of about 2%, the financial maturity of these silviculture scenarios would approximately coincide with the ages at which we observed maximum sawlog production to occur (45 and 50, as mentioned above). As discount rates in excess of 2% are considered, financial maturity occurs at increasingly younger ages. Again, we caution that the wood quality statistics reported for this study (Bicho *et al.* 2013, Duchesne *et al.* 2013) would very likely not apply to stand ages much below 45 years and the financial optima suggested by these analyses may therefore be misleading.

As has been shown with other financial analyses of silvicultural investment (e.g., Rollins *et al.* 1995, Hawkins *et al.* 2006), landowner NPV is highly influenced by the discount rate (i) used in the calculation (Fig. 4a). Clearly, the financial advantage of improved merchantable volumes and sawlog volumes stemming from PCT decreases dramatically as i is increased. If compensated strictly by timber royalties, landowners might be encouraged to undertake VM through discount rates as high as 8.5% (the IRR for this treatment), all other elements of the baseline scenario being held constant (Table 1). Beyond discount rates of about 3.5%, PCT appears to not offer any economic advantage over VM, unless buyers are willing to pay a premium for thinned stands, in which case PCT offers advantages over VM through rates as high as 6%.

The appropriate discount rate for comparing silvicultural scenarios has long been a topic of debate. Rates of 3% to 4.5% may approximate what is termed the social discount rate, or a government's time preference for achieving public policy objectives (Davis 1966, Klemperer *et al.* 1994, Hawkins *et al.* 2006); we chose our baseline scenario to fall within this range. It has been argued that higher rates approximate historical opportunity costs for capital in the private sector. Alternatively, there are situations where forest managers of very large forests may treat regeneration costs as current costs, similar to logging, and not subject them to interest accumulation over the rotation (Shepard 1925, Marty 1975, Reed and Baskerville 2001). In addition, decision-making on large forests is often influenced by non-timber values that are difficult to quantify in economic terms (New Brunswick Crown Lands Task Force 2011). Clearly, landowners/managers will have their own particular perspectives with respect to time preference and there is no single discount rate that correctly addresses all needs.

Site Productivity

The Green River experimental sites are considered to be "very good" sites for balsam fir (site indices between 19 and 21; Pitt and Lanteigne 2008). There is little question that the NPVs

Fig. 5. Net present value (NPV) for silvicultural scenarios involving precommercial thinning (PCT) and vegetation management (VM), as a function of changes in (a) silviculture costs, (b) sawlog stumpage value and (c) pulpwood stumpage value, given all other conditions held constant at the baseline outlined in Table 1. Value propositions based on timber royalties are shown as solid lines; the dashed line reflects the theoretical value of standing timber based on buyer's willingness to pay (WTP) a premium for wood from thinned stands.

generated by the baseline scenario (Table 1), are sensitive to the yield assumptions derived from the Green River data (Fig. 2), as indicated by the residual value chain NPVs plotted through changes in site productivity (Fig. 4b).

If the yield curves generated from the Green River data (PCT and VM; Fig. 2) are suppressed by about 30%, they very closely

match those used for natural spruce-fir stands (thinned and unthinned) by the province of New Brunswick in the current forest management plan for the Green River area ($r^2 > 0.98$) (data provided by Adam Dick, New Brunswick Growth and Yield Unit, December 9, 2011). These provincial curves were derived from a large number of sample plots reflecting a wide range of sites and are considered to represent an "average" site condition for the region. The ages of maximum sawlog production occur for these curves at 45 (4.3 m³/ha/yr) and 50 (2.7 m³/ha/yr) for the PCT and VM scenarios, respectively. At these ages, PCT generates \$260/ha of landowner NPV based on timber royalties; about 21% less than may be realized through VM alone (\$330/ha) (Fig. 4b). The IRR of the PCT treatment is 5.3%, compared to 7.3% for VM. However, if the landowner can attract a premium for managed-stand stumpage, NPVs could increase to \$551/ha (6.2%) following PCT. Thus, even with a 30% reduction in the yields observed in the Green River experiment, there may be financial advantages to PCT, given all other inputs outlined in Table 1.

However, the results illustrated in Fig. 4b clearly suggest that relatively small changes in site productivity may result in large changes in NPV, particularly as one moves away from the "good sites" observed at Green River. For example, the data suggest that a 5% reduction in site productivity will result in a 10% reduction in landowner NPV, regardless of the silvicultural scenario considered. Since silviculture dollars are invariably limited, these results underscore the fact that value is ultimately maximized by investing on the best sites available.

Silviculture costs

As is often touted, the costs of silviculture can significantly influence landowner NPV (Fig. 5a). For example, as PCT costs range from \$325/ha to \$975/ha (\$650/ha $\pm 50\%$), NPV falls from \$794/ha to \$319/ha ($\pm 43\%$), if all other inputs are held at baseline levels (Table 1). Similar percentage changes in VM costs do not influence NPVs as dramatically (\$120/ha $\pm 50\%$ translate to NPVs ranging from \$656/ha to \$553/ha, or $\pm 8\%$). When the costs of PCT exceed about \$585/ha ($i = 4\%$), landowners would be unlikely to thin unless they are receiving a premium for their thinned stands at the time of sale. Under this willingness-to-pay scenario, PCT appears to offer favourable returns through silviculture cost increases in excess of 50% of the baseline values ($> \$975/ha$ for PCT and $> \$180/ha$ for VM).

Timber royalty prices

In many jurisdictions, posted royalty rates for sawlogs and pulpwood dictate the direct revenue received by a landowner in exchange for the right to harvest wood. Because PCT and VM produce different proportions of these two roundwood products, the landowner value propositions illustrated in Figures 3 to 5 are heavily influenced by the preferential values ascribed

to sawlogs (Table 1). For example, as sawlog rates range from \$10.30/m³ to \$30.89/m³ (\$20.59/m³ $\pm$ 50%), landowner NPV following PCT increases from \$85/ha to more than \$1000/ha ($\pm$ 85%), if all other inputs are held at baseline levels (Fig. 5b). Such changes do not affect NPVs following VM quite as severely, due to the smaller proportion of sawlogs generated (NPV = \$291/ha to \$918/ha, or $\pm$ 51%). As sawlog rates fall below about \$22/m³, landowners would be unlikely to thin unless they are receiving a premium for their thinned stands at the time of sale (i = 4%).

One can argue that negotiated stumpage values should reflect different sizes of logs (e.g., random-length vs. studwood). Thinned stands contained nearly twice the volume of random-length sawlogs observed in VM stands (p = 0.01) and, as such, a landowner might realize an additional 5% to 10% increase in NPV from these stands, depending on the premium offered.

Not surprisingly, the effects of changes in pulpwood royalties have a much less dramatic effect on landowner NPV than changes in sawlog royalties (Fig. 5c). This is due to the relatively small proportion of pulpwood volume present in these stands (Pitt *et al.* 2013b).

Of course, the overall value of timber royalties has a direct influence on landowner NPV and can significantly influence the attractiveness of any silvicultural investment. If, for example, we apply the 10-year average Crown dues for the province of Ontario² to these analyses (all other inputs held at the baselines in Table 1), a landowner would likely just break even thinning unless a willingness to pay exists, in which case NPV = \$384/ha (58% less than the same landowner would receive in New Brunswick). There is a plethora of factors considered in the establishment of Crown stumpage rates across the country and we do not wish to delve into the argument of whether or not rates are sufficient to encourage silvicultural investment. However, when circumstances lead to stumpage prices that are less than market value, treatments such as PCT and VM must be valued by some means other than a NPV calculation.

Summary and Implications for Management

In northeastern Canada there are precious few rotation-length examples of the growing capacity of high-quality forest sites under managed conditions (full stocking to desired species with density regulation). The Green River precommercial thinning trial, established by Dr. Gordon Baskerville in northwestern New Brunswick in 1959, offers a rare, statistically rigorous view of the effects of precommercial thinning and brush control on the growth, yield and value of balsam fir dominated stands through an entire rotation. Economic analyses of these rotation-length data suggest that silvicultural investments such as precommercial thinning and vegetation management on “prime sites” (highly productive sites situated in close proximity to wood processing infrastructure) can make financial sense, given reasonable assumptions around future costs and benefits, despite the long-term nature of these investments.

We recognize that there are many different types of landowners and forest managers, each with their own unique objectives and constraints. To some, our stand-level economic analyses will seem overly simplistic in the sense that there are many worthwhile benefits provided by PCT and vegetation

management that have not been accounted for in these analyses. For example, we have not considered the potentially significant downstream economic significance of constant wood flow, enabled by moving stands ahead in a harvest queue (Reed and Baskerville 2001). We have not considered the intermediate revenues that could be generated through commercial thinning, an activity that will likely take place mid-rotation in many PCT stands. Similarly, we have not quantified the many potential non-timber benefits valued by Canadians, such as increased size and number of protected areas, recreational opportunities and wildlife habitat (e.g., Homayack *et al.* 2004), which may accrue as a result of the increased yield and stand structure changes incurred by thinning and vegetation management. Carbon sequestration is a non-timber issue of growing concern; a recent analysis of greenhouse gas emissions from a New Brunswick forest products company revealed the importance of increasing the forest products pool in sequestering more atmospheric carbon, facilitated through more intensive silviculture (Cameron *et al.* 2013). Clearly, when considering treatments such as PCT and VM, forest managers must often weigh a variety of costs and benefits that are difficult to incorporate into simple calculations of NPV.

Moreover, decisions that affect the management of very large forests in Canada must potentially be made with a view that extends beyond value creation by the “landowner”. The lumber (Duchesne *et al.* 2013) and pulp (Bicho *et al.* 2013) product values generated by the Green River treatments, for example, can be incorporated in the calculation of NPV, not to assess the value of standing timber to a landowner, but to estimate the value that the standing timber may contribute to the sector as a whole (Fig. 6). It is clear from this perspective that thinning and vegetation management offer significant potential to increase sector

Fig. 6. Theoretical net present value (NPV) available for stumpage, profit and risk across the value chain. In contrast to Fig. 3, these curves do not reflect the value accrued to the landowner or entity that has invested in VM or PCT; they are intended to show the value that the standing timber may contribute to the sector as a whole. The red dashed line indicates what might accrue through extensive, low-cost silviculture, assuming the same total volume generated by VM, but distributed as 60% conifer–40% intolerant hardwood, with a 10 year lag in the yield curve. All other conditions have been held constant at the baselines outlined in Table 1.

²Averaged between April 1, 2000, to March 31, 2010, including base stumpage and charges for forest inventory, Forest Futures Trust, and Forest Renewal Trust.

value along the value chain. This is particularly obvious when one compares the value contributed by thinning and vegetation management to what might theoretically accrue through extensive, low-cost silviculture. Such a comparison suggests that low levels of silvicultural investment could have long-term negative impacts on future timber supply and, concomitantly, the socio-economic well-being of rural communities dependent upon a sustainable forest resource (Auditor General of Ontario 2011, New Brunswick Crown Lands Task Force 2011).

Despite our not accounting for many of the ancillary benefits associated with PCT, our analyses of the rotation-length Green River data suggest that modest investment in thinning and vegetation management on the right sites may generate, through a fairly wide array of economic circumstances, increased land-owner timber revenues, which could ultimately contribute to a healthier forest sector. We hope that we have done justice to the efforts of Baskerville and his colleagues in providing forest managers with these analyses to use as a guide in choosing a silviculture regime that will sustainably maximize economic benefits in their forests. As more rotation-length data become available for Canadian growing conditions, it would be useful to evaluate other silvicultural interventions, such as planting, genetic improvement and commercial thinning, in a similar fashion.

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