PROJECT REPORT
December 31, 2007
FINAL PROJECT REPORT

sustainable forest management network

réseau sur la gestion durable des forêts

Role of pest management in sequestering carbon in forests: integration with CBM-CFS3 and economic analyses

Van A. Lantz
David A. MacLean
Barry Cooke
Chris Hennigar
Greg Slaney
Wei-Yew Chang

A Network of Centres of Excellence
Un réseau de centres d'excellence

Role of pest management in sequestering carbon in forests: integration with CBM-CFS3 and economic analyses

SFMN Project: Role of pest management in sequestering carbon in the 2008-12 Kyoto Commitment Period: integration with CBM-CFS3 and economic analyses

By:

Van A. Lantz - David A. MacLean
Faculty of Forestry & Environmental Management and Department of Economics,
University of New Brunswick, Fredericton, New Brunswick

Barry Cooke
Canadian Forest Service, Edmonton, Alberta

Chris Hennigar - Greg Slaney - Wei-Yew Chang
Faculty of Forestry & Environmental Management and Department of Economics,
University of New Brunswick, Fredericton, New Brunswick

December 31, 2007
Edmonton, Alberta, Canada.

ABSTRACT

This project addressed the potential for forest pest management (primarily use of insecticides) to contribute to measurable carbon stock sequestration. Specifically, we examined the outbreak patterns of several prominent forest pests in Eastern Canada, assessed the effects of applying insecticide during spruce budworm outbreaks on live timber biomass and carbon, evaluated the cost-effectiveness of this activity, and conducted a cost-benefit analysis of the long-term effects of this activity on society. The analysis of pest outbreak patterns revealed a significant risk of spruce budworm and forest tent caterpillar outbreaks over the 2008-12 period and beyond. Implementing insecticide programs under a number of spruce budworm outbreak scenarios were found to be capable of preventing widespread tree mortality and thereby maintaining relatively large amounts of carbon in living tree biomass. Scenarios of insecticide application during plausible future spruce budworm outbreaks applied to specific landbases in New Brunswick and Saskatchewan were found to be very cost effective relative to recent carbon credit prices posed on the Chicago Climate Exchange. Analyses also demonstrated that spruce budworm management generally results in long-term positive market and non-market net benefits. Overall, this project reveals a significant potential for the use of forest pest management to help Canada meet its Kyoto or other carbon commitments.

Keywords: Carbon sequestration, forest management, spruce budworm, decision support system, cost-benefit analysis, contingent valuation method.

ACKNOWLEDGEMENTS

We would like to thank all our project partners and collaborators that have contributed to the success of this project. Specific thanks goes to Dave Davies at Forest Protection Ltd., Kevin Porter and Ed Kettela at the CFS Atlantic Forestry Centre, Nelson Carter and Jeremy Gullison at the New Brunswick Dept. Natural Resources, Werner Kurz at the CFS Pacific Forestry Centre, and Rory McIntosh at the Saskatchewan Environment Department for their valuable insights throughout the development and implementation of this project.

TABLE OF CONTENTS

RESEARCH QUESTIONS AND OBJECTIVES

Forest pest management (primarily use of insecticides) is potentially amongst the most feasible means of measurable carbon stock sequestration over the short-term. In areas of active pest outbreaks, insecticide spraying would keep trees alive and prevent transfer of carbon in living biomass to dead organic matter and to the atmosphere. In order to better understand the potential role that such a program could play in forest carbon management to help meet Canada's carbon commitments, a scientifically credible methodology is needed for estimating the effects of insecticide spraying on live timber biomass and carbon, the cost-effectiveness of this program alterative, and the long-term effects of the activity on society.

The specific objectives of this project included: (i) evaluating the impact of insect outbreaks on forest carbon dynamics in the 2008-12 period and determining the influence of pest management on forest carbon dynamics; (ii) assessing the cost-effectiveness of investing in pest management activities for forest carbon sequestration; and (iii) exploring long-term costs and benefits of pest management activities.

KEY FINDINGS

1. *Research components:*

1.1. Evaluating the impact of insect outbreaks on forest carbon dynamics from 2008-12 and determining the influence of pest management on forest carbon dynamics

There were three phases to this analysis. The first phase involved the development and calibration of dynamic population simulation models for two of the most significant softwood and hardwood tree defoliators in Eastern Canada, namely spruce budworm (Choristoneura fumiferana Clem. (SBW)) and forest tent caterpillar (Malacosoma disstria Hbn. (FTC)). We used previously unsynthesized data, including: (a) historical defoliation maps for the period 1938-2003, and (b) bionomic and life history data that can be found in thousands of pieces of literature. These models served to replace the old models for SBW and FTC, which are no longer compatible with the best available data and theories on forest insect outbreak dynamics (Royama 1992).

The pest population models developed were climate-sensitive, stochastic, spatially simulated, and operated on real forest landscapes. Parameters simulated were periodicity, amplitude (intensity and duration), and spatial synchrony of population eruptions. The most recent data from 2000-02 were used to initialize model runs (SBW and FTC both being at low levels currently in Eastern Canada), and several runs were used to estimate the likely amplitude of population eruptions during the 2008-12 period and beyond.

The second phase of the analysis involved use of historical records to estimate impacts of various forest insects as a function of different levels of herbivory over time. The two dependent variables examined were tree death and annual growth increment, and independent variables included intensity, duration, and temporal pattern of herbivory. The relationships derived were used to improve calibration of timber impact functions for different pests and regions in Eastern Canada.

Finally, the third phase of the analysis involved estimating potential carbon savings generated through future SBW outbreak and protection (insecticide use) scenarios. SBW severely defoliates balsam fir (Abies balsamea (L.) Mill.) and spruce (Picea spp.) in large periodic outbreaks. Major insect outbreaks kill trees over large areas, prevent the living biomass from continuing to accumulate and store carbon, and result in carbon transfer to the atmosphere as dead trees decompose. The Spruce Budworm Decision Support System (SBW DSS), developed by the Canadian Forest Service, quantifies the marginal timber supply (m3/ha) benefits of protecting stands against SBW defoliation (MacLean et al., 2001). The Stand Management growth and yield model ((STAMAN; New Brunswick Dept. Nat. Res.) was used to forecast stand volume growth loss and increased mortality following SBW defoliation, as implemented in the SBW DSS, with the addition of three improvements: 1) ability to project salvageable volume from SBW-caused mortality; 2) modeled in-growth response of regenerating tree cohorts; and 3) explicit separation of relative defoliation differences expected between fir and each spruce species (Hennigar et al. 2007b).

Canada's forest sector Carbon Budget Model (CBM-CFS3; Kurz et al. 2002) was used to convert stand projections and SBW impacts for hardwood and softwood merchantable m3/ha into estimates of tons of carbon stored in living biomass (stem wood, foliage, stumps, branches, bark, coarse and fine roots) and dead organic matter (DOM) pools (litter, forest floor and soil detritus, standing snags and branches, coarse woody debris, and soil organic matter). An object-oriented windows application (Carbon-Object Tracker; COT; Hennigar et al. 2008, in prep.), was developed to simulate harvest product carbon transfer to alternative carbon pools through time (e.g. carbon in harvested roundwood, conversion to wood products, transfer to landfills and atmosphere, etc.). COT was developed using Visual Basic .NET 2005 and interfaces a Microsoft Access database used to store runtime options, pool properties such as age-dependant decay and transfer parameters, and simulation results. COT¬ handles carbon accounting methods and parameters used in the Canadian Budget Model of the Forest Product Sector (CBM-FPS; Apps et al. 1999), but unlike CBM-FPS, COT operates independently of CBM-CFS3.

We integrated STAMAN projections of impacts of SBW defoliation on m3/ha and carbon for forest live biomass, DOM, and harvested wood products from CBM-CFS3 and COT, into a forest estate timber supply optimization model (Hennigar et al. 2007a). Advantages of this integrated approach include using linear optimization to simultaneously re-optimize the harvest schedule, optimize salvage, and identify optimal areas for insecticide application to reduce SBW-caused loss of timber and forest ecosystem carbon stored in living biomass, DOM, and wood products.

A suite of scenarios (>200) of different sized protection programs were run on the 209,000 ha Black Brook District, in northwestern New Brunswick, owned and operated by J.D. Irving

Limited (JDI). The JDI 2002 'Woodstock' timber supply model and GIS data were used as the base scenario with no SBW outbreak.

1.2. Assessing the cost-effectiveness of investing in forest pest management activities for forest carbon sequestration

Cost-effectiveness of pest management for carbon sequestration was examined by extending the SBW DSS (MacLean et al., 2001) in two major ways. First, protection costs for spraying Bacillus thuringiensis (Bt) were integrated into the system using CASPER (Computer Assisted Spray Productivity and Efficiency Routine), developed by the USDA Forest Service (2007). CASPER required the input of six aircraft parameters (aircraft type, application rate, application and ferry speed, average turning time, swath width, and load capacity) as well as six cost parameters (load time, aircraft burn rate, number of applications, fuel cost, product cost, and aircraft rental rate. These parameters were estimated with assistance from our partner Forest Protection Limited. Then, a grid representing potential 10,000ha spray blocks was overlaid on the landbase and stands were assigned to a spray block based on their proximity to the grid cell. The program then calculated per ha cost for each 10,000ha spray block, prorated by total area protected within each spray block.

The second extension to the SBW DSS used CBM-CFS3 to simulate carbon in each forest stand type on a given landbase. Carbon components included softwood and hardwood biomass (bark, stem wood, foliage, branches and roots), DOM (coarse woody debris, forest floor litter and dead roots), and snags (stems and snag branches). Carbon yield curves were generated and input into SBW DSS to estimate marginal carbon losses for each landbase at the scheduled time of harvest. Marginal carbon losses were converted into CO2 losses based on the molecular conversion factor of 3.667. Carbon emissions from the protection program were netted-out of total carbon sequestration estimates by applying an emission coefficient on total fuel used by the aircraft.

Using the extended framework, we simulated an unprotected, moderate SBW outbreak beginning in 2002 on two land-bases: Crown timber License 1 in New Brunswick (521,900 ha), and the Prince Albert Forest Management Area (PAFMA) in Saskatchewan (5,038,168 ha). We defined three protection scenarios, all designed to limit defoliation to 40% of current year foliage per year but with three protection frequencies: (i) very aggressive (protecting in every year of the outbreak), (ii) aggressive (protecting the peak 3 years of outbreak), and (iii) semi aggressive (protecting every second year of outbreak). Each protection scenario was simulated for four program sizes: 10,000ha, 25,000ha, 100,000ha, and 150,000 ha, and . pest control costs per ton of CO2 sequestered were estimated for the twelve scenarios on each landbase.

1.3. Exploring long-term costs and benefits of forest pest management

Because forest pest management may have a number of long-term socio-economic impacts, we conducted a full cost-benefit analysis (CBA) of future SBW outbreak and control scenarios on Crown land in New Brunswick. The CBA was used to help determine which SBW control programs could be supported on socio-economic grounds. Here, market and non-market socio-economic benefits and costs of engaging in SBW control were considered. Market benefits were measured as the net value of timber saved (representing producer surplus gains), calculated by multiplying the volume saved estimated using the SBW DSS under different outbreak and control scenarios by product-specific benefit estimates of $30/m3 for sawlogs and $20/m3 for pulpwood (these values accounted for economic rent (stumpage prices) and producer surplus in the wood products market, following methods by van Kooten and Wang (1998)). All scenarios assumed that SBW outbreaks started in 2007 with aggressive protection (protecting the peak three years of outbreak) and were designed to limit defoliation to 40% of current year foliage per year. A total of 8 control scenarios were considered including two outbreak severities (moderate and severe) and four control program sizes (10%, 20%, 40% and 100% of susceptible area protected).

Non-market benefits of SBW control were measured as society's willingness to pay for protecting against future SBW outbreaks (representing consumer surplus gain) using the Contingent Valuation Method (CVM). The CVM is a survey–based, non-market valuation technique where a hypothetical market for ecological goods and services (EG&S) is created and values are contingent upon the scenario presented in a questionnaire given to the relevant public. Using this method, a random sample, public mail survey was sent to 1000 households in New Brunswick that asked participants to state their willingness to pay (WTP) to help the government control the next SBW outbreak. After providing some information about the scenario (e.g., timing and duration of the outbreak, expected timber supply impacts, etc), a double-bounded dichotomous choice question was asked: "Would your household be willing to pay $x per year income taxes for the next 5 years that would be used to protect against the next spruce budworm outbreak on forestland in New Brunswick?". The initial bid value ($x) was randomly selected from 10 bid values, with a range of $5-$200 (selected in consultation with a focus group meeting with selected members of the public). The parametric, average, annual WTP value per household was estimated using Cameron's (1988) bid function approach, assuming a normal distribution density function. The WTP estimate was aggregated to the provincial level by multiplying the per household WTP value by the total number of households in the province, and then adjusting for proportion in the sample who were in favor of pest control. Since this total WTP estimate was based on protection of all forestland in New Brunswick, and since Crown land represents roughly one half of all forestland in the province, the estimate was reduced by one-half in order to fit into the cost-benefit analysis of control scenarios on Crown land. Additionally, this amount was again proportionately adjusted when control program sizes less than 100% of the land base were simulated.

Market costs of SBW control via aerial spraying of Bt (representing producer surplus loss) were measured by combining land area treated from each outbreak and control scenario from the SBW DSS with an estimated average cost per hectare of pesticide product application ($30/ha was used as an average cost estimate).

Finally, non-market costs of SBW control were measured using the CVM. In this case, the CVM was used to ask those in the public who did not want SBW outbreak control, about their WTP for compensating those negatively impacted by an uncontrolled outbreak. Specifically, survey participants who preferred to let the infestation run its natural course were asked the following question: "Suppose the provincial government did not plan to engage in pest control during next pest outbreak. Would your household be willing to pay $x per year additional income taxes for the next 5 years that would be used to compensate those who suffer losses caused by next spruce budworm outbreak on forestland in New Brunswick?". The bid value was again randomly selected within a range of $5-$200, and the same procedure used in the indirect benefit analysis described above was used to analyze the data and produce the aggregate WTP estimate. This latter estimate is thought to effectively approximate the disutility (welfare loss) that some experience from SBW control programs.

Total benefits and costs were discounted over the lifetime of each SBW outbreak and control scenarios. Net present values (NPV) and benefit cost ratios (BCR) were then calculated in market and total (market and non-market) terms. Sensitivity analysis was conducted on the discount rate, timber product prices, and unit pesticide cost in order to examine the manner in which the NPV and BCR of each control program changed in response to a change in these parameters.

2. Research results and contributions

2.1. Historical and future SBW and FTC outbreaks in Eastern Canada

The recent expansion of SBW in Eastern Ontario and export of moths in large numbers from the Ottawa Valley into central Quebec indicates that the risk of outbreak in the 2008-2012 period is potentially high, despite low numbers since 1997. Tree ring work from the Appalachians in the US confirms the Gray et al. (2000) SBW forecast was generally correct except for the assumption of homogeneous periodicity. Outbreaks appear to occur slightly more frequently in the southern St. Lawrence basin than in the northern boreal forest, thus creating the occasional disconnect between cycles in the two regions.

Analysis of SBW defoliation data in Quebec from 1938-2001 indicates a possible gradient in outbreak periodicity from the St. Lawrence Valley to the higher Laurentian & Appalachian mountains. If periodicity estimates are correct, it suggests the current outbreak (which has been progressing very slowly, in fits and starts, since ~1996) will not be as well-synchronized as the last two, but may be split up into two component waves, with the first wave (in Western Quebec) already having been completed, and the second (in Eastern Quebec) coming some time after the 2008-2012 Kyoto period. The outbreak waves will certainly affect other Eastern Canadian provinces. However, the exact manner in which they will be impacted is uncertain since the SBW cycle is so slow (n=2 cycles over 64 years). Additional validation efforts need to be made using tree-ring reconstructions.

Recent dendrochronological data show that tree rings are a more sensitive indicator of low levels of SBW defoliation than are aerial fixed-wing surveys. Preliminary analyses of these data support the hypothesis that, in northern areas, climate warming may be increasing the susceptibility of high elevation forests to SBW attack. Thus, SBW may represent a greater long-term risk to black spruce growth increment than is widely believed. Risk in the south may be declining because of reduced variation in temperatures relative to budworm-critical thresholds. Additional sampling is ongoing.

Analysis of historical records of FTC outbreaks in Quebec over the 1938-2002 period indicates six outbreak cycles, with a 9-year cycle (last peaking in 2001) occurring in the aspen-dominated northwestern boreal forest, and a 13-year cycle (last peaking in 1993) in the maple-dominated southern Appalachian hardwood forest region (Cooke and Lorenzetti 2006). Cycle VII is expected to peak in ~2008 in the Appalachian region and ~2011 in the boreal region. Cycle amplitude appears to vary in a slow, smooth manner, for unknown reasons. This is an area for further research.

Analysis of FTC records from Ontario 1929-2002 were found to support conclusions from Quebec data (Cooke et al. 2007). Additionally, analysis of pheromone trap catch data for the entire province of New Brunswick over the last 3 years indicate that FTC populations in NB are currently endemic (as in southern Quebec). This reinforces the prediction that the next cycle will peak in ~2008 in the greater Appalachian region. That trap catches do not drop to zero indicates that populations do not go extinct during the endemic period, which validates some of our key population modeling assumptions.

2.2. The influence of SBW outbreaks and management on forest carbon dynamics

Over 200 scenario simulations were performed to explore effects of moderate and severe SBW outbreaks beginning in 2007, and optimum combinations of foliage protection (efficacy, frequency and spatial extent of application) and harvest strategies to reduce timber and C impacts on the 209,000 ha Black Brook District in New Brunswick. Following simulated severe defoliation from 2007-2016, maximum harvest reductions of 35% were predicted for a moderate outbreak during the 2012-16 period, and 46% for a severe outbreak during the 2017-21 period (Hennigar et al. 2007a). These impacts were reduced to 25% and 34% using re-optimized harvest scheduling and salvage. For areas containing fir and spruce, preliminary results show C in live biomass and merchantable timber inventories were reduced 18% (870,000 tons of carbon) and 26% (3.3 million m3) for the 2007-2016 period for a simulated moderate outbreak and 23% and 32%,respectively, for a severe outbreak scenario. Dead organic matter pools were relatively unaffected (<1%) by SBW outbreaks. Capturing salvageable volume was the main factor that reduced defoliation impact on harvest between base and defoliated harvest scenarios. Spatial optimization of protected areas gave similar results to those obtained using protection priority assignments based on marginal stand-level volume reduction calculated by the SBW DSS. However, spatial optimization reduced the required area to be protected, for an equivalent harvest level, from 20% of the landbase to 17%, from 40% to 33%, from 70% to 53%, and from 100% to 66±4% (Hennigar et al. 2007a). Combined, optimized salvage and harvest re-scheduling could reduce future harvest losses by up to 30%.

Overall, we have shown that incorporating tools such as optimized planning for salvage, alternative harvest scheduling and spatial allocation of foliage protection will reduce volume and carbon loss from SBW and minimize the area of insecticide application. Our modeling reinforces the fundamental importance of spatiotemporal scales and need for examination of all forest dependant carbon pools for developing sound forest policy to maximize forest contributions toward reducing atmospheric CO_2 during SBW outbreaks. Differences between SBW timber and carbon impacts and examination of optimum management trade-offs for timber, carbon, and other values are of key importance for effective forest planning to mitigate resources impacts from insects.

2.3 Cost-effectiveness of investing in SBW control programs for sequestering carbon in forests

The moderate, unprotected, SBW outbreak simulations in the PAFMA landbase in Saskatchewan and the Crown License 1 landbase in New Brunswick resulted in estimated losses of 13.3 and 13.7 million tons of carbon, respectively. SBW control program scenarios in the PAFMA resulted in a range of carbon sequestered, from a low of 0.33 million tons under a 10,000 ha aggressive control program to a high of 4.57 million tons under a 150,000 ha very aggressive control program. Likewise, control program scenarios in License 1 resulted in a range of carbon sequestered, from a low of 0.34 million tons under a 10,000 ha aggressive control program to 5.24 million tons under the 150,000 ha very aggressive control program.

Across the evaluated SBW control program scenarios in the PAFMA, cost per ton of CO_2 sequestered ranged from a low of $0.72 under a 10,000 ha aggressive control program to a high of $2.37 under a 150,000 ha very aggressive control program. Similarly, across the evaluated program scenarios for License 1, cost per ton of CO_2 protected ranged from a low of $0.57 under a 10,000 ha semi-aggressive control program to a high of $1.40 under a 150,000 ha very aggressive control program. Variation in the above estimates between landbases results largely from the different tree species composition and age classes present in the forest at the time of analysis.

Comparing the above cost estimates of carbon sequestration via pest management to a reported carbon credit cost of $2.05 per ton on the Chicago Climate Exchange (December 13, 2007), it is clear that pest management may offer an attractive investment opportunity. The final carbon sequestration cost estimates from pest management, however, would be marginally higher than those reported above since the cost of CO_2 credit verification would need to be accounted for. Additionally, it may be necessary to evaluate more precisely the complete lifecycle of carbon within the protected forest. Finally, carbon sequestration cost estimates from pest management would depend significantly on timing and severity of outbreaks, as well as region-specific characteristics of the forest. Therefore, if such an institutional arrangement were established, it would be necessary to keep an up-to-date SBW DSS calibrated to each land-base under consideration.

2.4. Long-term costs and benefits of investing in SBW control programs

In the analysis of Crown land in New Brunswick, SBW outbreak and control program scenarios resulted in a wide array of market and non-market benefits and costs. Present value market benefits (discounted at 5%) ranged from a low of $54.31 million under a moderate SBW outbreak and a 10% forest area protection program to a high of $268.23 million under a severe SBW outbreak and a 100% forest area protection program. Similarly, present value market costs ranged from a low of $28.91 million under a moderate outbreak with a 10% area protection program to a high of $386.39 million under a severe outbreak with a 100% area protection program.

For non-market benefits, based on a 29% survey response rate, we estimated an annual average household WTP (for a 5-year period) to control the next SBW outbreak (over 100% of the affected area) of $76.20. Aggregating this to the provincial level (after adjusting for the proportion of the population who prefer control, the relative size of the Crown land base within the province, and the different percentages of area protected), resulted in present value non-market benefits ranging from a low of $7.93 million under a 10% area protection scenario to a high of $79.34 million under the 100% area protection scenario. Using a similar method for non-market costs, we estimated an annual average household WTP (for a 5-year period) to compensate those negatively impacted by an uncontrolled outbreak of $59.80. Aggregating this to the provincial level (after again adjusting for the proportion of the population who would not prefer control, the relative size of the Crown land base within the province, and different percentages of area protected), resulted in present value non-market costs ranging from a low of $0.55 million under a 10% forest area protection program to $5.51 million under a 100% forest area protection program.

When combining costs and benefits for a moderate outbreak scenario, we found that protecting 10% of the Crown land base (i.e., ~330,000ha) produced the highest market and total (market and non-market) net present values at $25.40 million and $28.82 million, respectively, compared to all larger protection size scenarios. The benefit-cost ratio results were also highest under this scenario at 1.88 and 1.98, respectively. Net present values became negative and benefit-cost ratios became less than one when moving from the 20% to 40% protection programs.

Under a severe outbreak, the 20% area protection program size produced the highest market and total net present values at $116.47 million and $123.30 million, respectively. Slightly different results emerged for the benefit-cost ratio analysis were highest values were found under the 10% protection program scenario, at 3.72 and 3.77, respectively. Net present values became negative and benefit-cost ratios became less than one when moving from the 40% to 100% protection programs.

Sensitivity analysis revealed that lower discount rates, lower unit pesticide costs, and higher timber product prices generally tended to: (i) increase the net present value and benefit-cost ratio for each protection program and outbreak scenario; and (ii) cause the highest market and total net present value estimates to occur when protecting larger percentages of the Crown land base than previously determined. Higher discount rates, higher unit pesticide costs, and lower timber product prices tended to have the opposite effects.

Overall, it is clear that under the base-case prices and discount rates, protecting 10%-20% of the land base under both moderate and severe outbreaks can be justified on economic grounds. While larger protection programs may save more volume and product value, higher overall protection expenditures significantly diminish any net benefit from doing so. These results are consistent when including non-market values in the analysis. However, if discount rates and pesticide costs become significantly higher, or timber product prices become significantly lower than those used in the base-case analysis, protection programs may not produce a positive net benefit to society. On the other hand, changes to these parameters in opposite directions, and/or the inclusion of carbon credit payments into the cost-benefit framework would almost certainly provide justification for protecting larger percentages of the land base.

KEY DELIVERABLES

Publications

Chang, W.Y, V.A Lantz, D.A. MacLean, C.R. Hennigar, K. Porter, and J.J. Gullison. 2008. Cost-benefit analysis of forest pest control in New Brunswick (in prep)

Chang, W.Y, V.A Lantz, D.A. MacLean, and K. Porter. 200-8. Public attitudes about forest pest outbreaks and control options in New Brunswick and Saskatchewan (in prep.)

Cooke, B.J. and F. Lorenzetti. 2006. The dynamics of forest tent caterpillar outbreaks in Quebec, Canada. Forest Ecology and Management 226: 110-121.

Cooke, B.J., Nealis, V.G., Régnière, J. 2007. Insect defoliators as periodic disturbances in northern forest ecosystems. In: Johnson, E.A., Miyanishi, K. (Eds.), Plant Disturbance Ecology: The Process and the Response. Academic Press. Pp. 487-526.

Hennigar, C.R., MacLean, D.A., Porter, K.B., and Quiring, D.T. 2007a. Optimized harvest planning under alternative foliage-protection scenarios to reduce volume losses to spruce budworm. Can. J. For. Res. 37: 1765-1769.

Hennigar, C.R., MacLean, D.A., and Quiring, D.T., Kershaw J.A. Jr. 2007b. Differences in spruce budworm defoliation among balsam fir and white, red, and black spruce. For. Sci. (in press).

Hennigar, C.R., MacLean, D.A., Amos-Binks, L.J. 2008. An approach to optimize management strategies for carbon stored in forests and wood-products. (in prep.).

Patriquin, M., V. Lantz, R. Stedman, and B. White. 2008. Working Together: A Reciprocal Wood Flow Arrangement to Mitigate the Economic Impacts of Natural Disturbance. Forestry: An International Journal of Forest Research 11p. (in review).

Slaney, G.L., D.A. MacLean, V. Lantz, and K.B. Porter. 2007. Cost effectiveness of pest management investments: expanding PROPS to include costs, product value and carbon. SERG-I, Ayr, ON. Technical Note SERG-I 2006/06.

Slaney, G.L., V.A. Lantz, and D.A. MacLean. 2008. Cost effectiveness of pest management investments for forest carbon sequestration: evidence from land bases in New Brunswick and Saskatchewan (in prep.).

Presentations

Chang, W.Y, V.A Lantz, D.A. MacLean, and K. Porter. 2007. Socio-economic impacts of forest pest outbreaks and control options. Presentation to the New Brunswick Dept. of Natural Resources, Nov. 27, DNR Ancillary Building, Fredericton, NB.

Chang, W.Y, V.A Lantz, D.A. MacLean, and K. Porter. 2007. Public attitudes about forest pest outbreaks and control options in New Brunswick and Saskatchewan. Presentation at the Acadian Forest Science Conference, Oct 10-13, Hugh John Flemming Forestry Centre, Fredericton, NB.

Cooke, B, F. Lorenzetti and J. Roland. 2006. Insect defoliators and aspen decline: observations from the east and implications for the west. Proceedings of the Spray Efficacy Research Group International and USDA Forest Service Workshop, P. 113.

Hennigar, C.R. 2005. Influence of silviculture and pest management strategies on carbon sequestration by forests in New Brunswick Presentation given at the J.D. Irving Ltd. Forest Research Advisory Committee, Edmundston, NB., May 24, 2005.

Hennigar, C.R. 2007. Carbon modeling and results: Black Brook District. Presentation to the Forest Research Advisory Committee, JD Irving Ltd, Feb 21st, and Apr 4th, Fredericton, NB.

Hennigar, C.R. 2007. Recent improvements to the Spruce Budworm DSS, Nov 27th. Presentation made to NB Department of Natural Resource, Can. For. Serv., and Bio-Forest Limited.

Hennigar, C.R. and D.A. MacLean. 2007. Recent improvements to the Spruce Budworm DSS. Presentation to the New Brunswick Dept. of Natural Resources, Nov. 27, DNR Ancillary Building, Fredericton, NB.

Hennigar, C.R. and D.A. MacLean. 2007. Spruce budworm effects on optimum timber supply and carbon sequestered for an industrial forest in New Brunswick. P. 34. In: Decision for Sustainability: Forest Estate Models for the Future. June 11-14, 2007, Victoria, BC.

Hennigar, C.R., and D.A. MacLean. 2007. Optimizing carbon sequestration for managed forests and forest products in New Brunswick. Forest Carbon Offset Workshop, June 27, 2007, Augusta, ME. Manomet Center for Conservation Sciences.

Hennigar, C.R., MacLean, D.A., and Porter, K.B. 2006. Optimized harvest scheduling, salvage and insecticide application during large spruce budworm outbreaks. Presentation made at the Sustainable Forest Management Network Conf., June 21-23, Edmonton, AB.

Hennigar, C.R., MacLean, D.A., and Porter, K.B. 2006. Optimized salvage, harvest scheduling, and foliage-protection to reduce harvest impacts during large spruce budworm outbreaks.

Abstract and presentation: p. 50 In: Forest Science Across the Borders: Proceedings of the Eastern Canada/USA Forest Science Conference, Oct. 19-20. Québec City, QC.

Hennigar, C., D.A. MacLean, and D. Quiring. 2007. Quantifying spruce budworm defoliation differences among balsam fir and spruce species, and relevance to the SBWDSS. P.73. In: Proc. SERG International Workshop. Feb. 12-16, 2007, Quebec City, QC.

Hennigar, C.R., MacLean, D.A., and Porter, K.B. 2006. Integration of the spruce budworm DSS into Woodstock: case study on the Black Brook District, New Brunswick Canada. P. 185. Proceedings of the Spray Efficacy Research Group International and USDA Forest Service Workshop.

Kurz, W., G. Stinson, C. Dymond, E. Neilson, K. Porter, D. MacLean, and M. Campagna. 2007. Predicting the carbon impacts of anticipated spruce budworm outbreak in eastern Canada using the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3). In: Climate Change Impacts on Boreal Forest Disturbance Regimes, VI International Conference on Disturbance Dynamics in Boreal Forests, May 30- June 2, Fairbanks, AK.

Lantz, V., M. Patriquin, R. Stedman, and B. White. 2007. Working Together: A Reciprocal Wood Flow Arrangement to Mitigate the Economic Impacts of the Mountain Pine Beetle in BC. Feb. 26. Presentation at the BC Forum on Forest Economics and Policy, University of British Columbia, Vancouver, BC.

MacLean, D.A. 2005. Pest infestations and forest carbon. Event: Capturing Canada's Green Advantage: Biosphere Solutions for Climate Change and the Economy. 1st National Conference, Ottawa, ON. Feb. 2-3, 2005.

MacLean, D.A. 2005. Modeling effects of spruce budworm outbreaks on forest carbon. Seminar at Canadian Forest Service, Pacific Forestry Center, Victoria, BC., Feb. 16.

MacLean, D.A. 2005. Insect outbreaks as determinants of the structure and function of Canada's forests. The Kenneth Hammond Lectures on Environment, Energy, and Resources 2004/05 Series, Environmental Science and the Health of Terrestrial Environments. Presentation given at the Faculty of Environmental Sciences, University of Guelph, Guelph., Mar. 11-12.

MacLean, D.A. 2007. Spruce budworm and management planning. P. 47. In: Decision for Sustainability: Forest Estate Models for the Future. June 11-14, Victoria, BC.

Slaney, G.L., D.A. MacLean, V. Lantz, and K.B. Porter. 2007. Cost effectiveness of pest management investments: expanding PROPS to include costs, product value and carbon. P. 49. In: Proc. SERG International Workshop. Feb. 12-16, 2007, Quebec City, QC.

Slaney, G., V. Lantz, and D. MacLean. 2007. Cost effectiveness of forest pest management investments for sequestering carbon. Sustainable Forest Management Network Knowledge Extension Workshop, Mar. 8, Fredericton, NB.

Slaney, G., V. Lantz, and D. MacLean. 2007. Cost-effectiveness of investing in spruce budworm control programs for sequestering carbon in forests: application to land-bases in New Brunswick and Saskatchewan. Presentation to the New Brunswick Dept. of Natural Resources, Nov. 27, DNR Ancillary Building, Fredericton, NB.

Posters

Hennigar, C.R., and MacLean, D.A. 2006. A modeling framework to evaluate spruce budworm impact on carbon sequestration for large forests tracts and alternative pest management strategies. P. 37. In: Towards a Sustainable Bioeconomy: Biosphere Solutions for Energy and the Environment. BIOCAP Canada Conference, Oct. 31- Nov. 1, 2006, Ottawa.

Hennigar, C.R. and D.A. MacLean. 2005. A framework to evaluate the influence of silviculture and pest management strategies on carbon sequestration by forests in New Brunswick. Poster presented at the Fundy Model Forest Project Forum, Atlantic Forestry Centre, Fredericton, NB., Feb. 22, 2005.

Slaney, G.L, V.A Lantz, and D.A MacLean. 2006. Expanding the spruce budworm decision support system to include aerial spray costs and carbon. P. 38. In: Towards a Sustainable Bioeconomy: Biosphere Solutions for Energy and the Environment. BIOCAP Canada Conference, Oct. 31- Nov. 1, 2006, Ottawa.

Thesis supervision

- Student: Greg Slaney; Degree: MScF; Co-supervisors: Van Lantz and David MacLean; Period of supervision: 2004-present.
- Student: Wei-Yew Chang; Degree: PhD in Forestry; Supervisor: Van Lantz; Committee Members: David MacLean and Kevin Porter; Period of supervision: 2004-present.
- Student: Chris Hennigar; Degree: PhD in Forestry; Supervisor: David MacLean; Period of supervision: 2004-present.

Workshops organized

Workshop title: “Carbon Sequestration and Pest Management”; Place: University of New Brunswick; Date: May 19th, 2005; Presentations made by researchers involved in this project: (i) Title: Modeling Carbon Sequestration through Pest Management: integration with CBM-CFS3, presented by Chris Hennigar; (ii) Title: Modeling Carbon Sequestration through Pest Management: economic analysis, presented by Greg Slaney; and (iii) Preliminary insect outbreak projections, presented by Barry Cooke.

BENEFITS TO PROJECT PARTNERS AND OTHERS

Work on the SBW DSS is continuing under the auspices of the Dan Kneeshaw et al. 2007-2009 SFMN project “Reducing uncertainty in forest sustainability caused by insect outbreaks”. Analyses of effects of SBW on forest and wood product C pools for the Black Brook District is expected to be complete by December 2008. This integrated modeling framework as been adopted by the New Brunswick Department of Natural Resources and is currently being used in New Brunswick's provincial timber supply model through a partnered project with UNB to quantify provincial economic impacts caused by SBW for alternative forest-pest management scenarios (Hennigar, Gullison, and MacLean). More detailed stand-level modeling of biomass over time using STAMAN for alternative managed stand structures using tree-level allometric equations is being developed at UNB. STAMAN biomass projections will help to better quantify live biomass dynamics at the stand and forest level, and will be used to help validate CBM-CFS3 volume to biomass conversion parameters. The J.D. Irving, Ltd. (SFMN partner) Black Brook district landbase has been used as a test area for Hennigar et al. (2007a), and results have been regularly presented to JDI managers and their Forest Research Advisory Committee.

MANAGEMENT/POLICY IMPLICATIONS

Elements of the new SBW DSS have been adopted by the New Brunswick Department of Natural Resources in their forest management planning on Crown land. This addition is expected to more accurately project future timber supply by accounting for the next SBW outbreak, and allow managers to minimize the impacts of the outbreak through salvage harvesting and re-scheduling.

It is expected that Forest Protection Limited (one of our partners) and others will use the carbon and cost additions to the SBW DSS to facilitate their decision-making in the event that pest management carbon credits become a viable trading commodity.

SUGGESTIONS FOR FUTURE RESEARCH

Research on the costs of sequestering carbon through pest management can be expanded in many ways. On a practical basis, we need to better understand the costs involved in CO2 credit verification, and the manner in which the lifecycle of carbon within the protected forest would be dealt with in a carbon credit scheme. These factors may significantly affect the final costs of using pest management to sequester carbon. On a methodological basis, it would be of interest to examine the manner in which the SBW DSS extension made by Hennigar et al. (2007a), which allows for optimized salvage harvesting and harvest rescheduling, would influence the estimated carbon sequestration costs presented in this report.

Additionally, a number of extensions could be made to the cost-benefit analysis presented in this report. Specifically, it would be of interest to examine the extent to which carbon credit payments for pest control would affect the net present values and benefit cost ratios under different outbreak and control scenarios. There is much work needed on furthering our understanding of the non-market benefits and costs of pest management. There are concerns over the degree to which the public understands social, economic, and environmental impacts of pest outbreaks and control. Alternative non-market valuation techniques such as choice experiments or image-based contingent valuation methods delivered in person or over the web could provide useful information for this purpose.

Finally, applying the above methods to other land bases and pests would provide further insight into the potential for using pest management as a means of helping to meet Canada's future carbon sequestration commitments.

REFERENCES

Apps, M.J., W.A. Kurz, S.J. Beukema and J.S. Bhatti. 1999. Carbon budget of the Canadian forest product sector. Environmental Science & Policy (2): 25-41.

Cameron, T.A. 1988. A new paradigm for valuing non-market goods using referendum data: maximum likelihood estimation by censored logistic regression. Journal of Environmental Economics and Management 15: 355-379.

Cooke, B.J. and F. Lorenzetti. 2006. The dynamics of forest tent caterpillar outbreaks in Quebec, Canada. Forest Ecology and Management 226: 110-121.

Cooke, B.J., Nealis, V.G., Regniere, J., 2007. Insect defoliators as periodic disturbances in northern forest ecosystems. In: Johnson, E.A., Miyanishi, K. (Eds.), Plant Disturbance Ecology: The Process and the Response. Academic Press, 487-526.

Gray, D.R., Régnière, J., and Boulet, B. 2000. Analysis and use of historical patterns of spruce budworm defoliation to forecast outbreak patterns in Quebec. Forest Ecology and Management 127: 217-231.

Hennigar, C.R., MacLean, D.A., Porter, K.B., and Quiring, D.T. 2007a. Optimized harvest planning under alternative foliage-protection scenarios to reduce volume losses to spruce budworm. Can. J. For. Res. 37: 1765-1769.

Hennigar, C.R., MacLean, D.A., and Quiring, D.T., Kershaw J.A. Jr. 2007b. Differences in spruce budworm defoliation among balsam fir and white, red, and black spruce. For. Sci. (in press).

Hennigar, C.R., MacLean, D.A., Amos-Binks, L.J. 2008. An approach to optimize management strategies for carbon stored in forests and wood-products. (in prep.).

Kurz, W., G. Stinson, C. Dymond, E. Neilson, K. Porter, D. MacLean, and M. Campagna. 2007. Predicting the carbon impacts of anticipated spruce budworm outbreak in eastern Canada using the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3). In: Climate Change Impacts on Boreal Forest Disturbance Regimes, VI International Conference on Disturbance Dynamics in Boreal Forests, May 30- June 2, 2007, Fairbanks, AK.

MacLean, D.A., Erdle, T.A., MacKinnon, W.E., Porter, K.B., Beaton, K.P., Cormier, G., Morehouse, S., and Budd, M. 2001. The Spruce Budworm Decision Support System: forest protection planning to sustain long-term wood supplies. Can. J. For. Res. 31: 1742-1757.
Royama, T. 1992. Analytical Population Dynamics. Chapman and Hall, New York.

USDA Forest Service. 2007. Computer Assisted Spray Productivity and Efficiency Routine, Version 0.96. USDA Forest Service. Available at:
http://www.fs.fed.us/r8/foresthealth/sprayapps_new.shtml
(Accessed: Dec 10, 2007).

van Kooten, G. and S. Wang. 1998. Estimating economic costs of nature protection: British Columbia's forest regulations. Canadian Public Policy XXIV (Supplement 2): 63-71.