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Modeling insecticide protection versus forest management approaches to reducing balsam fir sawfly and hemlock looper damage

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ABSTRACT

A decision support system (DSS) for improved management decision making and to reduce impacts of forest insect outbreaks was developed and implemented for two defoliators, hemlock looper (*Lambdina fiscellaria fiscellaria* Guen.) and balsam fir sawfly (*Neodiprion abietis* Harris), in District 15, a 336,805 ha forest managed by Corner Brook Pulp and Paper Ltd. in western Newfoundland, Canada. Over the past 15 years, 56% and 12% of the landbase were defoliated by balsam fir sawfly and hemlock looper, which had major effects on forest growth and yield. Relationships between reduced growth and survival and cumulative defoliation were quantified for each insect, to permit calculation of relative impact per forest stand as a function of defoliation, stand age, and species composition. These were integrated into a forest estate model to project effects on timber supply for 25 years. Defoliation during 1996–2008 was estimated to reduce total operable softwood growing stock and softwood harvest level by 26% and 31%, respectively, for balsam fir sawfly, and by 2–3% for the smaller-scale hemlock looper outbreaks. Given the long-term influence on forest structure, effects of defoliation on yield were projected to continue for up to 60 years after defoliation ceased. Sensitivity analysis using different defoliation scenarios suggested that maximum reductions in harvest levels could be reduced from 40% to 17% by protecting the most susceptible 25% of the landbase using biological insecticides, and minimized further to 9% by re-optimization of harvest schedules to reduce losses. This DSS provides a tool to help forest managers decide when and where to use biological insecticides, and how to use rescheduling of harvest, forest restructuring or planned salvage to reduce future losses.

1. Introduction

In addition to human activities, natural disturbances like fire, insects, and diseases constantly affect forests. These natural disturbances reduce wood supply and complicate forest management due to changes in forest structure that affect wildlife habitat and other non-timber values (e.g., esthetics or recreational and biodiversity, etc.). Among natural disturbances, native insects have been prominent in Canada, with mountain pine beetle (*Dendroctonus ponderosae* (Hopkins)) killing an estimated 675 million cubic meters of pine in British Columbia (half of the commercial pine) from 1998 through 2009 (Canadian Council of Forest Ministers, 2010). In eastern Canada, defoliators like spruce budworm (*Choristoneura fumiferana* Clem.), balsam fir sawfly (*Neodiprion abietis* Harris), and hemlock looper (*Lambdina fiscellaria fiscellaria* Guen.) have undergone widespread outbreaks, up to 217, 0.4, and 2.3 million hectares, respectively, during 1975–2005 (Canadian Council of Forest Ministers, 2010). Balsam fir (*Abies balsamea* (L.) Mill.) is a dominant, extensively distributed softwood species throughout eastern Canada and is the primary host to all three of these defoliating insects.

Spruce budworm is the most damaging forest insect in Canada, having undergone three major outbreaks in the 20th century, typically lasting 10–15 years (MacLean, 1984). Budworm larvae severely defoliate balsam fir and spruce (*Picea* spp.) and feed extensively on current-year foliage. The last spruce budworm outbreak in Newfoundland, Canada occurred from 1972 to 1989, but during the last 20 years, balsam fir sawfly and hemlock looper have been the dominant insect defoliators in this province. In contrast to spruce budworm, balsam fir sawfly feeds only on old ($\geqslant$1 year old) foliage. Hemlock looper, on the other hand, consumes all age classes of foliage and is polyphagous (Carroll, 1956; Hebert et al., 2006), feeding on eastern hemlock (*Tsuga canadensis* (L.) Carr.), white birch (*Betula papyrifera* Marsh.), and sugar maple (*Acer saccharum* Marsh.) in addition to balsam fir and spruce. Balsam fir sawfly is a serious pest of young managed balsam fir stands in western Newfoundland, and the current outbreak, which began in 1991 and is the longest recorded, has caused an estimated 78–81% tree growth reduction (Piene et al., 2001; Moreau, 2006). Hemlock looper outbreaks

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Table 1
Area (ha) defoliated by balsam fir sawfly and hemlock looper in three 5-year planning periods, by defoliation severity class and as a percentage area of productive forest (336,805 ha).

Defoliation severity	Balsam fir sawfly (ha)				Hemlock looper (ha)			
	Period 1 1996–2000	Period 2 2001–2005	Period 3 2006–2008	Total (%)	Period 1 1996–2000	Period 2 2001–2005	Period 3 2006–2008	Total (%)
Moderate	909	5400	1639	2	13,849	7040	0	6
Severe	3170	40,645	9740	15	1584	12,495	0	4
Multiple years	22,626	102,109	17,526	39	0	7104	0	2
Total (%)	7	40	9	56	5	7	0	12

occurred in Newfoundland from 1910–1915, 1920–1926, 1929–1935, 1946–1955, 1959–1964, 1966–1972, 1984–1989, and 1995–2004 (Otvos et al., 1979; Canadian Council of Forest Ministers, 2010). Hemlock looper is of particular concern as severe defoliation of all age classes of foliage is very destructive, causing tree mortality after just 1 or 2 years of severe defoliation (Hudak et al., 1978; MaClean and Ebert, 1999; Iqbal et al., 2011a).

An effective decision support system can assist in making complex forest management decisions under disturbances like defoliating insects. Advances in computer and information gathering technology have made the evaluation of alternative management practices through model simulation a feasible and valuable tool for forest managers (MacLean, 1996). The Spruce Budworm Decision Support System (SBWDSS (Erdle, 1989; MacLean et al., 2001, 2002) was developed to project effects of outbreaks on tree growth, mortality, and timber supply, and to incorporate potential management actions into a decision-making framework. In the SBWDSS, annual defoliation data obtained from aerial surveys and various projected defoliation scenarios are converted into cumulative 5-year defoliation. These estimates are used to model tree growth reduction and mortality of stands in the inventory database of a Geographic Information System (GIS) (MacLean et al., 2001). Hennigar et al. (2007) improved the SBWDSS modeling framework by integrating stand-level budworm volume impacts into a Woodstock forest estate model (Remsoft Spatial Planning System, 2010), allowing pest management decisions such as foliage protection, harvest rescheduling, and salvage to be considered when maximizing timber flows during a budworm outbreak. Woodstock is flexible and widely accepted software for solving complex forest management problems using commercial linear optimization solvers and simulation modeling, and hence allows linear re-optimization of harvest schedule.

Although this DSS exists for spruce budworm, no such tool is available for other dominant defoliators like balsam fir sawfly and hemlock looper. The objectives of this study were to (i) compile impacts due to balsam fir sawfly and hemlock looper defoliation into a DSS framework, (ii) analyze forest-level impacts on total operable softwood growing stock and softwood harvest levels due to 1996–2008 balsam fir sawfly and hemlock looper defoliation for forest management District 15 in western Newfoundland using the DSS, and (iii) determine effects of insecticide protection and harvest schedule re-optimization on forest-level impacts.

2. Methods

2.1. Defoliation assessment

Over a large forest area, the most economic and feasible way to survey natural disturbances is through using aircraft (MacLean and MacKinnon, 1996). Newfoundland and Labrador Department of Natural Resources (NLDNR) conducts such surveys annually using helicopters, and records annual defoliation data on 1:50,000 scale survey maps. Aerial defoliation surveys are conducted during a 1–3 week period after the completion of feeding (usually from mid-late August). A distinct reddish-brown coloration of foliage due to the desiccation of damaged needles (MacLean and Ebert, 1999) helps the two observers in a helicopter judge and record the area and severity of defoliation. Though defoliation estimated by aerial survey differs somewhat due to feeding patterns of balsam fir sawfly and hemlock looper (Iqbal and MacLean, 2010), for spruce budworm similar aerial survey techniques have been found to be 82–85% accurate in differentiating three defoliation classes 0–30%, 31–70%, and 71–100% defoliation (MacLean and MacKinnon, 1996; Taylor and MacLean, 2009).

The defoliator (insect), defoliated area, and its severity in three defoliation classes (nil 0–30%, moderate 31–70%, or severe 71–100% of live crown foliage) were marked on annual aerial survey maps. The actual defoliating insect was determined based upon the defoliation pattern (current year defoliation for spruce budworm, versus 1 year and older defoliation for balsam fir sawfly) or ground survey in case of doubt. These maps were digitized and converted to digital GIS format. Areas defoliated by balsam fir sawfly or hemlock looper in forest management District 15 from 1996 to 2008 are shown in Fig. 1, by three 5-year periods and by defoliation severity class. Although depicted as discrete 5-year periods in Fig. 1, there was some overlap in defoliation across periods, and stand-level GIS data were used in analyses. An estimate of cumulative defoliation integrates annual defoliation severity over multiple years and has been found to be closely related to tree growth reduction and mortality estimates (MacLean et al., 2001). Since both balsam fir sawfly and hemlock looper feed on multiple age-classes of host tree foliage in a given year, Iqbal and MacLean (2010) developed a method to estimate cumulative defoliation from annual aerial survey estimates. Three cumulative defoliation severity classes occurred for both insects, and were significantly different (Iqbal and MacLean, 2010): (i) 1 year of moderate defoliation, (ii) 1 year of severe defoliation, and (iii) 2–3 years of moderate-severe defoliation. These classes are shown in Fig. 1 as 'moderate', 'severe', and 'multiple years'.

A total of 56% of the District 15 landbase was defoliated by balsam fir sawfly from 1996 to 2008, while only 12% was defoliated by hemlock looper (Table 1). Much of the balsam fir sawfly defoliation occurred over multiple years (39%) during 2001–2005 (40%). No hemlock looper defoliation occurred after 2005 and almost half of the total defoliated area was of low severity.

2.2. Tree/plot level impacts

Tree and plot-level impacts were quantified as growth reduction to defoliation and mortality to defoliation relationships for both hemlock looper (Iqbal et al., 2011a) and balsam fir sawfly (Iqbal et al., 2011b). Mortality relationships were derived from data for 48 and 67 NLDNR permanent sample plots defoliated during 1996–2008 for hemlock looper and balsam fir sawfly, respectively. A total of 2530 increment cores sampled in 2009 from the above plots were analyzed using dendrochronology techniques to derive