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NOTE

Historical spruce budworm defoliation records adjusted for insecticide protection in New Brunswick, 1965–1992

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INTRODUCTION

The spruce budworm, *Choristoneura fumiferana* Clem. (Lepidoptera: Tortricidae), is arguably the most damaging forest insect in North America's boreal and Atlantic Maritime forests (Hardy et al. 1983). Radial growth (measured at breast height) can be reduced by as much as 75% after several years of severe defoliation (Miller 1977). Mortality of host trees reached 89% (Ostaff and MacLean 1989) and 60% (Cappuccino et al. 1998) in separate outbreaks in Cape Breton, Nova Scotia and Abitibi, Québec, respectively. In Canada, this native defoliator occurs throughout most of the range of white spruce (*Picea glauca* (Moench) Voss), although its preferred host is balsam fir (*Abies balsamea* L. Mill.) (Miller 1963). As a result of their vast spatial extent (Hardy et al. 1986) and impact, spruce budworm outbreaks are potentially the major natural disturbance in Canada's boreal forest (Fleming 2000, Fleming et al. 2002).

Population densities of this native defoliator have exhibited a somewhat regular, approximately 30-40 year cycle over an extensive landscape for at least the last three centuries (Royama 1984; 1992). During outbreaks, larval populations can exceed 1000 per m^2 of host foliage (Ostaff and MacLean 1989). Between these outbreak periods, populations may be so low as to make it difficult to find a single larva among several hundred branches (Royama 1992). Outbreaks occur somewhat synchronously over extensive areas (Royama 1984; Candau et al. 1998; Gray et al. 1999; Williams and Liebhold 2000), but outbreak duration varies regionally from as few as one to as many as 20 years (Candau et al. 1998; Gray et al. 1999).

This combination of economic importance, large spatial extent and cyclic behaviour has made the spruce budworm a popular insect model for investigating various aspects of population dynamics at the landscape scale in recent years. However, this same spatial extent has forced researchers to utilize defoliation records in lieu of the usually preferable population densities (e.g., Candau et al. (1998); Gray et al. (2000); Williams and Liebhold (2000); Gray (2007)). At the landscape scale, estimates of the spatial extent and annual defoliation levels must necessarily come from aerial surveys and sketch mapping because this is the only source of data at these scales. Despite the widespread use of the method (Simpson and Coy 1999), relatively little has been done to evaluate its accuracy (MacLean and MacKinnon 1996). Nevertheless, aerial surveys remain the only method used to collect defoliation data at the large landscape scale.

Researchers who resort to aerially sketched defoliation levels as surrogate data for population levels should be aware that in some jurisdictions the application of insecticide(s) has reduced the estimate of defoliation from what would have occurred without foliage protection. If researchers use defoliation data from multiple jurisdictions, of which one has experienced intensive insecticide application, an unequal bias will be present in a subset of their data. In New Brunswick, aerial application of insecticides approached 50% of the moderately and severely infested areas in many years of the last outbreak and a significant reduction in defoliation was achieved (Webb and Irving 1983; Cadogan 1986). In the work described here, we have addressed this bias in the defoliation data by removing the estimated effect of insecticide application from the defoliation data in New Brunswick. Our objective was to provide a modified data set of "defoliation without protection" in New Brunswick that can be combined with defoliation data from other jurisdictions,

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Table 1. Sources of spray efficacy data in New Brunswick from 1965–1992.

Reference source	Years	Insecticide product[1]	Spray efficacy measurement: Foliage saved (eq.)	Spray efficacy measurement: Population reduction (eq.)	Summary type (A or I)[2]
Macdonald et al. (1968)	1965–1967	DDT; F; P		✓	I
Miller and Kettela (1975)	1968	DDT; F; P		✓	A
Miller and Kettela (1975)	1969–1970	F; P	✓	✓	A
Kettela and Varty (1972)	1971	F	✓		I
Miller and Kettela (1975)	1972–1973	F; P	✓	✓	A
Kettela (1995)	1974–1976	F; T	✓		A
Kettela et al. (1977)	1977	A; F; T	✓		I
Kettela (1995)	1978–1982	A; Bt; F	✓		A
Carter and Lavigne (Annual Reports (1984–1993))	1983–1992	A; Bt; F	✓	✓	I

[1] DDT = dichloro-diphenyl-trichloroethane; F = fenitrothion; P = phosphamidon; A = aminocarb; T = trichlorofon; Bt = *Bacillus thuringiensis* var *kurstaki*

[2] Annual summaries were either for all insecticides without distinction among products (A) or for individual products (I).

where insecticide application rarely reached even 5% of the moderately to severely defoliated areas, with less concern of a "downward bias" existing in the New Brunswick data set.

MATERIALS & METHODS

Digital maps of aerially detected spruce budworm defoliation, and of insecticide spray blocks, 1965–1992, were obtained from the New Brunswick Department of Natural Resources (NBDNR). The defoliation and spray block polygons were temporally and spatially intersected using ArcInfo (ESRI 2006). We characterized the intersection polygons with the midpoint of the NBDNR defoliation category (negligible (≤10%) = 5%; light (11–30%) = 20%; moderate (31–70%) = 50%; severe (71–100%) = 85%), and the insecticide used, if included in the original data set.

Where spray efficacy was reported as percent foliage saved,

$$efficacy_{FS} = \frac{\%defoliation_{untreated} - \%defoliation_{treated}}{\%defoliation_{untreated}} \text{ x } 100\%$$

the defoliation category midpoint was increased by the reported $efficacy_{FS}$ for the year×insecticide product×dosage combination. Where spray efficacy was reported as percent reduction in larval population,

$$efficacy_{LR} = \frac{\#larvae_{untreated} - \#larvae_{treated}}{\#larvae_{untreated}} \text{ x } 100\%$$

the defoliation category midpoint was increased by 35% if the reduction in larval population exceeded 74% for the year×insecticide product×dosage combination (Miller and Kettela 1975). Where spray efficacy was reported by either foliage saved or larval reduction, but without distinction among two or more insecticide products or dosages, the average efficacy of all spray blocks in the year was used. See Table 1 for a list of spray efficacy data sources and insecticide products. All spray efficacy data are from measurements taken on balsam fir.

Fig. 1. Reported spruce budworm defoliation in New Brunswick, 1965–1992. Note that defoliation categories 'negligible' and 'light' have been combined for graphical purposes.

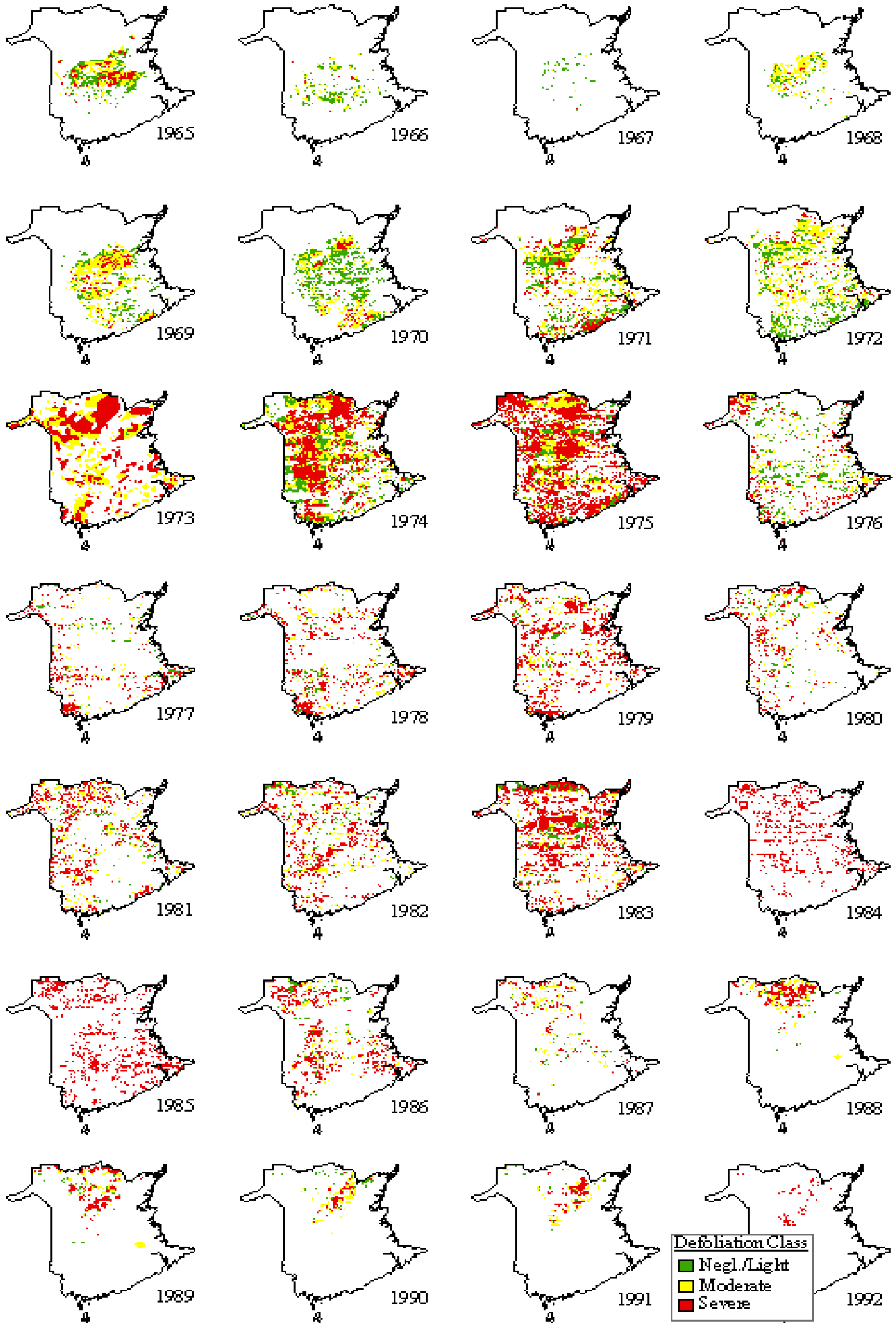


Fig. 2. Estimated spruce budworm defoliation without protection in New Brunswick, 1965–1992. Note that defoliation categories 'negligible' and 'light' have been combined for graphical purposes.

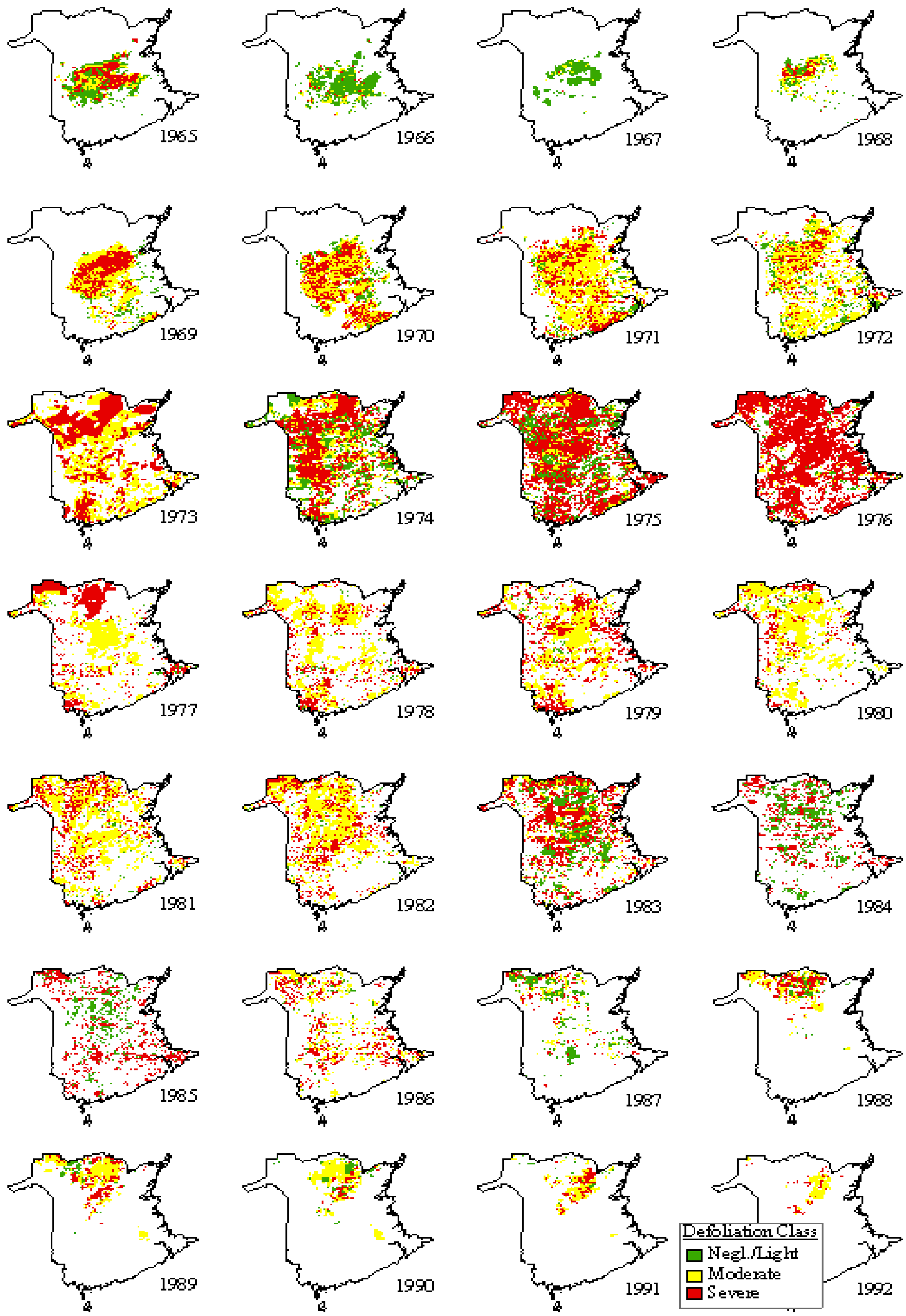
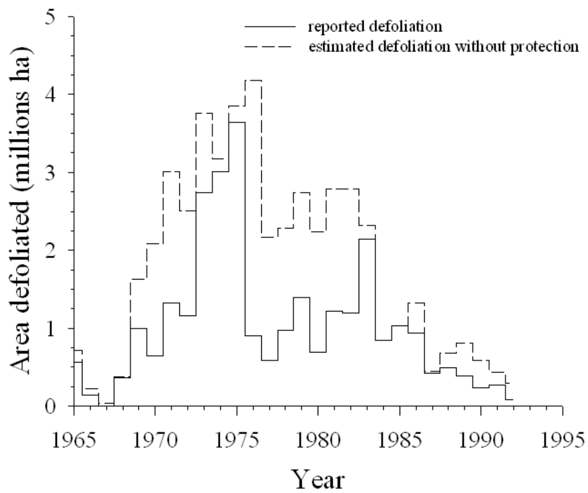


Fig. 3. Comparison of area reported with moderate to severe defoliation and estimated (without protection) in New Brunswick, 1965–1992.



RESULTS AND DISCUSSION

The reported spruce budworm defoliation levels in New Brunswick from 1965–1992, and our estimated "without protection" defoliation levels are contrasted in Figs. 1 and 2. As expected, the area of moderate and severe defoliation was greater in the "without protection" estimates than the reported estimates. Differences are greatest in the years 1976–1982 (Fig. 3) when insecticide application was most extensive.

Our "without protection" defoliation estimates do not take into account one effect of insecticide applications: the stand mortality that would have occurred from high levels of cumulative defoliation in the absence of protection. An uncontrolled spruce budworm outbreak in Cape Breton Island during 1976–1984 caused considerable spruce-fir mortality (MacLean and Ostaff 1989). Removing this effect of protection would be done by eliminating some observations of defoliation towards the end of the outbreak, as some stands with reported defoliation may have previously succumbed to the repeated defoliation had there been no protection. However, we know of no reliable method to remove this effect.

Nonetheless, our "without protection" estimates of defoliation are a useful modification to the existing long-term, spatially extensive data set that has been used by researchers to study aspects of population dynamics and/or spatial ecology at the landscape level. For example, Williams and Liebhold (2000) used historical levels of spruce budworm defoliation, as "a proxy for abundance", from Manitoba, Ontario, Quebec, Newfoundland and Labrador, New Brunswick, and Maine, 1945–1988, to examine how spatial scale may affect the detection of density-dependence. The binary classification of their data (<30% or ≥30% defoliation) was no doubt affected by insecticide application in New Brunswick. Gray (2000) and Candau (1998) restricted themselves to areas outside of New Brunswick where insecticide application was never extensive. But Gray and MacKinnon (2006) recognized the benefit of reducing the bias in New Brunswick when they examined outbreak patterns in eastern Canada. Gray (2007) used the modified data set when examining the effects of climate on duration and severity of outbreaks.

Our spatially-referenced "without protection" defoliation estimates are available in ArcInfo export format at http://www.atl.cfs.nrcan.gc.ca/internal/dgray/index.html and can be used by researchers who want to combine defoliation estimates from New Brunswick with other jurisdictions where insecticide applications were not extensive.

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