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EFFECTS OF MIMIC® BIOINSECTICIDE ON THE SPECIES DIVERSITY OF NON-TARGET FOREST LEPIDOPTERA IN AN OPERATIONAL SPRUCE BUDWORM (LEPIDOPTERA: TORTRICIDAE: *Choristoneura fumiferana* Clem.) SUPPRESSION PROGRAM IN NORTHWESTERN MANITOBA

BY

Diana E. Saunders

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of

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Abstract

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Effects of Mimic® Bioinsecticide on the Species Diversity of Non-target Lepidoptera in an Operational Spruce Budworm (Lepidoptera: Tortricidae: *Choristoneura fumiferana* Clemens) Suppression Program in Northwestern Manitoba.

Major Professor: A.R. Westwood

A new biochemical insecticide, Mimic® (Dow Agrochemicals), has recently been registered in Canada for the control of lepidopteran defoliators in forest ecosystems. The active ingredient, tebufenozide, mimics the insect molting hormone, 20-hydroxyecdysone, in larvae of some species of Lepidoptera inducing a premature molt, causing death. To date there has been only one published study on the effects of an operational spray program that has addressed the effects of Mimic® on non-target Lepidoptera in hardwood forest, and none in the boreal forest. Butler *et al.* (1997) found significant reductions in richness and abundance of non-target, larval macrolepidoptera of a hardwood forest following Mimic® application for control of gypsy moth, *Lymantria dispar* (L.). In 1999 and 2000, Manitoba Conservation applied Mimic® to areas of the boreal forest in northwestern Manitoba as part of an operational spruce budworm suppression program. In 2000 and 2001, moths and larvae were collected from twelve study sites within the spray area to determine the effect of Mimic® on spruce budworm and non-target Lepidoptera. Three 70 m^2 plots were within spray blocks sprayed once with 70g AI in 2.0 L/ha in June of 1999; three 70 m^2 were within spray blocks sprayed once in June of 2000 and six were in unsprayed areas. Variables measured within the study sites included percent defoliation for1999 and 2000, spruce budworm larvae per 45-cm branch, spruce budworm adults, number of understorey larvae, number of macrolepidoptera moths, and moth species richness, log series alpha diversity, evenness, and Berger-Parker dominance. A total of 178 macrolepidoptera species were collected in Luminoc® light traps over two field seasons, with 36 species making up 75% of the total catch and being considered common to both sprayed and unsprayed sites. Mimic® significantly reduced spruce budworm populations in sprayed plots versus unsprayed plots. Significant spray effects on number of moths and species richness were found at one year post spray for those sites sprayed in 1999. There were no significant spray effects on non-target Lepidoptera species diversity in either year of the study. Even spray plots that appeared to have been sprayed more effectively did not have significantly lower numbers of moths, species richness or diversity than the unsprayed plots. While 36 of the common non-target species appeared unaffected, two species from the Family Arctiidae and one from the Family Geometridae were consistently less abundant in sprayed plots in both sampling seasons 2000 and 2001. These results, along with Butler's (1997) study, indicate that aerial applications of this insecticide may have a negative impact on certain non-target lepidopteran species but not on overall diversity.

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CHAPTER I

INTRODUCTION

Large scale aerial spraying of insecticides to control defoliating caterpillar pests (e.g. spruce budworm, *Choristoneura fumiferana* (Clemens); jack pine budworm, *Choristoneura pinus* Freeman; and forest tent caterpillar, *Malacosoma disstria* Hübner) in Canada's forests has been used as a management tool to slow the spread of these pests and to prevent tree mortality for over five decades (Armstrong & Ives 1995). In Manitoba, insecticides have been employed to protect commercial timber supplies, preserve parks and natural areas from large-scale tree mortality, and to protect areas used for recreation and cottage subdivisions.

A new biochemical insecticide, Mimic® (Dow Agrochemicals), has recently been registered in Canada for the control of lepidopteran defoliators in forest ecosystems. Mimic® has been tested in Manitoba since the mid 1990s and the first large scale commercial applications began in Manitoba in 1997. Over 100,000 hectares of forest have been experimentally and operationally sprayed with Mimic® in Manitoba since 1994 and the product has also been applied under experimental permits in other provinces during the last several years. Manitoba is the only area in Canada with sufficient Mimic® usage to date to carry out an intensive investigation on the non-target effects of this product when used at a commercial scale. In 1999 and 2000, Manitoba Conservation applied

Mimic® to areas of the boreal forest in northwestern Manitoba as part of an operational spruce budworm suppression program.

The use of Mimic® is part of a trend that began in the late 1970s and early 1980s to move away from broad-spectrum synthetic insecticides, which killed a wide variety of forest insects, to narrow spectrum biologically based products, which are more pest specific and environmentally acceptable (Armstrong & Ives 1995). By the mid 1980s, *Bacillus thuringiensis* Berliner var. *kurstaki* (Btk), a naturally occurring insect bacterium, had replaced synthetic insecticide use to suppress defoliating caterpillars in Canadian forests (Bendall *et al.* 1986; Miller 1990; Miller 1992; Nealis *et al.* 1992; Otvos & Vanderveen 1993; van Frankenhuyzen 1993; Barber *et al.* 1995). By 1996, Btk was the only product registered in Canada for aerial application to suppress defoliating forest pests (Westwood 1997, 1998). Past performance of Btk has been erratic in certain instances across Canada and there have been ongoing efforts to increase its reliability and to search for more efficacious products with a similar narrow spectrum of activity (Westwood 1997,1998).

The active ingredient in Mimic®, tebufenozide, mimics the insect molting hormone, 20-hydroxyecdysone, in some larval insects and induces a premature molt. It appears to provide higher levels of pest insect control than *Btk*, and thus provides better protection to trees (Retnakaran 1995; Westwood 1997; Westwood 1998). In Canada, Mimic® has been tested mostly against spruce budworm and proved to be very effective (Smagghe & Degheele 1994).

Mimic's® narrow spectrum of activity make it an attractive alternative to other insecticides for forest insect pest suppression. However, limited studies have indicated that susceptible non-target Lepidoptera species might also be adversely affected. The widespread use of tebufenozide in the suppression of spruce budworm and other forest insect defoliators could lead to undesirable ecological effects. In forests, indiscriminate reduction of immature Lepidoptera could have a detrimental effect on trophic pathways and food chains.

Unlike Btk, there have been relatively few attempts to document the effects of tebufenozide on non-target lepidopteran communities under field conditions. Morris *et al.* (1975), Miller (1990, 1992), Sample *et al.* (1993), and Johnson *et al.* (1995) have all reported significant reductions in both species abundance and richness of non-target Lepidoptera following applications of Btk.

Only one published study has addressed effects of Mimic® on non-target Lepidoptera. Butler *et al.* (1997) found significant reductions in richness and abundance of non-target, canopy-dwelling larval macrolepidoptera of a hardwood forest following Mimic® application for control of gypsy moth, *Lymantria dispar* (L.). It is essential that the effect of Mimic® on non-target lepidopteran diversity in the boreal forest be carefully analyzed and understood. No study has been published to date that examines the effects of Mimic® (when applied under operational conditions) on non-target moths in Canada's northern boreal forest. This study tests the null hypothesis that Mimic application does not reduce species diversity of non-target moths in sprayed areas of boreal forest when compared with unsprayed areas.

CHAPTER II

LITERATURE REVIEW

2.1 - Boreal Forest Characteristics

The boreal forest covers over 2.6 x 10^6 km^2 in Canada forming a continuous, primarily coniferous belt from Newfoundland and Labrador to the Rocky Mountains and Alaska (Danks & Foottit 1989). In the boreal forest of northwestern Manitoba, the summers are short and warm and the winters long and cold, with an annual mean temperature of 0 °C; a mean summer temperature (June to August) of 16 °C; and a mean winter temperature (September to May) of –5.5 °C (Environment Canada, 2003). The growing season is short with approximately 157 frost-free days accumulated between June and September. The average annual precipitation is approximately 46 cm, with approximately 21 cm in rain between June and August and approximately 15 cm in snowfall (Environment Canada, 2003).

There is heterogeneity at the local scale of vegetation and this variation recurs consistently throughout the boreal forest (Danks & Foottit 1989) creating a considerably diverse ecosystem (Graham & Jain 1998).

Disturbance is increasingly recognized as the driving ecological force in all forest ecosystems (Pickett & White 1985) leading to and maintaining variation, especially in boreal ecosystems (Shugart *et al.* 1995). Barnes *et al.* (1998, p. 410) interpret a disturbance as "any relatively discrete event in time that disrupts ecosystems, their composition, structure, and function". Disturbances, such as fire, insect outbreaks and disease, are natural factors in the boreal forest whose effects in disrupting forest stand structure have long been incorporated in species' adaptations and ecosystem dynamics (Sousa 1984).

In the boreal forest a vegetation mosaic leading to plant and animal diversity is primarily the result of wildfires burning over diverse plots (Bonan & Shugart 1989). Wildfires play an important role in shaping the structure and composition of boreal forests creating a mosaic of conditions that allow a mixture of uneven-aged tree species to thrive (Graham & Jain 1998).

In some areas of the boreal forest, fire frequency is low and *C. fumiferana* (spruce budworm) outbreaks are considered the most important disturbance. In the last 70 years in Canada, 48% of the boreal forest was disturbed by fire, 39% by insects (mainly spruce budworm in eastern Canada) and 10% by logging (Bergeron *et al.* 1998). Fires (Payette 1992) and outbreaks of spruce budworm (Bergeron *et al.* 1998) are widespread disturbances in the eastern Canadian boreal forest. These disturbance regimes are not independent, and changes in one regime can affect the others (Bergeron *et al.* 1995).

2.2 - Spruce Budworm

The eastern spruce budworm, *C. fumiferana*, is the most important defoliator of coniferous forest trees in North America (Talerico 1984; Fleming 1990). Probably no species of Lepidoptera has been studied more intensively (Powell 1995). It is native to North America and a principal pest of balsam fir, *Abies balsamea* (Linnaeus) Miller, white spruce, *Picea glauca* (Moench) Voss, black spruce *Picea mariana* (Mill.) BSP and red spruce, *Picea rubens* Sargent (Mattson *et al.* 1988). The impact of the spruce budworm can be considerable, including growth loss by affecting photosynthesis, top kill, cone and seed mortality, increasing susceptibility of trees to secondary factors and widespread tree mortality (Kulman 1971; MacLean 1980). Any spruce-fir stand in eastern and central North America is susceptible to spruce budworm feeding (Mattson *et al.* 1988). Spruce budworm outbreaks have more effect on structure and function of the spruce-fir forests of eastern Canada than virtually any other factors (Baskerville 1975a; MacLean 1985, 1990).

Choristoneura fumiferana occupies forests of the east and central parts of the continent, associated mostly with the boreal forest, but also with the Great Lakes-St. Lawrence and Acadian forest regions (Rowe 1972). The range of *C. fumiferana* coincides almost completely with the range of its major hosts, balsam fir and red and white spruce (Mattson *et al.*1988; Sanders 1991).

Spruce budworm larval stages mine old needles, and feed on buds and the current year's needles from early May to late June. Balsam fir trees often die following three or four years of severe defoliation. White spruce, which is more tolerant of budworm feeding, may die after five or six years of severe defoliation (Ives 1974; Manitoba Conservation 2003).

The spruce budworm is univoltine (one generation per year), has six larval instars, and over winters as a diapausing 2nd instar larva (Morris 1963; Mattson *et al.* 1988). Emphasis is put on the feeding behaviour of spruce budworm larvae because the effectiveness of many of the insecticides used in management protocols depends on the ingestion of the active ingredient (van Frankenhuyzen 1990). The last three of the six larval instars feed openly on the rapidly expanding shoots and are usually the targets for control (Prebble 1975). Eighty to ninety percent of total larval food consumption occurs during the sixth-instar larval stage so depletion of current-year foliage is unlikely to happen prior to the budworm's sixth instar (Retnakaran1983; Carisey & Bauce 1997).

2.2.1 – Outbreaks

Populations of spruce budworm have reached outbreak levels on a more or less regular basis over extensive areas of northeastern and north central North America for at least the past three centuries (Blais 1954, 1965, 1981; Brown 1970; Kettela 1983; Morin *et al.* 1993). Periodic outbreaks of the budworm in eastern Canada are known to have occurred since the early 1700s (Blais 1965; Blais 1968; Blais 1983; Stedinger 1984). The most extensive and destructive outbreaks have occurred in the Maritime Provinces (New Brunswick, Nova Scotia, Newfoundland), Quebec, Ontario, Maine and the Great Lakes states (Harvey 1985; Mattson *et al.* 1988).

Outbreaks have two dimensions: time period between outbreaks and the geographical extent of the outbreak. Generally, when no treatment is applied, outbreaks last from five to fifteen years and non-outbreak periods average about 35 years in eastern Canada (Blais 1983, 1985a; Simmons *et al.* 1984; Solomon 1991).

Outbreaks seem to be controlled by a complex interaction of factors (Morris 1963; Solomon 1991; Sanders 1995). It appears that the natural enemies

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Of

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MASTER'S THESIS/PRACTICUM FINAL REPORT

The undersigned certify that they have read the Master's Thesis/Practicum entitled:

EFFECTS OF MIMIC® BIOINSECTICIDE ON THE SPECIES DIVERSITY OF NON-TARGET FOREST LEPIDOPTERA IN AN OPERATIONAL SPRUCE BUDWORM (LEPIDOPTERA: TORTRICIDAE: **Choristoneura fumiferana** Clem.) SUPPRESSION PROGRAM IN NORTHWESTERN MANITOBA

submitted by

Diana E. Saunders

in partial fulfillment of the requirements for the degree of

Master of Science

The Thesis/Practicum Examining Committee certifies that the thesis/practicum (and oral examination if required) is:

APPROVED

(Approved or Not Approved)

[X] **Thesis**

[ ] **Practicum**

Advisor: Richard Westwood

William P. Kempler

N. J. Holliday

K. Kenward

Date: 20 VIII 03

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of the budworm operate within a complex system along with other factors such as the composition, density and maturity of the forest (MacLean 1980; Mattson *et al.* 1988; Bergeron *et al.* 1995; Su *et al.* 1996; MacLean & MacKinnon 1997; Bergeron & Leduc 1998) and variations in weather (Wellington *et al.* 1950; Greenbank 1956; Ives 1974; Hardy *et al.* 1983; Blais 1985b; Mattson *et al.*1988). There are variations in the influence of the budworm on the trees and the subsequent reverse action of the food supply upon the budworm population (Blais 1985b; Mattson *et al.*1991). Outbreaks are also influenced by the long-distance movements of great numbers of adults (Greenbank *et al.* 1980). These interactions are further complicated by the use of insecticides and forest management practices designed to suppress outbreaks (Solomon 1991).

Outbreaks may start in epicenters, or foci, from which they spread by moth migration or even larval dispersal into neighboring budworm-free forest (Hardy *et al.* 1983; Blais 1985b). Others believe the spruce budworm is a cyclical outbreak species where populations go through more or less regular cycles or oscillations (Royama 1984; Wallner 1987; Régnière & Lysyk 1995).

The last countrywide spruce budworm infestation in Canada ended in the late 1980s but pockets have continued at very high intensities in Manitoba and Saskatchewan and to a lesser extent northern Alberta during the 1990s (Knowles, pers.com.). In northwestern Manitoba, the most recent spruce budworm outbreak began in 1995 and has continued to present. In 2002, approximately 111,480 hectares of spruce/fir forests experienced moderate to severe defoliation by spruce budworm in Manitoba (Manitoba Conservation 2003).

2.3 - Spruce Budworm Management

The spruce budworm is one of the most destructive forest insects in North America and consequently the target of most of the insecticides that are applied to boreal forests in Canada (Cadogan *et al.*1997). The objective of forest protection spraying in Canada is to prevent or reduce damage to the trees and forest stand (Prebble 1975).

Aerial insecticide applications, particularly the bacterial insecticide Btk and tebufenozide (Mimic®), are registered in Canada for managing spruce budworm. Decisions to implement spruce budworm control activities are usually based upon assessments of stand susceptibility (the probability that a stand will be attacked by the spruce budworm) and vulnerability (the probability of tree mortality resulting from a given level of budworm attack) to spruce budworm and assessments of spruce budworm numbers (Mott 1963; MacLean 1980; Lynch *et al.* 1985). These assessments are used to determine whether a stand should be sprayed in the current or next year and also to determine areas for protection, harvesting or salvage (Ennis & Caldwell 1991).

In general, in commercial forestry, the only options when faced with a budworm outbreak are: 1) to prevent tree mortality by insecticide spraying, 2) to do nothing and allow the timber to die and deteriorate, or 3) to embark upon presalvage (before mortality) or salvage (after mortality) programs in the affected stands (MacLean 1980).

Spruce budworm suppression programs usually target 4th and 5th instar larvae in order to lower levels of defoliation. Spruce budworm larvae are typically at these stages in early June in northwestern Manitoba. Non-target Lepidoptera species are most susceptible to Mimic® if their larval feeding periods are within this timing window of application. Sometimes adverse weather conditions restrict insecticide applications to 6th instar larvae (mid to late June) and defoliation protection is sacrificed for population suppression (Volney & Cerezke 1992).

Since 1980, there has been a dramatic increase in eastern Canada in the use of microbial insecticides based on the bacterium Bt (Albert 1991). There was an increase from 1% of the total area treated with Btk for *C. fumiferana* in 1979 to 52% in 1985 and 63% in 1986 (Morris *et al.* 1986; Hulme 1988; Ennis & Caldwell 1991; Sanders 1995).

Bacillus thuringiensis is a naturally occurring spore-forming bacterium that produces a crystalline toxin during sporulation (Angus 1971; Fast and Dimond 1984). Btk is toxic to larvae of Lepidoptera (Fast & Régnière 1984). While the mode of Btk gives it considerably more specificity than the more broad spectrum insecticides like diflubenzuron (Dimilin®) (Martinat *et al.* 1988, 1993; Sample *et al.* 1995; Butler 1995b), non-target Lepidoptera are also directly susceptible to Btk. Miller (1990) noted that Btk treatments for the gypsy moth in western Oregon reduced species richness and larval abundance for up to two years within a guild of native, non-target Lepidoptera feeding on oak. In 1992, Miller also observed