

An integrated management system for the Douglas-fir tussock moth in southern British Columbia

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Abstract

An integrated, long-term system to detect and treat infestations of Douglas-fir tussock moth in the Southern Interior of British Columbia was successfully implemented between 1984 and 1999. All aspects of recent research were implemented during an integrated control program conducted between 1991 and 1993. Many localized, incipient outbreak populations of tussock moth were detected prior to significant defoliation and treatments of a nuclear polyhedrosis virus (NPV) were applied. The application of NPV to sites with increasing tussock moth populations effectively terminated the localized infestations. The combination of early detection and application of NPV greatly reduced damage when compared to previous tussock moth outbreaks. Other program components were evaluated during the outbreak including: 6-trap cluster pheromone monitoring sites and singlet pheromone monitoring sites that correctly predicted outbreak level tussock moth populations; comparison between stored and new virus; comparison between virus formulations (Virtuss[®] versus TM Biocontrol-1[®]); evaluation of alternate swath versus entire coverage application of virus; and reduced dosages of virus. All virus trials were effective in reducing tussock moth populations to pre-outbreak levels. Future research and applications of the methodology are discussed.

KEYWORDS: *biological control, defoliation, Douglas-fir tussock moth, forest pest management, interior Douglas-fir, nuclear polyhedrosis virus.*

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Introduction

Douglas-fir tussock moth, *Orgyia pseudotsugata* McD., is a cyclical defoliator of dry-belt Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, in the South-central Interior of British Columbia. This insect feeds primarily on interior Douglas-fir, but other coniferous species may be fed upon during outbreaks, particularly in mixed stands when Douglas-fir is a leading component of the stand.

Adult moths emerge from their cocoons and mate from August through September (Beckwith 1978). The flightless females attract males by emitting a sex pheromone, (Z)-6-heneicosen-11-one (Daterman et al. 1976). Once mated, the female lays her eggs in a large mass on the empty cocoon. Eggs overwinter and larvae hatch in late May or early June and begin feeding on new foliage. Male larvae normally pass through five instars and females go through six, before pupation in early August (Beckwith 1976, 1978).

Endemic populations of Douglas-fir tussock moth (DFTM) are present in low-elevation, historically affected Douglas-fir stands. However, insect population density can increase rapidly and the resulting extensive defoliation can cause growth loss, top kill, and tree mortality. Outbreaks are cyclical and occur approximately every 10 years (Figure 1; Shepherd and Otvos 1986).

Public concerns over tussock moth outbreaks are significant, as historic outbreak areas in British Columbia are located in areas where urbanization is most prevalent.

Outbreaks begin as small patches. In subsequent years, these patches may coalesce as feeding larvae disperse (Shepherd 1980, 1994). After 1–5 years of defoliation, populations in a stand collapse (Mason 1974; Shepherd 1994). The collapse has primarily been attributed to a naturally occurring nuclear polyhedrosis virus (NPV). Other natural enemies, such as parasites and predators, may also play a role in the collapse of tussock moth outbreaks (Torgersen and Dahlsten 1978). The greatest percentage of tree mortality caused by tussock moth defoliation occurs during the first and second years of the outbreak cycle (Alfaro et al. 1987). During an outbreak between 1981 and 1984 in South-central British Columbia, a total of 26 000 ha was defoliated, with up to 30% mortality in severely affected stands (Ross and Taylor 1983). Following the collapse of an outbreak, affected stands are also at risk to Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopk., which builds up and kills trees weakened by tussock moth defoliation (Shepherd et al. 1984a).

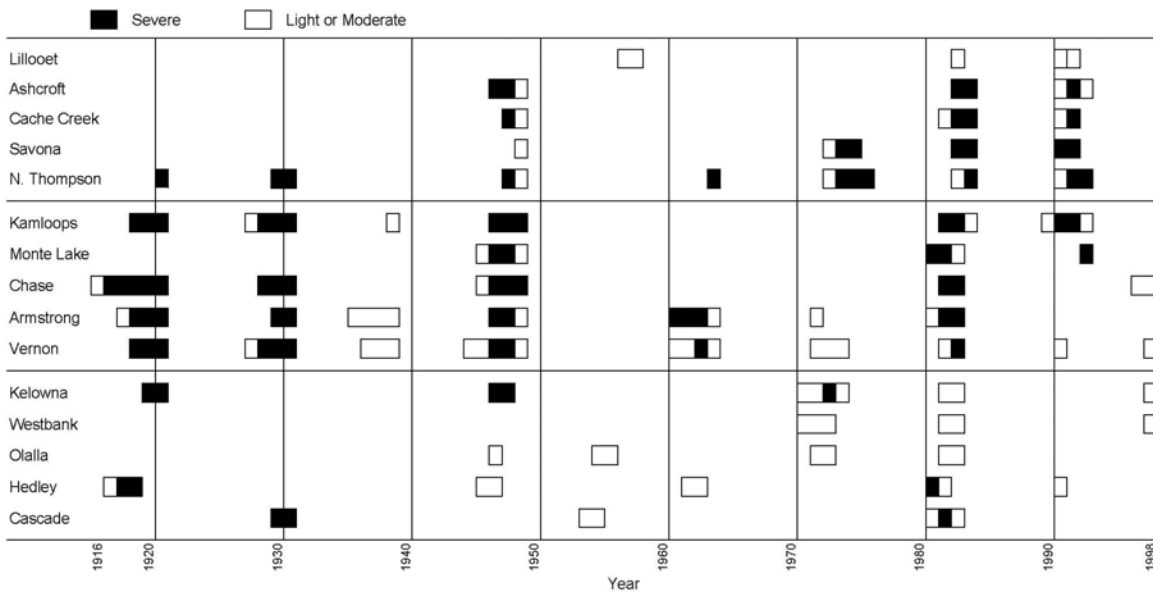


FIGURE 1. Histogram of Douglas-fir tussock moth outbreak periods from 1916 to 1998 by geographical location in south central British Columbia (taken, in part, from Shepherd and Otvos 1986).

Tussock moth outbreaks affect a variety of resource values. Tree growth loss and mortality reduce timber values in outbreak areas. Other values such as aesthetics, property values, and human health are adversely affected. Tussockosis, an allergic reaction to tussock moth larval setae (Perlman et al. 1976) affects some people who come in contact with the insect.

Public concerns over tussock moth outbreaks are significant, as historic outbreak areas in British Columbia are located in areas where urbanization is most prevalent (Figure 2).

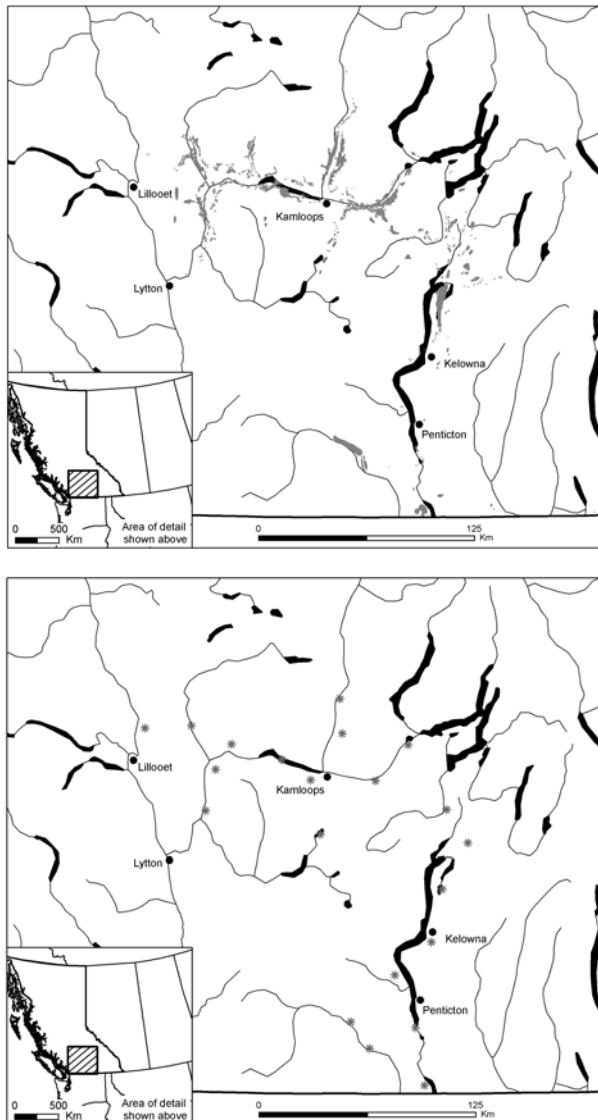


FIGURE 2. Historic outbreak areas of Douglas-fir tussock moth in south central British Columbia (upper map) and locations of permanent 6-trap cluster pheromone monitoring sites (lower map).

Prior to the 1980s, few tools were available for management of tussock moth outbreaks. Detection of outbreaks relied on aerial surveys but by the time defoliation was observed, most damage had occurred and application of insecticide would not have prevented losses. Further, few insecticides were registered for use against tussock moth and by the 1980s, chemical insecticides were not considered suitable for widespread use, particularly in urban or populated areas. Trials with biological insecticides, such as *Bacillus thuringiensis* var. *kurstaki*, were variable in effectiveness, often not providing adequate control of tussock moth (Shepherd 1980; Cook 2003).

The BC Ministry of Forests and Range (MFR) was interested in developing operational management tools to reduce losses caused by the tussock moth. Furthermore, landowners in the area affected by the 1981 outbreak strongly advocated that the provincial government deal with future infestations, and prevent extensive tree mortality which would result in further losses of timber and property values.

A substantial research effort was undertaken by the Canadian Forest Service (CFS) and the United States Department of Agriculture, Forest Service (USFS) in co-operation with the MFR, in the 1970s and early 1980s, to develop new management approaches for DFTM. A sex pheromone for tussock moth was identified (Daterman et al. 1976) and potential biological insecticides were tried with varying success (Stelzer et al. 1975). Additional large-scale trials of chemical and biological insecticides were also carried out jointly by the USFS and CFS (Shepherd 1980).

Research carried out in British Columbia during the 1981–1984 tussock moth outbreak provided or refined the tools necessary for effective management. These tools included monitoring of moth populations with pheromones to detect increasing populations prior to noticeable defoliation (Shepherd et al. 1985a), survey methods to forecast levels of defoliation (Shepherd et al. 1984a), and a use strategy for NPV to control tussock moth outbreaks before significant damage occurred (Shepherd et al. 1984b). Individual research findings were consolidated and an integrated management system for tussock moth was proposed (Shepherd and Otvos 1986; Otvos and Shepherd 1991). After the collapse of the DFTM outbreak in the early 1980s, the MFR then implemented an operational management program, which incorporated the above findings.

This paper begins by describing the administrative and operational aspects of the program necessary for early detection of DFTM. We then describe new operational research projects undertaken to improve detection, application of virus, and stand-level damage assessments. We conclude by documenting how the successful integration of research and operational practices can effectively reduce damage caused by DFTM.

Operational program implementation

After the collapse of the 1981–1984 outbreak and the successful conclusion of research conducted by MFR, CFS, and USFS, a proactive program to reduce future losses due to tussock moth outbreaks was initiated by the MFR and CFS. The following administrative and operational issues were addressed.

Administrative

- NPV was registered for use against the Douglas-fir tussock moth. Canadian registration was obtained in 1987 for virus formulations produced by the CFS (Virtuss®) and by the USDA Forest Service (TM Biocontrol-1®; Otvos and Shepherd 1991). The Canadian registration allowed use of the virus by provincial and federal agencies only.
- A stock of Virtuss® sufficient to treat 2000 ha was obtained from the CFS and an additional 8000 ha equivalents of TM Biocontrol-1® were obtained from the USDA Forest Service, and kept in storage at -2°C.
- Information material was developed and distributed to maintain public awareness of tussock moth-related survey results and planned treatments.

Operational

- High-hazard stands were identified based on areas of historic defoliation, forest type, and suitable climatic regime (Shepherd et al. 1985a; Shepherd and Otvos 1986; Shepherd 1994). High-hazard stands are located in the dry, relatively warm interior Douglas-fir and ponderosa pine ecosystems with a history of tussock moth outbreaks.

- Twenty-one permanent pheromone-monitoring sites were identified; placement and retrieval of traps were conducted annually each June and October, respectively. The permanent sites were located throughout the range of high-hazard stands (Figure 2). These sites comprised six pheromone traps each, and were intended to detect low levels of tussock moth and provide early detection of general population increases.
- Additional sites were identified for supplemental pheromone trapping. When an increasing population was noted at permanent trap sites, single traps were placed between sites in areas of concern to provide further information about population increases and more specific information as to where to conduct egg mass surveys. Sites were chosen as follows:
 - a) Fill-in areas between permanent trapping locations;
 - b) Additional sites in high-hazard stands; and
 - c) Areas of concern (i.e., recreation, wildlife, forestry, and public health) within a high-hazard area.

The objectives of the program were to: 1) detect increasing populations of tussock moth at an early stage; 2) locate and delineate building populations prior to visible defoliation; 3) apply NPV to sites expected to sustain unacceptable levels of damage; and 4) ensure a co-ordinated program that would respond quickly and effectively to a developing outbreak. Figure 3 illustrates expected population trends during a tussock moth outbreak and indicates critical times for management actions.

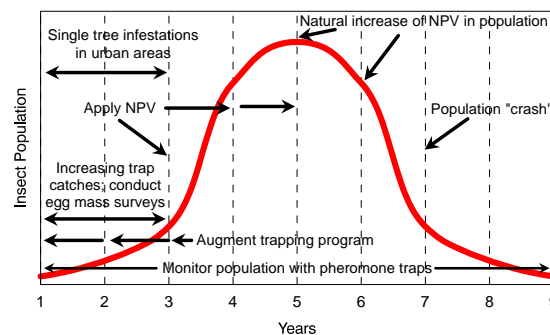


FIGURE 3. Douglas-fir tussock moth population trends in a typical outbreak period and critical management actions.

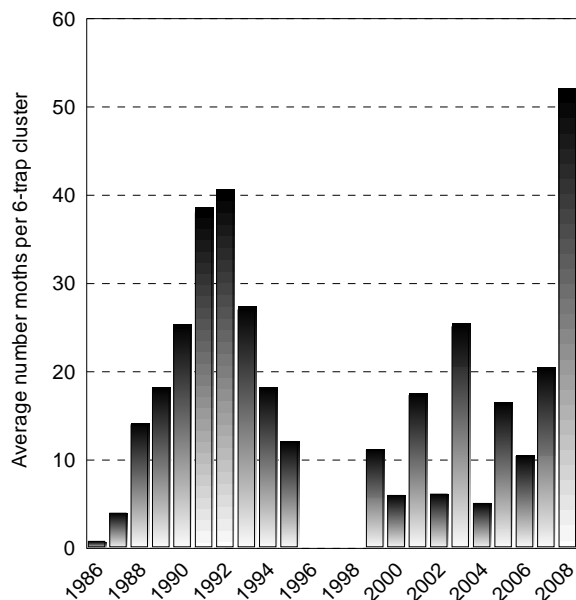
Early detection and suppression of Douglas-fir tussock moth: 1984–1994

Pheromone trapping

During the non-outbreak phase of the Douglas-fir tussock moth (Figure 3), there is no visible defoliation and insects are scarce. A combination of factors including climate, host resources, and the level of natural mortality agents is thought to trigger increases in tussock moth populations (Mason 1974). In order to predict future damage and minimize impacts, a method of annually monitoring population levels is necessary.

The pheromone monitoring system developed by Shepherd et al. (1985a) was established after the collapse of the 1981–1984 tussock moth outbreak. Each year, clusters of six pheromone traps per site were set out in early summer prior to male moth emergence, and retrieved in October after the completion of the flight period (Figure 4).

Few moths were caught at these monitoring sites between 1984 and 1987. In 1987, moth populations increased at sites in the Kamloops, Merritt, and Vernon areas (Figure 4). An additional 250 supplemental single trap sites were established in 1988 by the MFR to further delineate incipient outbreaks (Figure 4).



Egg mass surveys

Egg mass surveys commenced in susceptible stands when 20–25 moths were caught for two consecutive years at nearby 6-trap sampling sites (Shepherd et al. 1985a), or in any of the 250 additional trapping sites. Prioritization of stands for egg mass surveys was based upon trap catches (highest to lowest), historic outbreak records, stand hazard, and management objectives. All sites with trap catches exceeding the threshold were surveyed. There were three steps involved in ground identification and delineation of tussock moth population centres:

- 1) An informal walk-through of susceptible stands near the pheromone trapping site identified where the insect population was concentrated;
- 2) When increasing densities of egg masses were noted, a more systematic, grid-style survey of the area was done to locate localized pockets of egg masses; and
- 3) Sequential egg mass surveys (Shepherd et al. 1985b) were then conducted to provide an estimate of expected severity of defoliation.

Egg mass ground surveys were done from 1988 through 1990 in areas west of Kamloops. Ground surveys were conducted in susceptible forest types near trapping sites or in areas of concern. Forest edges and large, open-grown veteran Douglas-fir were emphasized during the preliminary surveys as these specific scenarios generally had higher populations of

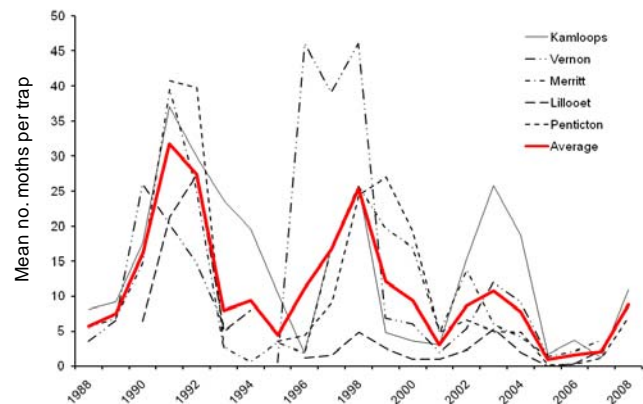


FIGURE 4. The left graph shows the mean number of male Douglas-fir tussock moths caught annually in the 21 6-trap clusters (1986–2008). The right graph shows the mean number of male Douglas-fir tussock moths caught in 250 singlet trap sites throughout the region (1988–2008).

DFTM early in the outbreak cycle. Surveys were conducted systematically throughout the stands and, if egg masses were found, sequential egg mass surveys (Shepherd et al. 1985b) were conducted to further define localized high population areas and obtain defoliation predictions. No infestations were identified in 1988 or 1989, although single isolated egg masses were found. Ground surveys conducted in the fall and winter of 1990 identified the first incipient populations suitable for treatment.

Virus treatments

The objective of the 1991–1993 Douglas-fir tussock moth program was to identify incipient infestations early in the outbreak cycle (Figure 3) and treat with a virus to cause the collapse of the population, thus protecting stands from severe damage. Both the Canadian and US virus formulations, Virtuss® and TM Biocontrol-1®, were used in this program.

Several comparisons using the two virus formulations, Virtuss® and TM Biocontrol-1®, were conducted over the course of the outbreak, including:

- 1) Stored (10 years in storage) versus newly produced Virtuss®;
- 2) Virtuss® versus TM Biocontrol-1® at full (standard) dosage rate;
- 3) Alternate swath application; and
- 4) Reduced dosage rate (2/3 application rate).

Virtuss® and TM Biocontrol-1® contain a minimum of 2.0 x 10¹⁰ polyhedral inclusion bodies (PIBs) per gram and 2.68 x 10⁹ PIBs per gram, respectively. The two products were applied at full- and 2/3-dosage rates as shown in Table 1 and in alternate swaths (rather than full block coverage).

TABLE 1. Application dosage rates for Virtuss® and TM Biocontrol-1®.

Product	Treatment rate per ha	
	Full dosage (g)	2/3 dosage (g)
Virtuss®	12.5	8.3
TM Biocontrol-1®	4.5	3.5

Both products are registered at 2.5 x 10¹¹ PIB/ha for the control of the Douglas-fir tussock moth in Canada. Individual egg masses were marked and monitored at each site to determine larval hatch. The optimal time for virus application is after larvae have hatched and started to disperse from egg masses. All treatments were applied in late May or early June (Table 2).

Preparation and mixing of each of the virus applications was done on site as follows:

- A sufficient quantity of water from municipal sources was stored on site for 24 hours to allow the escape of chlorine and other additives;
- One part food-grade molasses was added to three parts water by volume (as a sticker);
- Orzan® (or equivalent sunscreen containing sodium lignosulfonates) was added at approximately 12 kg per 200 litres of mix;
- Water, molasses, and Orzan® were mixed the night prior to treatment;
- Virus was added on the morning of the treatment; and
- The mixture was agitated to ensure thorough mixing.

TABLE 2. Date of virus application for all treatment regimes and products during the 1991–1993 control program in southern British Columbia.

Treatment regime	Virus product	Treatment date
Stored versus new at standard application rate	Virtuss®	June 6, 1991
New at standard application rate	TM Biocontrol-1®	June 6, 1991
Alternate swath	Virtuss®	June 3, 1992
Full block at standard application rate	Virtuss®	June 3, 1992
Reduced dosage rate (2/3 standard rate)	Virtuss®	May 28, 1993
Standard application rate	Virtuss®	May 28, 1993
Standard application rate	TM Biocontrol-1®	May 28, 1993

Virus application was done using a Hiller 12E turbine helicopter equipped with a Simplex® spray system and four Beecomist® nozzles. The spray system was calibrated to ensure an application rate of 10 litres/ha of virus mix with mean droplet diameters of 100–250 microns. Swath widths were 35 metres. Spraying was conducted during periods of low temperature (< 20°C), high humidity (> 50% RH), and low wind velocity (< 8 km/hr). Kromecote® cards were set in and outside of spray blocks to ensure adequate spray deposition. All cards were checked for the presence or absence of deposit and relative droplet size, but no formal droplet analysis was performed.

Many potential treatment sites were on or near private lands; therefore, ownership was determined for all sites. Landowners were informed about the tussock moth, the potential damage it could cause, and the treatment being proposed. They were contacted by telephone or letter. Consent from landowners was required to carry out the virus application on private lands. All landowners who were contacted consented to the treatment.

Ground surveys identified numerous sites where defoliation would occur and then sites were randomly delineated into treatment or check blocks. Pre- and post-spray larval sampling and subsequent defoliation and egg mass surveys were conducted to assess treatment efficacy. Larval sampling (BC Ministry of Forests 1995) was done the day prior to application (pre-spray) and at weekly intervals following application (post-spray) until > 50% of the insects were pupae or no larvae were found in samples. Pre-spray and post-spray assessments were done to determine population levels. Up to 15 sample trees

(7–15 trees) were selected in each spray and check area. In the pre- and post-spray samples, larval density was determined by clipping two 45-cm branch tips from the mid-crowns (north and south aspect) of pre-selected sample trees using extendable pole pruners with an attached basket. The number of larvae (live, infected, dead) and foliage area were then recorded. If few or no larvae were found on the third post-spray sample, then no fourth post spray sample was done on that block. Aerial surveys for defoliation were conducted in July. All newly detected areas of defoliation were mapped and then ground surveyed.

1. *Stored versus new Virtuss®*

Egg mass surveys conducted in the fall/winter of 1990–1991 identified 13 sites where detectable defoliation was forecast. Light, moderate, or severe defoliation was predicted at one, seven, and five sites, respectively. One site, predicted to incur moderate defoliation in 1991 (Table 3), was designated a check area and the remaining 12 sites were scheduled for virus treatment.

Stored and new Virtuss® were applied at 4 sites each in 1991, for a total of 100 ha (Tables 3 and 4). Another four sites received treatment with TM Biocontrol-1®. Sites designated for comparison were geographically separate from each other to avoid contamination. Treatments were applied on June 6, 1991. Pre-spray larval densities varied among sites, but by the final post-spray sampling (seven weeks), the percent mortality and Abbott's corrected mortality (Abbott 1925) were similar for both treatments (Table 4). Results of the post-treatment egg mass surveys showed that egg mass density increased more than ten-fold in the check area while

TABLE 3. Egg mass density and predicted defoliation before, and egg mass density and ocular estimate of defoliation, after treatment with new and stored Virtuss® in 1991. Egg mass density (average number of egg masses per two lower branches per tree sampled): < 0.7= nil to light, 0.7–1.9 = moderate, > 1.9 = severe predicted defoliation.

Treatment	Area (ha)	Egg mass density		Predicted defoliation	Defoliation
		Pre-spray	Post-spray	Pre-spray	Post-spray
Check	na ^a	1.64	21.0	moderate	severe
New Virtuss®	60	1.46	0.2	moderate	trace
Stored Virtuss®	40	4.85	0.1	severe	trace

^a not available; one entire site was used as a check area in 1991

TABLE 4. Larval densities before and after treatment with new and stored Virtuss[®] and resultant mortality in 1991.

Treatment	Area (ha)	Live larvae/m ²		Mortality	
		Pre-spray	Post-spray	Percent ^a	Abbott's ^b
Check	na ^c	33.8	12.2	62.2	na
New Virtuss [®]	60	90.1	5.9	93.5	73.6
Stored Virtuss [®]	40	113.9	5.9	94.8	85.8

^a not corrected for natural mortality; ^b corrected for natural mortality; ^c not available

few, if any, egg masses were found in the areas treated with virus (Table 3). The infestation was expected to continue in the check area and collapse in all treatment blocks, regardless of the age of the virus stock used. The virus was effective in terminating the outbreak; further, this trial shows that the virus can be stored for at least 10 years without losing its efficacy. None of the treated areas saw any subsequent defoliation by tussock moth and none required further treatment over the course of the outbreak.

2. *Virtuss[®] versus TM Biocontrol-1[®]*

The relative efficacy of Virtuss[®] and TM Biocontrol-1[®] was compared in 1991 and 1993. Only Virtuss[®] was used in 1992. Seven sites were treated with Virtuss[®] (308 ha) and eight sites with TM Biocontrol-1[®] (352 ha) over the two years that both virus stocks were compared (Table 5). Treatments were applied June 6, 1991, and May 28, 1993 (Table 2). Final post-treatment larval samples completed by August 7 in 1991 (62 days post-treatment), and by August 8 in 1993 (76 days

post-treatment). Samples were taken until approximately 50% of the larvae had pupated.

Results in the two years varied (Tables 5 and 6). In 1991, the outbreak was in the building phase and by 1993, it was collapsing naturally. In both years, calculated mortality due to treatment varied (Table 5). The initial larval density in blocks treated with TM Biocontrol-1[®] in 1991 was significantly lower than for either the check area or the areas treated with Virtuss[®]; this may explain the much lower population reduction. The lower larval density likely restricted or slowed the spread of the virus within the population due to reduced frequency of larval contact. At low larval densities, larvae may be able to avoid contact with virus for longer than at high population densities. Infected larvae add to the virus loading of the site when they die, increasing the insect-to-insect virus spread among surviving larvae. Subsequent egg mass sampling in treated and check areas (Table 6) indicated that the tussock moth population was substantially reduced as a result of treatment and no additional defoliation was observed in years following the treatments.

TABLE 5. Larval densities before and after treatment with Virtuss[®] and TM Biocontrol-1[®] and resultant mortality in 1991 and 1993.

Treatment	Year	Area (ha)	Live larvae/m ²		Mortality		
			Pre-spray	Post-spray	Percent ^a	Abbott's ^b	
Check	1991	na ^c	33.8	12.2	63.9	na	
	1993	na	56.9	21.1	62.9	na	
Virtuss [®] new	1991	60	90.1	5.9	93.5	73.6	
	stored	1991	40	113.9	5.9	94.8	85.8
		1993	208	84.3	2.9	96.6	93.6
TM Biocontrol-1 [®]	1991	100	13.9	4.6	66.9	14.6	
	1993	252	175.2	0.8	99.6	94.1	

^a not corrected for natural mortality; ^b corrected for natural mortality; ^c not available

TABLE 6. Egg mass density before and after treatment with Virtuss[®] and TM Biocontrol-1[®] in 1991 and 1993, and the predicted defoliation based on egg mass counts before and after virus treatment. Egg mass density is the average number of egg masses per two lower branches per tree sampled and equates to the following defoliation levels: < 0.7 = nil to light, 0.7–1.9 = moderate, > 1.9 = severe predicted defoliation.

Treatment	Year	Area (ha)	Egg masses/tree		Defoliation prediction	
			Pre-spray	Post-spray	Pre-spray	Post-spray
Check	1991	na ^a	1.64	21.0	moderate	severe
	1993	na	1.31	0.0	moderate	nil
Virtuss [®]	1991	40	4.85	0.1	moderate	trace
	1993	208	> 4.00	0.0	severe	nil
TM Biocontrol-1 [®]	1991	100	1.10	0.2	moderate	trace
	1993	252	2.90	0.0	moderate	nil

^anot available

3. Alternate swath versus full coverage

Virus has been shown to spread from the point of introduction through a tussock moth population (Otvos, unpublished data). Therefore, full, blanket-type spray coverage of an area may not be necessary to effect full control. To test this theory, virus was applied on alternate strips within a treatment block in 1992. The alternate swath treatment consisted of Virtuss[®] being applied aerially in 35-m swaths every 200 metres. The full spray coverage treated an entire block, with each swath overlapping and the full area within the block receiving Virtuss[®]. Treatments were applied June 3, 1992, and the final post-spray larval sampling was completed by August 5, 1992 (63 days post-treatment). Results shown in Tables 7 and 8 clearly indicate that the alternate swath method effected as much control as full coverage both in terms of larval mortality and subsequent defoliation.

4. Reduced dosage

Reduced dosage rates of both virus formulations were applied on May 28, 1993 (Tables 1 and 2). This would increase the cost-effectiveness of using virus for tussock moth control, and would extend the limited virus supply. Final post-spray larval sampling was carried out in late July 1993, followed by egg mass surveys (Tables 9 and 10).

The tussock moth infestation was beginning to collapse in southern British Columbia in 1993. Natural levels of virus were assumed to be increasing within tussock moth populations. This natural, background level of virus enhanced the effect of the operational virus applications. Approximately 63% of larval mortality in check areas was attributable to natural causes (Table 9). The full and reduced treatments of TM Biocontrol-1[®] achieved high mortality rates in 1993, as did the full treatment

TABLE 7. Larval density pre- and post- full and alternating swath coverage (35 m swath every 200 m) of Virtuss[®] and resultant mortality in 1992.

Treatment	Spray block area (ha)	Live larvae/m ²		Mortality	
		Pre-spray	Post-spray	Percent ^a	Abbott's ^b
Check	na ^c	28.6	18.0	37.2	na
Full coverage	600	22.9	1.6	92.9	88.9
Alternate swath	50	52.3	2.2	95.8	43.8

^anot corrected for natural mortality; ^bcorrected for natural mortality; ^cnot available

TABLE 8. Egg mass density and defoliation prediction before and after treatment with full and alternating swath coverage (35 m swath every 200 m) of Virtuss® in 1992. Egg mass density is the average number of egg masses per two lower branches per tree sampled and equates to the following defoliation levels: < 0.7 = nil to light, 0.7–1.9 = moderate, > 1.9 = severe predicted defoliation.

Treatment	Spray block area (ha)	Egg mass density		Defoliation prediction	
		Pre-spray	Post-spray	Pre-spray	Post-spray
Check	na	1.21	21.0	moderate	severe
Full Coverage	600	9.43	0.2	severe	trace
Alternate swath	50	6.05	0.05	severe	nil

Virtuss® application. The reduced-rate application of Virtuss® only achieved 39% larval mortality (14% Abbott's corrected mortality; Table 9), even though the post-treatment egg mass surveys showed a collapse of the population (Table 10). This low larval mortality attributable to the treatment may be due to low larval densities at the sites, leading to slower rates of infection in the population with much mortality occurring in the pupal stage. The results for the reduced-rate application trials are not as conclusive as in previous years due to high levels of natural mortality. However, larval mortality rates were similar to those seen with other successful treatments in preceding years. Indications are that these reduced dosage rates are as successful at causing population collapse as full dosage applications.

Treatment effectiveness

The 1991–1993 tussock moth outbreak was less severe than the outbreak of the early 1980s, possibly due to control actions taken and the early insertion of

the virus into building insect populations (Figure 1). Such short-duration outbreaks emphasize the need for prompt detection of population increases and immediate application of treatment in priority areas to avoid damage. Figure 5 shows yearly defoliation throughout the course of the outbreak. No defoliation was observed in the treated areas in years following treatment; however, new areas of defoliation were noted each year. Total mapped defoliation caused by the tussock moth in 1992 was approximately 2050 ha, with 600 ha being severely defoliated (Figure 5). These patches of defoliation mapped from the air represent approximately 1000 ha not detected through moth trapping and ground surveys. The relatively high levels of defoliation noted in 1992 and 1993 include areas that were missed during the pheromone detection program, or represent areas that were intentionally not treated or were used as check areas. The 1992 aerial surveys were unable to detect the low levels of defoliation in areas treated with virus in 1991.

TABLE 9. Larval density before and after treatment with full and reduced (2/3) dosages of Virtuss® and TM Biocontrol-1® and resultant mortality in 1993.

Treatment	Spray block area (ha)	Live larvae/m ²		Mortality	
		Pre-spray	Post-spray	Percent ^a	Abbott's ^b
Check	na ^c	56.9	21.1	62.9	na
Virtuss®	full	84.3	2.9	96.6	93.6
	2/3	15.3	9.3	39.2	14.0
TM Biocontrol-1®	full	175.2	0.8	99.6	94.1
	2/3	102.3	5.8	94.3	63.7

^a not corrected for natural mortality; ^b corrected for natural mortality; ^c not available

TABLE 10. Egg mass density and defoliation prediction before and after treatment with full and reduced (2/3) dosages of Virtuss® and TM Biocontrol-1® in 1993. Egg mass density is the average number of egg masses per two lower branches per tree sampled and equates to the following defoliation levels: < 0.7 = nil to light, 0.7–1.9 = moderate, > 1.9 = severe predicted defoliation.

Treatment	Spray block	area (ha)	Egg mass density ^a		Defoliation prediction	
			Pre-spray	Post-spray	Pre-spray	Post-spray
Check		na ^b	1.31	0.0	moderate	nil
Virtuss®	full	208	> 4.00	0.0	severe	nil
	2/3	148	0.67	0.0	moderate	nil
TM Biocontrol-1®	full	252	2.88	0.0	moderate	nil
	2/3	95	12.0	0.0	severe	nil

^a No formal 1993 egg mass surveys were performed as the number of observed egg masses was very low. Walk-throughs of 1993-defoliated areas produced very low numbers of detected egg masses therefore no 1994 defoliation was predicted or subsequently observed in these sites.

^b not available

Defoliation occurred over 1625 ha in 1993. However, 1993 was the last year of the outbreak, and these areas sustained only a single year of moderate or severe defoliation. Little or no significant damage was incurred. Subsequent surveys in the defoliated regions in 1994 and later showed no sign of symptomatic patch mortality. The total area visibly defoliated by the Douglas-fir tussock moth in the outbreak period of 1991-1993, was 3600 ha.

Fall ground surveys in 1993 indicated that there may have been a low level of natural virus in some tussock moth populations as indicated by the very low numbers of new egg masses in moderately to severely defoliated sites. Overall, pheromone-trapping sites showed a general decline in the tussock moth population (Figure 4). The pattern of decline was expected, as tussock moth outbreaks seldom last longer than four years in British Columbia.

Stand-level impact

An impact assessment was carried out in 1995 (Buxton et al. 1996). Areas defoliated by tussock moth during 1991–1993 were mapped from the air and ground surveyed, and levels of mortality and top-kill were assessed and then categorized into three damage classes (Table 11). The categories were as follows:

Light

- up to 30% of Douglas-fir trees with top-kill;
- top-kill usually under 30% of the stem height; and
- 0–5% of Douglas-fir trees killed.

Moderate

- top-kill variable; may occur on over 30% of surviving Douglas-fir trees;
- top-kill may be over 30% of stem height; and
- 6–59% of Douglas-fir trees killed.

Severe

- top-kill variable; may occur on over 30% of surviving Douglas-fir trees;
- top-kill may be over 30% of stem height; and
- 60% or more of Douglas-fir trees killed.

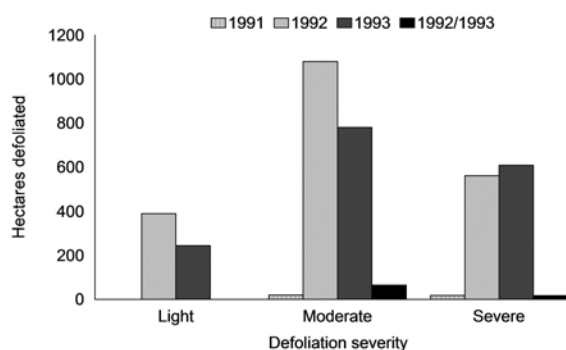


FIGURE 5. Area defoliated by DFTM from 1991–1993 as mapped from aerial overview flights. The area defoliated for two consecutive years (1992–1993) is also shown. The total area visibly defoliated by DFTM in this outbreak was 3600 ha.

TABLE 11. Estimated volume losses incurred during the 1991–1993 Douglas-fir tussock moth outbreak.

Damage category	Area affected (ha)	Estimated volume loss (m ³)		
		Mortality	Top-kill	Total
Light	1 343	3 002	105	3 107
Moderate	222	11 151	21	11 172
Severe	58	6 657	1	6 658
Total	1 623	20 810	127	20 937

Ground surveys were carried out in sample stands within each of the above damage categories, proportionate to the area affected. Surveys consisted of 10-m-wide strips; strip length varied with the size of the stand surveyed. In total, 13.3 km of strips were placed in lightly affected stands, 6.8 km were placed in heavily affected stands, and 1.7 km were placed in severely affected stands. Within the strip, diameter at breast height (DBH) measurements of all Douglas-fir > 1.3 m in height were tallied and trees classified as to whether they were healthy, top-killed, or killed. The degree of top-kill was estimated for all top-killed trees as a percentage of the stem height in 5% increments. Tree height and volume were calculated for each tree: height was calculated from diameter, and volume was calculated as per the BC Ministry of Forests volume equations for Southern Interior Douglas-fir (Brown 1962).

Mortality was the only significant type of damage sustained and was of concern only in severely affected areas. Stand-level mortality approaching 115 m³/ha indicated concentrated patch mortality. Stand-level mortality of about 2.2 m³/ha indicated lightly affected stands with individual dead trees at the epicentre of infested spots. Only trace levels of top-kill and no mortality were found in treated areas.

Discussion and recommendations

An integrated, long-term system to detect and treat tussock moth is necessary because of the dynamics of tussock moth outbreaks. Outbreaks arise suddenly in numerous patches over a broad geographic area. Damage and resultant value losses occur quickly and the outbreak then subsides. Management and avoidance of loss requires constant monitoring for increasing populations and prompt treatment of areas threatened with potentially unacceptable defoliation.

The 1991–1993 tussock moth control program was the first opportunity to apply all aspects of recent research in an integrated manner for detection, assessment, and treatment of an outbreak. The management system implemented for Douglas-fir tussock moth has proven to be successful. Many outbreak epicentres were detected prior to defoliation and virus treatments applied. The combination of early detection and treatment greatly reduced damage compared to previous tussock moth outbreaks. The application of NPV to sites with increasing population levels of tussock moth effectively terminated the localized epicentre for the duration of the outbreak.

Various trials and comparisons were conducted throughout the course of the outbreak. While the application of NPV has been shown to be effective in terminating an outbreak, infestation centres must be identified early in the outbreak cycle (year one) for treatment as soon as larvae hatch in the spring. Infestation centres that are not identified by means of pheromone trapping and egg mass surveys will miss treatment, and defoliation and damage will result. The overall intent of operations during the recent outbreak was met in that most incipient tussock moth populations were detected and treated with NPV,

The combination of early detection and treatment greatly reduced damage compared to previous tussock moth outbreaks. The application of NPV to sites with increasing population levels of tussock moth effectively terminated the localized epicentre for the duration of the outbreak.

thus avoiding losses to a variety of forest and land values and mitigating human health issues. Results also showed that both new and stored virus stocks were similar in their efficacy and effective in terminating an infestation (Tables 3 and 4). Therefore, virus stocks can be stored for prolonged periods, at least 10 years, without a reduction in potency. This provides good justification for creating and maintaining stockpiles of NPV for future use. While longevity of potency has been shown in this trial, future applications of existing virus stocks will require periodic evaluation of potency.

Tests carried out during the 1991–1993 outbreak in British Columbia showed that both products were equally effective when applied according to label directions (Tables 5 and 6). This trial was necessary as the MFR has a supply of each formulation; however, stocks of Virtuss® are small and future production of additional supplies are in doubt, whereas TM Biocontrol-1® has been produced and stockpiled in large amounts by the USDA Forest Service. The confirmation of equivalent effectiveness provides confidence that stocks will be on hand to deal with future outbreaks and will likely maintain their potency.

Both virus products were effective in terminating the outbreak when applied at full and reduced label dosages (Tables 5, 6, 9, and 10). Virtuss® was also effective when applied in alternate swaths (Tables 7 and 8). In the future, it may not be necessary to spray the entire affected area in order to collapse incipient outbreaks. In the alternate swath treatment, the virus spread from the treated swaths through the population, and infected any tussock moth larvae found in the 200-m untreated swath. While the full effect of the virus took longer due to the time required for spread, the final result was the same as for full coverage. One conclusion from these treatments is that the registered label dosage of both formulations may be in excess of what is required to control an infestation.

Further research is required to determine the minimum virus dosages and minimum swathing to achieve control. Determination of a lower effective dosage would be very advantageous, allowing virus stocks to be applied over greater areas of susceptible stands. The existing stockpiles of virus now held by the USFS and by the MFR will be used in future outbreaks; therefore, it will be necessary to determine the efficacy of the product in relation to longer storage times.

The decisions to treat or not to treat specific infestation centres will also be dependent on the assessment of values other than forest cover or forest products. Other values may include such factors as biodiversity and wildlife. Landscape management plans over specific areas would set values to be protected and thresholds for treatment.

Additional trials using the virus, particularly low-dosage-rate replicated trials, will be necessary during future outbreaks to determine the most efficient means of introducing an effective viral dose into infestation epicentres. Ground application of the virus may effectively control infestations if it is applied at the earliest sign of population buildup. It would be much more cost-effective if aerial application was not required. This type of treatment would also enable private landowners to treat their affected areas. Consideration would have to be given to allow private landowners to obtain and apply virus stocks. The program would further be strengthened by increasing the use of 6-trap cluster monitoring in high-hazard stands.

The decisions to treat or not to treat specific infestation centres will also be dependent on the assessment of values other than forest cover or forest products. Other values may include such factors as biodiversity and wildlife. Landscape management plans over specific areas would set values to be protected and thresholds for treatment.

The tussock moth program conducted by the MFR during the 1990–1993 outbreak provides an excellent example of the successful incorporation of research into an operational program. There are a number of reasons that this program was readily acceptable to the MFR, the agency responsible for implementing forest management activities:

- The initial issue was acknowledged by the Ministry as an important forest health problem;
- There was substantial public support for dealing with tussock moth;
- There was close co-operation between the management agency (MFR) and research

agencies (CFS and USFS) in the early stages of development of the research program;

- The management agency's structure and normal operating procedures were clearly communicated to the research agencies so that research directions did not encourage results that would require major shifts in management activities;
- MFR personnel participated in all phases of the research, from planning to ground operations, so the Ministry was familiar with requirements;
- The research effort was directed at developing a management system in parallel (monitoring, treatment, and evaluation) so that research results were not made available to the management agency in a piecemeal fashion; and
- The end products (pheromone monitoring, defoliation predictions, treatments, and final evaluations) were readily available to the management agency.

The development of this integrated management system for the Douglas-fir tussock moth is an excellent example of the benefits of close co-operation between management and research agencies.

This type of development and implementation ensures that research concentrates on priority issues and that recommendations resulting from research can be easily incorporated into regular management practices. The development of this integrated management system for the Douglas-fir tussock moth is an excellent example of the benefits of close co-operation between management and research agencies.

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Test Your Knowledge . . .

An integrated management system for the Douglas-fir tussock moth in Southern British Columbia

How well can you recall some of the main messages in the preceding Research Report?
Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. When is the optimal time in a Douglas-fir tussock moth outbreak cycle to apply NPV?
 - A) One year after seeing visible defoliation
 - B) One year prior to seeing visible defoliation
 - C) Third year of the outbreak cycle

2. Why is the Douglas-fir tussock moth a concern to rural interface areas?
 - A) It is costly to control
 - B) The visual impacts are great
 - C) It causes an allergic reaction in some people

3. How long after application of NPV will you see larval mortality?
 - A) 3 days post-spray
 - B) 4 weeks post-spray
 - C) 5 or more weeks post-spray

ANSWERS

1. B 2. C 3. C