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Integration of early virus treatment with a pheromone detection system to control Douglas-fir tussock moth, *Orgyia pseudotsugata* (Lepidoptera: Lymantriidae), populations at pre-outbreak levels

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ABSTRACT

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A naturally occurring virus often leads to the development of an epizootic late in the outbreak cycle of the Douglas-fir tussock moth, but not before significant damage occurs to the trees. This virulent virus can be mass-produced in the laboratory and, when applied early in the outbreak cycle, can prevent severe defoliation. This, however, requires that an early-warning system be integrated with a virus treatment. The development and integration of a pheromone monitoring system with a virus treatment is described. Stands susceptible to Douglas-fir tussock-moth outbreaks are defined by overlying maps of past outbreaks, forest and habitat types, and climatic zones. Pheromone-baited traps are placed and monitored annually at permanent locations in the susceptible areas. Measuring annual trends of moth density indicates the time and location of the next outbreak. Trap-catch data provide an early warning of impending outbreaks. This is confirmed by ground reconnaissance. Insect density and defoliation is predicted from egg-mass and larval sampling. The virus then can be applied from the air or from the ground into threatened stands to initiate an epizootic to prevent the development of an outbreak and to minimize tree damage. The virus appears to spread, and field tests with reduced dosages indicate that that small amount of virus applied can still decimate larval populations and prevent tree mortality, at considerably reduced cost.

BACKGROUND

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough) (Lymantriidae) is an important native defoliator of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), grand fir (*Abies grandis* Dougl.) Lindl.) and white fir (*Abies concolor* (Gord. & Glenn) Lindl.) in western

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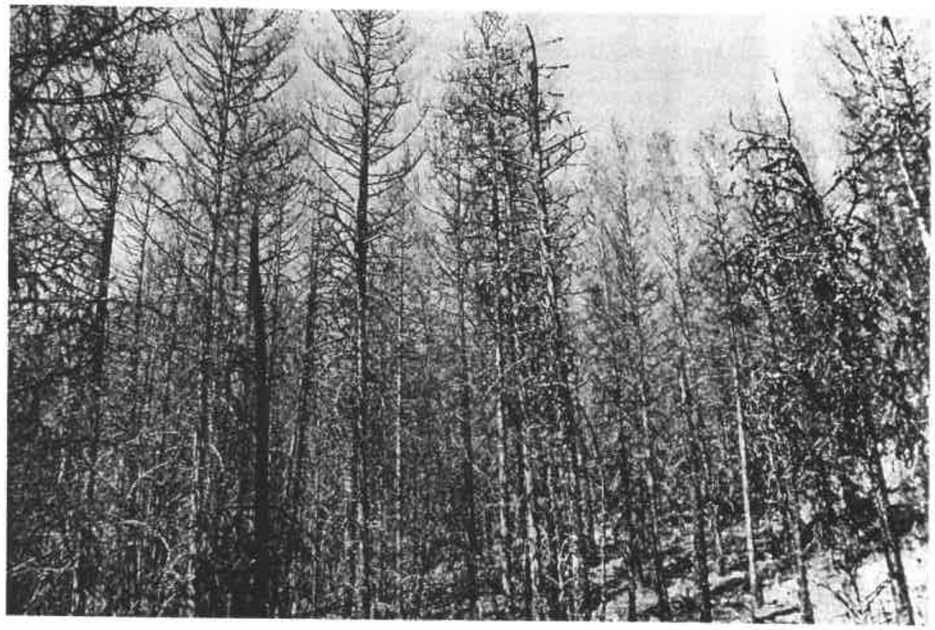

Fig. 1. A stand killed by Douglas-fir tussock moth.

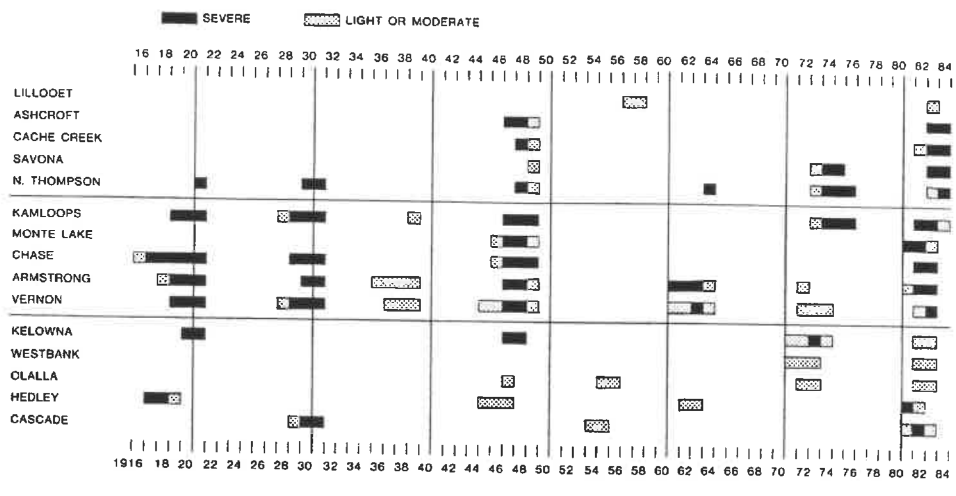

Fig. 2. Periodicity of outbreaks of Douglas-fir tussock moth in British Columbia.

North America, causing growth loss, top-kill and considerable tree mortality (Fig. 1) at high population levels (Wickman, 1978; Alfaro et al., 1987).

There is some evidence of a cyclic pattern in the population fluctuations of this insect. Outbreaks recur about every 7–10 years in British Columbia (Fig.

2) and the western United States. These outbreaks collapse after one to four years of defoliation, usually due to an epizootic caused by a nuclear polyhedrosis virus (NPV), but not before serious damage occurs to the infested stands (Shepherd et al., 1984b). Defoliation occurs in distinct patches, particularly in the 1st year, with some fill-in and coalescing in the 2nd and 3rd years of the outbreak.

The female is flightless and, after emerging from her cocoon and mating, she lays all her eggs in a single mass on that cocoon. The eggs overwinter, and larvae hatch the following spring just after the host trees flush (Wickman and Beckwith, 1978). Dispersal of the tussock moth is limited. The small, hairy larvae spin silken threads and are blown to surrounding trees and adjacent stands; this is probably the reason for the patchy pattern of defoliation.

THE VIRUS

Two morphotypes of NPV have been isolated from Douglas-fir tussock-moth larvae and identified as the cause of the epizootics (Hughes and Addison, 1970). In one type, termed unicapsid, the virus particles are embedded singly in the inclusion body matrix protein; in the other type, termed multicapsid, bundles of five to 15 virus particles are occluded. Both viruses, belonging to the Baculovirus group, have been used experimentally. Baculoviruses are highly species-specific and only infect the host target insect or closely related species of the same genus.

The virus is not available commercially; at present it is produced in Douglas-fir tussock-moth larvae by the USDA Forest Service at Corvallis, Oregon, and in whitemarked tussock-moth larvae, *O. leucostigma* (J.E. Smith), by Forestry Canada at Sault Ste. Marie, Ontario, Canada.

The first aerial spray trial in British Columbia with NPV on tussock moth was conducted jointly by personnel of Forestry Canada, the USDA Forest Service, and the British Columbia Ministry of Forests with three virus stocks: two multicapsid types and a unicapsid type. The multicapsid types, originally isolated from *O. pseudotsugata* in the U.S.A., were produced in the Douglas-fir tussock moth and whitemarked tussock moth. The third type, a unicapsid virus isolated from *O. leucostigma* in eastern Canada, was produced in the whitemarked tussock moth (Stelzer et al., 1977). High populations of tussock moth larvae were treated aerially in the 2nd year of the outbreak. All treatments caused high larval mortality, but the treated stands still sustained considerable damage so the experiment did not indicate whether an early treatment could prevent an outbreak. Early treatment is desirable, because the greatest tree mortality results from the 1st year's defoliation (Alfaro et al., 1987).

After these trials, the multicapsid isolate produced in Douglas-fir tussock moth was registered in the U.S.A. by the Environmental Protection Agency in 1976 under the name TM-BioControl-1 virus. The same virus, but produced in whitemarked tussock moth, received full registration in Canada in 1987 under the name Virtuss. The recommended dosage in polyhedral inclusion bodies (PIB) under both registration labels is 2.5×10^{11} PIB/ha (Shepherd et al., 1984b)

In 1981, by introducing the virus at the beginning of an outbreak to try to initiate an epizootic before it would occur naturally, we attempted to prevent outbreak development and significant damage. We also studied the spread of the virus and investigated whether the recommended application rate could be reduced without lowering its effectiveness in preventing damage to trees. The results of these tests are summarized here.

To introduce the virus at the beginning of an outbreak requires a reliable monitoring system that will indicate impending outbreaks. A separate study, concurrent with the virus work, developed a dependable and sensitive pheromone monitoring system for early warning of outbreaks (Shepherd et al., 1985).

PHEROMONE BAITING

Pheromone-baited traps were placed in susceptible stands, which were defined by overlaying maps of the eight previous outbreaks on forest habitat maps. The most susceptible habitat tended to be the driest part of the range of Douglas-fir, where it mixes with ponderosa pine (*Pinus ponderosa* (Laws.)). Within this forest habitat, 19 permanent monitoring stations have been selected where pheromone-baited traps are used to provide an annual measure of the density of male moths (Fig. 3).

Population trends in pheromone-baited traps were followed from endemic to epidemic levels. The number of successive years of upward trends of male moths caught is a better indicator of impending outbreaks than the average number of male moths per trap in any one year. The number of moths caught in the pheromone traps is too variable to estimate population density or damage the following year. Three consecutive years of increase in the number of male moths caught indicate that an outbreak is expected the following year (Fig. 4). The pheromone-trap system only gives an advance warning that an outbreak is imminent, and signals that other, more precise, sampling systems should be deployed in the area. Thus, after two years of upward trends an extensive network of additional traps is deployed around the indicator stations to locate the foci of the developing outbreak. An egg-mass survey is then required in the fall or winter to determine the insect density at the centre of the developing infestation and to predict potential damage (Shepherd et al., 1984a).

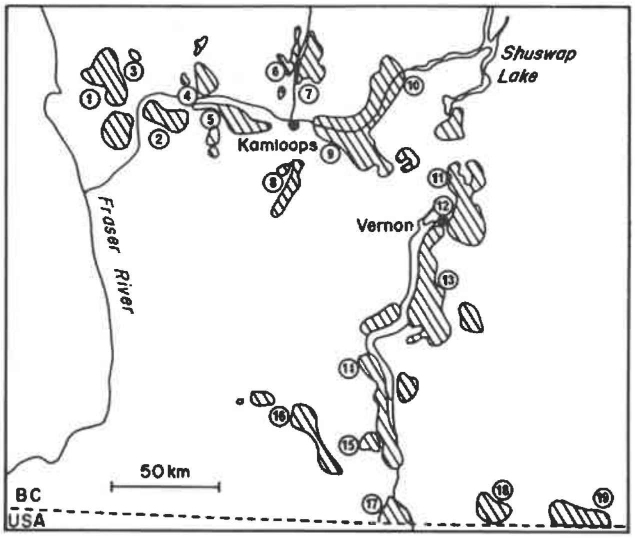

Fig. 3. Outbreak areas in British Columbia with pheromone-monitoring sample points indicated by numbers next to the hatched areas.

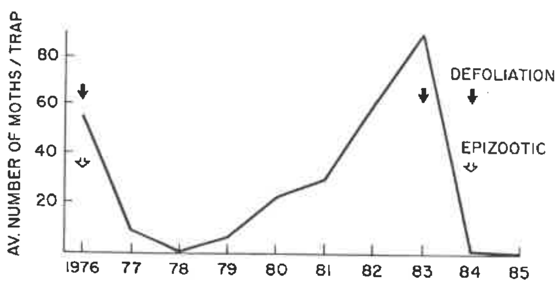

Fig. 4. Average number of male Douglas-fir tussock moths caught in British Columbia from 1976 to 1985.

A CASE STUDY

A developing Douglas-fir tussock-moth outbreak in south-central British Columbia was discovered before any defoliation occurred, and we treated four plots of varying tussock-moth population densities in 1981. Two plots were treated from the air by helicopter with 2.2×10^{11} PIB in 11.3 L/ha, and one of these plots had a low population ($\simeq 40$ larvae/m^2); two plots were treated from the ground, each tree receiving 2.4×10^{10} PIB in 4.5 L with a modified orchard-type sprayer.

The experiment showed that virus can be introduced into a Douglas-fir tussock- moth population at an early phase of the outbreak and a viral epizootic can be initiated by either aerial or ground treatment. Levels of virus infection were monitored and all treatments were successful even at a low population density (Fig. 5). Viral infection increased slowly over the first four weeks and an epizootic appeared five weeks after treatment. A naturally occurring virus was found in two of the control plots after eight weeks. This was unexpected, because naturally occurring virus is usually not prevalent at the beginning of outbreaks.

In the ground-spray application, 15 trees in a line through the center of a stand were treated. Both the treated and the intermediate trees between the treated trees were monitored as well as trees in lines 50 m and 100 m away. A line of the check trees was 200 m from the line of the treated trees. The epizootic developed slowly in this plot as well.

With the one exception of week 7 for the intermediate trees, the percent infection of the larvae followed expected rates assuming spread from an infection source. The percent infection decreased with increased distance from the treated trees. Ground treatment of individual trees in a line may be sufficient to start an epizootic up to about 100 m on either side of the treated trees. This suggests that treating a Douglas-fir tussock moth infestation in narrow

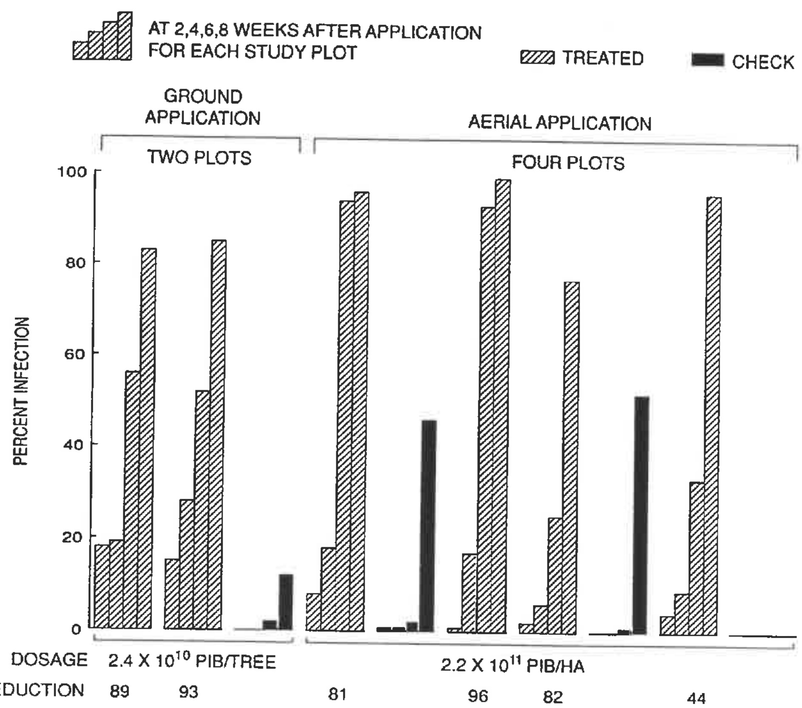

Fig. 5. Results of ground and aerial application of nuclear polyhedrosis virus against the Douglas-fir tussock moth in 1981 in British Columbia.

'bands' every 100–200 m may be sufficient to start an epizootic through the stand.

A comparison was made of oil and water formulations and reduced dosages of the virus in the oil formulation. These treatments were applied with a fixed-wing aircraft with boom and nozzle equipment calibrated to deliver the virus in 9.4 L/ha. Four plots with similar tussock-moth densities were selected as controls (Fig. 6; Table 1).

The virus deposit from the spray application caused an initial infection in about 10–30% of the larvae. These infected larvae die about two to three weeks after the spray and release polyhedra onto the foliage. A secondary virus epizootic then develops among the remaining tussock-moth larvae (tussock-moth larvae have a long feeding period), and in six to seven weeks after the spray the population collapses. Population reduction due to treatment was 65% in the plot receiving the lowest dosage (1.6×10^{10} PIB/ha), and varied from 87 to 95% in the remaining three plots (receiving 8.3×10^{10} and 2.5×10^{11} PIB/ha in oil and water; Otvos et al., 1987a). Percent infection and the development of the epizootic among the larvae in the four treated plots were related to dosage. In contrast, NPV was not detected in untreated control plots until five weeks after spraying. In the last sample, taken seven weeks after spraying, the highest infection level in a control plot was 43% and this was attributed to naturally occurring NPV. In the three other control plots, infection ranged

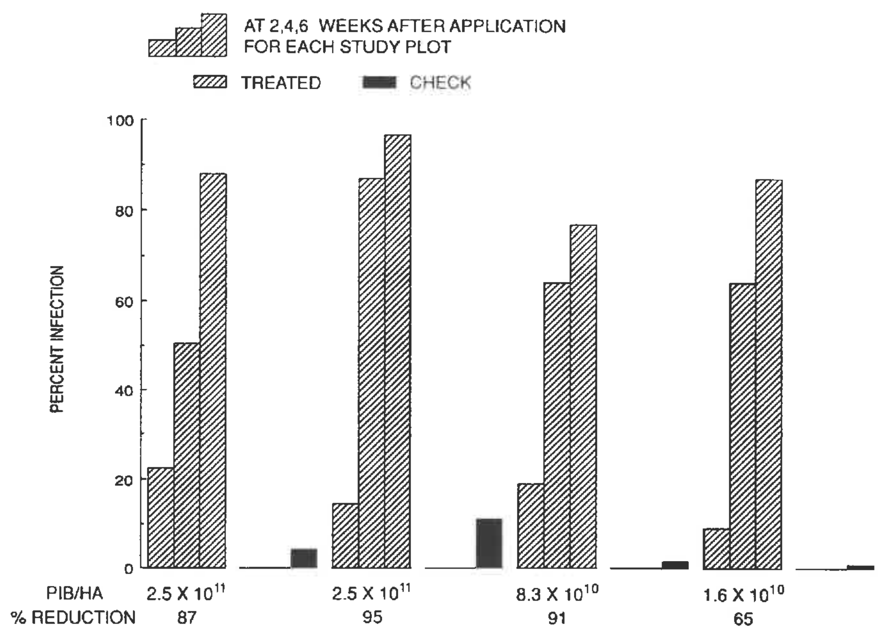

Fig. 6. Results of aerial application of nuclear polyhedrosis virus of various dosages against the Douglas-fir tussock moth in 1982 in British Columbia.

TABLE 1

Population densities of Douglas-fir tussock-moth (DFTM) larvae in the year of application and cumulative proportion of trees killed 1 and 2 years following application in four plots treated with Virtuss in 1982 and in matching control plots, British Columbia

Plot No.	Treatment	1982 pre-spray DFTM/m^2	Population reduction (%)[1] 1982	Sample trees killed by DFTM (%)	
				1983	1984
T1	1.6×10^{10}-O	182.8	64.7	0	0
T2	8.3×10^{10}-O	145.8	90.6	2	7
T3	2.5×10^{11}-O	302.0	95.1	0	4
T4	2.5×10^{11}-W	41.8	86.6	0	0
$\bar{x}$				0.6	2.8
C1	Control	197.5		53	60
C2	Control	136.9		cut	
C3	Control	360.6		60	62
C4	Control	81.2		0	0
$\bar{x}$	Control			37.8	40.7

[1]Due to treatment.

from about 1 to 23%. We concluded that the virus application in our tests caused the collapse of the Douglas-fir tussock-moth population in the treated plots earlier than if it had been left to the naturally occurring NPV epizootic, and thus prevented significant tree mortality in these plots. Tree mortality was negligible in the four treated plots 1 year after treatment, and averaged 3% two years after treatment. The comparable tree mortality was 38% and 41% in the check plots (Otvos et al., 1987b).

In summary, the results of experiments over the past number of years with pheromone-baited traps and NPV indicate that Douglas-fir tussock-moth outbreaks may be prevented by the application of the virus at the beginning of an outbreak (Shepherd and Otvos, 1986). The virus application at reduced dosages makes it economically more acceptable, and gives forest managers a practical alternative to the use of chemical insecticides. The cost of virus application may be further reduced by alternating swath spraying of infested stands.

These strategies will be tested when the next Douglas-fir tussock-moth outbreak occurs in British Columbia.

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