Operational Field Trials Against the Douglas-fir Tussock Moth With Chemical And Biological Insecticides

An International Research and Control Program Conducted in British Columbia, 1975-1976

Canadian Forestry Service / Pacific Forest Research Centre
BC-X-201, April, 1980, Victoria, B.C.

AGENCIES AND OFFICERS CO-OPERATING ON THE PROJECT

Canadian Department of Fisheries and the Environment
Canadian Forestry Service
Pacific Forest Research Centre, Victoria, B.C.
R. F. Shepherd (Ed), J. R. Carrow, S. Ilnytzky and V.G. Marshall

Forest Pest Management Institute, Sault Ste. Marie, Ont.
J.C. Cunningham, P.D. Kingsbury and B.B. MacLeod

Environmental Protection Service, Pacific Region, Vancouver, B.C.
D.M. Wilson and M. Wan

United States Department of Agriculture
Secretary's Office - Expanded Douglas-fir Tussock Moth Research and Development Program, Portland, Oregon
K.H. Wright and J.E. Dewey

U.S. Forest Service
Pacific Northwest Forest and Range Experiment Station, Portland, Oregon
J.A. Neisess, M.J. Stelzer and C. Sartwell Jr.

Pacific Southwest Forest and Range Experiment Station, Berkeley, California
J.S. Hard

Region 6 - Forest Insect and Disease Management, Portland, Oregon
G.C. Trostle

Region 1 - Forest Insect and Disease Management, Missoula, Montana
J.D. Ward

British Columbia Ministry of Forestry, Kamloops and Victoria, B.C.
V.D. Craig, T.R. Gibbs and J.M. Finnis

British Columbia Department of Recreation and Conservation
B.C. Fish and Wildlife Branch, Kamloops, B.C.
J.S. MacDonald and D.J. Low

Simon Fraser University, Burnaby, B.C.
P.C. Oloffs and S.Y. Szeto

Additional copies of this report, or more detailed information on specific subjects can be obtained through:

Canadian Forestry Service,
Pacific Forest Research Centre,
506 West Burnside Road,
Victoria, B.C.,
Canada V8Z 1M5.

or

Pacific Northwest Forest and Range Expt. Station,
USDA Forest Service,
Portland, Oregon,
USA 97208.

ABSTRACT

An aerial spray program of *Bacillus thuringiensis* against the Douglas-fir tussock moth *Orgyia pseudotsuga* (McDunnough), in 1975, was only partially effective in controlling the outbreak. Experimental trials with different formulations, volumes and concentrations showed that molasses mixtures of Thuricide[R] were the most effective if applied at 9.5 ℓ /ha. Sorbitol[R] mixtures or lower volumes decreased effectiveness and higher concentrations of *B.t.* did not improve effectiveness.

The Douglas-fir bark beetle increased rapidly in 1975 and 1976, particularly in trees weakened by defoliation, leading to a large trap-log program to control this insect.

The induction of a nucleopolyhedrosis virus disease through aerial application controlled the insect population. Defoliation in the year of application was moderate but no trees died and no larvae could be found the following year.

Acephate and Dimilin[R] were tested experimentally in 1975 and acephate was used operationally in 1976. Both materials were effective in reducing populations and preventing defoliation. Acephate was fast acting with a short residual effect, while Dimilin[R] acted slower but persisted for a longer period. Effects on non-target organisms were minimal.

RÉSUMÉ

Un programme d'arrosage aérien avec *Bacillus thuringiensis* contre la chenille à houppes du Douglas, *Orgyia pseudotsugata* (McDunnouth), en 1975 n'a pu enrayer l'infestation que partiellement. Des essais d'expérimentation de formules, concentrations et volumes divers ont montré que le maximum d'efficacité à cet effet s'obtenait avec des mélanges de mélasse de Thuricide[R], appliqués à raison de 9,5 ℓ /ha. Des mélanges de Sorbitol[R] ou des volumes plus faibles de matière active diminuaient l'efficacité, de même que de plus fortes concentrations de B.t. ne l'augmentaient point. Le dendroctone de l'écorce du Douglas s'est répandu rapidement en 1975 et 1976, particulièrement sur les arbres affaiblis par la défoliation, ce qui a conduit à un programme important de grumes-pièges pour combattre cet insecte.

L'induction d'une maladie provoquée par le virus de la polyédrose nucléaire par voie aérienne a permis d'en enrayer l'infestation. Au cours de l'année du traitement, la défoliation a été modérée sans mortalité des arbres et l'année suivante, aucune larve n'a été observée.

On a expérimenté en 1975 l'acéphate et la Dimiline[R] puis on a utilisé l'acéphate sur une base opérationnelle en 1976. Les deux produits ont réussi à réduire les populations et à prévenir la défoliation. L'acéphate s'est avéré un agent rapide, ayant un bref effet résiduel, alors que la Dimiline[R] agissait plus lentement mais demeurait efficace plus longtemps. Les effets sur les organismes non visés ont été minimes.

MOTS - CLÉS

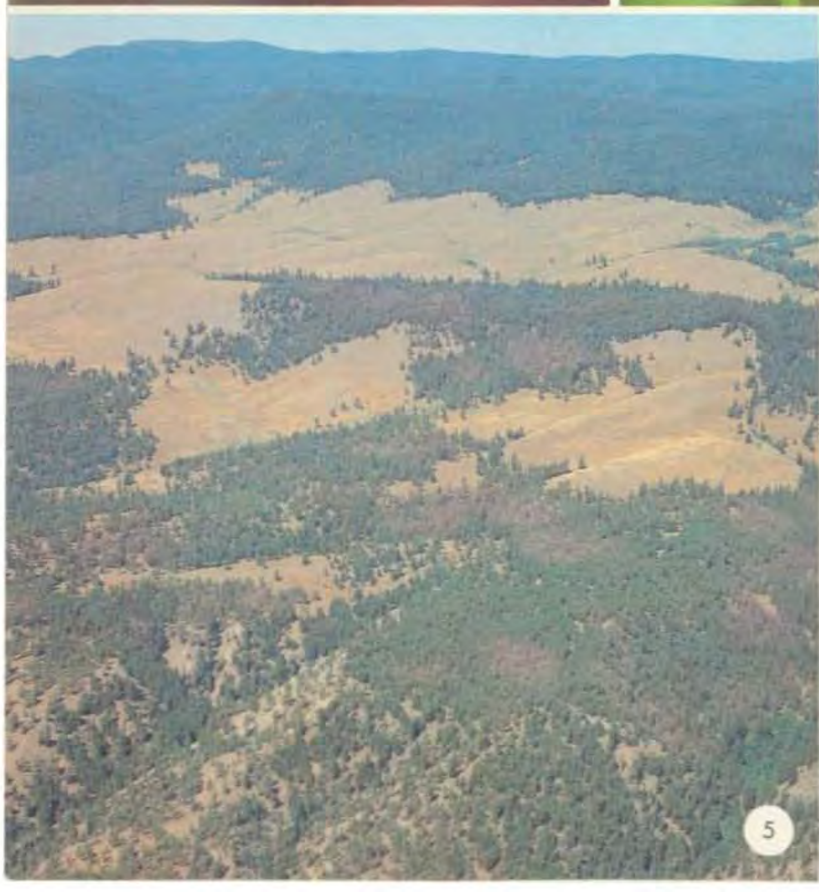
Orgyia pseudotsugata
virus
Bacillus thuringiensis
Dimiline
acéphate

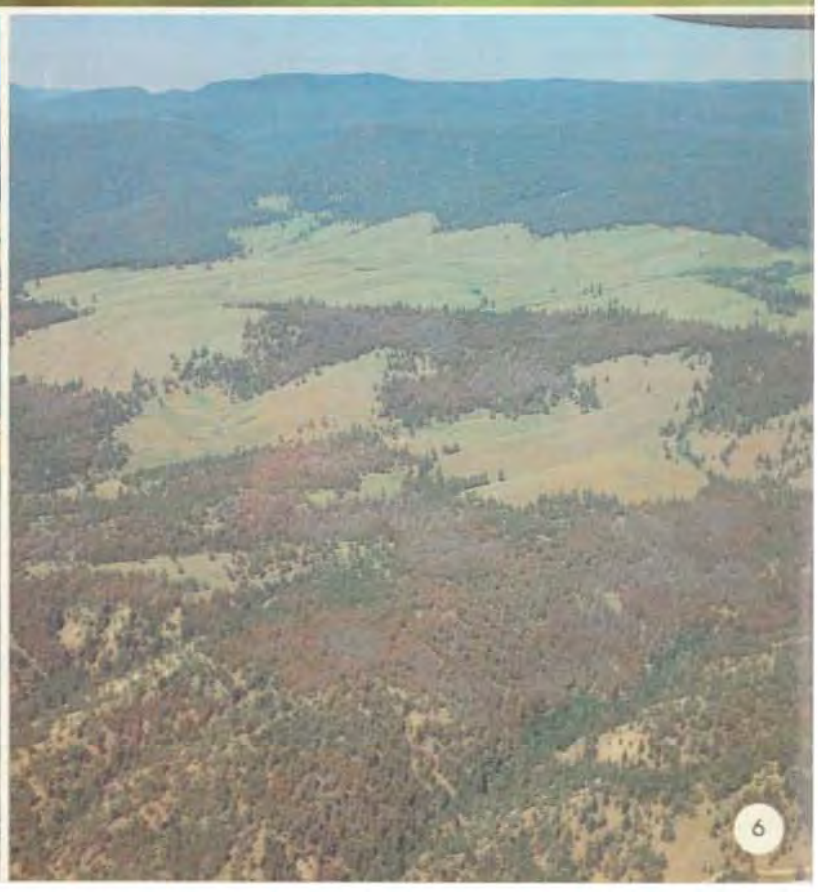

1


Conair
2


3


4


5


6

THE PROBLEM

The Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough) occurs periodically in outbreak densities in British Columbia and in the western states of the U.S.A. Populations are often extremely high and their effects on trees are dramatic, causing severe defoliation and mortality. Adequate control systems utilizing modern materials had not been developed for this insect in Canada or the U.S.A; no materials were registered for control of Douglas-fir tussock moth in Canada. This problem was approached by a research team representing both countries with a co-ordinated program to maximize returns from the resources available. The efficacy of *Bacillus thuringiensis*[1] (*B.t.*), two strains of a naturally-occurring tussock moth virus, and two insecticides, acephate[2] and Dimilin[R3], were studied against Douglas-fir tussock moth, along with the effects these materials had on non-target organisms. The research work was conducted near Kamloops, B.C., in conjunction with an operational spray program conducted by the British Columbia Forest Service. In 1975, *B.t.* was used as the control agent in this operational program.

The operation was extended into 1976 to control the tussock moth, and information obtained by the research program of 1975 indicated that acephate was the most effective control agent currently available.

Fig. 1 Mixing spray materials and loading aircraft.

Fig. 2 Application with a fixed-wing aircraft.

Fig. 3 New shoot destroyed by the feeding of young larvae.

Fig. 4 New shoot with damage stopped at an early stage through spraying with acephate.

Fig. 5 Patchy distribution of defoliation in 1974.

Fig. 6 Spread and coalescence of defoliation in 1975 from initial patches of 1974.

1 Dipel[R], Abbott Laboratories, North Chicago, Illinois., and Thuricide[R], Sandoz-Inc., Homestead, Florida.

2 Orthene[R], Chevron Chemical Co., Richmond, California.

3 Thompson-Hayward Chemical Co., Kansas City, Kansas.

In 1976, reduced concentrations of both Dimilin[R] and acephate were evaluated, as well as an early application of acephate. Non-target organisms were again monitored. This report summarizes the information on these research studies and control operations. Hopefully, it will prove useful to forest managers by describing the control techniques available and outlining the research necessary to develop them.

LIFE HISTORY AND OUTBREAK CHARACTERISTICS OF THE DOUGLAS-FIR TUSSOCK MOTH

The Douglas-fir tussock moth overwinters in the egg stage and hatches about June 1. In British Columbia, larvae feed through June and July, pass through five or six growth stages or instars and spin cocoons on the lower side of branches and foliage, in late July to early August. The females cannot fly and lay a single batch of eggs on the cocoons from which they emerge (Fig. 7). Dispersal occurs only in the spring when newly hatched larvae spin silk threads and are blown away by the wind (Fig. 8). These threads are intercepted by surrounding trees, thus restricting most of the spread to zones surrounding groups of trees infested the previous year.

Douglas-fir, *Pseudotsuga menzesii* (Mirb) Franco, is the main host in B.C., although grand fir, *Abies grandis* (Dougl.) Lindl., and white fir, *Abies concolor* (Gord. and Gland.) Lindl., are also primary hosts in the U.S.A. Larvae are often present in extremely high numbers and are capable of defoliating and killing trees in a single season. Young larvae restrict their feeding to current foliage, while

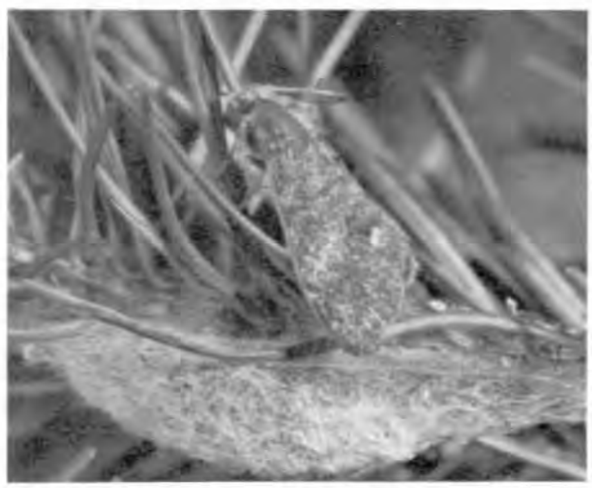


Fig. 7 Male Douglas-fir tussock moth and cocoon.

Fig. 8 Newly hatched larvae spinning from an egg mass.

older larvae feed on foliage of previous years. If populations are high, all foliage may be consumed before trees can develop buds for the next year and therefore the trees die. If populations are moderate, new buds are formed before most of the foliage is consumed and the trees may survive. The next year, however, such trees are wholly dependent upon the flush of foliage from those buds and a relatively small insect population can consume that foliage, thus killing the trees. Hence, if trees are to be saved, new growth must be preserved by implementing control as soon as larvae hatch and begin to feed; timing is therefore critical and prompt action is necessary. If possible, the objective of any control action should be to minimize initial defoliation (Figs. 3 and 4), because even if tree mortality is prevented, badly damaged trees may become highly susceptible to attack by the Douglas-fir beetle *Dendroctonus pseudotsugae* Hopkins. This problem arose in the Kamloops area in 1976, and a large trap-log program had to be carried out to control the beetle within the tussock moth-defoliated stands. Trees with the most severe defoliation were attacked more often by the beetle and also produced the

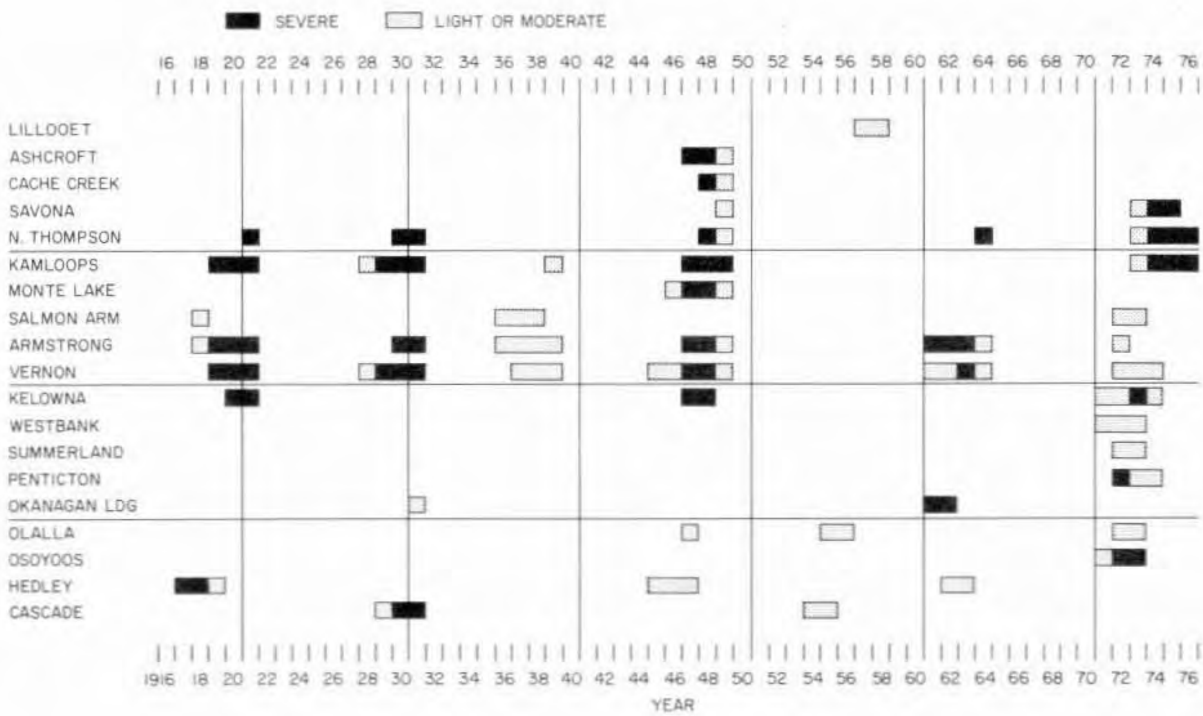


Fig. 9 Table of outbreak periods from 1916 to 1976 by geographical locations in British Columbia.

largest broods. The damage caused by the Douglas-fir bark beetle following tussock moth defoliation resulted in increased mortality, lumber degrade and costs.

Six outbreaks of tussock moth have occurred in British Columbia since 1916 (Fig. 9) usually in the driest Douglas-fir stands adjacent to grasslands or stands of ponderosa pine (Fig. 10). The most recent outbreak began in 1971 in the Okanagan Valley and was part of a larger one that extended into Washington and Oregon. By 1974, populations had decreased in the Okanagan Valley, but intensified in the North Thompson River Valley and south of Kamloops Lake.

Tussock moth outbreaks usually last 2 to 4 years in an area before subsiding. Defoliation begins in patches that tend to spread and coalesce in subsequent years (Figs. 5 and 6). Tree mortality occurs in the center of these patches, and spreads if the tussock moth population persists. Egg parasites, virus disease and starvation are often contributory factors to a population collapse. If these natural population regulating agents appear early in the outbreak, no additional control action is necessary. However, when populations are extremely high and natural controls occur late, as observed in 1974 and 1975, intervention by man is necessary to prevent tree mortality (Fig. 24). A natural outbreak of virus occurred in 1976, when larvae were almost fully grown, but it was too late to prevent severe defoliation. Without treatment, tree mortality would have been considerably greater.

ORGANIZATION

In the winters of 1974/75 and 1975/76, the outbreak situation was reviewed by provincial and local forest pest review committees representing the

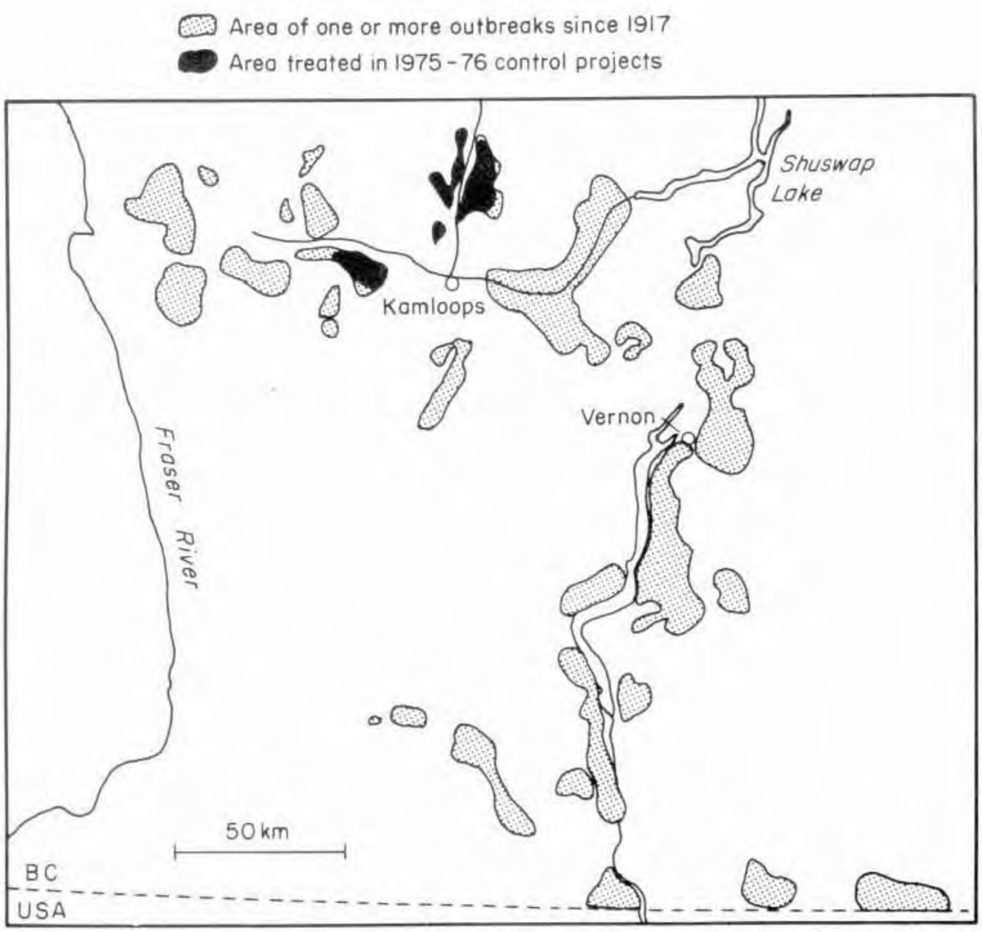


Fig. 10 Areas in British Columbia that have sustained one or more outbreaks since 1916 and the area treated in 1975-76.

following agencies: British Columbia Ministry of Forests; British Columbia Ministry of Environment, Water Rights Branch and Pollution Control Branch; British Columbia Ministry of Recreation and Conservation, Fish and Wildlife Branch and Parks Branch; British Columbia Ministry of Health; Canada Dept. of Fisheries and the Environment, Canadian Forestry Service and Environment Protection Service; Interior Lumber Manufacturers' Association, and Cariboo Lumber Manufacturers' Association. Data on current defoliation patterns and egg mass densities had been collected by the Canadian Forestry Service, in co-operation with the B.C. Forest Service, and presented to these committees. The B.C. Forest Service, in consultation with these committees decided, in 1975, to implement a spray program, utilizing the bacterium, *Bacillus thuringiensis* (*B.t.*), and recommendations were made on buffer zones, safety aspects and monitoring of non-target organisms. *B.t.* was applied on 12 140 hectares (30,000 acres) to reduce defoliation and prevent tree mortality, at a cost of $7.53 per acre.

A program was carried out to inform the public of the proposed control project through press releases, radio and television interviews and newspaper advertisements. A special Information Day was held in Kamloops, with displays, photographs, live larvae on damaged foliage, and a team of experts to answer questions; only a few people visited the information room. Letters were sent to property owners explaining the program and requesting permission to spray their land; all responses were positive.

At the same time as the operational control program with *B.t.* was carried out, a co-operative research team, made up of scientists from the United States Forest Service, the Canada Forestry Service and the British Columbia Forest Service, undertook further spray trials using two chemicals, acephate, and Dimilin[R] and two strains of virus, as well as different formulations and concentrations of *B.t.* in a continuing search for safe, effective control materials and application techniques. The Fish and Wildlife Branch of the British Columbia Ministry of Recreation and Conservation monitored bird and selected rodent populations in the chemical test area and the Environmental Protection Service of the Canada Department of Fisheries and the Environment monitored non-target insects.

By autumn 1975, it was evident that the *B.t.* operational control project was only partially successful. Populations were reduced sufficiently to keep most of the trees alive, but not enough to prevent residual populations from building up to destructive levels in 1976. In some places, patches of forest died and salvage logging was initiated to utilize these trees before checking and decay became severe (Fig. 11).

In 1976, a control operation was again undertaken by the British Columbia Forest Service and, by using the knowledge gained from the 1975 research, acephate was selected as the most effective treatment available. This operation successfully preserved the 1976 foliage and prevented further tree mortality. Average cost was $7.13 per acre for all applications. Co-operative research was again carried out by the above-mentioned agencies, except that non-target organisms were monitored by the Canadian Forestry Service. Staff from Simon Fraser University undertook a study on the residual life of acephate on foliage and, in collaboration with the Canadian Forestry Service, carried out a study on the effects of acephate on an ant predator, *Formica integroides* Emery. Research on several other aspects, such as larval dispersal (Fig. 26), sex attractants (Fig. 27), food reserves of defoliated trees, subsequent attack of damaged trees by Douglas-fir beetle, and the impact of defoliation upon tree growth were also undertaken.

OPERATIONAL ASPECTS

Spray mixing and aircraft loading, in 1975, took place at the Kamloops airport for the control operation and the experimental trials (Figs. 1 and 2). In 1976, the aircraft used for the research plots worked from this airport, but mixing and loading were done on a small gravel strip about 40 km north of Kamloops. In 1975, three Cessna "Agtrucks" were used. They had interchangeable spray booms capable of using Micronair rotary atomizers that produced a narrow droplet diameter spectrum, and conventional booms and flat fan nozzles (Tee-jet 8010) that produced a wider droplet spectrum. Each aircraft carried 380-570 ℓ (100 - 150 U.S. gal) of spray formulation and flew at about 180 kph (110 mph). With the Micronair delivery system, a swath width of about 60 m (200 ft) was obtained, whereas only 30 m (100 ft) was obtained with boom and nozzle. Calibration of the aircraft dispersal system was carried out by measuring delivery rates and droplet distribution at set flying speeds, height and pump pressures.

Fig. 11 Salvage logging of stand killed by Douglas-fir tussock moth.

Two trailer-mounted holding tanks of 2270 ℓ and 4540 ℓ (600 and 1200 U.S. gal) and a 300 ℓ (80 gal) mixing tank, a flow meter and two centrifugal pumps with hoses and valves were used to mix and load the spray formulations. At the airport, the insecticide was stored in a locked hangar and a truck with a hydraulic tail-gate was used to haul each day's requirements to the mix site. A truck was used in 1975 to haul water from the South Thompson River (pH 7.9) for formulation of *B.t.* sprays to avoid the chlorinated, alkaline water on site at the airport.

Spray blocks were marked on aerial photographs, using easily visible boundaries such as ridges, valleys and grassland edges, for use by the pilots and ground personnel. Plot corner and boundary markers of white, yellow or orange plastic or cloth were placed on tree tops by shooting a monofilament line over a tree with a line gun or crossbow and pulling the marker up into position (Fig. 21). All aircraft were in radio communication with ground personnel on the spray block and at the mixing sites, which allowed for good control of aircraft, minimized drift and facilitated co-ordination of mixing requirements.

The Dept. of Fisheries and Environment, Atmospheric Environment Service, Vancouver, provided daily spray weather forecasts. Trained personnel near every spray block monitored the weather, placed out spray deposit cards and watched spray cloud behavior. They were responsible for supervising the application and when spray started to drift, the operation was stopped. The length of time when conditions were suitable for spraying varied from 0 to 5 hours per day, with an average of 3 hours. Block assignments took into consideration the persistence of stable air conditions on different slopes; usually the north- and west-facing hillsides were the most stable and maintained descending air drainage later in the day than south- or east-facing hillsides. In some cases, unpredictable showers washed off deposits and the applications were repeated.

In 1976, when acephate was used as the operational material, special precautions were necessary to protect domestic bees. Each beekeeper in the area was contacted the night before spraying and asked to cover his hives and prevent bee exits until after 10:00 a.m.; by this time, the acephate was dried onto the foliage. This worked satisfactorily, except in two instances where hives were not blocked and bees suffered high mortality. Special field monitoring of wind currents and timing of application was carried out in one case to ensure that no insecticides drifted onto a garden where predators had been imported to control vegetable pests. Aeroplanes were prohibited from flying near a turkey farm, in case the noise might disrupt the flock.

Egg hatch and larval development were monitored regularly by the Canadian Foresty Service throughout the proposed spray area. Generally, hatch and larval development varied with temperature, which was influenced by elevation, aspect and the amount of sunlight penetrating the stand. On the west side of the North Thompson Valley, development was 7 to 10 days ahead of that on the east side. Also, development in areas defoliated the previous year was about 7 days ahead of areas with little or no defoliation. Spraying started in 1975 when 80 to 90% of the insects were in their second instar, which was about 10 days after 90% hatch. Spraying was delayed until the second instar so that a rapid-feeding population would be present to consume the short-lived *B.t.* Consequently, severe damage of current foliage occurred in some areas. In 1976, operational spraying with acephate was, therefore, started as soon as 90% of the eggs had hatched and the larvae had moved out to feed. In one experiment, spray was applied when only 70% of the eggs had hatched, but larvae had not necessarily moved out to feed, in order to test if earlier treatment would be more successful.

ASSESSMENT METHODS

Larval mortality was determined by clipping two branches from the mid-crown of 15 to 25 suitable trees in each study plot and counting the number of larvae per unit of branch area (Fig. 22). Larval density was established before spraying and at 7, 14, 21 and 35 days after the application. Samples were obtained in a similar manner from non-sprayed plots and the mortality owing to the spray treatment was calculated from the difference in survival between the two plots, using the following formula:

$$\% \text{ control} = \frac{a - b}{a} \times 100$$

where a = % survival between the pre- and post-spray samples in non-sprayed plots and b = % survival between the pre- and post-spray samples in sprayed plots.

DIPEL					THURICIDE		
1	1	1	2	NUMBER OF SPRAYS	1	1	2
4.74	4.74	3.56	3.56	VOLUME / HECTARE / SPRAY	9.47	4.74	4.36
25.5	17.0	17.0	17.0	BIU / HECTARE / SPRAY	17.0	17.0	17.0
MOLASSES		SORBITOL		ANTIEVAPORANT ADDED	NONE		

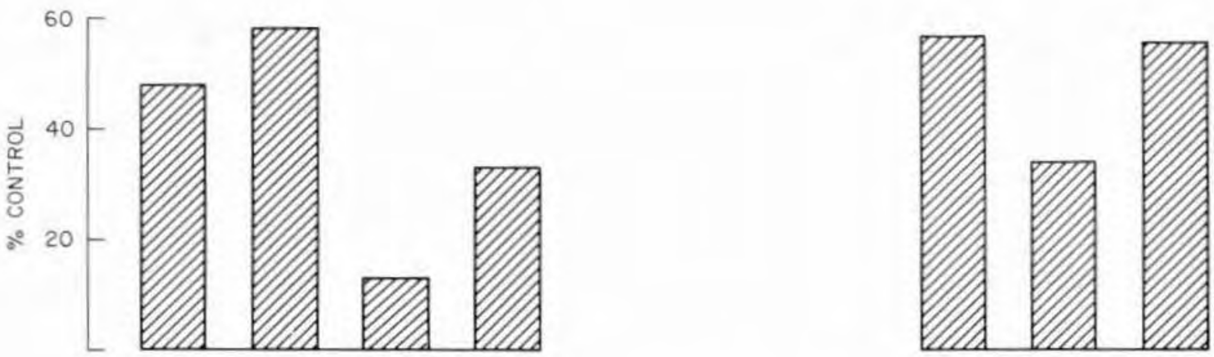


Fig. 12 Effectiveness of different formulations of *Bacillus thuringiensis* field tested by aerial application against the Douglas-fir tussock moth.

Fig. 13 Larva killed by nucleopolyhedrosis virus.

Foliage protection was assessed on each treated and non-treated plot by visually estimating defoliation before egg hatch and after larval feeding was complete. Trees were selected that had little or no previous defoliation. Defoliation was established separately for current foliage and older foliage at three crown levels.

EFFECTIVENESS OF MICROBIAL INSECTICIDES

The 1975 operational spray with *B.t.* was carried out using two commercial preparations: Thuricide-HPC^R and Dipel-SC^R, at 17.0 Billion International Units per hectare. With Dipel^R, sorbitol was added as an anti-evaporant to comprise 30% of the volume of the water mix; 3.56 ℓ /ha of the mix was applied. With Thuricide^R, 4.74 ℓ /ha of water mix was applied. Later, when it was apparent that the effectiveness of Dipel^R was low, a second application of the same formulation was applied on some areas. A single application was made on 12 488 hectares (30,858 acres) and a double application on 5 245 hectares (12,961 acres). A separate test was made with two applications of Thuricide^R for comparison.

The various operational and experimental treatments with *B.t.* resulted in a wide range of effectiveness. Even the best treatment resulted in less than 60% control, which did not adequately protect trees against defoliation or reduce populations sufficiently to prevent a rebound to high densities in the next generation.

At 21 days after spraying, larval mortality attributed to the operational spray averaged 34% (Fig. 12). Mortality ranged from a high of 57% achieved with Thuricide^R to a low of 13% with a single application of Dipel^R. A second application of either material and a higher volume of Thuricide^R gave 20% more control than a single application at normal volume, but doubling the concentration of Dipel^R

resulted in no significant change. An experiment using molasses instead of sorbitol as an anti-evaporant resulted in a significant increase in effectiveness of Dipel^R, bringing it up to the same level as Thuricide^R.

Applications of either single or double concentrations of Dipel^R provided little foliage protection. During 1975, 59% of the total crown on non-sprayed trees and 50 to 58% on Dipel^R-sprayed trees was destroyed. Defoliation in Thuricide^R-sprayed areas was only 18 to 25%, indicating that some foliage protection was achieved.

A re-assessment of foliage loss was made in the spring of 1976 before bud growth. In Dipel^R-sprayed plots, an average of 44% of the trees were severely defoliated; i.e., had lost 90% or more of their crowns, whereas there were no trees severely defoliated in the Thuricide^R-sprayed plots.

Nucleopolyhedrosis virus disease can be a major factor in the natural decline of outbreak populations of Douglas-fir tussock moth (Fig. 13). However, this disease often does not terminate an outbreak until after considerable defoliation and stand damage have resulted. The feasibility of inducing this disease in healthy populations at an early point in the outbreak cycle was tested.

Three virus isolates were compared. One came from and was propagated in Douglas-fir tussock moth in Oregon. The second was also from this same source, but was propagated in white-marked tussock moth (*Orgyia leucostigma* J.E. Smith). The third was isolated from white-marked tussock moth in Nova Scotia and was propagated in that insect host.

Some plots were treated with virus suspended in a 25% molasses-water formulation to which an ultra-violet screen (5% w/v Shade^R[4]) had been added at 60 g/ℓ (0.5 lb/U.S. gal). On other plots, the virus was formulated in a commercial microbial spray adjuvant (50% Sandoz V^R). Application rates of 9.3 and 18.7 ℓ/ha (1 and 2 U.S. gal per acre) were compared. A dosage of 247 billion viral inclusion bodies per hectare (100 billion per acre) was used in all tests. Applications were made when the larvae were in the second to third instar, by which time most of the current foliage was severely damaged. Plot size varied from 8 to 513 hectares (20 to 1,267 acres), with a total treated area of 1 071 hectares (2,647 acres). Non-treated check plots were established for comparative purposes.

When larval counts were made, samples of tussock moth larvae were collected for laboratory rearing. Pre-spray rearing provided a base line for estimating the level of natural virus infection in the test populations. Post-spray rearings indicated the incidence of the induced virus disease in the field population.

All virus treatments provided control of the tussock moth and no significant differences could be detected between strains or formulations. Mortality averaged 56, 67 and 88% at 21, 28 and 35 days post-spray, respectively. These population reductions were associated with high levels of virus infection induced by the spray applications. Only moderate defoliation (4 to 11%) of the older foliage occurred on all virus-treated plots except one, where adverse weather conditions during treatment caused poor spray deposit. In contrast, the check areas suffered extensive defoliation (60 to 70%) of the old foliage and some tree mortality. No egg masses could be found in the virus plots the year after treatment.

These trials provided part of the information necessary for registration of the Oregon strain of virus for control of Douglas-fir tussock moth in the U.S.A. by the U.S. Environmental Protection Agency. At the time of writing, there are no viruses registered for insect control in Canada.

EFFECTIVENESS OF CHEMICAL INSECTICIDES

The two chemical insecticides evaluated in field experiments were selected because of their relatively low mammalian and bird toxicity, combined with effective insect control. Acephate was already registered for control of other insect pests and field tests in 1975 were conducted to test its efficacy against Douglas-fir tussock moth and measure its impact on non-target organisms. Based upon the results of this research, acephate was selected for operational use in 1976. When tested in 1975, Dimilin^R was not registered for any use in Canada and required further testing before acceptance. The objective for treatment with both these chemicals was to obtain maximum foliage protection.

Orthene is an organophosphate insecticide which is water soluble and appears to be absorbed to

4. Sandoz Inc. Homestead, Florida

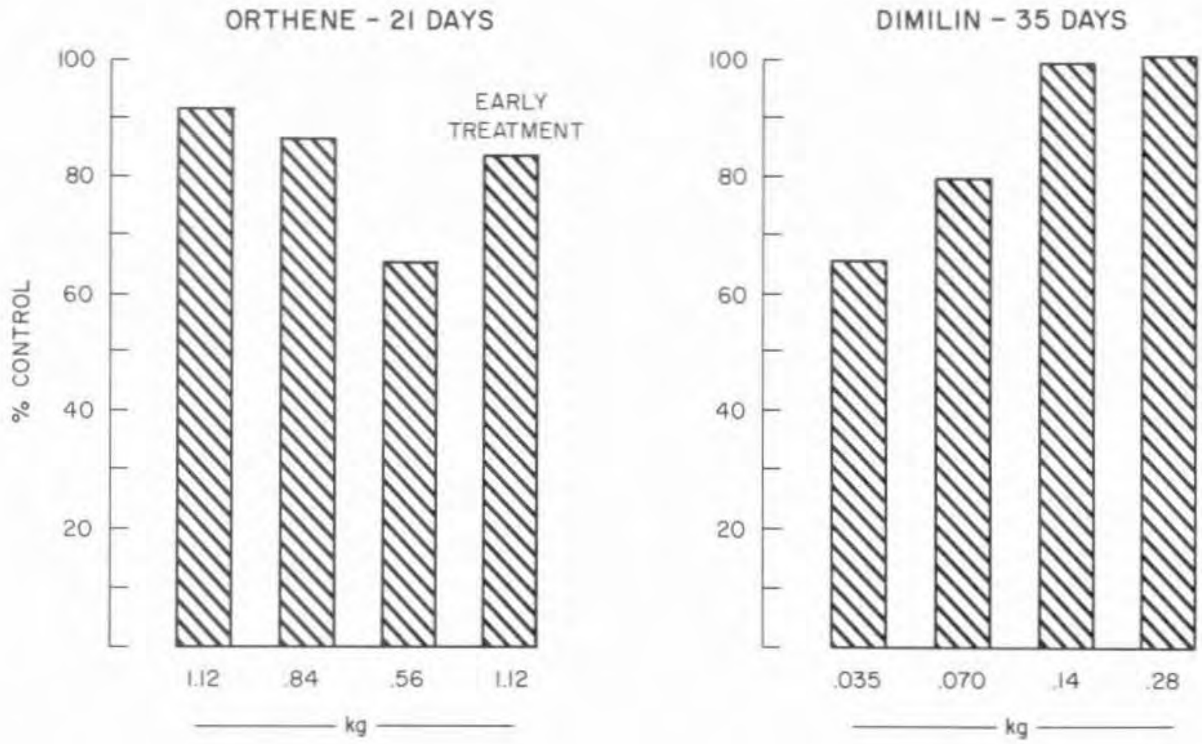


Fig. 14 Effectiveness of different concentrations of acephate and Dimilin[R] and of an early treatment of acephate.

some extent into foliage. Dimilin[R] is a wettable powder with an unprecendented mode of action. Insects use a material called chitin as a main constituent of their body wall and Dimilin[R] inhibits its formation. Therefore, Dimilin[R] affects only organisms producing chitin; *i.e.*, arthropods.

The acephate formulation had 1.12 kg active ingredient (A.I.), 0.41 ℓ ethylene glycol and sufficient water for application of 3.8 ℓ /ha (1 lb A.I. in 1 U.S. gal/acre) experimentally in 1975 and operationally in 1976. Reduced rates of .56 and .84 kg A.I. and 0.4 ℓ ethylene glycol in 3.8 ℓ /ha (1/2 and 3/4 lb in 1 U.S. gal/acre) were tested in 1976. The treatment was applied when 90% of the egg masses had hatched and the larvae had moved out to feed. In addition, three 200-hectare (500 acre) blocks were treated with 1.12 kg/ha when 70% of the egg masses had hatched but the larvae had not necessarily moved out to feed. Subsequent cool weather slowed larval movement to the shoots until the spray had lost some of its effectiveness and hence mortality was reduced. The Dimilin[R] formulation had 25% A.I. and was applied at the rate of 0.28 kg A.1. plus 0.4 ℓ ethylene glycol in water to deliver 3.8 ℓ /ha (4 oz A.I./acre) in 1975 and at .035, .070 and .14 kg/ha (1/2, 1, 2 oz/acre) in 1976. Both insecticides were mixed in a water solution with 10% ethylene glycol to reduce evaporation and increase droplet breakup. The dye, Rhodamine B Extra S, was added at the rate of 2 gm/ℓ to all formulations for deposit assessment.

Acephate proved to be effective operationally at 1.12 kg/ha and experimentally at both 1.12 and .84 kg/ha but did not attain adequate control at .56 kg/ha (Fig. 14). Its effect on the insects was rapid and appeared to be complete by 7 days, with little mortality occurring after that time. Chemical analysis of foliage indicated that acephate persisted for up to 60 days, but not in sufficient concentration to have any effect on insect survival (Fig. 15). Dimilin[R], on the other hand, acted more slowly but retained its effectiveness for a longer period of time (Fig. 16). Dosage of 0.28 and 0.14 kg/ha gave almost complete mortality, but 0.07 and 0.035 kg/ha did not give acceptable results (Fig. 14). Because of the faster action of acephate, tree defoliation was less (3.4%) than with Dimilin[R], (11.9%), although the latter was still quite acceptable as compared to the non-treated areas (73.7 and 90.8%, respectively).

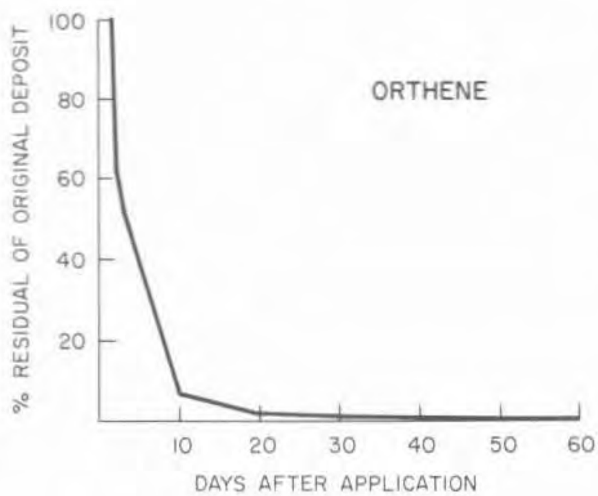


Fig. 15 Rate of loss of activity of aerial-sprayed acephate on Douglas-fir foliage.

These trials provided part of the information necessary for registration of acephate applied at 1.12 kg A.I. in 3.81 water/ha for control of Douglas-fir tussock moth. No registration has been obtained for Dimilin[R] at the time of writing.

EFFECTS ON NON-TARGET ORGANISMS

ARTHROPODS

There are many insects and other arthropods living in the forest ecosystem, most of which are beneficial. It would be expected that, even though the control program was aimed at one insect species, other species might also be affected.

Census systems were utilized to detect the population disruptions of non-target insects with a series of traps in the different vegetative layers of the forest. Ultraviolet light traps were used to catch night-flying insects (Fig. 23); pitfall traps were used to catch ground arthropods; net sweeping was used on short-grass undergrowth, and tree beating was used to sample arboreal arthropods on the lower crowns. All methods were utilized before and after the spray application in treated and non-treated plots. Unfortunately insect activity is directly related to weather and the efficiency of all these systems varied considerably from day to day, thus decreasing their sensitivity to detect changes that could be attributed to the chemical treatments.

Some evidence of reduction in total numbers of arboreal arthropods was found following the

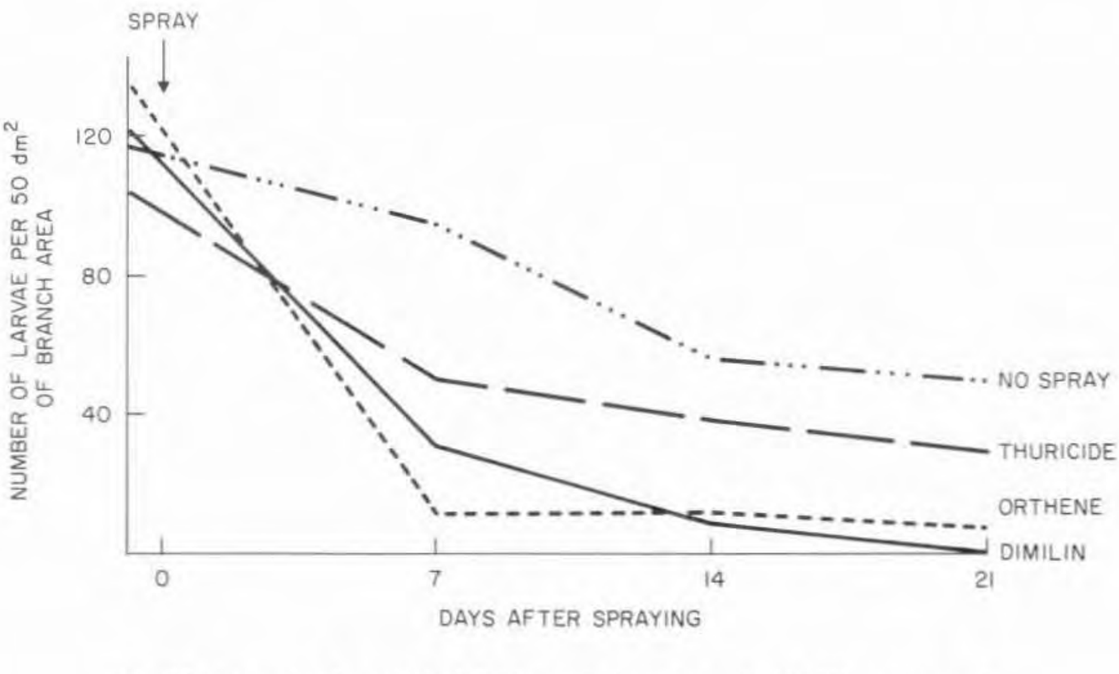


Fig. 16 Example of survival of field populations sprayed with different control materials and of a non-sprayed check population.

acephate and Dimilin[R] applications and of the grass-dwelling arthropods following the acephate application (Fig. 17 and 18). Populations of flying insects may have been affected during the second and third nights after the acephate application, but numbers appear normal thereafter (Fig. 19). Populations of parasitic wasps, predaceous spiders and ants were reduced in the grasses and lower crowns of trees following the acephate and Dimilin[R] applications. However, the extreme natural variability of these populations made it difficult to judge the significance of these apparent population reductions.

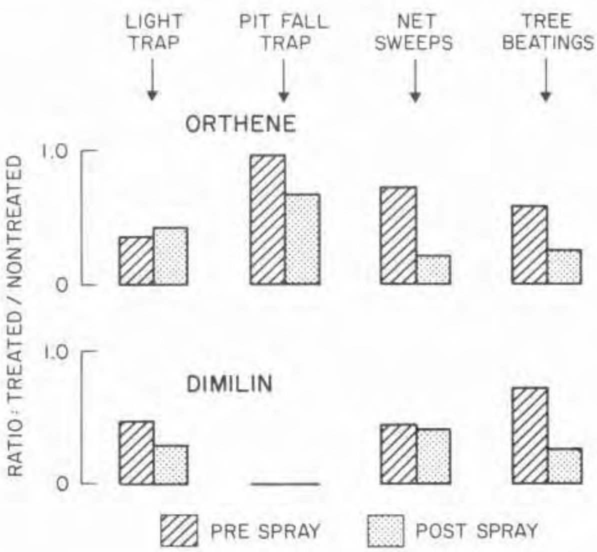


Fig. 17 The change in the ratio of the number of non-target organisms caught by different sample systems before and after spraying.

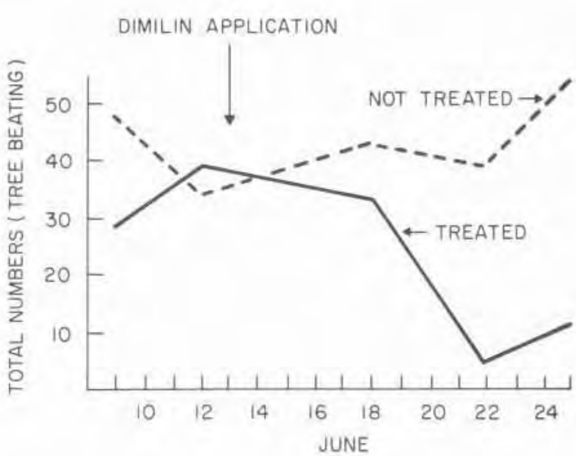


Fig. 18 The total number of organisms found in tree beatings before and after the time of spraying in areas treated with Dimilin[R] at 4 oz/acre and in non-sprayed areas.

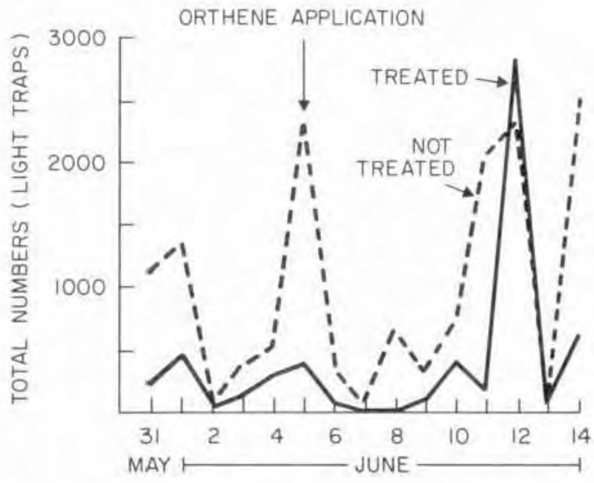


Fig. 19 Example of the number of insects of all species caught in light traps before and after the time of spraying in an acephate-treated and a non-treated area.

Specific survival studies were made of the ant *Formica integroides* Emery following acephate application. Ants in dishes exposed directly to the aerial spray were all killed and even those screened under

Fig. 20 Mound-building ant nest in the outbreak area.

Table 1

Ratio of number of species of soil organisms in Dimilin^R-treated and non-treated plots.

	Treatment			
	140 g/ha			280 g/ha
Taxon	Pre-spray	11 days post-spray	3 months post-spray	1 year post-spray
Nematodes	1.09	1.86$^+$	0.79	1.11
Enchytraeids	0.64	0.00*	2.13	0.41*
Tardigrades	1.10	0.09*	0.36*	1.77
Collembolans	1.40	0.54*	0.52	1.08
Mites	1.17	1.26	0.94*	1.16

+ significant increase in sprayed plots, as compared to changes in non-sprayed plots.

* significant decrease in sprayed plots, as compared to changes in non-sprayed plots.

the forest canopy suffered 37% mortality as compared to 10% in the non-treated checks. Observations of colonies of these mound-building ants (Fig. 20), which are predators of the tussock moth, indicated that all colonies exposed to the spray were reduced in size and many were completely killed. Even when the mounds were covered with plastic during spraying, the colonies were severely reduced, presumably because of the contaminated material brought into the nest. In subsequent years, residual colonies increased in size and re-colonized some vacant nests.

Fig. 21 Shooting a monfilament line over a corner tree with a cross bow to pull plot markers up to the tree tops.

Fig. 22 Dropping a clipped branch onto a cloth to count the number of larvae and measure the size of the branch.

Fig. 23 Ultraviolet light trap for night-flying insects.

Fig. 24 Stand killed by Douglas-fir tussock moth.

Fig. 25 Bird nest exposed by defoliation of the trees.

Fig. 26 Installing weather instruments used for larval dispersal studies.

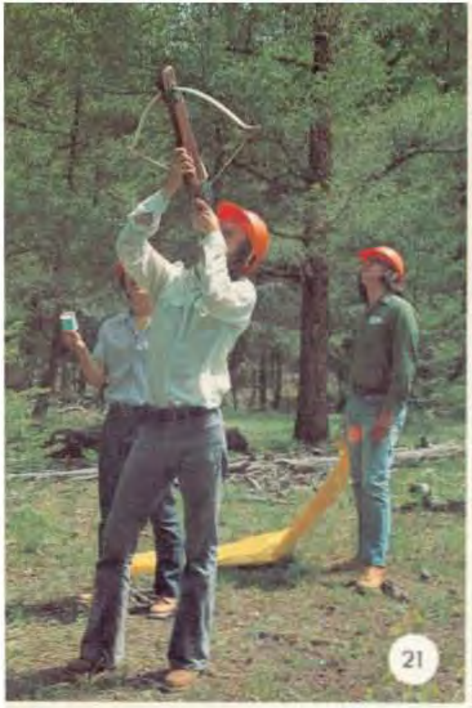
Fig. 27 Examining a sticky trap that caught adult male moths attracted by a synthetic sex pheromone.

Fig. 28 Mapping territories of singing male songbirds in sprayed and non-sprayed areas.

SOIL FAUNA

The possibility of Dimilin^R affecting soil animals, such as nematodes, annelid worms and arthropods, directly or indirectly through contaminated food was investigated. Soil samples were taken to study changes in numbers of species and relative composition of animals in the top 6-cm soil layers, at various dates, following two different application rates of Dimilin^R. Ratios of numbers of species in treated and non-treated sites are summarized in Table 1.

The tardigrades, collembolans and mites showed decreases during the first 3 months after spraying in the site treated at 140 g/ha, but most of these groups were near "normal" 1 year after the Dimilin^R application, even on the site treated with 280 g/ha. No specialized feeding group was adversely affected, with increases and decreases occurring among saprophages and predators. However, the lower numbers of tardigrades in the site treated with 280 g/ha, and the failure to collect


21


22


23


24


25


26


27


28

Fig. 29 Sampling aquatic fauna in a test area.

certain species in the sprayed plots, as compared to the check, suggest that continued monitoring of the plots is warranted.

BIRDS

Study areas for birds consisted of 8 ha (20 acre) plots, with a 9.75 m (132 ft) grid marked throughout. Plots were located in acephate and Dimilin^{R}-sprayed blocks and in non-sprayed blocks. Each study plot included some grassland adjacent to the infested trees in order to include species of birds with a forest edge habitat. Each day singing males were recorded by grid location (Fig. 28). By repeating this daily for 3 days before spraying, the territorial males of selected species were identified and mapped. The process was repeated for 3 days after spraying and any absent birds were noted. As many nests as possible were also located and fledgling survival was recorded. No effects were detected in 1975; however, in 1976 acephate plots, a noticeable depression of singing activity occurred on the day of spray application but again no bird mortality was detected.

AQUATIC ARTHROPODS

Sampling for aquatic arthropods was carried out in two creeks and one pond within areas treated with the highest concentration of Dimilin^{R} and in one pond within the acephate-treated area (Fig. 29). No gross effects were found that could be attributed to the spray. Assessing aquatic arthropod populations is difficult and the techniques employed were not sensitive enough to detect small changes.

SMALL MAMMALS

Before spraying, trap lines with 167 to 250 snap traps were established in acephate-sprayed and non-sprayed plots. Trapping on two successive nights was carried out before spraying and on two nights after spraying, with a different line used each night. Of the animals caught, the white-footed deer mouse was the only species taken in sufficient numbers to serve as an indicator. No effects were detected (Fig. 30).

% trap catches of deer mice

	Prespray	Postspray
Orthene		
Non Treated	8.4	7.4
Treated	4.2	5.7
Dimilin		
Non Treated	6.3	3.9
Treated	10.7	7.6

Fig. 30 Percent of the traps that caught deer mice before and after spray application in areas treated with acephate at 1.12 kg/ha and Dimilin^{R} at 0.28 kg/ha and in non-treated areas.

SUMMARY

Predictions for 1975 indicated that tree damage would be severe as a result of defoliation of Douglas-fir by the tussock moth. The B.C. Forest Service, in consultation with other agencies concerned with forest land management in the affected area, decided to spray *Bacillus thuringiensis* (*B.t.*) to control this pest. *B.t.* was selected because of its safety to non-target organisms and its previous effectiveness in U.S. control programs, but it proved to be ineffective in stopping the outbreak. Tussock moth larvae were killed and some foliage was saved, but residual numbers of the insect pest were high enough to propagate threatening populations for the next year and, in some places, tree mortality occurred. Various formulations and dosage rates of *B.t.* were tried. The addition of molasses to the formulation and doubling the volume emitted, but not the concentration, enhanced the efficacy of the material, but not to a level considered satisfactory to prevent defoliation. As a result, the operation had to be repeated the following year with a more effective material.

The defoliation that occurred in 1975 also led to a further complication. The Douglas-fir bark beetle increased rapidly in 1975 and 1976, particularly in trees weakened by defoliation. Subsequently, a large trap-log and salvage program was organized to reduce the beetle populations.

Aerial spray trials conducted in 1975 demonstrated that the induction of a nucleopolyhedrosis virus disease controlled the Douglas-fir tussock moth and prevented tree mortality. Naturally-occurring virus disease frequently terminates outbreaks of this pest and the introduction of virus at an early stage of the outbreak provides regulation of the insect population before tree damage has occurred. Nucleopolyhedrosis virus diseases have the added advantage of being host specific and thus safe to non-target species.

Acephate and Dimilin^R were field tested experimentally in 1975 and both were effective. Acephate was fast acting and broke down rapidly, while Dimilin^R was slower acting but effective over a longer period. Acephate was selected for operational use in 1976 because of its faster action and because it had previously been registered for control of other insect pests, whereas Dimilin^R was still in the experimental testing stage. In 1976, both insecticides were field tested at reduced dosages. Many of the trees in the area treated with *B.t.* in 1975 were severely defoliated and depended for survival upon new shoots developing from current year's buds. Predictions for 1976 indicated that tussock moth populations would be high enough to defoliate and kill trees within 2 or 3 weeks of bud break, necessitating the use of a quick-acting material applied with precise timing. The acephate application was successful in this regard, both in reducing insect populations and in preserving foliage.

Acephate- and Dimilin^R-treated areas were monitored for effects on birds, mammals, aquatic insects and terrestrial arthropods. An interruption of male bird songs was detected on one occasion the day acephate was sprayed, but they resumed the following day and bird numbers remained stable. There appeared to be a 2-day reduction in numbers of night-flying insects and a reduction of insects on foliage and interspersed grassland. Mound-building ants, which are predators of tussock moth larvae, were severely affected by the acephate, and certain groups of soil organisms were somewhat affected by the Dimilin^R application.

Effects on non-pest insects in the forest are, of course, inevitable following application of broad spectrum insecticides and their loss must be balanced against tree mortality, growth loss and habitat destruction which would have occurred had no control action been undertaken.

BC-X-201, April, 1980, Victoria, B.C.

Additional copies may be obtained from

Canadian Forestry Service
Pacific Forest Research Centre
506 West Burnside Road
Victoria, British Columbia V8Z 1M5

or

United States Forest Service
Pacific Northwest Forest and Range
Experiment Station
809 N.E. Sixth Avenue
Portland, Oregon 97232