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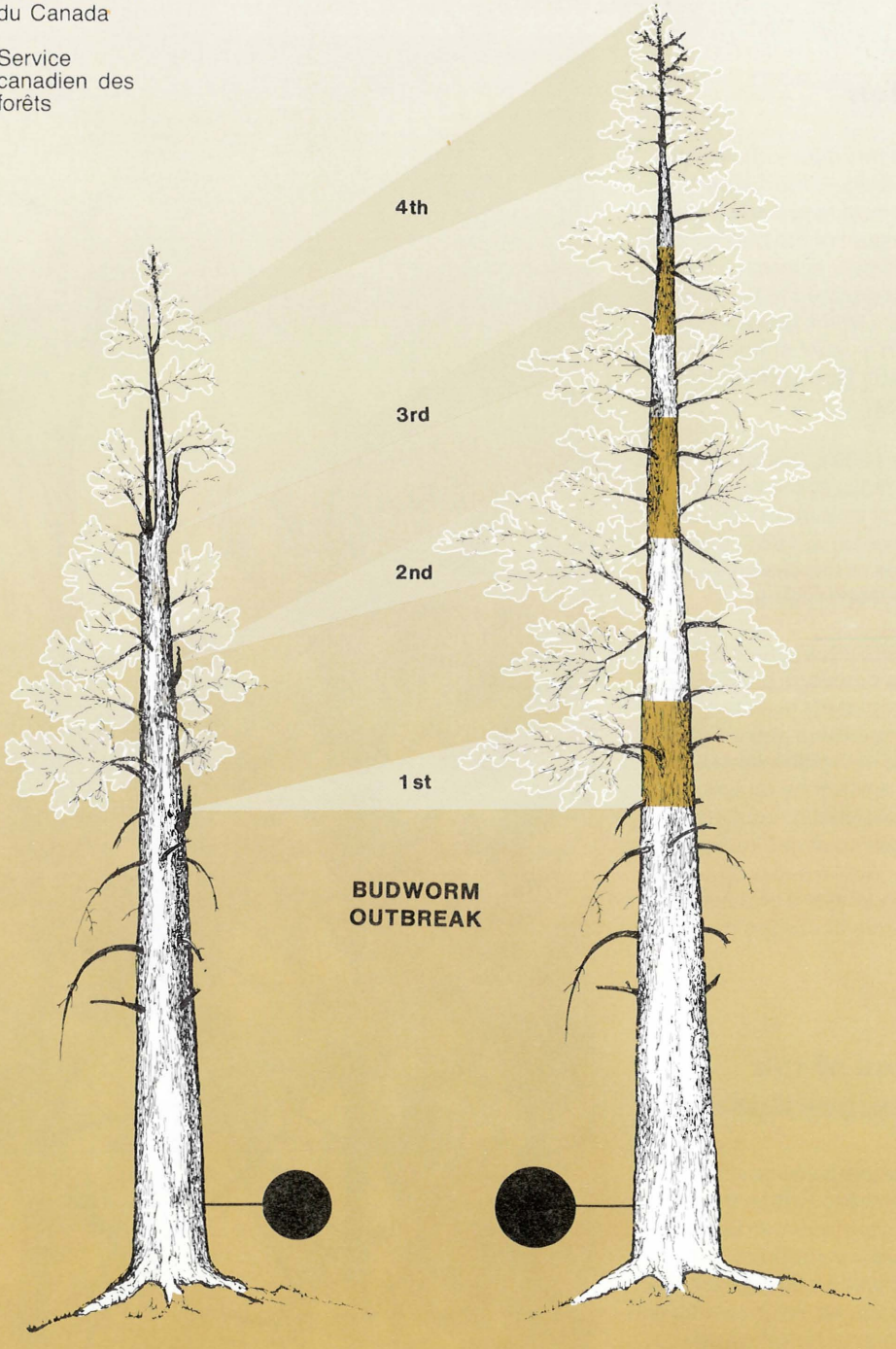


SPECIAL SPRUCE BUDWORM EDITION

The Western Spruce Budworm Feeding on Douglas-fir

by Terry VanderSar

Introduction

The purpose of this information bulletin, devoted entirely to the western spruce budworm, is to provide a comprehensive account of the biology and damage caused by this forest insect. Although closely related to the eastern spruce budworm which defoliates and kills spruce and balsam fir trees, the western budworm feeds primarily on Douglas-fir trees.

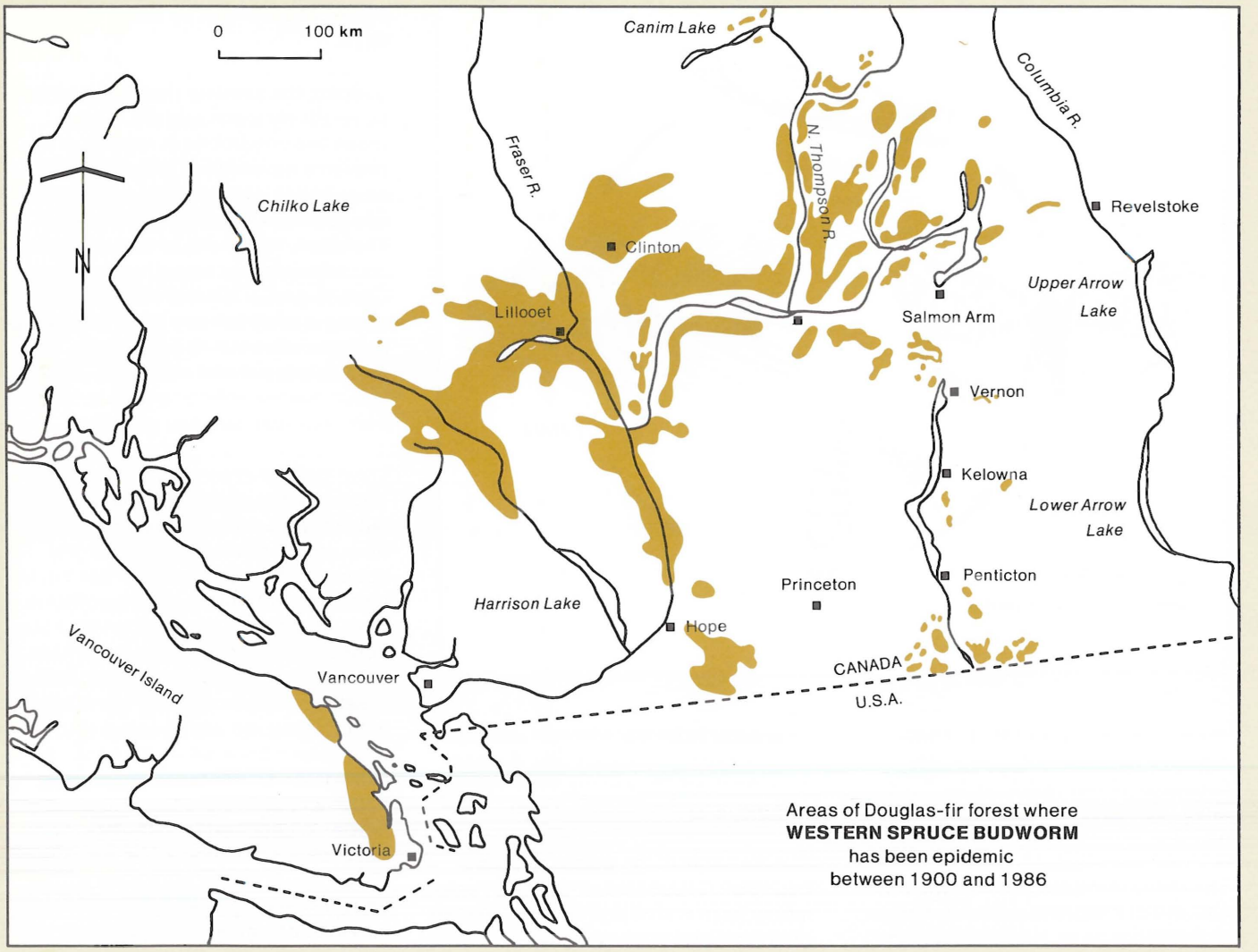
Since the early 1900s, there have been five major outbreaks of the western spruce budworm in southern British Columbia. Currently, in 1987, there is a major outbreak of this insect in progress in the Kamloops region.

Although periodic infestations of the western spruce budworm are a natural event in the Douglas-fir forests of British Columbia, scientists at the Pacific Forestry Centre in Victoria have been diligent in their search for answers. This information bulletin highlights knowledge gathered at this research center over the last 15 years as scientists strive to understand and curtail the losses this insect causes in our forests.

Distribution of the Western Spruce Budworm

The western spruce budworm is an insect that is native to British Columbia. It is widely distributed in Douglas-fir forests across the southern half of the province as well as throughout the western United States. As indicated on the map, budworm outbreaks have occurred from Vancouver Island in the west to Shuswap Lake in the east and from the Canim Lake region south to the Canada-U.S. border. In 1986 more

Douglas-fir tree defoliated by the western spruce budworm



than 413 000 ha of mature and immature Douglas-fir in four forest regions were defoliated by the budworm. This was nearly double the area defoliated in 1985 and was the most expansive budworm infestation recorded in B.C. during 50 years of Forest Insect and Disease Surveys (FIDS).

Most years, the western spruce budworm goes unnoticed when comparatively few caterpillars cause minimal damage to the new foliage of Douglas-fir trees. When the numbers or population of this forest insect increase dramatically, however, an outbreak or infestation can occur and may persist for a period of years as is the case currently in the Kamloops region.

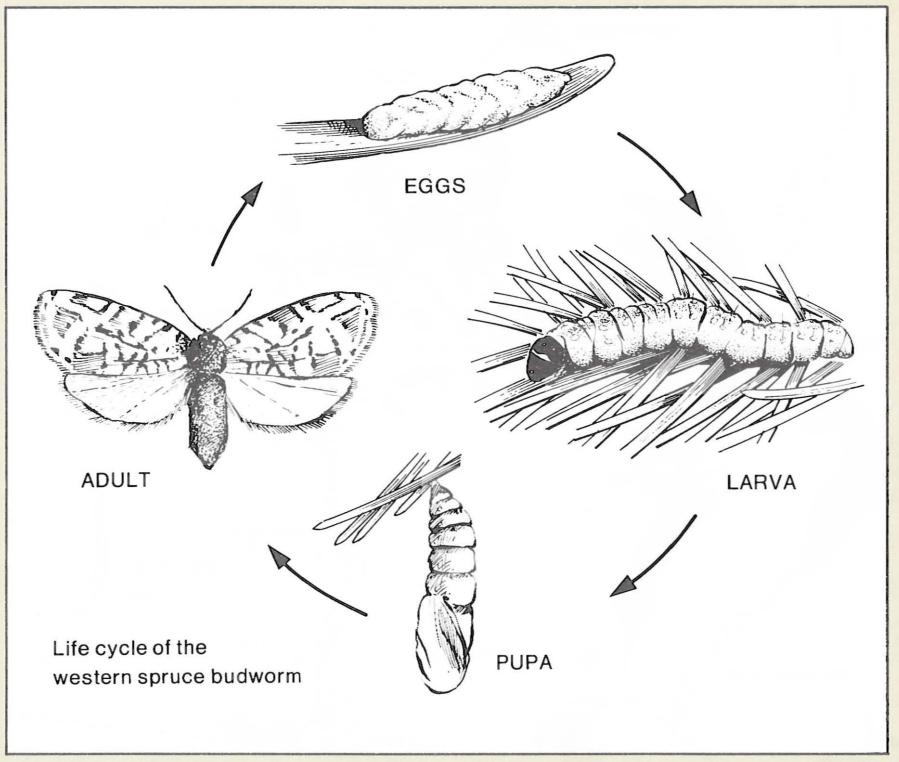
Douglas-fir trees defoliated by an outbreak of the western spruce budworm are easily recognized in the field. By late June or early July, the partially-eaten needles of damaged trees discolor to give the forest an overall reddish-brown appearance. When a severe infestation of the budworm persists for several years, dead trees become visible to the naked eye as grey skeletons that have lost all their needles.

Life Cycle of the Western Spruce Budworm

The western spruce budworm, referred to by scientists as *Choristoneura occidentalis*, is the caterpillar of a small moth that is greyish-brown in color and has a wingspan of approximately one inch. This caterpillar, which is reddish-brown in color with rows of pale dots along the length of its body, can cause severe damage to the Douglas-fir forests so valuable to the resource economy of British Columbia. The budworm damages these trees by feeding on the needles and in the buds of these conifers.

As is the case for most other insects, the western spruce budworm has four different stages in its annual life cycle. Adult moths deposit their eggs in clusters on the underside of fir needles during August. This egg mass is green in color with the eggs overlapping like the shingles on a roof.

In about 10 days, these eggs hatch to produce larvae or caterpillars. At this



Life cycle of the western spruce budworm

stage, budworms do not feed but almost immediately spin a protective cocoon of silk in which each young larva then spends the cold winter months.

The following spring in May, the tiny caterpillars become active and begin to feed at once on the foliage of the Douglas-fir trees. Some larvae mine inside the one-year-old needles, while others chew their way inside the soft new buds at the tip of the branches.

After these buds have opened or flushed (provided they have not already been killed), the caterpillars begin to feed on the tender new needles. A silken web contributed to by each feeding larva encloses the developing shoot and protects the feeding budworms from birds and insect predators. Individuals may feed for five to seven weeks, moving to the older foliage when the new needles have all been consumed.

When each budworm is approximately one inch long, it prepares to pupate. Anchored to the damaged fir twigs by silken threads, the pupa is yellow to reddish-brown in color and measures about one-half inch in length. About seven to 10 days are required for the caterpillar to be transformed into the mature moth inside the pupa. By mid-July, most adults emerge from the pupa and disperse.

The life cycle of the western spruce budworm is repeated when the female moths have mated and begin to deposit their fertilized eggs on Douglas-fir needles by August.

Outbreaks of the Western Spruce Budworm

Two major factors appear to determine whether or not an outbreak of the western spruce budworm is likely to occur or decline in a given region of the province.

First, there must be a good match between the time that the budworm larvae become active in the spring and the time that the new buds flush or open on the Douglas-fir trees. Under optimal conditions, larval emergence precedes bud flush by about 17 or 18 days.

Second, the summer that follows must be relatively warm and dry. Given these two conditions in regions of the province susceptible to the budworm, an outbreak of this insect is almost certain to follow. According to **Dr. Alan Thomson**, if only one of these major conditions is met an outbreak is less likely to occur. If larval emergence in spring is early but bud flush is delayed, these larvae have no new foliage available to eat and will starve. As a result, too few larvae survive to benefit from favorable summer weather.

From long-term weather patterns, Dr. Thomson has concluded that the collapse of a budworm infestation is not necessarily related to a cold or wet summer, nor to late frosts in spring. Instead, exceptionally warm weather in the autumn after the adult moths have deposited their eggs appears to have a critical impact on budworm survival. Weather that is unusually warm results in the larvae remaining active rather than locating places where each can overwinter. Under these conditions, active larvae deplete their reserves of nutrients obtained from the egg. Without such food reserves, the majority of larvae would starve during the winter and early spring before they could do serious damage to the Douglas-fir trees. In other words, the outbreak of the western spruce budworm would collapse. If, on the other hand, the budworm larvae become active in spring well before food is available in the form of swollen new buds, many would starve and the outbreak is equally likely to collapse.

Besides weather factors, naturally occurring parasites and diseases can affect outbreaks. During the 1970's outbreak 25 species of parasites were found in the western budworm larvae, pupae or eggs. Parasitism levels as high as 69% were observed. Although disease levels were generally low, B.t. (*Bacillus thuringiensis* — a naturally occurring soil bacteria) and viruses (even budworms can catch a cold) have been isolated periodically from budworms. By augmenting or earlier application of these agents, nature's ul-

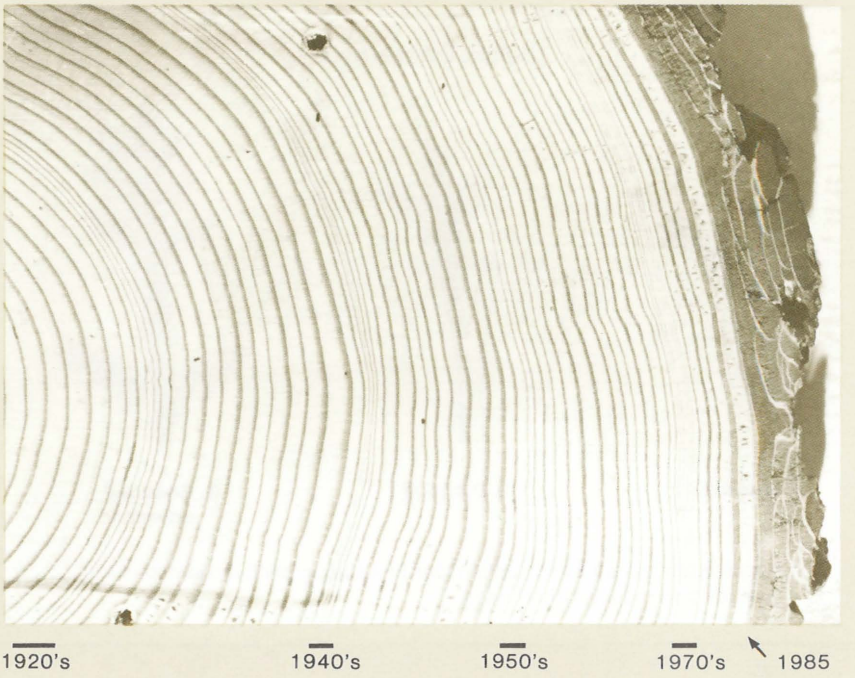
timate control of outbreaks can be hastened before significant damage results.

The Forest Insect and Disease Survey continues to conduct egg surveys each fall and monitors populations and levels of natural control agents in order to more accurately forecast budworm trends and probable damage. From 57 stands examined in June 1987 the area defoliated by budworm could again exceed 400 000 ha for a second consecutive year. Based on infested bud counts which were as high as 90% and averaged 33%, defoliation is forecast to be severe in 1987 at about half the sites, moderate at 20% and light at the balance. To date parasitism has averaged only 8%, too low to effectively reduce populations.

Damage caused by the Western Spruce Budworm

With increasing intensity since even the early 1950's, staff of FIDS have conducted annual ground and aerial observations, collections and assessments of budworm populations and visible damage. These were reported in regional and national publications and specimen material is curated within the permanent collection for detailed study. Historical and reference material is essential to understand outbreak trends, in planning studies and for decision regarding possible control actions.

Beginning in the 1970s, scientists at the Pacific Forestry Centre in Victoria have studied in detail the damage caused by the western spruce budworm feeding on the foliage of Douglas-fir. Outbreaks of the budworm often last a number of consecutive years and damaged trees often require a number of additional years in order to recover fully from such an outbreak. In addition, the permanent damage incurred to Douglas-fir trees by an outbreak of the budworm usually takes several different forms.



Cross-section of a Douglas-fir tree showing reduced rings produced after each of 4 infestations by the western spruce budworm

Loss of Radial Growth in Douglas-fir

An outbreak of the western spruce budworm which results in the defoliation of Douglas-fir trees produces a significant reduction in the growth rate of the trees affected.

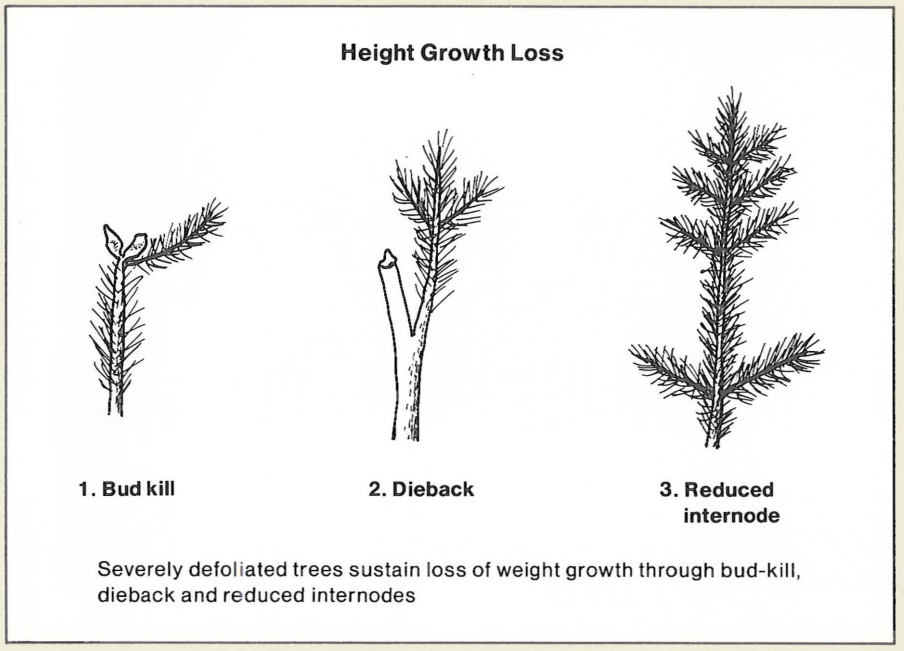
By measuring the width of the growth rings laid down by a Douglas-fir tree in each year of its life, **Dr. René Alfaro** has determined the effect that an outbreak of the western spruce budworm has on the radial growth of defoliated trees.

One year after an outbreak of the budworm has started, there is a significant decrease or reduction in the width of the growth ring produced. This loss in radial growth is most pronounced for young dominant trees growing on good sites. Suppressed trees whose growth rate is already reduced by the competition between trees do not show as marked a loss in radial growth due to defoliation. However, such trees are more likely to die as a result of the budworm outbreak.

For each subsequent year that the outbreak continues, the width of the growth rings laid down becomes progressively more narrow. This declining trend also continues for the first year or sometimes two after the outbreak of the budworm has collapsed. In short, the percent loss in the radial growth of a particular tree increases with the duration of the budworm outbreak and also with the severity of defoliation in each year of that outbreak.

It is not until two or three years after an infestation has collapsed that the growth rings of the more vigorous Douglas-fir trees begin to increase in width; that is to say, the trees have started to recover. Even so, damaged fir trees usually require a number of years in order to recover fully from repeated defoliation. Recovery is complete when the tree once again lays down annual growth rings of normal width similar to those laid down before the budworm infestation started.

In a study of an 80-year-old stand of Douglas-fir near Pemberton, Dr. Alfaro established the incidence of four different outbreaks of the budworm since



Severely defoliated trees sustain loss of weight growth through bud-kill, dieback and reduced internodes

the 1920s. The combination of these four outbreaks resulted in a 12% loss of the estimated radial growth. In this stand of trees, the most recent outbreak of the budworm in 1970-1974 caused a total of 10 years of subnormal growth, five years due to annual defoliation and five years of recovery after this outbreak had collapsed.

Loss of Height Growth in Douglas-fir

Since caterpillars of the western spruce budworm mine the soft, swollen new buds of Douglas-fir trees in spring, particularly those in the upper tree crown, this forest insect has a serious impact on the height growth of trees. Mining the large terminal bud which normally produces the new leader of the tree frequently destroys the tree's height growth for that year.

By dissecting the trunks or stems of 80-year-old Douglas-fir trees cut down in a stand near Pemberton, **Dr. Allan Van Sickle** demonstrated that each of four different outbreaks of the western spruce budworm caused a serious reduction in the height growth of damaged trees.

In the years when the budworm was actively feeding, no height growth occurred at all. The terminal bud was presumably destroyed by mining each spring or, if the damaged bud survived, the new leader was destroyed by the budworm after this bud had flushed or opened.

After each outbreak had collapsed, each year of gradual recovery of the weakened fir trees produced an increment of height growth; that is to say, a new leader. The leaders, however, were below average in length and vigor when compared to the annual increments of height growth or leaders produced prior to the outbreak. Normal height growth resumed about three or four years after the outbreak.

Where Dr. Alfaro estimated a loss of about 12% in the potential radial growth of Douglas-fir trees in a stand defoliated in four different outbreaks of the western spruce budworm, the top-killed trees in this same stand suffered an estimated loss of 32% of their potential height growth during the same period.

Top-kill of Douglas-fir

In trees repeatedly defoliated by the western spruce budworm, top-kill or die-back of the existing tree stem below the terminal bud often occurs and contributes to the net loss in height growth. In an extensive survey of top-kill conducted by the Forest Insect and Disease Survey and Dr. Alfaro, die-back in the tree crown was detected in 85% of 65 Douglas-fir stands examined. Twenty-five percent of the more than 6 000 trees examined showed at least some evidence of top-kill.

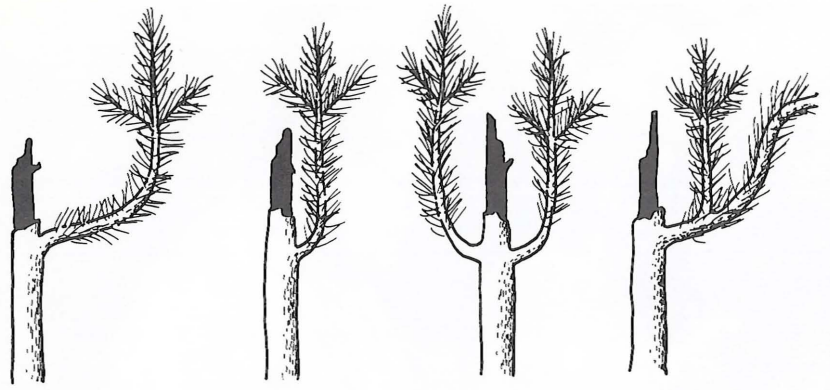
The impact of die-back in the tree crown may be almost as serious as the annual destruction of the terminal bud in causing a loss of height growth in Douglas-fir. Dr. Van Sickle has calculated that 57% of the height loss produced in each budworm outbreak can be attributed to the periods of active budworm feeding and subsequent tree recovery. The remaining 43% of height loss he attributed to die-back of the leader.

Not only does top-kill result in an immediate loss of height growth, it also produces defects in the wood during the recovery period. Particularly in young, vigorous trees, top-kill may produce defects that reduce the commercial value of the stem or trunk. In some trees, the dead top breaks off and the wound heals over completely after a new terminal is produced from an adventitious bud growing on the stem immediately below the injury or on a lateral branch. In other trees, top-kill may produce multiple leaders as a result of competition among several lateral branches. In this case, the trunk or stem of the damaged tree will have no commercial value above the original injury.

The more vigorous or dominant fir trees in a stand show less evidence of top-kill in the crown than do those trees of intermediate height and/or diameter. Suppresssed trees in a stand are most susceptible to top-kill, a fact that Dr. Alfaro attributes to the lack of adequate reserves of nutrients needed to withstand defoliation.

In a stand of Douglas-fir, the percentage of trees affected by top-kill increases with the number of years of defoliation. On average after one year of an outbreak, only 1% of trees show evidence of top-kill whereas 39% of all trees are affected when a stand has been defoliated for seven consecutive

Defect Formation



Leader Recovery From

1. Large branch **2. Small branch** **3. Multi leader** **4. Adventitious**

Severe stem defects may develop in severely defoliated trees which have sustained top-kill. The magnitude of the defect is related to the manner in which the tree recovers from the top-kill.

years. There can be, however, considerable variation among stands of Douglas-fir.

Although for a given defoliation intensity, the terrain, slope and elevation of a fir stand do not appear to influence the proportion of trees affected by top-kill, sites deemed to be of poor quality show the highest percentage of trees with die-back. Presumably those fir trees growing on poor sites are already under physiological stress and lack sufficient reserves of nutrients required to withstand severe defoliation.

Loss of Wood Volume in Douglas-fir Trees

In order to determine the impact that the western spruce budworm has on stands of Douglas-fir trees, it is important to relate an outbreak to subsequent losses in wood volume and quality.

By combining the loss in radial growth with the loss in height growth calculated for Douglas-fir trees that have been defoliated in one or more outbreaks of the budworm, it is possible to estimate the net loss in wood volume. Such estimates may then be pooled to calculate the loss of wood volume in a stand as a whole.

In the 1970-1974 outbreak of the budworm in the Pemberton region, Dr. Alfaro has estimated an average loss in wood volume of approximately 13% per tree in a stand that was severely defoliated. Larger, more dominant trees in the canopy lost proportionately less of their potential wood volume than did smaller suppressed trees. As a result of four different outbreaks in the Pemberton area since the 1920s, the average fir tree in this severely defoliated forest was estimated by Dr. Alfaro to contain just 44% of the total wood volume these trees could have yielded had defoliation not taken place.

Mortality of Douglas-fir caused by the Western Spruce Budworm

The majority of Douglas-fir trees defoliated by the budworm survive these outbreaks with losses in both radial and height growth that depend both on the severity of defoliation and the duration of the outbreak. A percentage of fir trees, however, are also killed as a direct result of a budworm outbreak. As is the case for the frequency of top-kill, suppressed Douglas-fir trees growing on poor sites are most likely to be killed by defoliation.

Although fir trees first start to die during the outbreak when the budworm is actively feeding, tree mortality may not peak until several years after an outbreak has collapsed.

After the 1970-1974 outbreak of the budworm in a severely defoliated stand of fir trees in the Pemberton area, Dr. Alfaro established that 39% of all trees per hectare of forest were killed by the budworm. As a result of this outbreak, 78% of all suppressed trees were killed, whereas only 17% of the vigorous, more dominant trees in the canopy were killed. Clearly, the more vigorous the tree, the better able it is to withstand injury or death due to repeated defoliation.

In general, Dr. Alfaro does not consider the death of suppressed trees in a stand of Douglas-fir a serious consequence of a budworm outbreak. Such weaker trees are expected to die in any case before they can be harvested as a result of the natural competition between trees for space and sunlight.

The Douglas-fir forests in the Kamloops region, however, are a special case. Owing to high temperatures in summer, fir seedlings require the shade of mature trees to become established. When these younger trees are killed by the western spruce budworm, foresters cannot harvest the canopy of mature trees since to do so would mean no subsequent regeneration of the forest. In this special instance, therefore, mortality among younger trees is a serious consequence of a budworm outbreak.

Losses in Timber Yield on a Stand Basis

The final consequences of a budworm outbreak are those losses in timber yield that foresters notice when a stand of Douglas-fir trees is harvested. This loss includes all trees that were killed as well as the growth deficit or re-

duction in the surviving fir trees. Exact losses, however, are difficult to predict. These depend not only on the duration and severity of the outbreak but also on the age of the stand when it was first affected by the budworm.

Dr. Alfaro has observed that the younger a stand of trees is when first attacked, the greater will be the losses in timber yield when that stand is harvested. This fact is particularly evident in young stands which sustain extensive top-kill. As indicated earlier, severe top-kill reduces the height growth of fir trees. Top-kill of a young tree will often prevent that tree from eventually producing a commercial log above the point of injury. Top-kill of an older tree is less serious since that tree will often yield one or more logs below the point of injury when harvested.

Losses in timber yield due to tree mortality are, in general, fairly low. However, Dr. Alfaro has observed considerable variability in mortality among stands. In some stands, tree mortality may be as high as 90% of all trees. In some special circumstances where the incidence of top-kill is low in a dense stand of trees, some tree mortality may, in fact, be beneficial in terms of thinning the stand. Following an outbreak of the budworm in such a stand, those trees released from competition put on additional growth that compensates, in part, for earlier losses in timber yield.

Using a computer simulation model of budworm damage, Drs. Thomson and Alfaro have calculated that after six years of moderate defoliation by the budworm, particular stands of Douglas-fir trees suffer losses in timber yield of 18% to 29% depending on the age of the stand when first attacked.

Control of the Western Spruce Budworm

At present, there is not yet available an effective agent that can be used widely, but selectively, to control outbreaks of the western spruce budworm.

Dr. Roy Shepherd in cooperation with the Forest Insect and Disease Survey is currently calibrating pheromone traps for the budworm in order to relate the number of moths trapped to the overall population density. Also in conjunction with staff from the British Columbia Ministry of Forests, Dr. Shepherd has examined the effect on the budworm of microbial insecticides applied by aerial spraying.

One agent, a nuclear polyhedrosis virus (NPV), was obtained from the eastern spruce budworm, *Choristoneura fumiferana*. This virus which persists for as long as five years has been applied in eastern forests since 1971, and has exerted at least some measure of control over the eastern spruce budworm which defoliates and kills white spruce and balsam fir.

Although up to 87% of the population of the western spruce budworm was infected with NPV 15 days after aerial spraying, and up to 48% of the population was killed in experimental plots, this insecticide failed to provide Douglas-fir trees with consistent protection from defoliation.

Similar test results were obtained following aerial spraying with a bacterium, *Bacillus thuringiensis*. Between 32% and 91% of the budworm population was killed 15 days after spraying was carried out, but defoliation of Douglas-fir trees remained severe.

Considerably more research and field trials are required before either of these microbial insecticides can be considered an effective operational agent for the biological control of the western spruce budworm in British Columbia.

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Dr. G. Allan Van Sickle

Dr. G. Allan Van Sickle is currently head of the Forest Insect and Disease Survey (FIDS) for British Columbia and the Yukon. Prior to this appointment, Allan worked in forest damage appraisal as a research scientist, an area in which he remains a key player in close collaboration with other scientists.

Each year, FIDS prepares a summary report of forest pest conditions throughout the province and the Yukon territory. Over 30 different pests and diseases are monitored including the western spruce budworm and the black-headed budworm, mountain pine beetle, spruce beetle, Douglas-fir tussock moth, and the larch casebearer. Serious diseases include dwarf mistletoes, stem rusts, and root rots.

In the case of the western spruce budworm, FIDS monitors the incidence and severity of budworm outbreaks every year. Egg surveys are carried out in late summer in order to predict budworm populations anticipated the following year.

FIDS also maintains 15 stations located primarily along the coast and the Canada/US border to monitor the potential effects of acid rain. To date, no visible symptoms that can be attributed to acid rain have been detected in B.C. forests.

Allan graduated from forestry at the University of British Columbia, and received his doctorate in pathology from Pennsylvania State University. He joined the Canadian Forestry Service in 1965 and worked in Alberta and the Maritimes before joining the Pacific Forestry Centre in Victoria in 1974.

Dr. Alan J. Thomson

Dr. Alan J. Thomson is leader of the forest systems project within the forest growth and biology program. He stresses the collaborative nature of his work with that of other scientists at the Pacific Forestry Centre to devise computer simulation models for the effects on forest yield of current forestry practices, insect pests and plant diseases. Alan also generates computer analyses of the impact on the forest resource of pests such as the western spruce budworm, the mountain pine beetle and the white pine weevil on Sitka spruce.

Currently, Alan is working on computer analyses of the growth and yield of coastal Douglas-fir, as well as site preparation methods for white spruce.

Alan received his bachelors degree in zoology (specializing in entomology) from Glasgow University and earned his doctorate from McMaster University in the fields of ecology and parasitology. He joined the Pacific Forestry Centre in 1976.

Dr. René I. Alfaro

Dr. René I. Alfaro is leader of the forest pest damage appraisal study within the larger forest growth and measurement project. He joined the Pacific Forestry Centre in 1980 and, in addition to the western spruce budworm, has carried out research projects on the impact of the Douglas-fir tussock moth, the white pine weevil on Sitka spruce, and dwarf mistletoe on western hemlock.

With a strong background in forestry and applied entomology, Rene has applied standard techniques in forestry to measure the impact of the western spruce budworm on Douglas-fir forests of southern British Columbia. One major research objective is to establish the relationships between the level and duration of a budworm outbreak to subsequent tree damage and mortality. Rene also works with Dr. Alan J. Thomson on a computer modelling program to integrate budworm biology and damage into a useful tool for predicting the incidence and severity of future outbreaks of this forest pest.

Rene earned a forestry degree in his native Chile as well as a Master of Pest Management degree and his doctorate from Simon Fraser University.

Dr. Roy F. Shepherd

Dr. Roy F. Shepherd heads up a research team that studies the use of insect pheromones and kairomones and the manipulation of insect parasites and predators as agents or tools for biological control. Target insect pests include the western spruce budworm, the black army cutworm, the white pine weevil, and the Douglas-fir tussock moth.

Pheromones are natural attractants that are particularly useful in monitoring the population density of a potential insect pest. Roy and his team have refined pheromone traps for the Douglas-fir tussock moth to provide advance warning of a pending epidemic. In this way, a natural virus can be introduced to control the rising insect population before significant damage is done to Douglas-fir forests.

In the case of the western spruce budworm, Roy, in cooperation with the Forest Insect and Disease Survey, is currently calibrating pheromone traps to determine what the number of moths trapped means in terms of the overall population density.

Roy received his bachelors degree in forestry from UBC, and earned his masters and doctorate degrees in entomology from the University of Minnesota. He joined the Canadian Forestry Service in Calgary in 1952 and moved to Victoria in 1970.

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