FIDS Report 92-12

DOUGLAS-FIR TUSSOCK MOTH IN BRITISH COLUMBIA

1916-1991

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H. P. Koot
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Forestry Canada
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5

Phone: (604) 363 0600
FAX: (604) 363 0775

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ABSTRACT

The Forest Insect and Disease Survey (FIDS), as part of its mandate, annually detects, monitors and appraises defoliator infestations by sampling larval populations, trapping adults, conducting egg surveys and by observing and mapping defoliation from light aircraft. This report summarizes the results of these efforts, many from unpublished reports, along with those of others associated with FIDS, with respect to outbreaks of the Douglas-fir tussock moth, Orgyia pseudotsugata in British Columbia from 1916 to 1991.

The Douglas-fir tussock moth is an important defoliator of all age classes of Douglas-fir, predominantly in drier areas of southern British Columbia. Populations periodically increase sharply, persist for a few years, then suddenly decline. High populations frequently cause tree mortality over limited, well-defined areas. Since 1916, eight outbreaks have occurred in the Interior Douglas-fir (IDF) Biogeoclimatic Zone and its transition with the Ponderosa Pine (PP) and Bunchgrass (BG) zones along broad bands within valleys. Many of these areas now have portions in gradual land-use transition from timber production and range to non-timber uses such as residential, recreational, and amenity-valued lands. Outbreaks usually last two to four years before they collapse.

Sampling larvae after their dispersal from egg masses is effective in predicting the potential for defoliation. The timing of outbreaks and the locations of threatening populations can be determined before damage occurs with the aid of a pheromone trap monitoring system. Tree mortality and top-kill have been observed in most interior infestations. Populations decline due to natural factors, most commonly a nuclear ployhedrosis virus infecting larvae, and less commonly to egg parasites.

A new outbreak developed on 135 ha near Kamloops, in several isolated pockets near Keremeos, and in the Fraser Valley in 1991.

INTRODUCTION

The Douglas-fir tussock moth, Orgyia psedotsugata (McDunnough) (Lepidoptera: Lymantriidae), was first reported causing damage in British Columbia in 1916 near Chase. Since then, there have been several outbreaks in southern B.C., resulting in substantial top-kill or tree mortality of Douglas-fir. Damage typically occurs on open-growing trees, groups of trees, or in fairly dense immature stands. Populations of the tussock moth build up to infestation proportions quickly, remain at damaging levels from 1 to 4 years, and then suddenly collapse. Infestations in the Thompson, Okanagan, and Similkameen valleys seem to occur at intervals of 8 to 12 years. Between outbreaks, there are years when few or no larvae are collected in routine sampling for defoliators throughout the host range of tussock moth.

BIOLOGY

Hosts and Distribution

The preferred host of the tussock moth in B.C. is Douglas-fir, and all age classes are affected. Occasionally, ponderosa pine and western larch have also been severely defoliated when adjacent to infested Douglas-fir trees. When grown as ornamentals, spruces, especially blue spruce, are common hosts during the initial stages of an outbreak (eg. Kamloops, 1990). In the western United States, grand fir and white fir are commonly attacked, and even preferred in some locations. When larvae have completely defoliated their favored hosts, they may migrate to other species and continue feeding. These include understory shrubs, as well as orchard trees such as apple or ornamentals such as poplar.

The Douglas-fir tussock moth is predominantly found in the drier areas of the Kamloops Forest Region and the southwestern portion of the Nelson Forest Region. Shepherd (1977) classified the tussock moth as "Non-spreading - Zone Restricted" with infestations mainly confined to the very hot Interior Douglas-fir subzone (IDFxh) and the Ponderosa Pine (PP) zone classifications of the Biogeoclimatic Ecosystem (Lloyd et al., 1990). These areas include the Thompson, Okanagan, Similkameen and Kettle valleys. Tripp (1974) states that most of the B.C. outbreaks may represent extensions of outbreaks originating in the United States, because the general trend of spot infestations in B.C. has been from south to north. Top-stripping of scattered single trees has occurred in the Coastal Douglas-fir Zone near Victoria in 1967-72 and in the Fraser Valley near Clearbrook and Abbotsford in 1969-72, 1982-83 and 1990-91. No outbreaks have occurred in the dry IDF subzones in the East Kootenay, although there are two larval collection records - Cranbrook (1955) and Elko (1954). Expected pheromone trapping in 1992 in these areas may help to clarify its distribution. There are also scattered records in the Interior wet belt area at Rogers Pass, Arrowhead, and near Lardeau.

Description (Fig. 1)

Egg: the eggs are laid on the empty female cocoon in a mass of about 200, embedded in a frothy cement covered with hairs from the female's body. Eggs are white and spherical. Parasitized eggs appear grey.

Larva: up to 30 mm (1¼ inches) long; head glossy black; body hairy, grey and black with small red tubercles, and with a broken orange-yellow stripe on each side. On the fore-part of the body are two prominent black lateral pencil-tufts (thoracic horns); on the posterior is one black dorsal pencil-tuft (anal tuft) preceded by a shorter recurved rust-colored tuft (auxiliary tuft). Dense rust-colored toothbrush-like tufts (abdominal tufts) occur on the back of the mid-body. The general color variations of larvae range from light cream to dark grey or black.

Pupa: the larva spins a 20-25mm (3/4 - 1 inch) long grey-brown spindle-shaped cocoon of silk and larval hairs in which it changes into a brown pupa. Tussock moth cocoons are usually found on the lower side of foliage and twigs and sometimes trunks of trees.

Adult: the grey to dark brown female moth is stout and wingless, 16 mm (5/8 inch) long. The male has a slender body; wing-spread, 32 mm (1¼ inches); wings, brown with a small white spot near the posterior margin of the fore-wing.

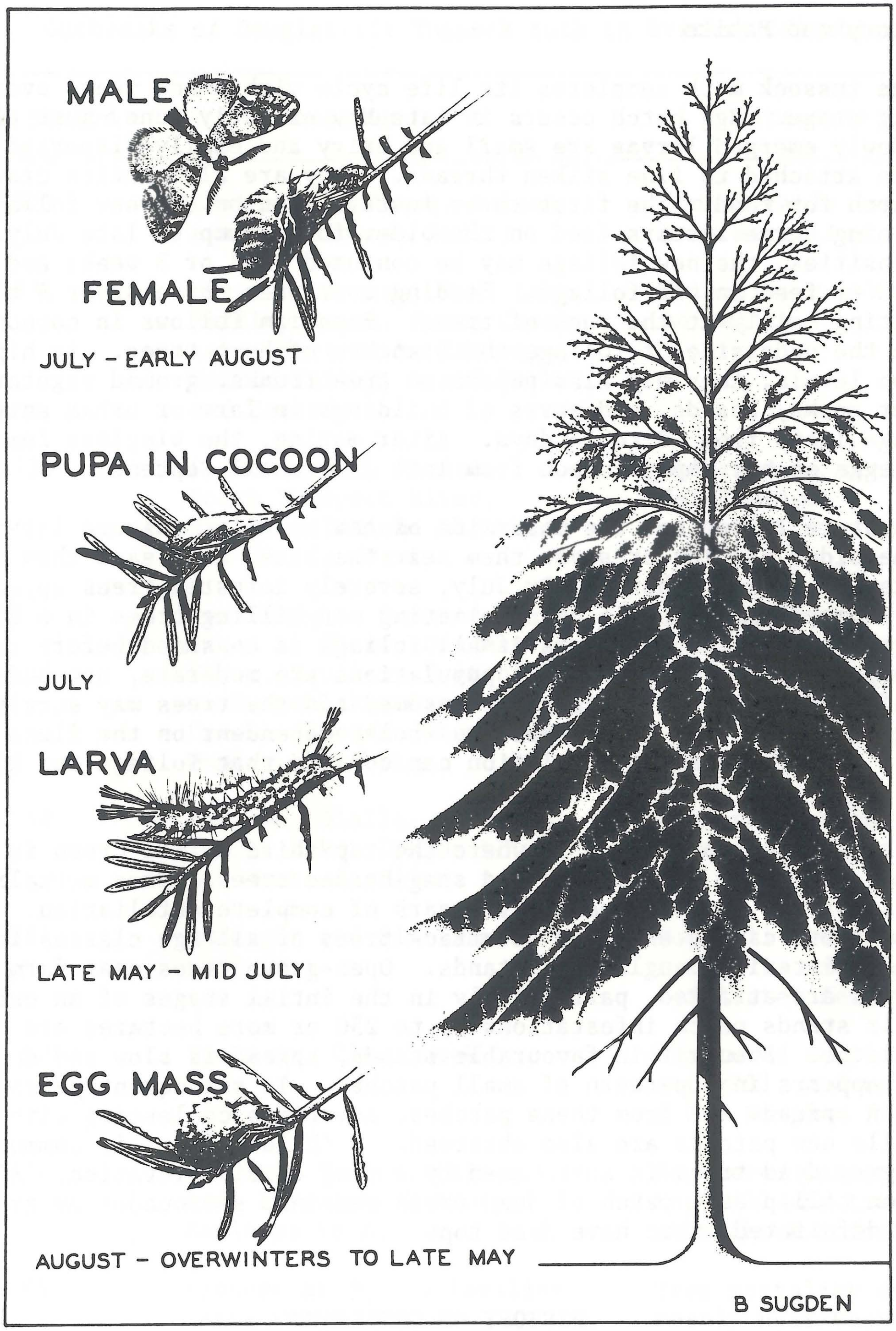


Figure 1. Life cycle of Douglas-fir tussock moth

Life History and Habits

The tussock moth completes its life cycle within one year, overwintering in the egg stage. Egg hatch occurs in late May or early June, just after bud flush. Newly emerged larvae are small and hairy and easily dispersed by the wind while attached to fine silken threads. They are also active crawlers in their search for food. The first three instars feed on the new foliage while the remaining three instars feed on the older foliage up to late July. At high larval densities, the new foliage may be consumed in 2 or 3 weeks and the larvae are forced to feed on old foliage. Feeding continues for another 4 to 6 weeks, concentrating mainly at the tops of trees. Pupation follows in cocoons formed mostly on the underside of foliage and branches of host trees. At high population levels, they may also pupate on tree trunks, ground vegetation, or even under rocks, boards, and eaves of buildings in farm or urban settings. The pupal stage lasts from 10 to 14 days. After mating, the wingless female moth deposits eggs on her empty cocoon from late July until September.

Immature larvae eat the underside of new needles. Mature larvae may eat all of the older needles or sever them near the base, and leave them entwined and uneaten in silken webbing. By July, severely infested trees appear scorched. Larvae are capable of defoliating and killing trees in a single growing season. This only occurs if all foliage is consumed before trees can develop buds for the next year. If populations are moderate, new buds are formed before most of the foliage is consumed and the trees may survive. The following year, however, such trees are wholly dependent on the flush from those buds and a relatively small population can consume that foliage and kill the tree.

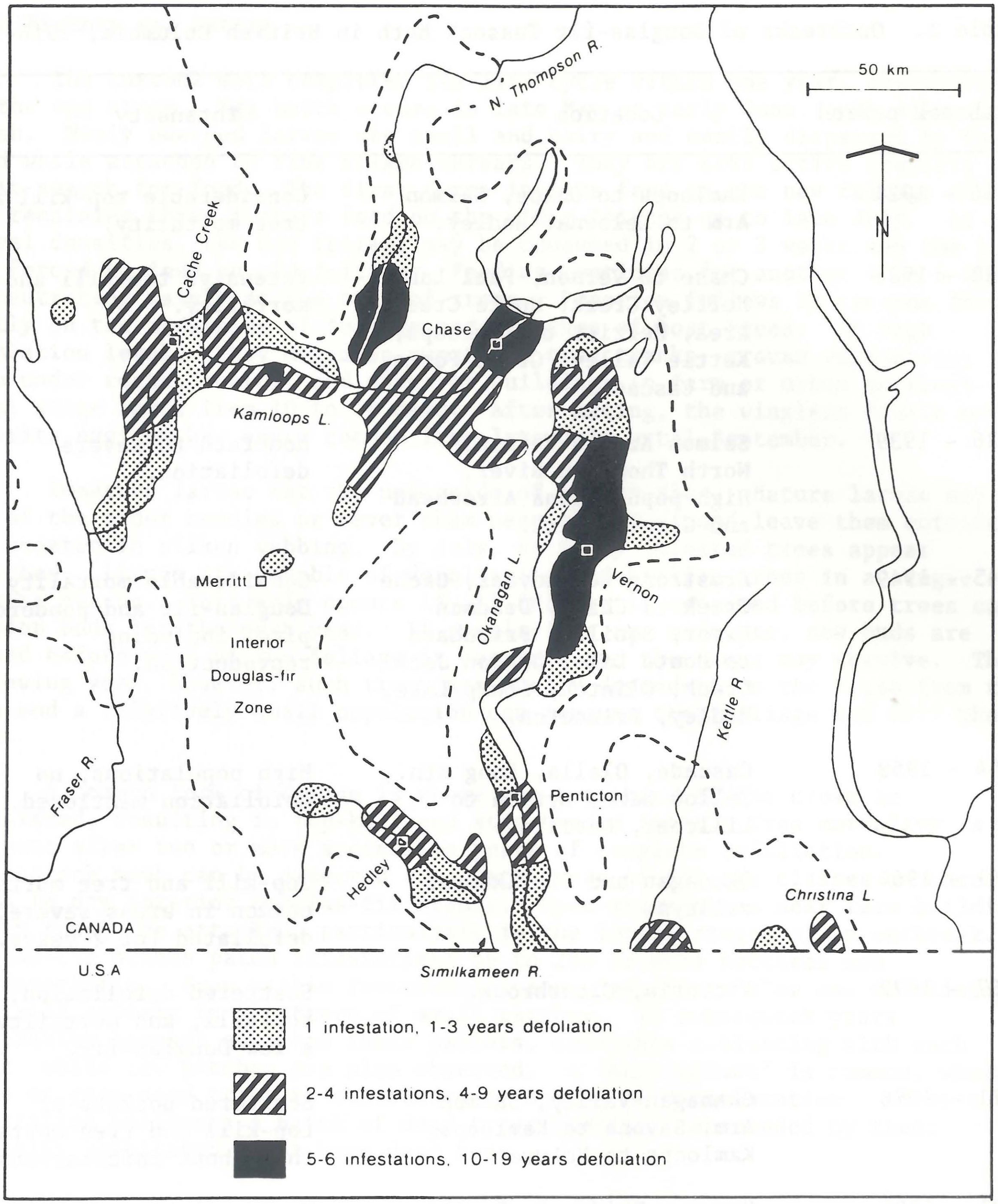
A common form of damage is where the top third of the crown is defoliated, resulting in top-kill and stag-headed trees. Tree mortality is more frequent after two or more successive years of complete defoliation.
The tussock moth can be expected to attack trees of all age classes in chronic areas in dry interior Douglas-fir stands. Open-grown trees near farm buildings and in towns are attacked, particularly in the intial stages of an outbreak. In Douglas-fir stands patch infestations up to 250 or more hectares are characteristic. Even within favourable stands, spread is slow and defoliation initially appears in a pattern of small patches. In subsequent years defoliation spreads out from these patches, sometimes coalescing with each other, while new patches are also observed. A 'halo-effect' is common, where a group of grey dead trees is surrounded by a ring of discoloration. After the infestation collapses a patch of dead trees remains, surrounded by trees partially defoliated, that have dead tops.

HISTORY OF OUTBREAKS

Forestry Canada FIDS records dating back to 1916 show that Douglas-fir tussock moth has appeared in outbreak proportions eight times in the interior of B.C. (Table 1). These were from 1916 to 1921, 1928-1931, 1936-1939, 1945-1949, 1954-58, 1961-1964, 1971-1976, and 1981-1985 (Map 1), (Fig. 2). Infestations on the Coast were restricted to two small outbreaks from 1967 to 1972 at Victoria and in the Fraser Valley.

Table 1. Outbreaks of Douglas-fir Tussock Moth in British Columbia, 1916-1991.

Outbreak period	Location	Intensity
1916 - 1921	Kamloops to Chase, Salmon Arm to Kelowna, Hedley.	Considerable top-kill and tree mortality.
1928 - 1931	Chase to Vernon, Paul Lake, Heffley Creek, Monte Creek area, Merritt to Kamloops, Kettle Valley, Grand Forks, and Cascade.	Extensive top-kill and tree mortality.
1936 - 1939	Salmon Arm to Vernon, North Thompson River, High populations Arrowhead and Glacier Park.	Moderate to severe defoliation.
1945 - 1949	Armstrong to Osoyoos, Cache Creek to Chase, Deadman River, Squilax, Pritchard to Monte Lake, Oregon Jack Creek, Clinton, Stump Lake, Hedley, Princeton.	Considerable mortality of Douglas-fir and ponderosa pine, including reproduction.
1954 - 1958	Cascade, Olalla, Long Mtn., Yellow Lake, Lytton to Lillooet, Pavilion.	High populations, no defoliation mentioned.
1961 - 1964	Okanagan and Similkameen valleys.	Top-kill and tree mortality common in areas severely defoliated for 2 years.
1967 - 1972	Victoria, Clearbrook.	Scattered defoliation, top-kill, and mortality of a few Douglas-fir.
1971 - 1976	Okanagan Valley, Salmon Arm, Savona to Kamloops, Kamloops to McLure.	Scattered pockets of top-kill and tree mortality throughout infestations.
1981 - 1985	Spences Bridge to Pavilion, Cache Creek to Chase, Kamloops to Barriere, Stump Lake, Okanagan, Similkameen and Kettle valleys.	Tree mortality on 5500 ha mostly near Cache Creek and from Kamloops to Pritchard, following defoliation of nearly 28 000 ha.
1991 -	Kamloops, Okanagan, Hedley, Fraser Valley.	Increased populations; severe defoliation of 135 ha near Kamloops in 1991.



Map 1. **Locations most likely to have Douglas-fir tussock moth infestations in southern interior British Columbia, rated by the number of infestations and years of defoliation that have occurred since 1916, recorded by FIDS.**
(Ref. J.W. Harris, 1985)

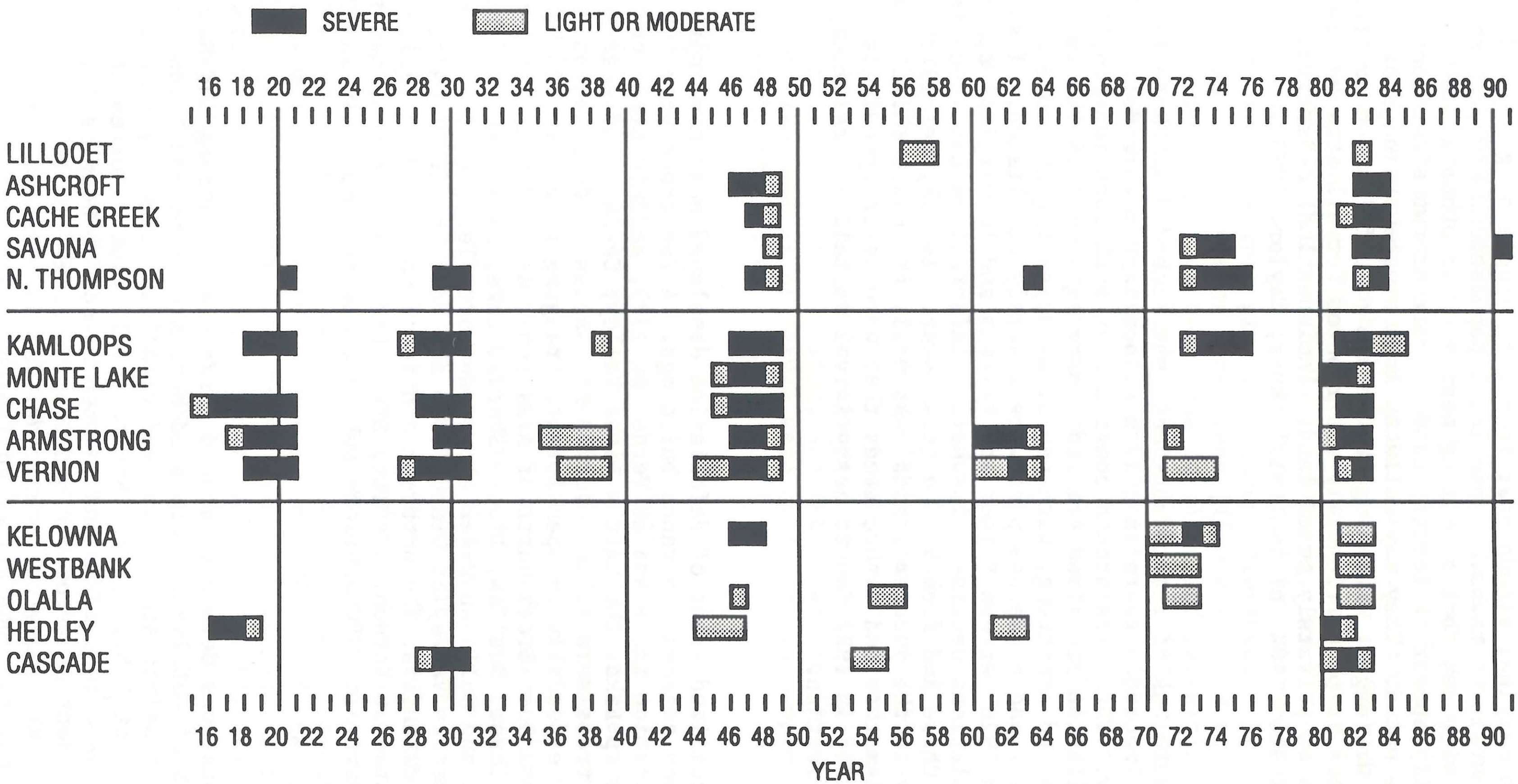


Figure 2. Histogram of Douglas-fir tussock moth outbreak periods from 1916 to 1991 by geographical locations in British Columbia.

As an outbreak period develops, localized damage typically occurs the first few years in marginal stands near towns, on single or groups of trees near farms or on ornamentals in towns. These local populations may persist and expand or decline with new foci appearing nearby or in other areas. Infestations usually appear in forest stands a year or two after localized areas of defoliation are noted. They may build up in a single drainage or throughout several different drainages. Assuming the chance of defoliation or tree mortality occurrence is proportionately distributed for all attacked lands, the amount that occurs on privately owned lands (includes Indian Reserves) in the Kamloops Region is about 40% of the total (Ross, Taylor. 1983).

1916 - 1921

The first outbreak of the tussock moth was recorded at Chase in 1916. Tree mortality was recorded there in 1917 and localized severe defoliation occurred at Hedley. The infestations continued at both locations in 1918 with new areas of defoliation at Salmon Arm and Armstrong. In 1919 the infestations continued at Chase and Armstrong, with new areas appearing at Kamloops Lake and Vernon. Douglas-fir and ponderosa pine were severely defoliated. Tussock moth remained active in 1920 between Vernon and Kelowna and in marginal stands near Kamloops, but populations declined elsewhere. Infestations continued in 1921 at Kamloops Lake and Chase and from Vernon to Kelowna. Totally defoliated trees died, particularly in the younger stands. As well, the upper third of the crown was killed on semi-mature and mature trees that were severely defoliated. The infestation collapsed in 1922 due to heavy larval mortality, presumably as a result of virus infection.

1928 - 1931

In 1928, localized areas of defoliation developed near Kamloops, Pritchard and Vernon adjacent to ranch buildings. A few trees were 90% defoliated. Defoliation increased at Vernon in 1929, and new areas occurred at Chase, Little Shuswap Lake, the Kettle River Valley, Cascade and near Heffley Creek where young trees were killed over 40 ha. Areas of defoliation continued to expand in 1930, especially in open forests, ranging from 1 to 400 ha in the following locations: Deep Creek north of Armstrong; near Vernon; along the South Thompson River at Chase, Squilax, Little Shuswap Lake, Paul Lake, and Ducks Range; near McLure and Sullivan Creek along the North Thompson Valley; near Kamloops; in the Kettle Valley at Grand Forks and Rock Creek. Tree mortality and top-kill were extensive. The outbreak continued to expand in 1931. New areas were defoliated at Vernon, Merritt, Stump Lake and Westwold, and from Knutsford to Barnhartvale. Populations subsided almost completely in 1932 from undetermined causes.

1936 - 1939

Small infestations developed around farms near Armstrong and Salmon Arm in 1936. New areas of defoliation appeared near Armstrong and Vernon in 1937. The infestation near Salmon Arm was sprayed with lead arsenate, (Annual Report of Vernon Forest Insect Lab., 1937). Severe defoliation occurred near Vernon and Armstrong in 1938 around farms and in open stands of Douglas-fir. High populations were present at Arrowhead and Glacier Park. In 1939, there was moderate defoliation at Lavington, Armstrong, Vernon, Okanagan Landing, Larkin and north of Kamloops, but populations collapsed in all areas as larvae were killed by a virus disease. Only a few larvae were collected at Larkin, Vernon, Barriere and Kettle Valley from 1940 to 1944.

1945 - 1949

In 1945 small infestations occurred in localized areas at Vernon and Hedley. These continued in 1946 and new infestations appeared at Princeton, Monte Lake and north of Cache Creek. Up to 100% defoliation occurred at Monte Lake. In 1947 a series of infestations occurred from the Cache Creek and Kamloops areas south through the Okanagan Valley to Osoyoos, where there was severe defoliation near Chase, Squilax, Pritchard, Monte Lake, Stump Lake, Oregon Jack Creek, Clinton, Hedley, Armstrong, and Vernon. Severe defoliation was widespread in 1948, and included most of the above locations. Mortality of Douglas-fir and ponderosa pine was common throughout. Two of the largest infestations were at Oregon Jack Creek (1600 ha) and Monte Creek (1300 ha). Late larval mortality was heavy due to virus and parasitism. In 1949, infestations collapsed following 10 to 100% defoliation of stands at Savona, Criss and Clemes creeks, and scattered patches of light defoliation elsewhere. Mortality of young Douglas-fir and ponderosa pine was heavy at Monte Creek and Ducks Range where many of the larger trees were top-killed. Larvae were scarce from 1950 to 1953.

1954 -1958

A small infestation developed at Cascade in 1954, but subsided in 1955 due to virus, and a localized epidemic at Olalla in 1955 collapsed from virus in 1956. Low populations were present at Long Mountain and near Yellow Lake in 1955, but there was no reported damage. Populations persisted in these areas in 1957, and near Lillooet, Pavilion, and Seton Lake in 1958, but collapsed in 1959. Very low numbers of larvae were collected in samples until the start of the next outbreak in 1961.

1961 -1964

The beginning of the outbreak in 1961 developed in the North Okanagan, where defoliation was common on single and groups of trees near Armstrong and Vernon. Populations also increased in the South Okanagan and Similkameen valleys. The outbreak increased and intensified initially in 1962, but some populations collapsed following infection by increased virus disease. Severe defoliation occurred at Armstrong, with spot infestations at Irish Creek, Vernon, Lavington, and from Keremeos to Hedley. Two small infestations were sprayed experimentally with DDT and Malathion at Armstrong and Okanagan Landing respectively; both gave satisfactory control. In 1963, extensive defoliation continued between Hedley and Keremeos and near Vernon, causing top-kill on trees defoliated for two years. Smaller areas of moderate to severe defoliation occurred between Armstrong and Kelowna, with isolated patches at Olalla and Ashnola River. A nucleo-polyhedrosis virus (NPV) and starvation caused high larval mortality. Larvae were common north of Kamloops and at Spences Bridge, but there was no damage. Populations collapsed in 1964 in the Okanagan and Similkameen valleys, but persisted in a localized area at Ellison Lake. Many severely defoliated stands suffered up to 50% mortality, although recovery was good in the Similkameen Valley.

A small infestation in Victoria occurred annually from 1967 to 1971 at the Gorge Vale golf course where several trees were severely defoliated. A few single trees were also defoliated in Saanich. In 1971, scattered Douglas-fir were infested from Abbotsford to Cloverdale and moderate to severe defoliation occurred at Clearbrook. The infestation in the Fraser Valley continued in 1972, with some top-kill and mortality of single scattered trees in Clearbrook, and then collapsed in 1973.

1971 - 1976

In 1971, defoliation occurred in the Central Okanagan at Oyama, Winfield, Glenmore, Westbank and Kaleden. The outbreak expanded in 1972 to over 700 ha from Salmon Arm to Osoyoos, with most defoliation near Kelowna. Some tree mortality was evident in areas previously defoliated. Infestations expanded over more than 2000 ha in 1973. Defoliation near Kelowna covered 1000 ha in which trees over about 400 ha were killed. At Kilpoola Lake near Osoyoos, tree mortality covered 20 ha and top-kill occurred over 40 ha. Virus infected larvae in many areas of the Okanagan by mid-summer. In 1974, infestations declined to 230 ha in 8 areas between Salmon Arm and Penticton. Defoliation by tussock moth and western false hemlock looper, *Nepytia freemani*, covered 3000 ha north of Kamloops between Westsyde and McLure and 325 ha south of Kamloops Lake. The infestation expanded to more than 8300 ha in 1975 between Cherry Creek and Savona and north of Kamloops to McLure. Tree mortality was common in areas of severe defoliation. Infestations in the Okanagan collapsed. Over 12 000 ha were aerially sprayed with a bacterium, *Bacillus thuringiensis* (Bt), resulting in reduced larval populations. More than 8 000 ha were sprayed with acephate in 1976 in the Kamloops area, but severe defoliation occurred on 1780 ha beyond the spray boundaries. A virus (NPV) infected late instar larvae which caused populations to collapse late in 1976, (see CONTROLS viz.).

1981 -1985

Douglas-fir over 1080 ha were defoliated in 1981 in 20 separate patches from Monte Creek to Niskonlith Lake, near Falkland, Armstrong, Cache Creek, Scottie Creek, Hedley, and Cascade (Christina Lake). Defoliation was severe over 650 ha from Monte Creek to Pritchard and near Armstrong, and moderate elsewhere. Infested stands near Hedley were strip-sprayed with NPV to reduce populations. The 1982 outbreak lightly to severely defoliated stands over 12 770 ha in 23 separate infestations near Rock Creek, from Hedley and Olalla into the Okanagan Valley to Shuswap Lake, from Chase to Monte Creek, near Kamloops, from the Deadman River to Cache Creek north to Carquile, and south to Spences Bridge. Tree mortality and top-kill occurred between Pritchard and Monte Creek. At Cascade, 20 ha were aerially sprayed with acephate (Orthene), and near Chase, 120 ha were sprayed with carbaryl (Sevin-4 Oil). At Veasy Lake near Cache Creek, an experimental spray of NPV reduced populations by 60-90%.

In 1983 infestations expanded to 27 990 ha, the largest outbreak on record. Areas of defoliation ranged in size from several hectares to 1850 ha, extending from the Okanagan Valley to Kamloops and north to Barriere, and west of Kamloops to Spences Bridge. Notable expansions occurred north of Kamloops to Barriere and west to Savona, near Cache Creek, and in the Kettle River Valley near Rock Creek and Midway. Infestations declined in the South Okanagan and Similkameen valleys. Tree mortality was recorded on more than 4750 ha. Incidence of NPV was high in many areas and egg mass counts were low. The only defoliation recorded in 1984, was on 160 ha along the south side of Kamloops Lake. Areas of severe tree mortality, mostly north of Cache Creek and north and east of Kamloops, covered 5500 ha. The only defoliation recorded in 1985 was four small patches totalling 70 ha along Kamloops Lake.

1991 -

After four years of increasing populations, defoliation occurred in 1991 in eight 10 to 40 ha patches totalling 135 ha between Kamloops and Savona. Severe defoliation occurred at Indian Gardens Ranch, near Pat Lake and at Brussels Lake, where small patches of trees were totally stripped. Elsewhere, defoliation was limited to single Douglas-fir and ornamental spruce in urban areas, including Kamloops, Vernon, Kelowna and Penticton. Virus infection and parasitism in some late instar larvae and cocoons may have contributed to a decline of populations between Keremeos and Hedley.

SAMPLING AND SURVEY METHODS

The present method for assessing current populations is the use of FIDS standard three-tree beating samples. Defoliation is mapped from the air and ground using three intensity levels. Methods of determining tussock moth population trends is through trapping male adults in pheromone traps, followed up by egg mass surveys.

Larval sampling

The main purpose of larval sampling is to obtain an estimation of population levels which can be used for comparison by year and location to predict the potential for defoliation (Fig. 3). This is best accomplished, using the three-tree beating system, which generally requires sampling the host, Douglas-fir at both random and permanent sample locations. The procedure employs a standard 2 x 3 m cloth ground sheet placed beneath the selected tree. The accessible branches are then beaten with a 2.5 - 3 m pole to dislodge larvae onto the sheet. This sampling method is effective only during the active larval stage of the tussock moth. Synchronization of insect and host development is an important element in determining when larval sampling can begin. Research has shown that early larval sampling can proceed approximately three weeks after initial bud burst, when larvae are dispersing off egg masses and shoots are 50% or more elongated. To be accurate, insect sampling should be done when the larvae are well dispersed in the foliage.

Aerial detection surveys

Defoliation is sketchmapped between mid-July and early August, using fixed-wing aircraft flown at 300 to 600 m above the forest canopy, onto 1:100 000 or 1:125 000 scale topographic maps using standard FIDS classification:

Light defoliation - discolored foliage barely visble from the air, some branch tip and upper crown defoliation.

Moderate defoliation - pronounced discoloration, noticeably thin foliage, top third of many trees severely defoliated, some completely stripped.

Severe defoliation - bare branch tips and completely defoliated tops, most trees more than 50% defoliated.

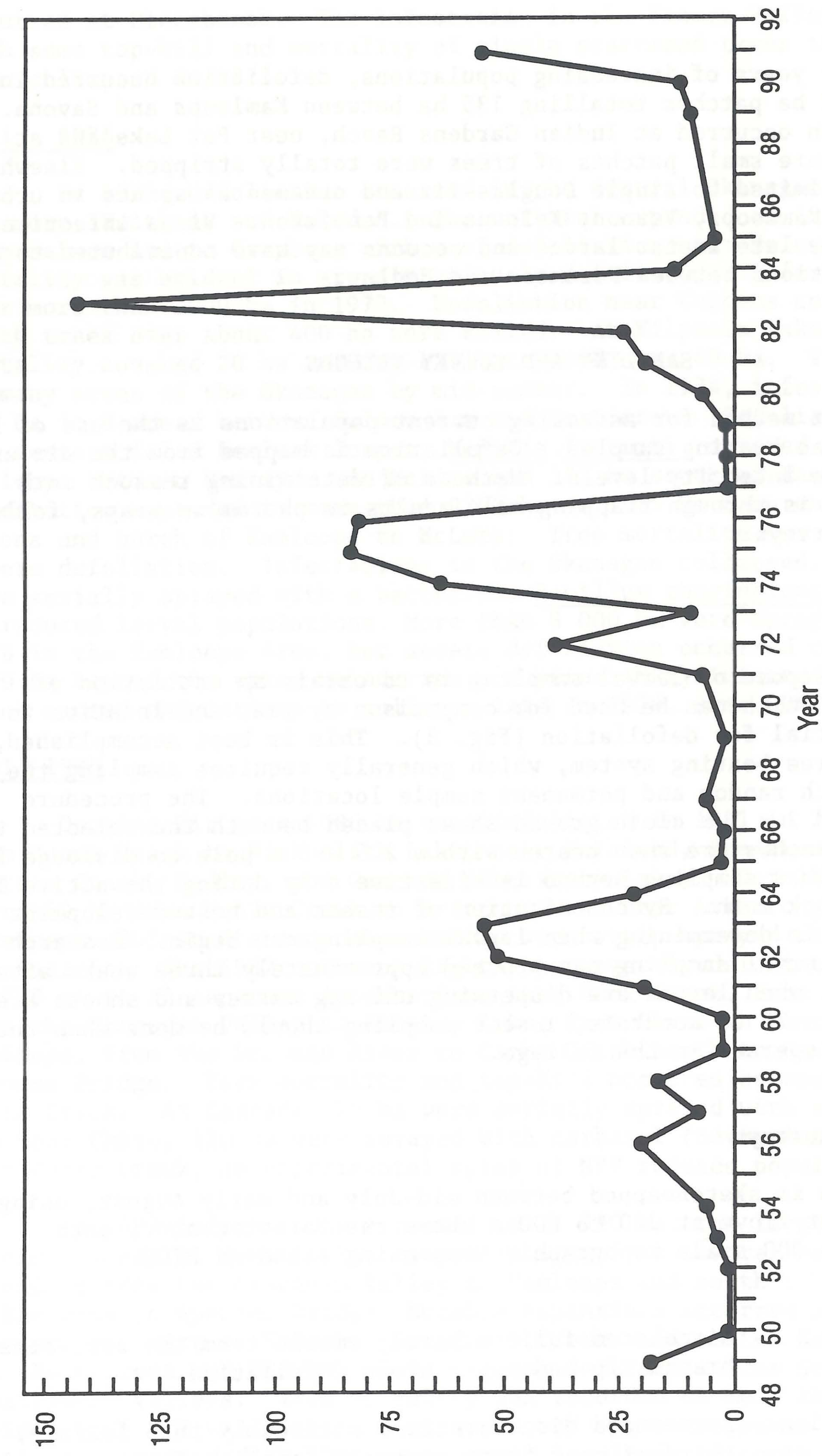


Figure 3. Average number of larvae per sample*, Kamloops Forest Region, 1949-1991.

* Sample= Standard FIDS three-tree beating per Douglas-fir.

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The most recognizable feature of defoliation is discoloration of foliage. However, stand age and weather conditions such as rain can alter the impression of defoliation severity. Ground observations may be necessary after the aerial survey to aid in correcting for these variations.

The area of defoliation can be calculated using the dot grid method at the conclusion of the survey, or the information can be digitized, using the GIS.

Pheromone trapping

Douglas-fir tussock moth populations exhibit rapid changes from endemic to epidemic levels, and they are highly aggregated, resulting in patchy defoliation. With the aid of a pheromone monitoring system, (Shepherd, R. et al, 1985.) the timing of outbreaks and locations of threatening populations can be determined before damage occurs.

The use of pheromones to monitor tussock moth population trends in British Columbia began in 1974. Based on research studies, permanent pheromone monitoring sites were established in 1983 at 18 Douglas-fir stands considered susceptible to tussock moth outbreaks. Each year, six triangular shaped traps (milk carton type) with sticky inside surfaces, each with a lure containing 0.01% pheromone by weight, are hung about 40 m apart at each site. These traps are recovered in early October after moth flight has ceased. The moths caught in each trap are counted. Rusty tussock moth, Orgyia antiqua badia, is commonly found in the same traps, but is not included in the tally. As consistency is the key to determining annual trends, it is important that the sites, traps, and lures, remain constant with monitoring procedures. When a consistent upward trend is found in a given stand for two years, and the average trap count is 8 - 10 moths per trap in the stand, the next outbreak could be two summers away. This threshold was reached in 1988 at several locations in the Kamloops and Okanagan TSAs (Table 2), and was followed by the first signs of defoliation in a forested area at Six Mile Point west of Kamloops in 1990. At this threshold level distribution traps are deployed at 1 to 3 km intervals to determine the location of incipient infestations. When the average number of moths caught per trap at the permanent sites reaches 25 or more, an infestation is probably imminent and egg surveys should be initiated the same autumn in the vicinity of all the traps with the highest catches.

Table 2. Number of male Douglas-fir tussock moths in pheromone-baited sticky traps monitored by FIDS in the Kamloops Forest Region, 1986-1991.

TSA and Location	Average number of moths per trap*					
	1986	1987	1988	1989	1990	1991
Kamloops TSA						
Carquile	0	0	<1	<1	6	6
Battle Creek	0	<1	2	7	50	59
Barnes Lake	3	<1	0	<1	14	27
Six Mile Ranch	-	-	47	66	87	90
Cherry Creek	0	24	64	58	76	88
Stump Lake	0	0	0	<1	2	3
Heffley Creek	<1	0	<1	6	25	49

(Cont'd)

Table 2. (Cont'd)

TSA and Location	Average number of moths per trap*					
	1986	1987	1988	1989	1990	1991
Kamloops TSA						
Monte Creek	0	0	4	17	21	62
Chase	0	0	0	4	14	3
Kaneta (Whispering Pines)	0	0	-	1	<1	2
Okanagan TSA						
Winfield	5	23	40	56	21	49
Summerland	0	0	2	0	1	0
Kaleden	2	5	20	22	41	59
Blue Lake	<1	2	19	28	45	50
Vernon	0	5	18	52	27	46
Armstrong	<1	1	0	<1	0	4
Merritt TSA						
Stemwinder Prov. Park	<1	<1	2	16	13	33
Lillooet TSA						
Pavilion	0	0	<1	0	<1	<1
AVERAGE	<1	4	14	18	25	35

* Monitoring traps - 6 per location

Egg sampling

While trap monitoring indicates when an outbreak is expected, a ground reconnaissance for egg masses is required to locate infestations. A ground search of susceptible stands is made in the vicinity of pheromone traps indicating impending defoliation. When egg masses are found, the center and extent of the infestation is delineated by visually scanning the lower branches of surrounding trees. A sequential sampling of egg masses is used to determine the severity of damage that can be expected (Shepherd, R.F. et al. 1985). This system is designed to determine the average number of egg masses within 20% of the true average, 95% of the time. The resulting defoliation predictions are for the worst spot, so the rest of the stand is likely to have less damage.

At random, 20 trees are selected at the infestation center and three full-sized lower branches are scanned for egg masses. Male cocoons and hatched egg masses from the previous year are not included in the count. The total number of egg masses is determined for the three branches on each of 20 trees and checked against a table of required sample size. Sampling continues until the total number of egg masses is 40 or greater, or until the egg mass density is equal to or lower than a threshold level as indicated on the tally card.

Damage predictions are made from the average number of egg masses per tree as follows:

If the average number of eggs on the three lower branches of each tree is:

- **less than** 0.7 : expect light or no defoliation at all in that stand the following year.

- **between** 0.7 **and** 1.9 : expect moderate defoliation which will be highly variable in intensity between trees. Some growth loss is likely to occur.

- **more than** 2.0 : expect severe defoliation and significant growth loss. Some top-kill and tree mortality may also be expected.

DAMAGE

Tree mortality and top-kill have been observed in at least 6 of 8 interior infestations since 1916. However, precise measurements of damage were available only following research studies of the 1981-85 outbreak.

During the 1961-64 epidemic, data collected by FIDS in four plots in the Okanagan Valley found that tree mortality varied from 2 to 45%. The comparatively high mortality rate of 45% in one plot was attributed to overstocking, small crowns and severe defoliation for two years. Between 1974 and 1980 the Damage Appraisal section of FIDS examined 477 previously defoliated Douglas-fir in 77 plots in the North Thompson Valley, and found that tree mortality averaged 44% (range 20 to 66%). After allowing sufficient time for tree recovery and to ensure better delineation of affected stands, an aerial survey in 1979 determined that significant tree mortality had occurred on 1530 ha in the North Thompson Valley.

The most comprehensive damage appraisal data was obtained during the outbreak from 1981 to 1985 in the Kamloops Region, which increased from 1050 ha in 1981 to 25 750 ha in 1983, then collapsed to 160 ha in 1984 and 1985. A study to quantify the levels of top-kill and mortality in stands defoliated by tussock moth, (Alfaro et al. 1987) examined trees in 45 defoliated and 16 non-defoliated (control) plots in immature and mature Douglas-fir stands, (Fig.4).

Defoliation

Excluding the check plots, average tree defoliation was 84, 68, 53, and 40% for the years 1982 to 1985, respectively. The initial high defoliation intensity followed by a rapid decline reflects the voracity of the tussock moth and the explosive and short-lived nature of the infestations. The outbreak developed very quickly and resulted in severe defoliation in one or two seasons of feeding. Average defoliation of surviving trees remained relatively high (40%) in 1985, 2 years after the population collapse. This is because normal recovery of the foliage complement takes several years after severe defoliation, and partly because of some feeding damage from increasing populations of western spruce budworm in some plots starting in 1984.

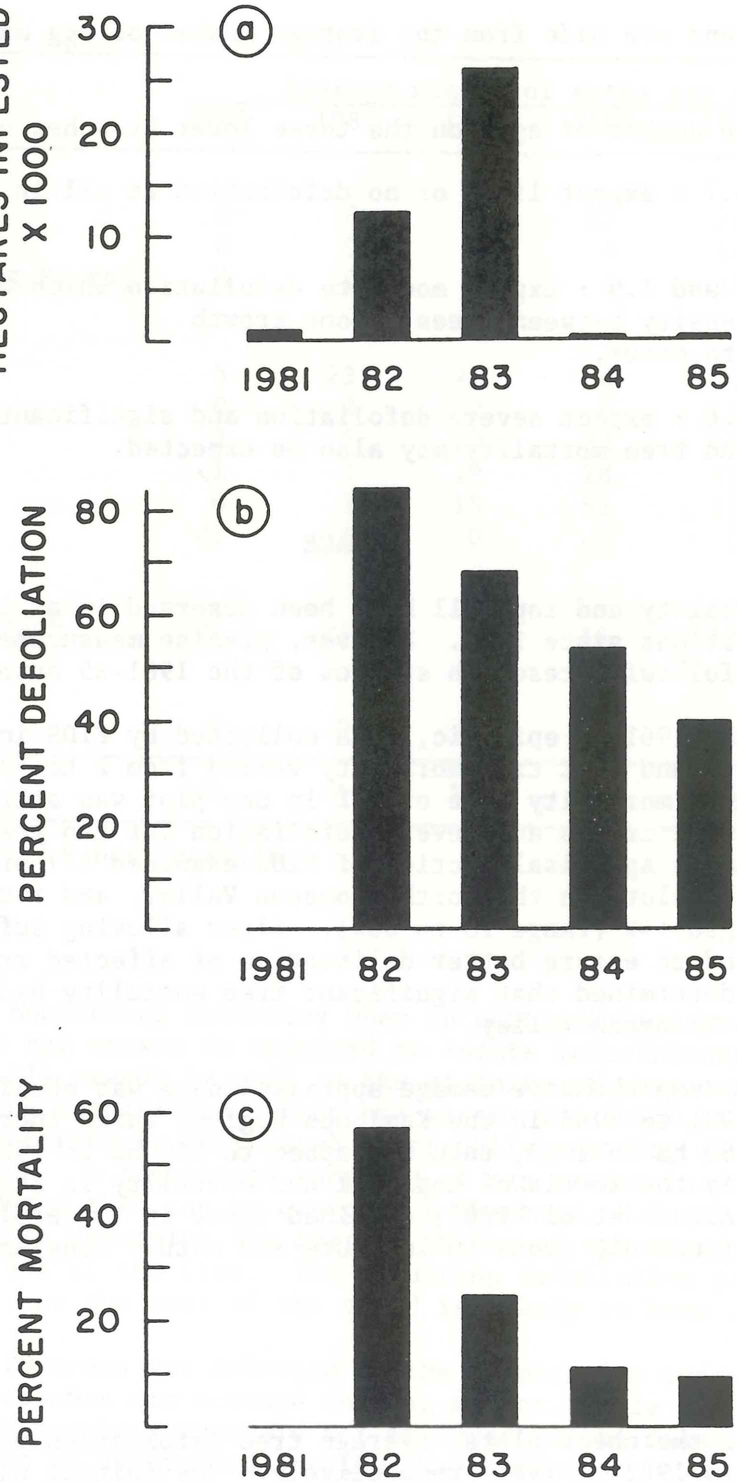

Figure 4. Area infested (a); average tree defoliation (b), and percentage of the total mortality (c) by year following a Douglas-fir tussock moth infestation in the Kamloops Forest Region of British Columbia.
(Ref. Alfaro et al. 1987)

Top-kill

Top-kill averaged 11% (range 0-67%) on surviving trees in defoliated plots. Seventeen plots (53%) had no top-kill; 11 (35%) had between 1 and 25% of the trees top-killed; 1 (3%) was in the 26-50% top-kill class; and 3 (9%) were in the 51-75% top-kill class. The dead portion of the crown was less than 1 m long in 40% of trees with top-kill, 1 to 3 m in 19%, 3 to 5 m in 23%, and 5 to 14 m in 18% with top-kill. These results appear to be consistent with those of Wickman (1978), who found that most top-killed trees loose only the leader.

The incidence of top-kill was found to be significantly related to the number of years of defoliation and to defoliation intensity (Fig.4). Top-kill occurrence averaged <1% in plots with no defoliation, 7% with 1 year, and 14% with 2 or more years of defoliation; and <1% in plots with no defoliation, 4% with light to moderate, and 15% with severe defoliation. In addition to these factors, there was a greater frequency of top-kill in mature (average 20%) versus immature stands (average 2%) (Fig. 5).

Less than 1% of the trees in check plots suffered top-kill due to reasons other than tussock moth (eg. wind-breakage, freezing or other insect pests).

Tree mortality

By 1985, cumulative mortality averaged 51% of stems (range 0-100%) or 49% of the volume in the 45 defoliated plots. No mortality occurred in 9 of those plots. Fifty-six percent of the tree mortality occurred after only 1 or at most 2 years of defoliation by 1982 (Fig.5). An additional 24, 11 and 9% died in 1983, 1984 and 1985 respectively. Tree mortality averaged 34% in plots defoliated for one season and 59% in plots defoliated for two or more seasons. Mortality did not differ significantly between mature and immature stands. It was also shown that defoliation intensity had a greater impact than number of years of defoliation in determining the amount of mortality. It appears that when stands are severely defoliated, irrespective of the number of years of defoliation, high mortality can be expected.

This study also found that tree mortality occurrred only to those trees defoliated 80% or more in any year (Fig.6). The defoliation threshold for mortality is considered to be 90%, since 99% of tree moratlity occurred at that figure or higher.

The Douglas-fir beetle, <u>Dendroctonus pseudotsugae</u>, played only a minor role in causing tree mortality in the study (Alfaro et al., 1987); only 2.4% of all defoliated trees containing beetles died. Most apparently died as a consequence of defoliation, with only 2 of 37 trees actually killed by beetle attacks. As is characteristic of the beetle, there was a preference for the larger diameter trees and nearly all the beetle-attacked trees had been defoliated from 90 to 100%. Researchers in the U.S.A. have found higher percentages of trees killed by Douglas-fir beetle in association with defoliation from tussock moth.

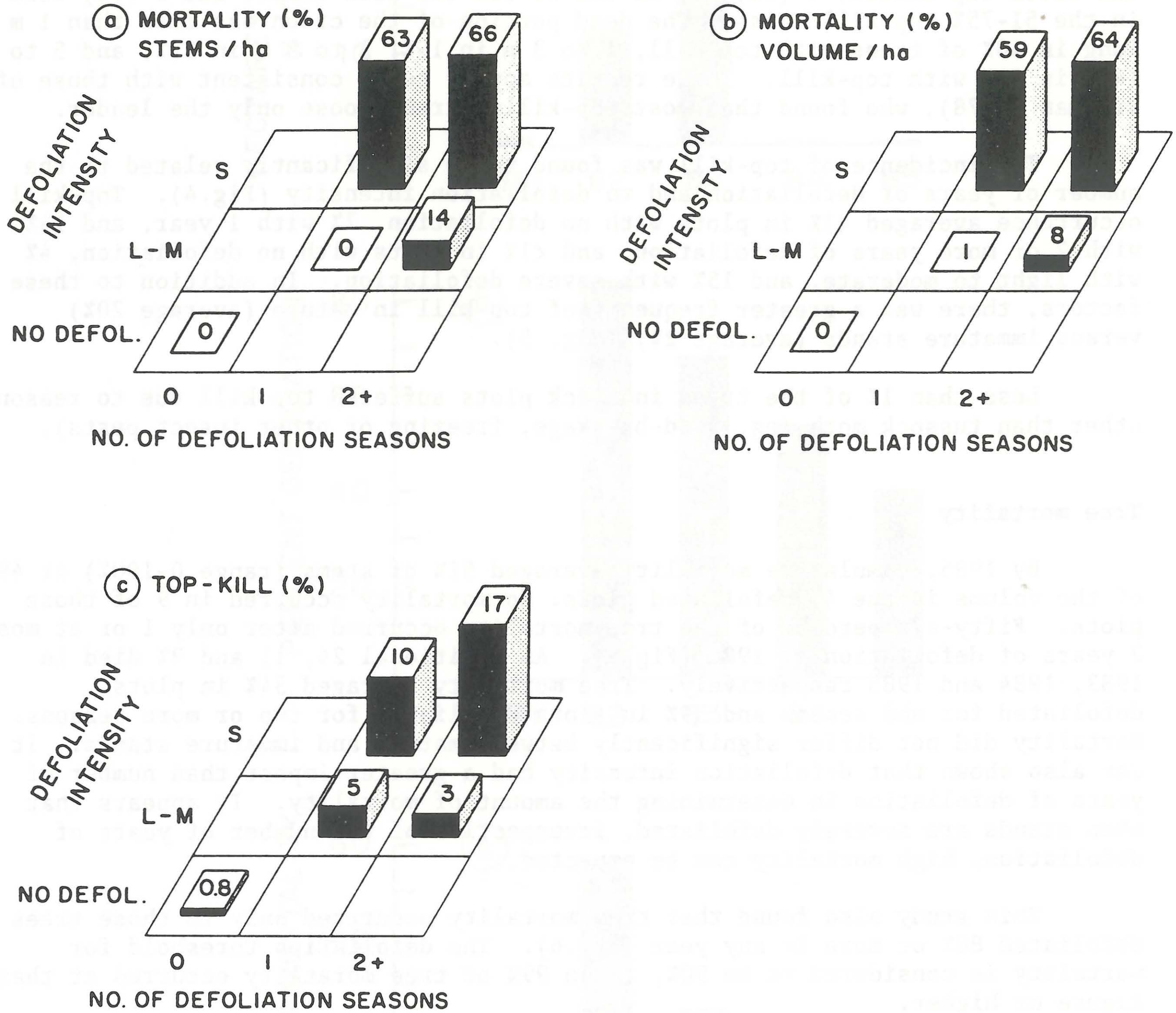

Figure 5. Relationship of percent mortality [trees (a), volume (b)] and top-kill (c) to defoliation intensity and number of seasons of defoliation. Intensities were as follows: No Defol. = not defoliated; L-M = light to moderate: less than 50% of the plot trees with defoliation of 50% or greater; S = severe: 50% or more of the plot trees had defoliation of 50% or greater. No. of seasons of defoliation were: 0 = not defoliated; 1 = defoliated only one season (1983); and 2 = defoliated 2 or 3 seasons (1982 to 1983).
(Ref. Alfaro et al. 1987)

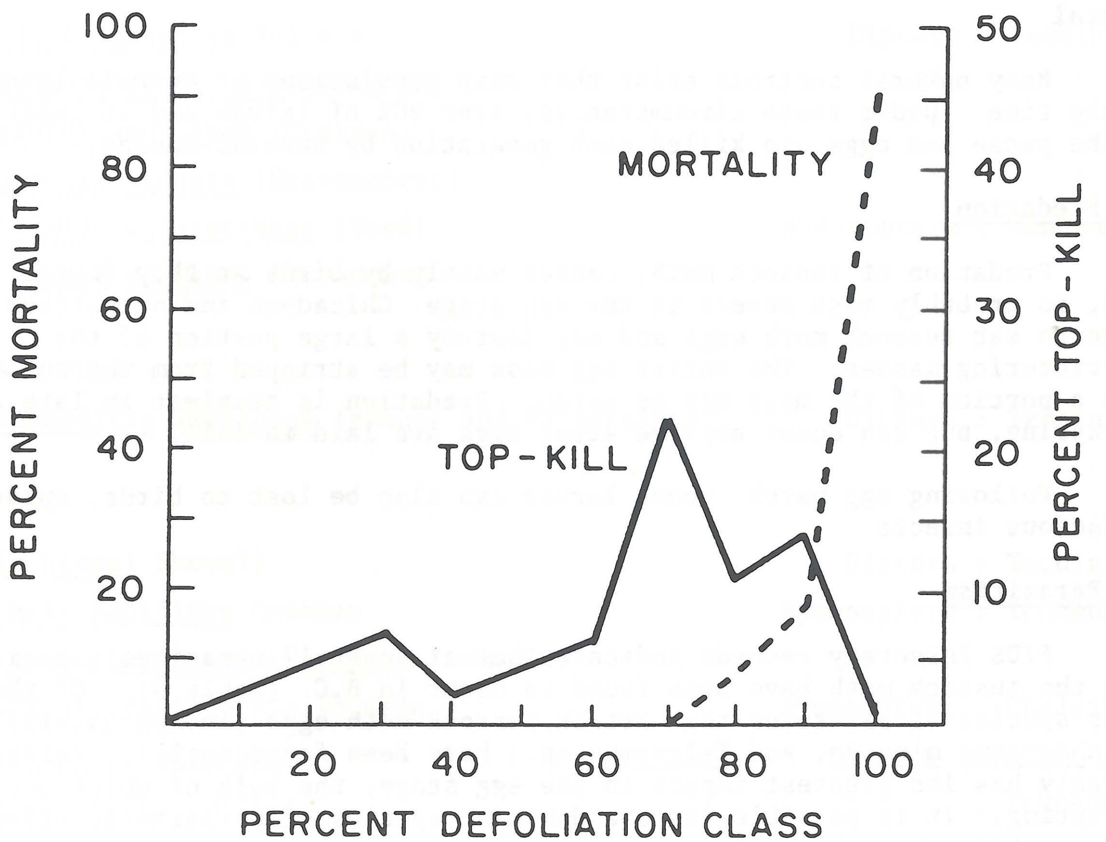

Figure 6. Percent mortality in mature and immature trees (– – – –) and top-kill in mature trees (———) related to defoliation by the Douglas-fir tussock moth in the Kamloops Forest Region of British Columbia. Top-kill was very infrequent in immature stands.
(Ref. Alfaro et al. 1987)

The first record of attacks by Douglas-fir beetle in stands defoliated by the tussock moth in British Columbia were recorded by FIDS in 1976, when an average of 14% of the trees were killed in 7 areas near Kamloops. Tree mortality linked to beetle attack averaged 27% in 4 of 16 tussock moth defoliated stands between Pritchard and Cache Creek, surveyed by FIDS in 1984.

CONTROLS

Tussock moth outbreaks usually last from two to four years in an area before they collapse. Predators, parasites, pathogens and starvation are all contributors to population collapse. Among these mortality factors, virus is generally regarded as the most important natural cause of the decline.

Natural

Many natural controls exist that keep populations at endemic levels most of the time. Under these circumstances, over 90% of larvae and at least 75% of the pupae and eggs are killed each generation by natural causes.

a. Predation

Predation of tussock moth, caused mainly by birds as they forage for food, is probably most severe in the egg stage. Chicadees and nuthatches are known to eat tussock moth eggs and may destroy a large portion of the overwintering masses. The entire egg mass may be stripped from the cocoon, or only a portion of the mass may be eaten. Predation is heaviest in late winter and spring, but can occur anytime after eggs are laid in fall.

Following egg hatch, young larvae can also be lost to birds, spiders, and predaceous insects.

b. Parasitism

FIDS Insectary records indicate that at least 17 parasites associated with the tussock moth have been found to occur in B.C. (Table 3). Of the four major species of parasites that attack tussock moth eggs (Anonymous. 1977), two (*Trichogramma minutum*, and *Telenomus* sp.) have been found in B.C. Parasitism probably has its greatest impact in the egg stage, the bulk of which occurs in the spring. It is possible for one dominant species of parasite to effectively reduce a tussock moth population.

Table 3. Parasites found associated with Douglas-fir tussock moth in British Columbia, based on FIDS Insectary records.

Host stage affected and Parasite		Order : Family
EGG		
Telonomus sp.		Hymenoptera : Scelionidae
Trichogramma minutum Riley		" : Chalcididae
LARVA		
Carcelia olenensis Sellers		Diptera : Tachinidae
Compsilura concinnata (Meighen)		" "
Hyposoter annulipes (Cresson)		" "
Itoplectis viduata (Gravenhorst)		" "
Phobocampe clisiocampae (Weed)		Hymenoptera : Ichneumonidae
Phobocampe pallipes Provancher		" "
LARVA & PUPA		
Leschenaultia americana (Brauer and Bergenstamm)		Diptera : Tahcinidae
PUPA		
Agria housei Shewell		Diptera : Tachinidae
Apechtis pacificus Cushman		Hymenoptera : Ichneumonidae
Iseropus sterocorater orgyiae (Ashmead)		" "
Pediobius crassicornis Thomson		Hymenoptera : Chalcididae
Pediobius pseudotsugatae Peck		" : "
Scambus hispae (Harris)		" : Ichneumonidae
Theronia atlantae fulvescens (Cresson)		" : "
HYPERPARASITES		
Perilampus hyalinus Say	(attacks Tachinids)	" : Chalcidae

c. Virus

Among the natural mortality agents of Douglas-fir tussock moth, nuclear polyhedrosis virus (NPV) is generally regarded as the most important. Its presence, in combination with other mortality factors, frequently causes collapse of outbreak populations. The natural occurrence of virus usually happens after 2 or 3 years of defoliation, when there has already been some growth loss, dieback and tree mortality.

The virus disease affects the tussock moth at all stages of larval and pupal development. Following death, the diseased larvae are usually found hanging from a needle or branch with the body contents liquified. The fragile, virus-laden larvae rupture and contaminate adjacent foliage, which is then consumed by, and infects, other larvae. Egg masses can be contaminated by rain and snow which has been in contact with diseased pupae. First-instar larvae become infected when they consume a portion of their own egg while hatching. Infected larvae usually die 7 - 14 days after hatch. Although the virus is highly contagious, the spread is slow during the first four or five instars, but increases dramatically as the larvae reach maturity and begin to pupate. Experiments in the U.S.A. indicate that populations in which at least 25% of the larvae are infected with virus at hatch will collapse from an epizootic before unacceptable tree damage has occurred. Between outbreaks, NPV remains viable in the soil.

d. Starvation

In the absence of viral disease, outbreak populations are for the most part limited by quantity and quality of available food. Early defoliation of the new growth eliminates the preferred food and forces larvae to feed on less nutritious older needles. This results in starvation and lowered production and survival of eggs, and helps reduce the population to a level where they are again regulated by their usual natural enemies.

Applied

Due to the relatively high frequencey of outbreaks and the destructive nature of the insect, various experimental and operational control programs were initiated in British Columbia over the past 30 years. The use of virus as a biocontrol agent was considered as early as 1962, but the first aerial spray trials with viruses to regulate tussock moth populations were conducted in 1974-1976, and then in 1981-1982, and again in 1991 (Table 4). Small scale operational and experimental use of chemicals took place in 1962, 1975-76, and 1982, (see also pages 15-17).

Table 4. Materials applied to control outbreaks of Douglas-fir Tussock Moth in British Columbia, 1962-1991.

Materials	Year	Method	Area (ha)	Location	Results
BOLOGICAL					
Virus (NPV)	1962	handsprayer	1	Okanagan Valley	Good control
	1972	handsprayer	18 trees	Winfield	Up to 70% larval mortality
	1974	aerial	10	Savona	96.8% population reduction
	1976	aerial	12 150	Kamloops area	Population collapsed from spray and natural causes
	1981	aerial and ground	6 plots, 0.5-9.0 ha.	Hedley-Keremeos	Outbreak prevented
	1982	aerial	40	Veasy L.	Initial 10 - 30% larval mortality, rest secondary infection
	1991	aerial	200	west of Kamloops	Defoliation reduction in treated plots.
Pheromone (confusion trial)	1991	aerial	8	Hedley	Mating by moths impeded by elevated pheromone amounts. More tests in 1992.
B.t. (Dipel & Thuricide)	1975	aerial	12 400	Kamloops	Mixed results
CHEMICAL					
Malathion	1962	aerial	80	Okanagan Landing	Successful-no defoliation in 1963.

(Cont'd)

Table 4. (Cont'd)

Materials	Year	Method	Area (ha)	Location	Results
CHEMICAL					
DDT	1962	aerial	-	Armstrong	Satisfactory control
Acephate (Orthene)& Dimilin	1975, 1976	aerial	12 000+ each year	Kamloops area	High larval mortality and foliar protection
Sevin-4-Oil	1982	aerial	120	Niskonlith Indian Reserve	Successful, no post spray defoliation

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