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Major Outbreaks of the Douglas-fir Tussock Moth in Oregon and California

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ABSTRACT

Case histories of five tussock moth outbreaks that occurred in California and Oregon between 1935 and 1965 are discussed. Information is given on the size and duration of the outbreaks, the presence of natural control agents and the damage caused. Most of the outbreaks were eventually treated with DDT. However, enough information was available from untreated portions to show the probable trend of natural events in the absence of direct control. Repeated patterns observed in each of the outbreaks enabled certain generalizations to be made about natural population behavior and tree impact.

All infestations followed a 3-year cycle with inconspicuous to minimal defoliation the first year, severe foliage loss the second year, and ultimate collapse of the population by the end of the third year. The most severe tree damage occurred in the second year. Additional loss of foliage before population collapse in the third year was usually of minor importance in terms of total impact. Although other natural factors were involved, a virus disease appeared to be the principal cause of insect mortality during collapse.

Keywords: Douglas-fir tussock moth, *Hemerocampa pseudotsugata*, population, tree damage, DDT, control.

PREFACE

The Douglas-fir tussock moth is one of the most destructive forest pests in western North America. A very severe infestation is now in progress on some half million acres in the Blue Mountains area of northeast Oregon and southeast Washington. Heavy damage has already occurred, and more is expected in 1973 and perhaps later. Forest managers are much concerned and looking for alternative ways of dealing with the situation.

To assist in this problem, the PNW Station felt it desirable to assemble all available information, both published and unpublished, on histories of previous outbreaks, damage that occurred, insect population trends, and effectiveness of natural and applied controls, Hopefully this information will be helpful in guiding control considerations and strategies for the present outbreak.

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SUMMARY

1. Tussock moth populations can increase in a single year from relatively inconspicuous levels to numbers causing severe defoliation. Detection at low levels is difficult. Most of the outbreaks reviewed were not detected or adequately assessed until visible defoliation had occurred, which was the second year (outbreak phase) of the cycle. Outbreaks can collapse naturally at the end of the second, or most commonly in the third, year (decline phase). To use direct control action most effectively for preventing damage, outbreaks must be detected during the first year of their cycle (release phase) before significant defoliation has occurred.

2. In each of the five outbreaks described, there was no significant spread of defoliation in subsequent years beyond the initial area of infestation. Local outbreaks apparently develop largely from resident populations which build up slowly over several years before entering the outbreak cycle. Although early-instar larvae are easily dispersed by wind, they are not relocated in enough concentration to cause significant damage before the natural collapse of the outbreak.

3. A nuclear polyhedrosis virus appears to be the major mortality factor causing population collapse in most tussock moth outbreaks. In natural virus epizootics, egg masses are usually contaminated by the beginning of the decline phase and disease-caused mortality occurs throughout the larval cycle. However, there is usually continued defoliation of new needles before the population collapses. To prevent this defoliation and possible added tree mortality before population collapse, chemical control has often been applied, but always during the declining population phase. Thus, the actual effectiveness of control applied at that stage of an outbreak can be difficult to demonstrate. For example, limited comparisons in California of two chemically treated with two untreated areas showed no significant differences in total tree mortality.

4. Almost half the total tree mortality occurs in patches coincident to the distribution of high population centers; the remainder is scattered throughout severely defoliated areas. Control treatments should be applied early and selectively to prevent these "hot-spots" of tree mortality.

5. As much as one-third of the stand can be killed in large outbreaks, but aside from the patches of tree mortality, recovery of the other severely defoliated areas can be rapid. Two outbreaks suffering heavy tree mortality 33 and 25 years ago have shown such rapid growth in surviving trees that light, selective cuts have been made recently.

INTRODUCTION

The Douglas-fir tussock moth is a serious pest of fir forests in western North America (Wickman et al. 1971). It defoliates Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and grand fir, *Abies grandis* (Dougl.) Lindl., in Oregon and white fir, *Abies concolor* (Gord. & Glend.) Lindl., in California and south-central Oregon, Since 1936, six serious infestations have recurred at about 10-year intervals in the two States. The timing of several outbreaks is similar to that reported by Sugden (1957) in British Columbia, but different host types and population behavior are involved. Severe defoliation of California white fir stands has resulted in tree mortality, top-killing, and growth loss (Wickman 1963).

During the course of every major outbreak, land managers ask questions like: "How much tree mortality and other timber damage will occur? When will the populations subside? Will the infestation spread next year? If we do not treat, when will natural agents cause the outbreak to collapse?" Some of these questions have been at least partially answered, and others are in various stages of study and reporting. We believe that a history of the large outbreaks in California and Oregon will be of value by pulling together all published and unpublished information on population trends, natural and applied control, and resulting damage.

Our restriction of covering only California and Oregon outbreaks is based on availability of published information, unpublished file records, and experience of the authors and others. We include only those outbreaks that were large enough to warrant control action or that resulted in the publication of biological data (fig. 1, table 1). This excludes a severe outbreak that occurred over limited areas in eastern Oregon from 1937 to 1939 (Keen 1952). Buckhorn[1/] reported this outbreak detected in 1937 and extending over an area of 6 by 20 miles on Rudio Mountain (between the Malheur and Umatilla National Forests), "Considerable" timber was reportedly killed before the infestation subsided in 1939.

We have also excluded several small, severe outbreaks that were first discovered in the central Sierra Nevada during the summer of 1971 and which declined the same year from unknown causes.

The following records are compiled from published data and file records from the Pacific Southwest Forest and Range Experiment Station, Berkeley, California, and the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, and the authors' personal observations and unpublished data. The outbreaks are discussed chronologically.

1/ *Unpublished typewritten report, "Douglas-fir tussock moth, history and extent of outbreaks," by Walter J. Buckhorn, USDA, Bureau of Entomology and Plant Quarantine, Forest Insect Laboratory, Portland, Oreg. (Undated, probably 1947.)*

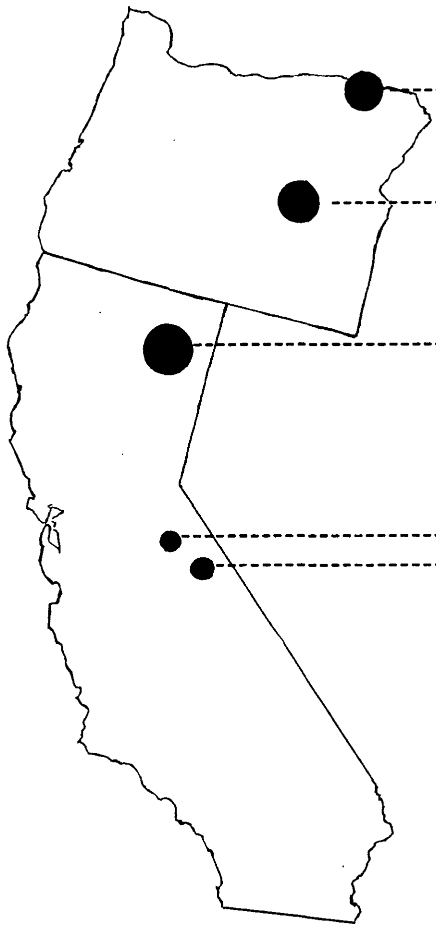

Figure 1.--*Location of 5 major Douglas-fir tussock moth outbreaks in California and Oregon, 1936-65.*

Table 1.--*Statistics of major tussock moth outbreaks in California and Oregon*

Location	Dates	Detection	Major defoliation	Insecticide treatment	Virus discovery	Total infested	Treated
						------*Acres*------	
Mammoth Lakes, Calif.	1935-37	1936	1936	--	1937	15,000	0
Troy, Oreg.	1945-47	1946	1946	1947	1947	56,065	14,000
Stanislaus National Forest, Calif.	1954-56	1954	1955	1956	1955[1]	10,000	9,560
Northeastern California	1963-65	1963	1964	1965	1964	76,000	57,079
Burns, Oreg.	1963-65	1963	1964	1965	1964	65,945	65,945

1/ Heavy natural mortality of larvae observed but cause of death not recorded.

OUTBREAK HISTORIES

Mammoth Lakes, California, 1935-37

This outbreak was first reported and visited by entomologists in 1936. In June 1937, J. E. Patterson visited the area and summarized the outbreak situation.[2] Eaton and Struble (1957) have reported this outbreak as occurring from 1931 to 1938, dates obtained from Patterson's handwritten field notes. Where Patterson obtained these dates is a mystery since his official survey report cites the detection date as August 1936 (see footnote 2). This report states that 1935 cocoons were found in 1936 by D. DeLeon. In early June 1937, Patterson reported severe defoliation on six areas comprising a total of 1,930 acres (Patterson subsequently expanded this to 15,000 acres in his field notes). Patterson's notes state that the infestation reached a peak in 1936 and 1937. By late August and September 1937, a "wilt" disease was found on 25 percent of 200 caterpillars examined, The infestation completely subsided in 1938 (Patterson implied that no caterpillars were found in 1938). A natural virus apparently suppressed the population completely within 1 year, and the infestation did not spread beyond the original outbreak areas, Fortunately, Patterson established a 5-acre study plot in the middle of one of the most severely defoliated areas. This plot was checked annually for white fir mortality until 1942, reestablished in 1957, and used for research purposes through 1970. The damage on'the plot was summarized by Wickman (1963). Briefly, tree mortality amounted to 29 percent of the white fir green stand volume or 10,596 board feet per acre. Growth reduction occurred during the years 1935-38; however, there was a prolonged drought in the area from 1930 to 1934, so the growth picture is complicated (Wickman 1963). The infestation can also be dated by tracing year of top-kill. An evaluation of decay organisms in top-killed trees at Mammoth Lakes, 33 years after the outbreak, showed that top-killing did not start until 1936 (Wickman and Scharpf 1972). This was most likely the first year of severe defoliation, especially since Patterson's report noted severe defoliation in early June 1937, which would have resulted from 1936 feeding,

This is the only outbreak that can be analyzed for long-term effects of defoliation. A study on the plot area showed that decay defect in trees top-killed 33 years ago was not economically serious (Wickman and Scharpf 1972). Also, 29 percent of the white fir stand was killed on the severely defoliated plot area, However, 33 years later, in 1970, the residual stand on the plot had grown fast enough to support a selective white fir cut of 2,158 board feet per acre (Wickman and Scharpf 1972).

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[2] *Unpublished typewritten report, "Tussock moth,* Hemerocampa oslari: *Preliminary examination of infested areas on the Inyo and Mono National Forests, California, June 23-25, 1937," by J. E. Patterson, USDA, Bureau of Entomology and Plant Quarantine, Forest Insect Laboratory, Berkeley, Calif.*

Troy, Oregon, 1945-47

This outbreak was first detected by entomologists in August 1946. It was estimated that the infestation covered 10,000 to 12,000 acres of grand fir-Douglas-fir forests, and almost complete defoliation had occurred on 500 to 600 acres in patches ranging up to 50 acres.[3/] Local residents indicated that defoliation had begun in some areas in 1945. There was a concurrent and much larger outbreak in Idaho against which control action using DDT aerial spray was being planned. Therefore, a thorough aerial survey was carried out in March 1947 by W. J. Buckhorn. He found, after this survey, that the infested area comprised 56,065 acres west and north of Troy on private lands and the Umatilla National Forest. Severely defoliated patches of timber occurred on 1,265 acres.[4/] Buckhorn mentioned in this second report that there was a possibility that a major portion of the threatened timber might be killed and that the outbreak might expand beyond its existing limits. After a ground check by R. L. Furniss and Buckhorn in April 1947, they predicted that the "prospects are that the outbreak will subside late this season, after most of the feeding is over, or in 1948. Relatively little spread is anticipated beyond the 56,000 acres already infested, in varying degrees. Most of the outlying parts of the area harbor too light an infestation to be a serious threat--at least not in 1947." They recommended treatment of 14,000 acres of forest that was most severely defoliated.[5/] The 14,000 acres near Troy were then included in the Idaho Control Unit and sprayed with 1 pound of DDT in 1 gallon of fuel oil per acre from June 24 to July 2, 1947.

W. J. Buckhorn spent the spring and summer of 1947 studying tussock moth biology and monitoring the spray project on this outbreak. His field notes give the following course of this infestation. By May 28, egg hatch was nearly complete. By June 11, where populations were high, most or all of the new (1947) foliage had been fed upon by larvae in the second and third instar, the larger larvae beginning to feed on older foliage. On June 18, great numbers of larvae of all instars were seen migrating on ground and up and down trees, creating much webbing. "Millions of larvae dead in webbing." Thousands were also falling to the ground at base of trees. The next day, June 19, Buckhorn noted many third-instar larvae falling to the ground at the base of trees. Many

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[3/] *Unpublished typewritten report, "First memorandum on the Doughs-fir tussock moth outbreak near Troy, Oregon," by Walter J. Buckhorn, USDA, Bureau of Entomology and Plant Quarantine, Forest Insect Laboratory, Portland, Oreg., Sept. 23, 1946.*

[4/] *Unpublished typewritten report, "Second memorandum on the Douglas-fir tussock moth outbreak near Troy, Oregon," by Walter J. Buckhorn, USDA, Bureau of Entomology and Plant Quarantine, Forest Insect Laboratory, Portland, Oreg., Apr. 10, 1947.*

[5/] *Unpublished typewritten report, "Third memorandum on the Douglas-fir tussock moth outbreak near Troy, Oregon," by R. L. Furniss and W. J. Buckhorn, USDA, Bureau of Entomology and Plant Quarantine, Forest Insect Laboratory, Portland, Oreg., Apr. 25, 1947.*

sluggish larvae were found in webbing, and piles of dead larvae were found at the base of the majority of mature trees. On June 24, DDT spraying was begun and completed by July 2. By July 17, mature larvae were found and parasitism was noted, presumably on the untreated areas, Parasites were numerous by July 23, and on July 28 many apparently parasitized larvae were seen wandering and dying and pupation was found. On August 6 this entry: "Very little increase in numbers of cocoons. Live larvae are very scarce. Numbers of dead ones have increased considerably. Many at bases of trees, others hanging on trunks or branches, It appears that the infestation (presumably on the unsprayed areas) is disappearing through disease and parasites."

The last entry states: "pupation about complete and little mortality at Mosier Corral" (a lightly defoliated area not visible from the air on the west end of the infestation). There are no reports of increased tree mortality in 1947, and by 1948 natural control factors brought the scattered spots of surviving infestation under control.

There is an additional statement made by Buckhorn in another unpublished report that is worth quoting (see footnote 1).

> On the nearby Wallowa National Forest an infestation was reported on some 1,500 acres near Promise, Oregon, in June of 1947. Some 320 acres of the most heavy infestation were sprayed from the air on July 15, 1947, with a dosage of DDT similar to that applied on the Idaho and Troy areas. Apparently the large larvae were more resistant to the small dosage of DDT (1 lb. per acre) which caused complete mortality of the smaller larvae on the other two projects, as little mortality occurred. A short time later, however, natural factors, disease and parasites, brought about almost complete control. Two other small spots of infestation, 800 and 200 acres respectively, found west of the Promise center, were also wiped out by natural control.

Stanislaus National Forest, California, 1954-56

This outbreak in Calavaras and Tuolumne Counties in the central Sierra Nevada was characterized by a series of seven infestation centers (mostly on ridgetops) totaling 10,000 acres, strung out for 35 miles at about the 5,000-foot level. The infestation was first found by entomologist G. L. Downing in 1954 and was checked by G. C. Trostle on the ground and aerially mapped in the fall of 1955. By this time defoliation was so severe that many white fir trees had lost most of their foliage.[6] Areas around the centers with visible defoliation

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6/ Unpublished mimeographed report, "Douglas-fir tussock moth, Crane Meadows and Thunder Hill areas, Stanislaus National Forest, fall 1955 appraised survey," by G. C. Trostle, USDA Forest Service, California Forest and Range Experiment Station, Berkeley, Calif., Feb. 15, 1956.

were ground checked and they showed light or no damage. "The lightly defoliated areas could not be discerned from the air." Trostle observed that the infestation first became epidemic in 1953, based on the number of old pupal cases found in 1955. It is not clear how or why 1953 pupal cases were distinguished from 1954 cases unless "1953" is a typographical error and should read "1954." Based on observations of G. L. Downing, defoliation first became noticeable in 1954 in the Stanislaus outbreak. There were some areas further north (Eldorado County) that were defoliated in 1953 but did not become outbreaks. Trostle goes on to say that there were indications the epidemic peaked and had started to decline in 1955. This was based on the difficulty of finding larvae and pupae in some of the infestation centers and discovery of "fairly high" parasitism and numbers of dead larvae, cause of death unknown. However, it was assumed that even if 1956 was the year of heavy brood mortality, "defoliation will be completed before the majority of the larvae die, so tree mortality may occur whether the population declines or not" (see footnote 6).

Additional air and ground surveys were made in the spring of 1956. Three additional small centers were located by this survey. In early May 1956, egg-mass collections were made from areas that could be reached to get some indication of the success of the overwintering population. The egg masses were force reared in the laboratory and an excellent hatch resulted, indicating another season of heavy defoliation could be expected.[7/] However, these larvae were not retained and reared for virus determination, so the incidence of this natural control factor was unknown.

A total area of 9,560 acres was treated from the air with 1 pound of DDT in 1 gallon of fuel oil per acre, on July 31 and August 1-2, 1956. The visible infestation centers on ridgetops were the only areas sprayed. The larvae were three-quarters grown at that time and control was excellent (see footnote 7). The senior author of this publication observed, prior to spraying, that some patches of white fir had been completely stripped of foliage in 1955 and were dying, And the insects were sprayed rather late in their larval development, resulting in the removal of all the new foliage and some older foliage in the heavy population areas.

There were no sampling methods developed for the Douglas-fir tussock moth at that time, so population appraisals were made by looking for evidence of current feeding on selected trees on survey lines. (By today's standards this gives a crude approximation and even results in biased and inaccurate estimation.) No tussock moth egg masses could be found in the fall of 1956, in either the sprayed outbreak centers or the untreated, lightly infested areas between. There were no check areas or larval collections made, so the presence or incidence of natural virus in the population was unknown.

7/ Unpublished processed report, "Control of an infestation of the Douglas-fir tussock moth with DDT aerial spray, Calaveras and Tuolumne Counties, California," by R. E. Stevens, USDA, Forest Service, California Forest & Range Experiment Station, Berkeley, Calif., Feb. 1956 (error: should be February 1957).

Studies of damage caused by the tussock moth were started in July 1956 by establishing permanent plots throughout the infestation, The first year's examination of the plots, in 1957, showed that 21 percent of the trees were killed in the heavily defoliated plots. One-fourth of this mortality was caused by defoliation alone; other defoliated trees,were killed by bark beetles (Wickman 1958). These studies of tree damage were continued for 5 years and showed that 20 percent of the merchantable white fir volume, or 11,071 board feet per acre, died in the heavily defoliated outbreak area (composed mostly of virgin timber); another 1,113 board feet per acre was lost owing to radial growth reductions in partly defoliated trees; 12 percent of these trees were top-killed (Wickman 1963). These losses are amazingly similar to those suffered after the Mammoth Lakes outbreak, also occurring in virgin timber.

Northeastern California, 1963-65

This outbreak in Modoc, Lassen, and Plumas Counties covered 76,000 acres in five infestation centers. By late summer 1964, tree mortality was occurring on heavily defoliated areas in the largest recorded outbreak in California (California Forest Pest Control Action Council 1965). Several tussock moth'larvae were found in Modoc County in the summer of 1962; by late summer of 1963, egg masses were found in an area scheduled for treatment to control white fir sawfly. In August 1964, defoliation was visible on thousands of acres and there were patches of completely defoliated white fir scattered throughout the outbreak. Forest Service entomologists spent much of the summer and fall of 1964 evaluating the outbreak. Cocoons and egg masses were sampled during a thorough and intensive cooperative survey.[8/] The populations on each outbreak center were evaluated separately and the tussock moth evaluation report made recommendations for each area. For the largest area--Knox Mountain, 59,730 acres--it was predicted that if the outbreak was not halted, damage would increase and probably spread the following year to all the fir type in the Knox Mountain area (see footnote 8). Consequently plans were made to use DDT to control the Douglas-fir tussock moth during the summer of 1965.

In June and July 1965, 57,079 acres in two of the largest outbreak centers were aerially sprayed with three-quarters of a pound of DDT in 1 gallon of fuel oil per acre.[9/] [10/] The first posttreatment evaluation report stated (see footnote 9):

8/ *Unpublished mimeographed report, "Douglas-fir tussock moth infestations in northern California--1964," by John R. Pierce. USDA, Forest Service, Region 5, Division of Timber Management, San Francisco, Calif., Dec. 14, 1964.*

9/ *Unpublished mimeographed report, "Preliminary report of the results of the Douglas-fir tussock moth control projects, California, 1965." USDA, Forest Service, Region 5, Division of Timber Management, San Francisco, Calif., July 21, 1965.*

10/ *UnpubZished processed report, 'The Doughs-fir tussock moth in California, a cooperative control project." USDA, Forest Service, Region 5, Division of Timber Management, San Francisco, Calif., Mar. 1966.*

> Data from mortality sampling points throughout the sprayed areas indicates that over 99 percent of the tussock moths are dead in the treated areas. In addition to mortality counts made at established mortality sampling points, beating samples taken at numerous other points have failed to detect any tussock moth populations except very scattered individual larvae which survived the spray. These survivors probably are late hatching stragglers which emerged from the egg after the effectiveness of the DDT had diminished and are so few in number as to pose no threat of continued damage in treated areas.

A later, more comprehensive report of the control operation was issued (see footnote 10). This report gave the results of larval mortality determinations made on groups of caged larvae that were treated and on those that were not treated with DDT. Mortality of treated larvae 10 days after spraying averaged 99.6 percent and untreated larvae, 45.1 percent. Cause of death for untreated larval mortality was not stated, but there was a significant virus incidence in the area where the larval mortality determinations were made.

A natural virus was widely distributed in the outbreaks, and all of the untreated populations suffered heavy larval mortality and were completely suppressed by the end of 1965 (Dahlsten and Thomas 1969). In October 1965, egg mass surveys were made of all outbreak areas and no new egg masses were found in either the treated or untreated outbreaks (see footnote 10).

The nontreatment of several areas offered one of the few opportunities to study the biology and natural course of a tussock moth outbreak and damage in treated and untreated areas; Consequently, several studies were carried out for the next several years. Reliable sampling techniques were developed for various stages of the Douglas-fir tussock moth for the first time (Luck and Dahlsten 1967, Mason 1969, 1970); parasites were determined (Dahlsten et al. 1970); the presence and identity of virus were confirmed (Dahlsten and Thomas 1969); the natural collapse of an outbreak was recorded (Mason and Thompson 1971); feeding behavior was recorded (Mason and Baxter 1970); and an aerial photography technique was developed to sample tree mortality (Wert and Wickman 1968, 1970). These studies resulted in the first comprehensive understanding of Douglas-fir tussock moth outbreaks, collapse, and damage.

Larvae did a considerable amount of feeding the year virus suppressed the population. Larvae on an untreated area removed all new foliage and some older foliage before being killed by virus. Larvae also removed much of the new foliage on treated areas before they were sprayed. Visual estimates of individual tree defoliation on a treated plot area (Stowe Reservoir) with a comparable untreated plot area (Roney Flat), both before (May) and after (August) treatment in 1965, showed the following. Defoliation increased on 51 percent of the 107 sample trees on the untreated plot. Only 12 lightly defoliated trees changed to a heavy defoliation class. The other trees with increased defoliation were all in the heavy class in May, and they lost an additional 5 to 25 percent of their remaining foliage by August. None of the trees showed foliage gains during the summer. Defoliation increased on 11 percent of the 105 trees on the treated plot, but 40 trees showed improvement with increased foliage growth by August. Spraying with DDT apparently did save foliage. However, tree mortality (measured in 1966 on a series of 0. 2-acre plots) was essentially the same on both areas--27 percent of the trees on the untreated Roney Flat and 25 percent of the trees at Stowe Reservoir (Wert and Wickman 1968). By 1967, Stowe Reservoir suffered 32-percent tree mortality; there was no comparable measure at Roney Flat.

There was no spread of visible defoliation from those areas untreated in 1965. A small, new center was found 40 miles northwest of Stowe Reservoir in late 1965, but populations declined without spread in 1966 (Mason and Thompson 1971).

Tree damage was intensively investigated at the 450-acre Stowe Reservoir outbreak center during studies with aerial photography. The second-growth white fir stand suffered 2, 518 board feet per acre tree mortality (25 percent of the stand), and 19 percent of the surviving trees were top-killed (Wert and Wickman 1970). An assessment was made of the distribution of tree mortality because the Douglas-fir tussock moth has typically killed trees in patches up to 50 acres in size. A sample of five patches of dead trees showed that an average of 84 percent of the trees was killed in these patches; this type of damage was concentrated on 14 percent of the area and contained 40 percent of the total tree mortality in the Stowe Reservoir outbreak.[11/]

Burns, Oregon, 1963-65

In 1963, tussock moth defoliation was recorded on 15 acres in mixed and pure stands of Douglas-fir and white fir on Antelope Mountain in the Malheur National Forest. By the end of the summer in 1964, defoliation, as ascertained from aerial surveys, covered 39,000 acres on the Malheur and an additional 1,000 acres on the Ochoco National Forest. Ground surveys for eggs in the fall of 1964 increased the total infestation acreage in both forests to almost 56,000 acres.[12/] Defoliation during 1964 was heavy in most of the outbreak areas on the Malheur but relatively light on the Ochoco.

By the end of 1964, it was estimated that the tussock moth had killed immature timber on 1,050 acres and 2.6 million board-feet of mature timber. Losses at that time were valued at $219,000. Perkins and Dolph (1967) reported that an additional 33, 700 acres of young trees and 262. 5 million board feet of

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11/ Unpublished data of B. E. Wickman, 1970 field studies on file, USDA, Forest Service, Pacific Northwest Forest & Range Experiment Station, Forestry Sciences Laboratory, Corvallis, Oreg.

12/ Unpublished report, "Entomological evaluation of the Douglas-fir tussock moth in eastern Oregon, 1964," by D. McComb. USDA, Forest Service, Region 6, Portland, Oreg., 1965.

mature timber were threatened in 1965. These estimates presumably were for the already infested acreages. They further estimated that 122,000 acres of immature timber and 950 million board feet of mature timber would be ultimately threatened, apparently by spread into uninfested areas, "unless control was achieved in 1965."

For ease of description and evaluation the infestation was partitioned into five natural geographic areas: Antelope Mountain, King Mountain, Gold Hill, and Vance Creek on the Malheur National Forest and Silver Springs (Snow Mountain) on the Ochoco National Forest. Natural virus disease was detected in 1964 larval populations at Antelope and King Mountains and at Gold Hill (see footnote 10). Subsequently, virus was also found in 30 percent of the fall egg masses.[13/]

However, in the fall of 1964, new egg masses outnumbered the old in all areas except Gold Hill. On Antelope Mountain, the new to old egg mass ratio was 14 to 1. The consensus among foresters and entomologists late in 1964 was that the tussock moth population was increasing and that natural control factors were insufficient to stop the epidemic before serious damage occurred. They felt that large tussock moth populations would be present in all infestation areas the next spring and that more tree killing was imminent unless effective control measures were taken.

During the period of June 10 to July 1, 1965, a total of 65,945 acres were sprayed with DDT for control of early-instar larvae (Perkins and Dolph 1967). Application was by helicopter and at the rate of 0.75 pound DDT in 1 gallon of fuel oil formulation per acre. Because of public concern at this time about side effects of DDT in the environment, impact of the spray on other resources, including fish, water, soil, forage, and cattle, was evaluated by scientists working independently of the project (Crouch and Perkins 1968, Tarrant et al. 1972). In addition, a small test was made of two other candidate insecticides, Dursban, an organic phosphate, and Zectran, a carbamate.[14/]

Effectiveness of the control project was determined by comparing pre- and post-spray larval counts and new 1965 egg masses to the number of 1964 egg masses. Larval mortality averaged 98 percent, and no new egg masses were found in any of the fall surveys. The spray project was "considered highly successful with virtually complete mortality of the target insect" (Perkins and Dolph 1967).

[13/] *Personal data of C. G. Thompson, Principal Insect Pathologist, USDA, Forest Service, Pacific Northwest Forest & Range Experiment Station, Forestry Sciences Laboratory, Corvallis, Oreg.*

[14/] *Unpublished report, "Dursban and Zectran pilot control study for Douglas-fir tussock moth," by D. McComb. USDA, Forest Service, Region 6, Portland, Oreg., 1966.*

The tests of Dursban and Zectran proved significant, not because of their affect on the tussock moth, which was generally unsatisfactory, but because of the series of .methodical observations made in the test area after treatment (see footnote 14). Study plots for observing larval mortality were established in each of the two spray-treatment areas and in an unsprayed control area. The test was conducted on July 8, 1965, when larvae were mostly in the third instar. Evaluations were made by counts of larvae 1 day before spraying and 1, 3, and 10 days after spraying. These counts showed that, although there was a reduction of larvae on the sprayed plots 1 day after spraying, a considerable number of larvae were unaffected by the insecticides. However, within a few days, larvae on all plots began to succumb to disease. In his report of the test, McComb described this incident as follows: "Sometime between the third and tenth day after spraying, larval mortality from a polyhedral virus disease began to occur throughout the study area. Therefore, all the moth population reduction occurring during this period cannot be attributed to the insecticides," In reference to egg ratio surveys made in October after the test, McComb stated further that they "were of no value in measuring effectiveness of the insecticide as the virus disease had wiped out the entire larval population in the study area prior to pupation. On the transect lines, 2,062 old egg masses were collected without a single new egg mass being found."

Aerial spraying of DDT obviously brought about an abrupt termination of larval feeding in early summer. It is also clear that the outbreak was simultaneously declining from disease and that it collapsed completely by fall from natural causes.

OUTBREAK PATTERNS

It is important to maintain an historical perspective of biological events, Such events are not always easy to interpret; but if a pattern develops during the recurrence of events, an examination of that pattern helps us understand what is happening and, through association, gives us some ability to predict the outcome of events in the future.

We feel that the careful examination of five Douglas-fir tussock moth outbreaks over the last 36 years in California and Oregon has shown some consistent patterns. A brief discussion of population buildup, decline, and tree damage resulting from defoliation describes these patterns.

Population Behavior

To understand tussock moth outbreaks we must first know something about how populations change. Enough empirical information from past outbreaks is now available to make fairly good predictions about expected population change, Without going into the mathematics or biology of change, we can simply observe patterns that have occurred time and again to gain insight for prediction.

Outbreaks of forest defoliators can be viewed as going through three phases of population change: release, outbreak, and decline (Greenbank 1963). With some defoliators, each phase may cover several years. In outbreak cycles of the Douglas-fir tussock moth, all phases seem to be compressed into about 3 years (fig. 2). That is, 1 year for release, 1 to 1-1/2 years of outbreak, and 1/2 to 1 year for decline. In the release phase, defoliating larval populations may multiply five to 10 times or more and, thus, increase from a relatively insignificant level to one of outbreak proportions in a single year. Several years of inconspicuous buildup are probably required to reach the level where quick release can occur. The second year, or the outbreak phase, is the period of most conspicuous tussock moth defoliation. This, of course, is the year when the "blow up" is usually first recognized. Some outbreaks apparently collapse naturally at the end of this second year, but frequently a large number of eggs laid that fall indicates a further population increase the next year. However, the third season of the cycle inevitably spells a population decline, especially at high outbreak levels, If defoliation has been severe and egg masses are abundant, survival during the early larval instars is apt to be low. Trees may be defoliated of new needles again in the third year, but the population usually begins to collapse during the summer. Significant oviposition rarely occurs the third year.

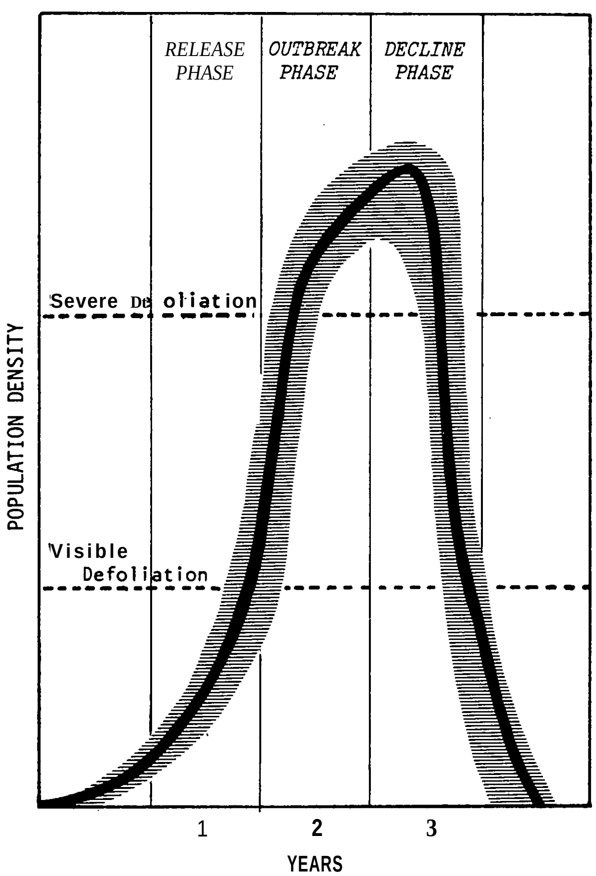

Figure 2. --*Hypothetical model of an outbreak cycle of the Douglas-fir tussock moth.*

Considerable speculation and rhetoric through the years have centered on spread of tussock moth outbreaks. During the Troy outbreak, a Ranger was quoted as saying "the moths were traveling toward a large stand of virgin timber but it was believed the threat had been eliminated (by DDT)."[15/] Justification of large spray programs has frequently been based on the assumption that outbreaks will spread extensively beyond a population center or "hot-spot" unless controlled. This, of course, assumes that outbreaks are often the result of spread from some point of origin rather than the natural buildup of a resident population. Historically, there is no sound evidence to indicate that tussock moth outbreaks ever expand much beyond the boundaries of the initial infestation. The female moth is wingless; thus, oviposition almost always occurs at the site of pupation. Spread must be by early-instar larvae which are easily wing-borne and perhaps can be carried many miles. Although small larvae undoubtedly can be easily dispersed from population centers and may enrich the gene pool of other populations, they apparently do not invade new habitats in the concentrations required to cause significant first-year defoliation. As described in table 1, most outbreaks suffer an overall collapse within 3 years of their inception, so there is little chance for dispersed larvae to build to outbreak levels,

We have found[16/] that tussock moth outbreaks develop after a buildup of populations that have been resident in the habitat for at least several years. Similar results have also been shown for other forest defoliators, which usually exist not as discrete colonies but as individuals scattered in various concentrations over an area (Graham 1963). Tussock moth buildup apparently occurs simultaneously throughout the suitable forest habitats in the area, so that populations of most centers are chronologically within a year or two of each other in terms of abundance, The most favorable habitats for population growth probably reach the release phase first and suffer the most severe defoliation during the outbreak phase. In large outbreaks there may be considerable mixing of larvae so that separate population centers coalesce and end up behaving as a single population. This apparently explains why all populations in a large outbreak, regardless of their abundance level, collapse the same year.

Virus Epizootiology

A nuclear polyhedrosis virus appears to be the major factor in the dramatic population collapse that characteristically terminates major tussock moth outbreaks. The virus does not appear to be a significant factor in endemic population fluctuations nor in sporadic flare-ups of endemic populations. The controlling factor in these endemics is usually a complex of parasitic insects, although other biological and environmental factors may also be involved. The virus spreads so explosively, in high population densities of the tussock moth, that

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15/ *From a news item in the* Oregon Journal, *July* 18, 1947.

16/ *Unpublished data* of *R. R. Mason on file at USDA, Forest Service, Pacific Northwest Forest & Range Experiment Station, Forestry Sciences Laboratory, Corvallis, Oreg.*

it tends to preclude any possible control by entomophagous insects. If the virus were not present in such situations, it is probable that other control factors would soon take over, although perhaps somewhat later than the virus would have. Even in major outbreaks, the virus can only rarely be detected before populations causing heavy defoliation have developed. Nuclear polyhedrosis epizootics have been studied in Washington, Idaho, Oregon, California, and Arizona. Although two distinct strains of the virus have been found which have a tendency toward geographical separation, the course of polyhedrosis epizootics has been the same throughout the West (Hughes and Addison 1970).

Typically, the virus incidence is so low that we have not been able to detect it in the release phase of an outbreak. The disease sometimes, but not always, becomes evident during the later instars during the outbreak phase. If the virus disease is found in phase two, its occurrence is usually spotty and may require intensive surveys to determine its distribution. The decline phase of a tussock moth outbreak has always begun with a virus contamination of the egg masses. The source of this egg contamination is puzzling, since it has occurred in populations which in the previous year were apparently free of the virus as well as in populations with a high virus incidence. The virus present on the overwintering eggs produces mortality which almost always occurs at the end of the first larval instar. Usually this first-instar virus incidence is relatively low--even among larvae hatching from contaminated egg masses. Virus-contaminated egg masses are found throughout the infested area at the beginning of the decline phase, although the incidence is usually highest in the areas suffering the heaviest defoliation the previous year.

Although the source of egg mass contamination has not yet been satisfactorily explained, the course of the epizootic following egg hatch can be explained by the contagious nature of the disease. The initially infected larvae dying in the first instar contaminate foliage which is fed upon by some of the surviving healthy larvae, which in turn become infected, die, and contaminate more foliage. The larvae which die in the early instars are very inconspicuous and usually escape detection by the casual observer. The larvae dying in the last instar, on the other hand, are quite conspicuous. This has lead to a general misconception that the polyhedrosis virus only kills last-instar larvae. Actually, in most of the epizootics studied, the majority of the tussock moth larvae died in the earlier instars (Mason and Thompson 1971).

The speed at which an epizootic develops apparently depends on two major factors: (1) the initial rate of egg mass virus contamination and subsequent first-instar mortality and (2) the density of the tussock moth population. The higher these two factors, the faster the epizootic develops. Our experience has been that if 10 percent of a defoliation-level population is infected in the first instar, the population will be essentially eliminated the same year although a few individuals may survive to pupation. Initial polyhedrosis incidence of 1 to 10 percent resulted in a population collapse the same year; but defoliation may have been greater, and, in one observed case, a small inconsequential population survived until the following year, If 50 percent of the population is initially infected, population collapse may be expected by the third or fourth instar, *Tree Damage*

As previously mentioned, most of the defoliation occurs in the outbreak phase (the year of discovery, in most cases), and most of the tree mortality can be associated with that defoliation. Tree mortality is heavy the year after severe defoliation and continues for an additional year after the collapse of the populations (fig. 3). Most of the mortality the second year is aided by bark beetles which are associated with about three-quarters of the total merchantable volume killed (Wickman 1958).

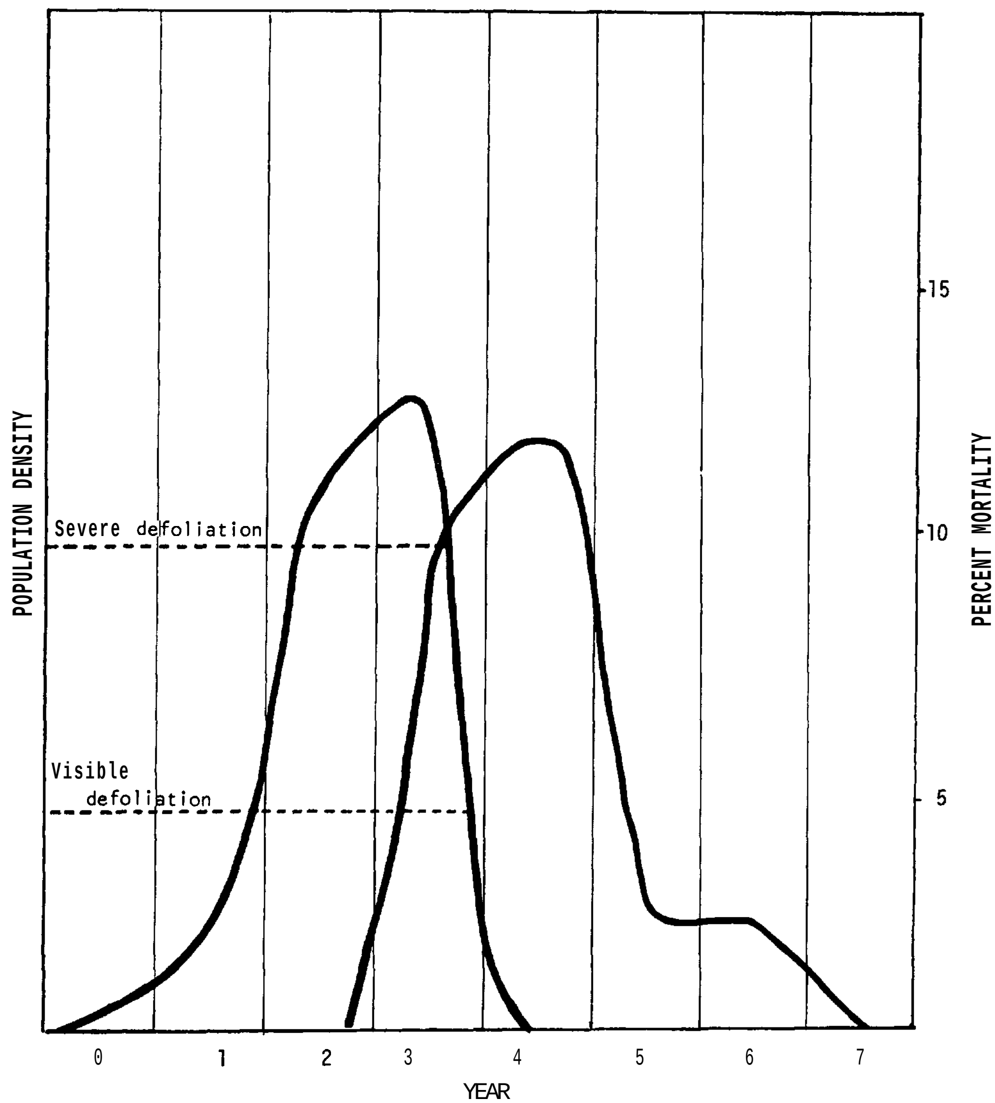

Figure 3. --*Percent tree mortality through a hypothetical Douglas-fir tussock moth outbreak cycle.*

Defoliation occurring the year of decline may be very conspicuous but does not seem to influence the course of events started by the first year of severe defoliation. For instance, feeding by larvae during the year of population collapse can be severe enough to remove all current foliage and many older needles. In one study area where populations were declining due to virus, 51 percent of the sample trees had additional defoliation before the larvae disappeared. However, this occurred primarily on trees already 75 to 90 percent defoliated. This resulted in additional defoliation on trees that were highly susceptible to death anyway and could be why similar tree mortality losses have been measured on both treated and untreated areas (e,g., Stowe Reservoir and Roney Flat, Stanislaus National Forest and Mammoth Lakes).

As would be expected, the heaviest tree mortality occurs in patches coincident to the distribution of high population centers. These patches of killed trees amounted to almost half the total mortality in an outbreak area. If the patch mortality is left standing, it may create a fire hazard for as long as a decade. Salvage of dead trees must usually be done within a year to recover wood values. And after logging, a clearcut remains. If natural regeneration is difficult to obtain, planting may be necessary with its added costs. Treatment applied early enough to prevent these "hot-spots" of tree mortality should be the primary objective in control considerations.

Aside from the patches of tree mortality, recovery of moderately to severely defoliated stands can be rapid. For example, the 5-acre plot at Mammoth Lakes lost 29 percent of the green stand volume yet supported a light, selective, white fir cut 33 years later because of increased growth on surviving trees. The 1947 Troy outbreak area is being selectively cut at this time, indicating growth recovery in that stand as well.

In lightly defoliated areas, tree damage in the form of growth loss has ranged from 31-percent reduction to an almost undetectable amount. These areas apparently recover completely within a few years after the outbreak.

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