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Recurrent Outbreak of the Douglas-Fir Tussock Moth in the Malheur National Forest: A Case History

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Abstract

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Characteristics of an outbreak of the Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough)) in 1991-95 on the Burns Ranger District of the Malheur National Forest (eastern Oregon) are given and compared with an earlier infestation in the same area in 1963-65. Results of monitoring with pheromone traps, evaluating populations by sampling larvae, and predicting trends and defoliation are reported in detail for the latest outbreak. Temporal patterns of each outbreak also are described and compared with the classic behavior of other tussock moth outbreaks. Findings of this analysis, and the recurrent behavior of tussock moth outbreaks in general, reinforce the importance of maintaining a system for detection, evaluation, and prediction in managing Douglas-fir tussock moth populations in the future.

Keywords: Douglas-fir tussock moth, *Orgyia pseudotsugata*, insect outbreaks, sampling insects, pheromone traps, population monitoring.

Introduction

The Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough)) is a major insect defoliator of true firs (*Abies* spp.) and Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) in the interior Northwest. Its populations are characterized by regular fluctuations and sometimes explosive growth, often leading to abrupt and unexpected defoliation of trees. An ever increasing abundance of fir trees in mixed-conifer forests during the late 20th century has created stands with a chronic risk for outbreaks of this insect.

Early history of tussock moth outbreaks in the Malheur National Forest is briefly documented in old survey reports. The first record of an outbreak in the Malheur was a minor infestation in 1928-29 near Seneca, Oregon (Buckhorn 1948). From 1937 to 1939, a large and apparently severe outbreak also occurred in the Rudio Mountain area in the northwestern corner of the Forest (USDA 1946); and in 1947, two small infestation areas were reported in the southwestern part of the Forest (Buckhorn 1948). Although these early outbreaks developed in the Forest at fairly regular intervals, they did not reoccur at the same locations.

The first major tussock moth outbreak in the Malheur National Forest to be completely described occurred in 1963-65, north of the city of Burns, Oregon. In this infestation, known as the “Burns Outbreak,” defoliation was concentrated in the Antelope Mountain, Gold Hill, and King Mountain areas in the south half of the Forest. Unusual insect activity was first noticed in 1963 when minor defoliation occurred in the tops of trees on 15 acres on Antelope Mountain. By summer 1964, defoliation of true fir and Douglas-fir suddenly became visible over 38,960 acres (Orr and others 1965). In 1965, the portion of the outbreak in the Malheur National Forest was terminated by aerially treating 62,650 acres with an application of DDT (Crouch and Perkins 1968, Perkins and Dolph 1967). For many years, this infestation was considered to be one of the more significant tussock moth outbreaks on record (Wickman and others 1973).

Almost 30 years later in 1991-95, a second major outbreak of tussock moth erupted in two of the same areas of the Malheur: Gold Hill and King Mountain. By this time, however, detection and evaluation procedures had improved, thereby making it possible to quantify insect populations and forecast trends that could not have been done 30 years earlier. Because considerable effort went into following the course of this second outbreak, we believe the results should be permanently documented, both for scientific and historical reasons and for use in managing future tussock moth outbreaks. Accordingly, in this paper we have chronicled basic features of the outbreak, including how resurgence of the population was detected first by trapping moths and how subsequent trends in the population and defoliation were predicted by monitoring larval densities. As our activities were not part of a designed study, results are presented as a case history comparing explicit findings from the second outbreak with general descriptions of the first outbreak. We hope our experience will benefit others facing similar problems.

Methods

Description of Outbreak Area

The 1991-95 outbreak occurred in the southern end of the Malheur National Forest, 15 to 30 miles north of Burns, Oregon. The total infestation included about 112,640 acres. For management purposes, it was divided into three parts: the Rattlesnake (37,120 acres), Thompson Springs (40,960 acres) and Gold Hill (34,560 acres) Analysis Units. Geographical location of the first two units was analogous, although larger in size, to the former 1965 King Mountain Spray Unit (27,334 acres). Location of the Gold Hill Analysis Unit was similar to the 1965 Gold Hill Spray Unit (11,655 acres) but was larger (fig. 1).

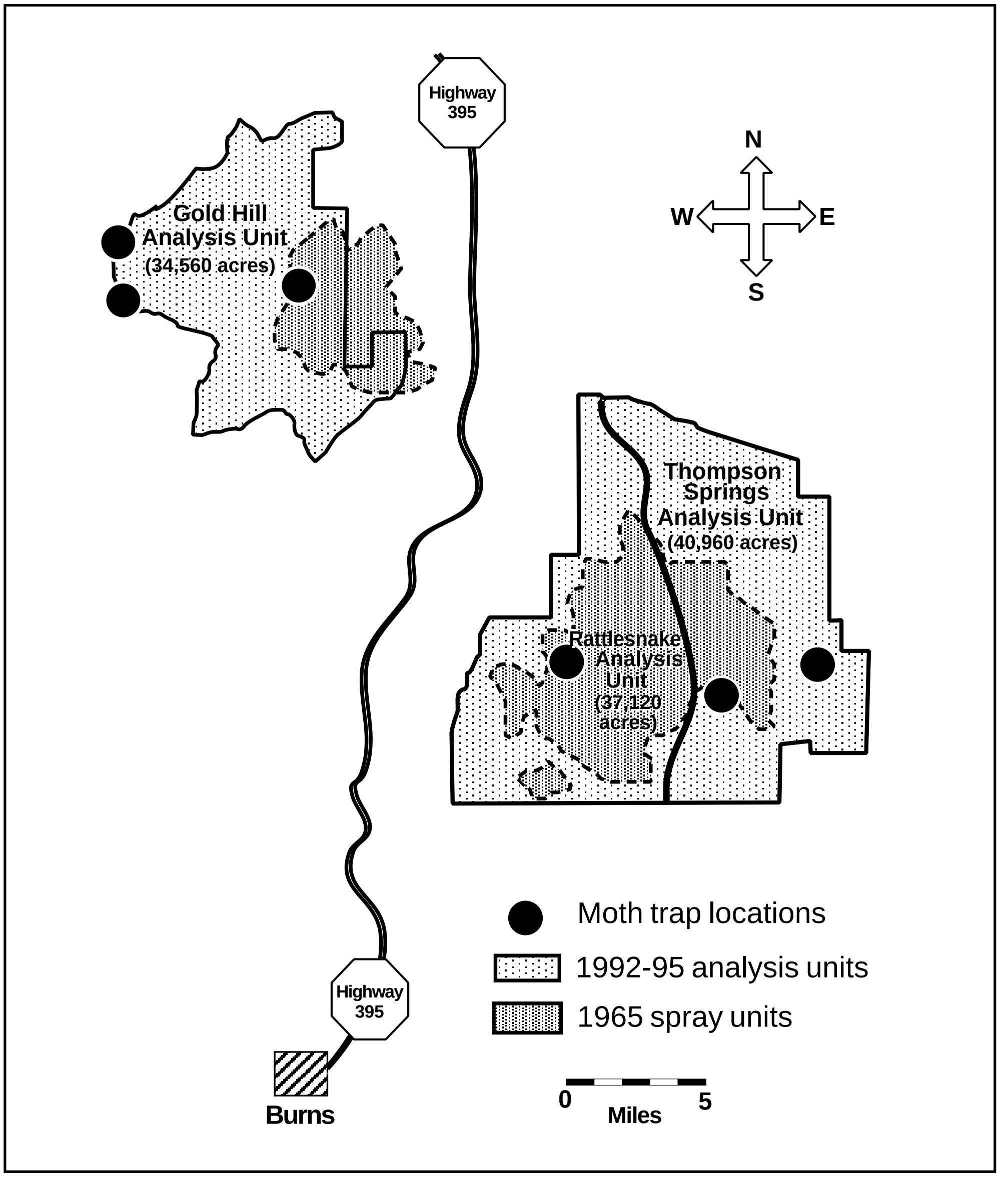

Figure 1–Geographic locations of 1991-95 and 1963-65 outbreaks of Douglas-fir tussock moth, Malheur National Forest.

Analysis units were comprised largely of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and mixed-conifer types of ponderosa pine, Douglas-fir, and white fir (*Abies concolor* (Gord. and Glend.) Lindl. ex Hildebr., *Abies grandis* (Dougl. ex D. Don) Lindl., or a hybrid of the two). White fir, the most common host species of Douglas-fir tussock moth in the area, usually occurred either as understory beneath old-growth ponderosa pine or as released stands after the harvesting of pine. Since 1937, the proportion of such mixed-conifer types, often dominated by late-successional species like white fir and Douglas-fir, had nearly tripled because of natural succession accelerated by fire exclusion and the removal of pine (Agee 1993, Powell 1994). Elevations in the units range from 5,000 to 6,800 feet, and precipitation averages about 20 inches annually, mostly as snowfall in winter. Between 1982 and 1986, this portion of the Malheur National Forest also was part of a regionwide outbreak of the western spruce budworm (*Choristoneura occidentalis* Freeman) that caused considerable defoliation of fir trees during that period (Powell 1994, Sheehan 1996a). In summer 1983, part of the area was treated with the chemical insecticide carbaryl to suppress budworm populations (Sheehan 1996b).

Adult Monitoring

Presence of male adults lured to pheromone-baited traps is widely used today as an “early warning” of potential outbreaks. On the Burns Ranger District, moths have been trapped annually since 1981 to detect such population increases. Standard procedures of monitoring adult flight were followed each year at permanent trap sites (Daterman and others 1979). Preceding moth flight in early August, five sticky traps, baited with synthetic attractant of the female tussock moth, were hung at 1-chain intervals along a line at each site. Traps then were retrieved after flight was complete in October. Results were summarized annually by the mean number of moths caught per trap at each loca- tion. Data on moth catch used for this analysis were limited to the six trap sites on the District that fell within the 1991-95 outbreak area (fig. 1). Means of these six trap sites were used to summarize flight activity in the outbreak area each year.

Larval Sampling

From 1992 to 1995, density of early larvae (instars I, II) was estimated annually for each analysis unit. The estimates for each year were based on a sample of 22 to 64 plots systematically located over the unit. Each plot included five host trees (white fir or Douglas-fir) on which three 18-inch branch tips in the lower crown were sampled for larvae. The branch tips were beaten in place to remove larvae, which were caught on a drop cloth held underneath the branch (Paul 1979). Numbers of larvae sampled per tree were averaged for the plot and converted to a standard expression of density per square meter (1,550 square inches) in the midcrown (Mason and Paul 1994). A density of about 30 early larvae per square meter is usually the threshold at which defoliation in the crowns of trees first becomes visible (Mason and Wickman 1988). Larval density for an analysis unit was calculated as the mean of the included plot densities.

In 1995, after unexpectedly high moth counts had reoccurred in fall 1994, additional larval sampling was conducted near moth trap sites to confirm the previously established downward trend of populations. For this sample, a larger plot of 50 trees was sampled at each site to obtain a more precise estimate of larval density for the specific location (Mason and Paul 1994).

Defoliation

Visible defoliation in the outbreak was mapped in 1992-95 by annual aerial surveys conducted cooperatively by the USDA Forest Service and the Oregon Department of Forestry. Number of defoliated acres each year was obtained from the digitization of mapped defoliation polygons (McConnell 1987).

Mortality Factors

Populations were not systematically sampled to determine causes of mortality. Field observations of the condition of mature larvae and pupae, however, were made at plot locations in early fall 1993. In addition, 30 egg masses were collected over the outbreak and later bioassayed in the laboratory for disease incidence (Stelzer 1979). In midsummer 1994 and 1995, larvae also were collected at random at several sample points in each analysis unit. These larvae then were reared on artificial media in the laboratory where they were observed for the presence of disease or parasitism.

Analyses

To facilitate analyses, mean densities of larvae per square meter were multiplied by 100 to express all densities in terms of numbers per 100 square meters of branch area. A value of 1.0 also was added to all mean densities to eliminate zeros in the data set before transformation.

Population trends were examined visually by graphing mean trap data and mean larval densities over time. Differences in means between years or analysis units were compared by inspecting standard error of the mean (SEM) bars. Finite rates of change, R, in larval density were calculated annually for each analysis unit by,

$$R_t = N_{t+1}/N_t \, , \tag{1}$$

where N is mean density of larvae per 100 square meters, and $_t$ is the generation. After sample estimates of larval density for 1992 and 1993 became available, R was predicted for subsequent years by a second-order autoregressive model,

$$\ln R_t = 1.54 - 0.065 \ln N_t - 0.482 \ln N_{t-1} \pm 2.114 \, , \tag{2}$$

where lnN is the natural log of mean density of larvae per 100 square meters and 2.114 is the standard error of estimate (SEE). This model was developed previously from time series of Douglas-fir tussock moth populations in the Umatilla and Wallowa-Whitman National Forests (Mason 1996). One-year predictions of log larval density, ln N_{t+1}, then were calculated for 1994-96 by adding the estimate of ln R_t to ln N_t so that,

$$\ln N_{t+1} = \ln N_t + \ln R_t \pm 2.114 \, . \tag{3}$$

Predicted and observed trends in density were graphed and compared visually.

Means of larval density usually include a wide range of plot densities. This explains the patchy nature of defoliation in tussock moth outbreaks where visible defoliation occurs only in stands where densities exceed the threshold of 3,000 early larvae per 100 square meters. Size of the defoliated portion of the outbreak was predicted each year from the distribution of plot densities after normalization by logarithmic transformation. A standard normal deviate, Z, was calculated by

$$Z = (\ln 3000 - \bar{x})/s \, , \tag{4}$$

where X is the mean of log-transformed plot densities and s is the standard deviation. Probability of a value greater than Z, which represents the portion under a normal curve that exceeds a density of 3,000 larvae, was read from a standard statistical table (Steel and Torrie 1960). Predicted acres of defoliation were then calculated by multiplying this probability by total area of the outbreak (112,640 acres). Accuracy of the predictions was judged by comparison with mapped acres of defoliation.

Results

Trends of Larval Density

Duration and intensity of the outbreak were clearly illustrated by the synchronous behavior of larval densities in the three analysis units (fig. 2). In 1992, the first year that larvae were sampled, mean densities were similar in all units and still increasing. Populations peaked, however, in 1993 at mean densities above the defoliation threshold in each analysis unit. Mean densities then declined steadily over the next 2 years. This trend is summarized well by the finite rates of change for each analysis unit (table 1). Between 1992 and 1993, mean densities increased in all units but at a faster rate in the Rattlesnake Analysis Unit (10.81X) than in the Thompson Springs (6.64X) or Gold Hill Analysis Units (5.73X). Consequently, population mean of the Rattlesnake Analysis Unit peaked at a significantly higher density than in other analysis units. Decline of mean density was fastest in the Gold Hill Analysis Unit.

Outbreak Phases

Patterns in the overall trend of small larvae conformed reasonably well with the sequence of phases observed in classical tussock moth outbreaks (Mason and Wickman 1988, 1991) (fig. 2). Such outbreaks typically begin with at least 2 years of rapid change when the population increases quickly from a low density to a high or peak density. Although larval sampling did not begin until 1992, 1991 most likely was a year of sharp population increase or “release” and the beginning of the outbreak (phase 1) (table 1). Other phases followed in sequence, with 1994 apparently being the last year of significant activity and, consequently, the end of the outbreak (phase 4). This conclusion was supported by the low densities estimated in the final year of larval sampling in 1995.

Trap Counts and Larval Density

Pheromone traps clearly signaled a significant increase in tussock moth abundance beginning in 1990 (fig. 3). After the outbreak was underway, however, some anomalies emerged. The high trap count in fall 1990 (42.6 moths per trap) warned of a probable larger number of larvae than usual. The forecast was repeated in 1991 when counts were even higher (57.5 moths per trap). These predictions ultimately were confirmed by results of larval sampling in 1992 that showed mean densities in analysis units to be approaching outbreak numbers, with many plots already at larval densities above the defoliation threshold (fig. 2). Trap counts continued to rise in fall 1992, and larval densities multiplied an average of eight times by early summer 1993 (table 1). Surprisingly, the moth count then dropped precipitously in fall 1993 even though larval densities continued at a lower but still relatively high density in 1994 (fig. 3). More surprisingly, however, the count rebounded again in 1994, bringing into question the downward trend established by larval sampling earlier in the year. This anomaly was short-lived, however, when extensive sampling in 1995 confirmed the continuing decline (fig. 2). Additional intensive sampling of larvae at trap sites in the same year also produced nearly identical results as the extensive sample (138 vs. 111 larvae per 100 square meters, respectively) and supported the virtual population collapse.

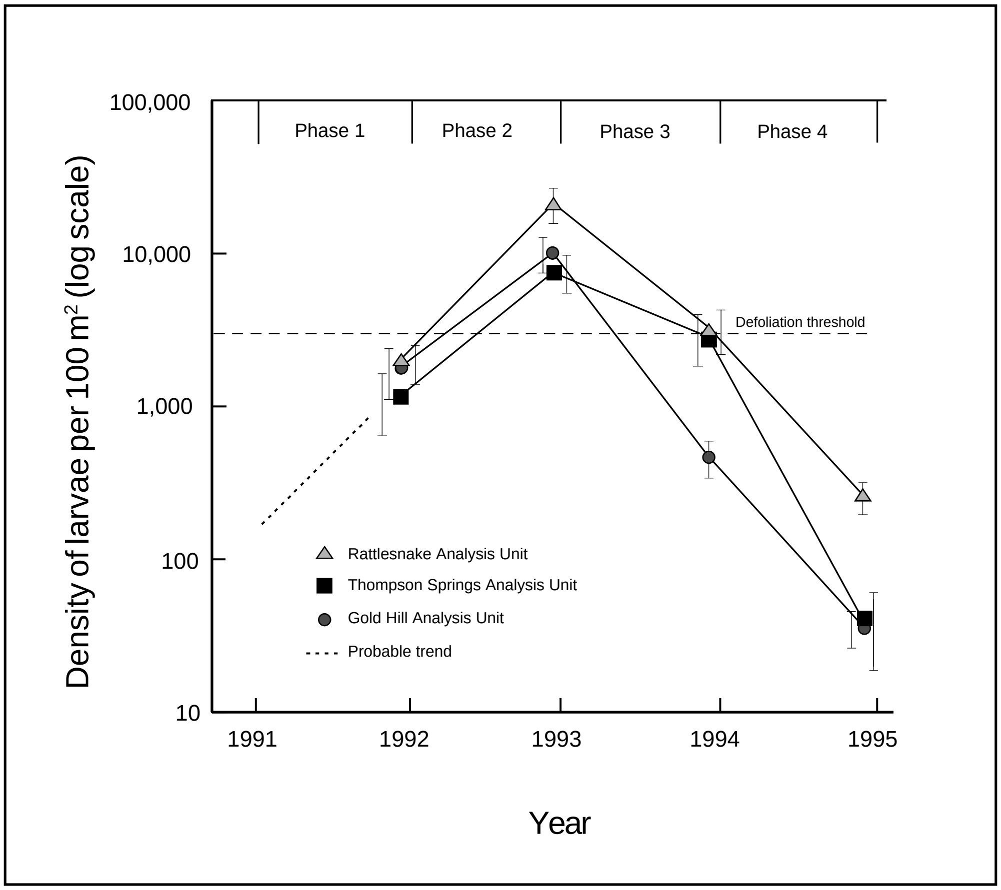

Figure 2—Trends of density (mean ± SEM) of Douglas-fir tussock moth larvae in three analysis units, Malheur National Forest, 1992-95.

Table 1—Finite rates of change (R)[a] of Douglas-fir tussock moth larvae by year, outbreak phase, and analysis unit, Malheur National Forest, 1991-95

		Analysis unit			
Year	Phase	Rattlesnake	Thompson Springs	Gold Hill	Whole outbreak
1991	1	—	—	—	—
1992	2	10.81	6.64	5.73	8.00
1993	3	.15	.38	.05	.17
1994	4	.08	.01	.08	.05
1995	4+	—	—	—	—

[a] $R_t = N_{t+1} / N_t$

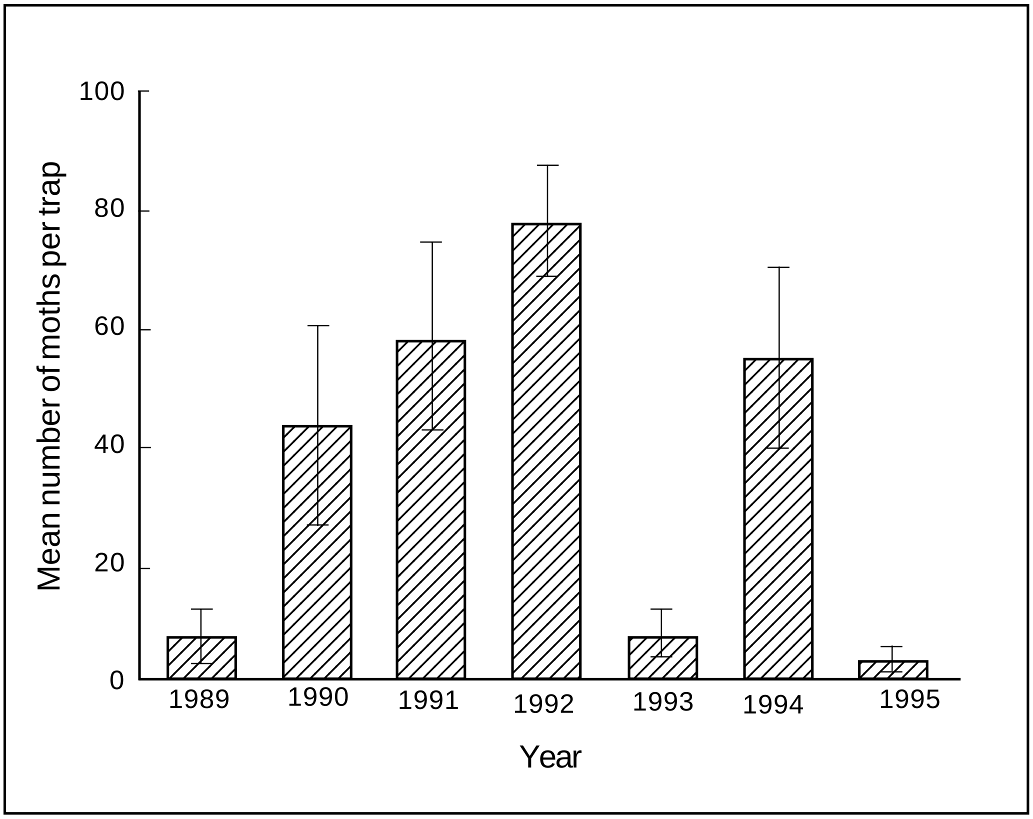

Figure 3—Number (mean ± SEM) of Douglas-fir tussock moth adult males caught in pheromone traps in outbreak area, Malheur National Forest, 1989-95.

The above results indicate that artificially baited traps may have been less efficient at high population densities because of increasing competition from natural pheromone released by female moths. Once the outbreak developed, trap counts likely dropped because of competition from natural sources of pheromone, and then increased again as the population declined and competition from natural sources eased. Pheromone traps, obviously, are most efficient at monitoring low-density populations, where they are highly effective as an early warning of initial increases in abundance.

Mortality Factors

Systematic studies of natural mortality were not conducted in the infestation. In field observations and laboratory rearings of larvae, however, the same mortality factors commonly associated with tussock moth outbreaks were identified. Nucleopolyhedrosis virus (NPV), especially, was widely observed in larvae and pupae as early as late summer 1993. Virus also was found later to be present in 43 percent of the egg masses collected at the same time. In 1994 and 1995, 37.3 and 28.8 percent, respectively, of early to mid larvae sampled in all analysis units were infected with NPV (table 2). Although these percentages indicate a significant presence of virus disease in the population, they do not necessarily reflect a between-year difference in disease incidence because of the inadequate sample and different ages of larvae collected. Parasitization of larvae was lower, but rates were typical for this stage of an outbreak (Mason 1976, Mason and Wickman 1988).

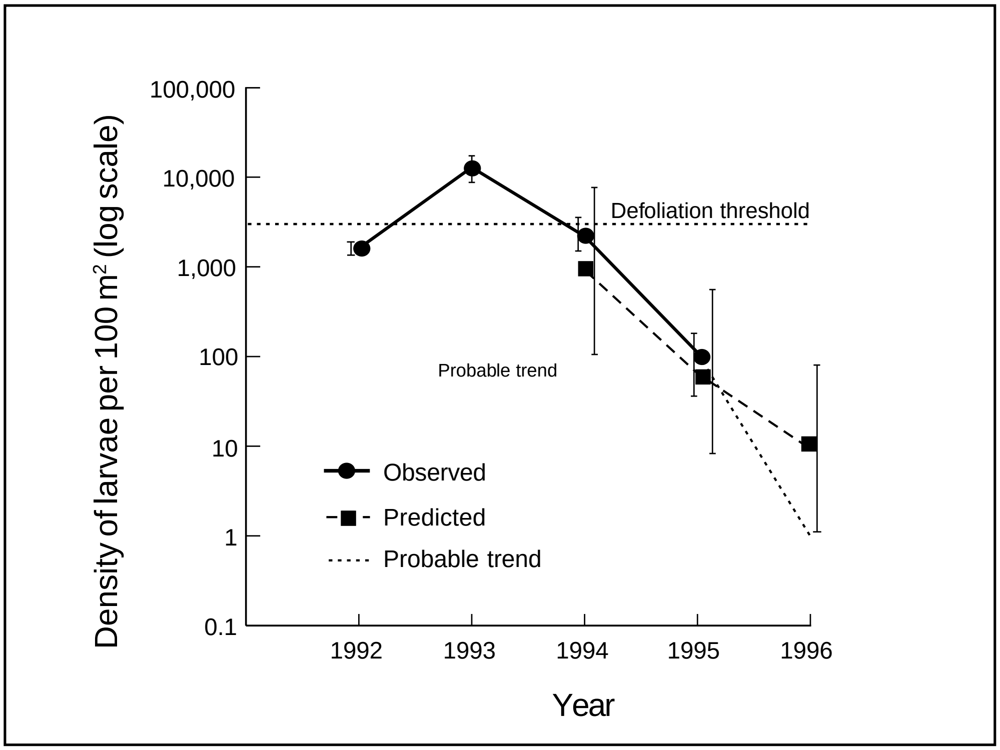

Figure 4—Observed trend of density (mean ± SEM) of Douglas-fir tussock moth larvae compared with 1-year predictions (± SEE) of autoregressive model, Malheur National Forest, 1989-95.

Table 2—Mortality in laboratory-reared field collections of Douglas-fir tussock moth larvae, Malheur National Forest, 1994 and 1995

Date of collection	No. of larvae and (instars)	Mortality factor	Number died	Percent mortality
July 11-12, 1994	59 (III, IV)	Virus disease[a]	22	37.3
		Insect parasitoids[b]	3	5.1
		Unknown	1	1.7
		Total	26	44.1
July 11-13, 1995	52 (I, II)	Virus disease	15	28.8
		Insect parasitoids[b]	10	19.2
		Unknown	11	21.2
		Total	36	69.2

[a] 43 percent of 30 egg masses collected in the previous fall (1993) also contained virus.
[b] *Phobocampe pallipes* (Provancher) (Hymenoptera: Ichneumonidae).

Predictions of Population Trend

Mean densities of larvae calculated from equation (3) produced a downward trend generally analogous to the actual trend observed in the last 3 years of the outbreak (fig. 4). Systematic sampling was not conducted in 1996, but all observations indicated that larvae were rare and probably had declined to low densities similar to those predicted. Although the error bars are large for predicted densities, there is little doubt of the overall downward trend forecast for the outbreak. Predictions based on the model for any year are strongly dependent on delayed feedback of larval densities in the previous generation so that high densities, such as those in 1993, always will foretell a decline 2 years later.

Predictions of Defoliation

Over large areas, sample plot densities of Douglas-fir tussock moth larvae usually have a log-normal distribution (Mason and Paul 1994). Transformation of arithmetic plot densities to natural logarithms, therefore, adjusted density frequencies each year toward a more normal distribution (fig. 5). The small size of plots unfortunately resulted in a large number of zero values that skewed distributions to the left, especially for years with relatively low mean densities. Data sets, however, were close enough to normality for predicted frequencies to represent observed values. Considering the many possible errors associated with sampling larvae and mapping the infestation, the number of defoliated acres predicted for each year was surprisingly similar to the number actually observed (table 3). The largest discrepancies occurred late in the outbreak (1994 and 1995) when considerably more acres were observed with defoliation than predicted. These could have been caused partially by the cumulative effects of damage in tree crowns, thereby making current defoliation viewed from the air difficult to separate from year-old defoliation. The thresholds at which defoliation becomes visible also may be lower in crowns where foliage has been depleted by previous feeding, thereby causing new defoliation to show up at lower overall larval densities. Either of these possibilities could have inflated the observed number of currently defoliated acres. Regardless of acreage discrepancies, the pattern of amount of defoliation predicted each year was similar to that observed and illustrates how total area impacted in an outbreak can be estimated from the mean and variance of larval density.

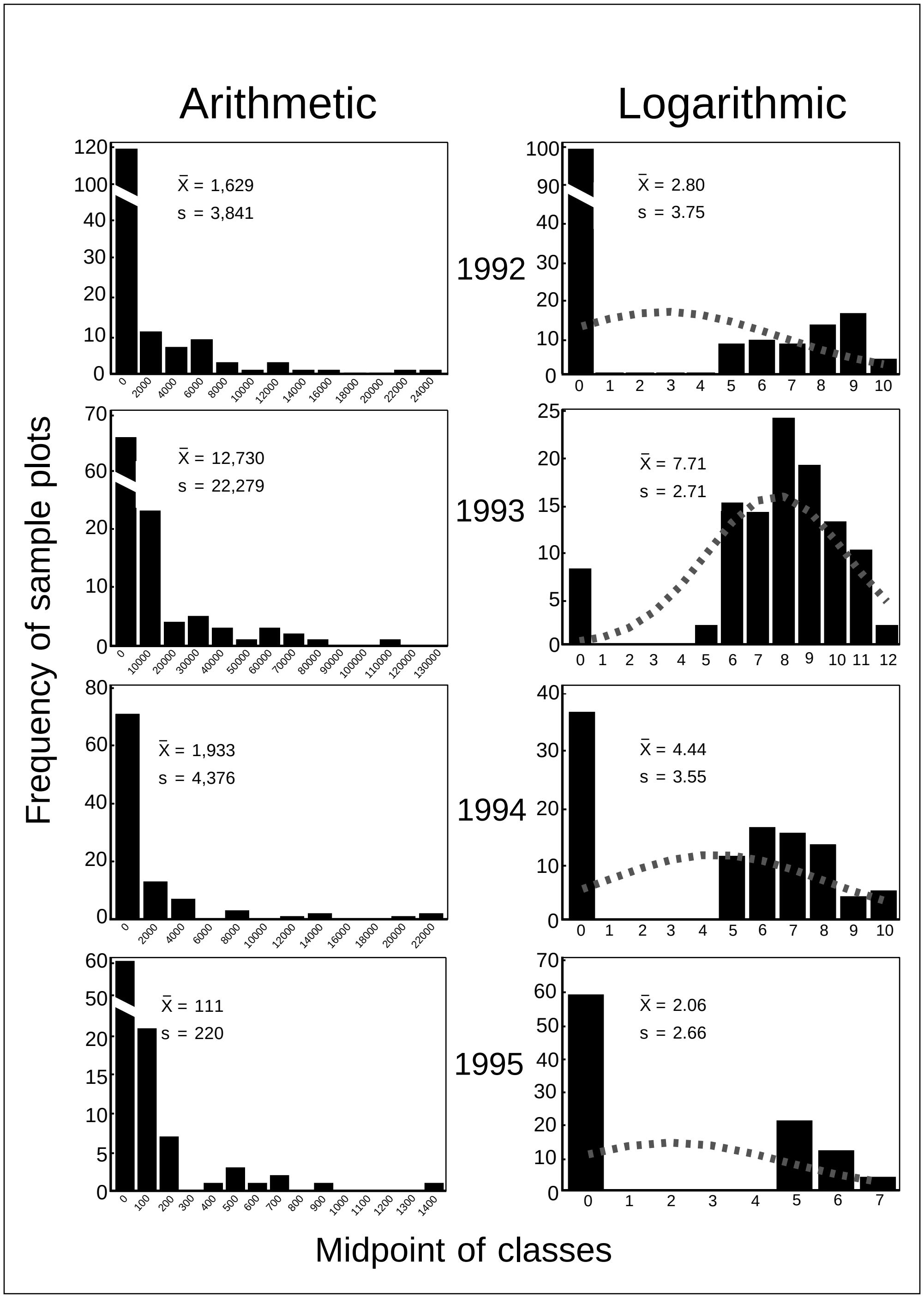

Figure 5—Frequency distributions of arithmetic and log-transformed densities of Douglas-fir tussock moth larvae in all sample plots by year, Malheur National Forest, 1992-95. Broken line in each year is the normal curve for given mean and standard deviation of transformed densities.

Table 3—Comparison of acres of current defoliation predicted by sampling Douglas-fir tussock moth larvae and observed by aerial survey, Malheur National Forest, 1992-95

Year	Acres predicted[a]	Acres observed
1992	9,315	6,004
1993	51,420	45,351
1994	17,718	26,530
1995	1,430	2,931

[a] Number of infested acres (112,640) X probability of density greater than 3,000 larvae per 100 square meters.

Discussion and Conclusions

The 1991-95 tussock moth outbreak appears to be simply another episode in what likely has been a long series of population eruptions in this part of the Malheur National Forest. It is now common knowledge that numbers of tussock moths fluctuate between low and high densities with some regularity and that population peaks occasionally reach outbreak densities in favored habitats. The extent to which densities fluctuate seems to be more limited (stable) in some environments than in others (unstable) for reasons not yet fully understood. The variability with which densities in an area have fluctuated before, therefore, is a good measure of the likelihood of an outbreak occurring in the future (Mason 1996).

Although reporting between outbreaks has been inconsistent, there are enough records of tussock moth larvae being found in the Malheur National Forest at other times in the past to indicate that populations probably are always present at lower densities. Trap records, for example, clearly showed increased tussock moth activity in the early 1980s even though no outbreaks were reported. For these reasons, as well as because of the increasing abundance of susceptible host type, much of the Forest should be regarded as a high risk for future outbreaks.

Comparing phases of the two infestations is difficult without having estimates of larval density from which population trends can be positively established. However, the fact that populations erupted in 1964 to cause extensive defoliation, after almost no defoliation was reported in 1963, clearly identifies 1963 as the year of population release in the first outbreak (Orr and others 1965, Wickman and others 1973). New versus old egg mass comparisons in fall 1964 showed that populations may have peaked that year at Gold Hill but still were increasing at King Mountain (Perkins and Dolph 1967). Virus disease also was detected in dead larvae throughout the outbreak in 1964, with rates being especially high at Gold Hill (51 percent) (Perkins and Dolph 1967). Such observations indicate that tussock moth populations in 1963 and 1991 were of a similar dynamic state, with numbers still relatively low but poised to increase dramatically by the next year (phase 1). Conditions also were comparable in 1964 and 1992 when defoliation was observed over a relatively large area for the first time in both outbreaks (phase 2). The 1965 suppression project, most likely, was conducted against a population in which densities had just peaked and, thus, were analogous to the peak densities of 1993 (phase 3). The difference was that the first outbreak was terminated in the third phase by DDT treatment, whereas the second outbreak continued on to cause more defoliation in that phase and for another year during population decline (phase 4).

It is noteworthy that virus disease was conspicuously present in phase 3 of the second outbreak but did not necessarily bring about a quick overall collapse of the population. This supports other observations where, even though virus epizootics have contributed significantly to population decline, they have not always terminated outbreaks with the speed that sometimes is expected (Mason 1981). Direct suppression of outbreaks before NPV develops naturally, as occurred in 1965, prevents production of virus in older larvae and has been suspected of reducing the accumulation of virus in forest soil where it is available for infecting future outbreak populations (Thompson and Scott 1979). On the other hand, there also is speculation that NPV has a destabilizing effect on tussock moth populations in general so that, ultimately, it may be primarily responsible for the rapid changes in density that lead to outbreaks in the first place (Berryman and others 1990). The overall influence of virus disease in tussock moth dynamics obviously is complex and remains somewhat of an enigma.

Besides documenting details of the 1991-95 tussock moth outbreak, much can be learned from the above analysis in the way of evaluation techniques. When used in low-density situations, monitoring adults with baited traps is an efficient technique for early detection of a population buildup. After an outbreak has developed, however, moth traps no longer are reliable for predicting changes in population density. High trap counts indicate only the potential for an outbreak and signal the need for more intensive evaluation (Daterman and others 1979). Followup sampling of larvae then is the most efficient method for estimating basic population parameters to establish population trend, predict larval densities, and forecast defoliation. All these procedures produce important information needed for decisionmaking in dealing with outbreaks and should be a permanent part of any tussock moth management system.

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Literature Cited

Agee, James. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p.

Berryman, A.A.; Millstein, J.A.; Mason, R.R. 1990. Modelling Douglas-fir tussock moth dynamics: the case for simple theoretical models. In: Watt, A.D.; Leather, S.R.; Hunter, M.D.; Kidd, N.A.C., eds. Population dynamics of forest insects. Andover, UK: Intercept: 369-380.

Buckhorn, W.J. 1948. Defoliator situation in the fir stands of eastern Oregon and Washington, season of 1947. Unnumbered rep. Portland, OR: U.S. Department of Agriculture, Bureau of Entomology and Plant Quarantine, Forest Insect Laboratory. 11 p.

Crouch, Glenn L.; Perkins, Randall F. 1968. Surveillance report, 1965 Burns Project, Douglas-fir tussock moth control. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 20 p.

Daterman, G.E.; Livingston, R.L.; Wenz, J.M.; Sower, L.L. 1979. How to use pheromone traps to determine outbreak potential. Agric. Handb. 546. Washington, DC: U.S. Department of Agriculture. 11 p.

Mason, R.R. 1981. Numerical analysis of the causes of population collapse in a severe outbreak of the Douglas-fir tussock moth. Annals of the Entomological Society of America. 74: 51-57.

Mason, R.R. 1996. Dynamic behavior of Douglas-fir tussock moth populations in the Pacific Northwest. Forest Science. 42: 182-191.

Mason, R.R.; Paul, H.G. 1994. Monitoring larval populations of the Douglas-fir tussock moth and western spruce budworm on permanent plots: sampling methods and statistical properties of data. Gen. Tech. Rep. PNW-GTR-333. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 23 p.

Mason, R.R.; Wickman, B.E. 1988. The Douglas-fir tussock moth in the interior Pacific Northwest. In: Berryman, Alan A., ed. Dynamics of forest insect populations, patterns, causes, implications. New York: Plenum Press: 180-209.

Mason, R.R.; Wickman, B.E. 1991. Integrated pest management of the Douglas-fir tussock moth. Forest Ecology and Management. 39: 119-130.

Mason, Richard R. 1976. Life tables for a declining population of the Douglas-fir tussock moth. Annals of the Entomological Society of America. 69: 948-958.

McConnell, Tim. 1987. Region six forest pest management annual aerial insect detection survey map processing handbook. Unnumbered rep. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Forest Pest Management. 76 p.

Orr, P.E.; Pettinger, L.F.; Dolph, R.E. 1965. Forest insect conditions in the Pacific Northwest during 1964. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 90 p.

Paul, H. Gene. 1979. How to construct larval sampling equipment. Agric. Handb. 545. Washington, DC: U.S. Department of Agriculture. 11 p.

Perkins, Randall F.; Dolph, R.E. 1967. Operational and entomological report, 1965 Burns Project, Douglas-fir tussock moth control. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 28 p.

Powell, David C. 1994. Effects of the 1980s western spruce budworm outbreak on the Malheur National Forest in northeastern Oregon. Tech. Publ. R6-FI&D-TP-12-94. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 176 p.

Sheehan, Katherine A. 1996a. Defoliation by western spruce budworm in Oregon and Washington from 1980 through 1994. Tech. Publ. R6-NR-TP-04-96. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 9 p. (plus appendix)

Sheehan, Katherine A. 1996b. Effects of insecticide treatments on subsequent defoliation by western spruce budworm in Oregon and Washington: 1982-92. Gen. Tech. Rep. PNW-GTR-367. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 54 p.

Steel, Robert G.D.; Torri, James H. 1960. Principles and procedures of statistics with special reference to the biological sciences. New York: McGraw-Hill. 481 p.

Stelzer, M.J. 1979. How to determine the occurrence of virus in egg masses. Agric. Handb. 548. Washington, DC: U.S. Department of Agriculture. 7 p.

Thompson, C.G.; Scott, D.W. 1979. Production and persistence of the nuclear polyhedrosis virus of the Douglas-fir tussock moth, *Orgyia pseudotsugata* (Lepidoptera: Lymantriidae), in the forest ecosystem. Journal of Invertebrate Pathology. 33: 57-65.

U.S. Department of Agriculture, Bureau of Entomology and Plant Quarantine. 1946. Forest insect conditions in Oregon and Washington, 1938-1942. Unnumbered rep. Portland, OR: Forest Insect Laboratory. 57 p.

Wickman, Boyd E.; Mason, Richard R.; Thompson, C.G. 1973. Major outbreaks of the Douglas-fir tussock moth in Oregon and California. Gen. Tech. Rep. PNW-5. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 18 p.

Mason, R.R.; Scott, D.W.; Loewen, M.D.; Paul, H.G. 1998. Recurrent outbreak of the Douglas-fir tussock moth in the Malheur National Forest: a case history. Gen. Tech. Rep. PNW-GTR-402. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 14 p.

Characteristics of an outbreak of the Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough)) in 1991-95 on the Burns Ranger District of the Malheur National Forest (eastern Oregon) are given and compared with an earlier infestation in the same area in 1963-65. Results of monitoring with pheromone traps, evaluating populations by sampling larvae, and predicting trends and defoliation are reported in detail for the latest outbreak. Temporal patterns of each outbreak also are described and compared with the classic behavior of other tussock moth outbreaks. Findings of this analysis, and the recurrent behavior of tussock moth outbreaks in general, reinforce the importance of maintaining a system for detection, evaluation, and prediction in managing Douglas-fir tussock moth populations in the future.

Keywords: Douglas-fir tussock moth, *Orgyia pseudotsugata*, insect outbreaks, sampling insects, pheromone traps, population monitoring.

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