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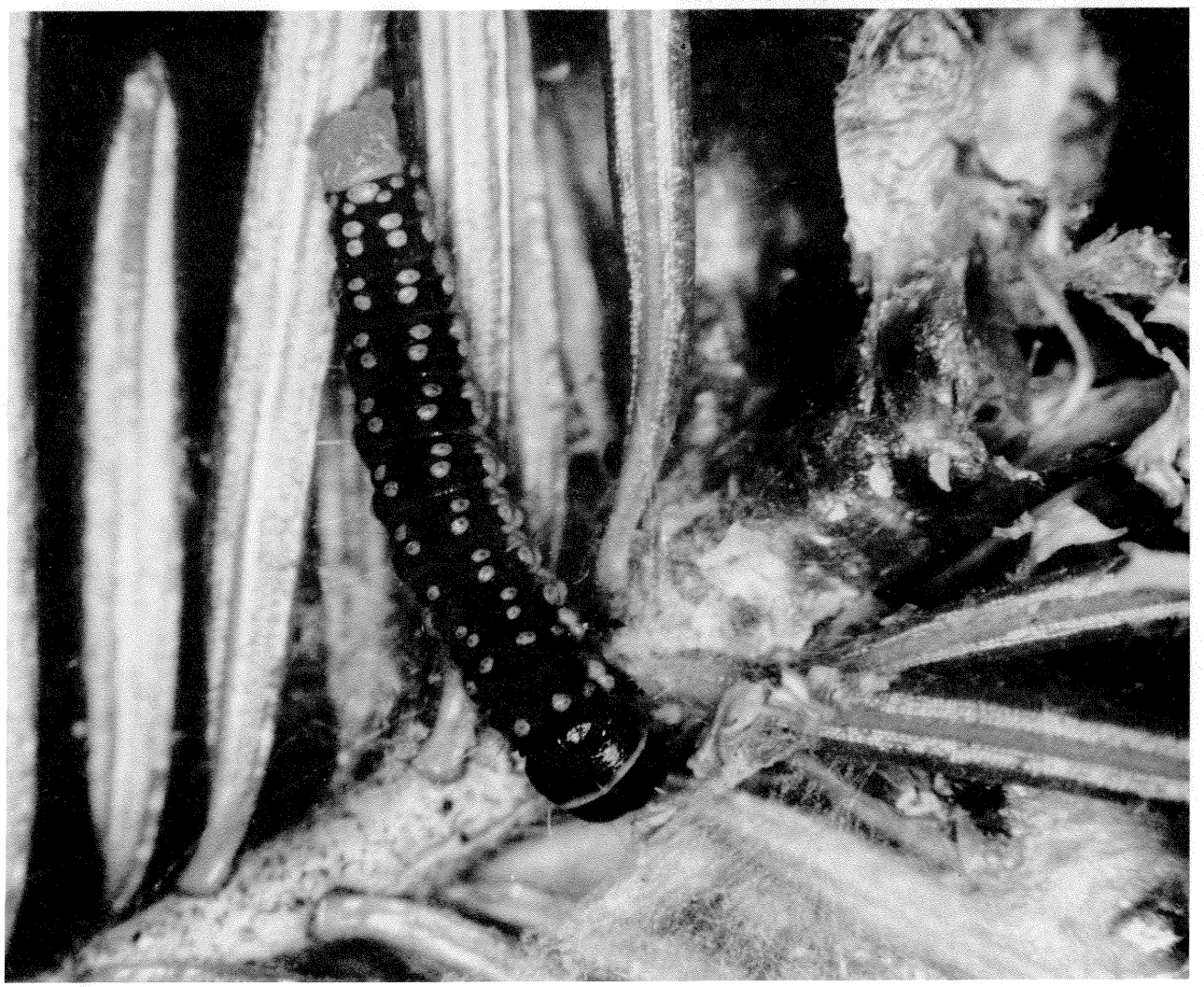
Mortality of Spruce and Fir in Maine in 1976-78 due to the Spruce Budworm Outbreak



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Abstract

The spruce budworm population in Maine's spruce-fir forests has been at epidemic levels since the early 1970's. Spruce-fir mortality in 1976-78 is compared with predictions of what mortality would have been had the natural mortality rates remained at the levels experienced before the budworm outbreak. It appears that mortality of spruce and fir has increased 2½-fold since the 1960's, that is, 60 percent of the mortality can be attributed to the budworm outbreak.

Introduction

The spruce budworm has been at epidemic levels in Maine since the early 1970's. One indication of the extent of budworm outbreak is the size of the spray program. In the 1960's, an average of 90,000 acres was sprayed annually. Between 1970 and 1974, an average of 400,000 acres was sprayed annually. In 1975, the spraying increased to 2.2 million acres. The acreage sprayed peaked at 3.5 million acres in 1976. Between 1 and 2 million acres have been sprayed annually since 1976.

This paper compares estimates of the annual mortality of spruce and fir in Maine in 1976-78 with predictions of what the mortality would have been had the mortality rates remained at levels experienced in the 1960's, a period when the budworm was at endemic levels.

At high population levels, the budworm can defoliate and kill balsam fir and spruce over large areas. In uncontrolled budworm outbreaks, mortality usually shows up 4 or 5 years after the beginning of the outbreak and is generally complete within 10 years (MacLean 1980).

Our estimates of mortality due to the budworm are for a large region which includes areas that were heavily infested and possibly sprayed. The areas of infestation were expanding for at least 5 years before the time for which the mortality is reported.

Methods

Two sources of data were used to estimate the volume of spruce and fir mortality: (1) The Spruce Budworm Growth Impact Study; and (2) The USDA Forest Service Maine Forest Survey.

The need for data to evaluate the effects of the budworm epidemic on Maine's spruce-fir resource was recognized by the State of Maine in the fall of 1974 and the Spruce Budworm Growth Impact Study was initiated. The study is based on a probability sample of 406 permanent plots. The area covered by the Growth Impact Study encompasses 7 million acres of softwood and mixedwood stands in the following counties: Aroostook, Franklin, Penobscot, Piscatiquis, Somerset, and Washington. The Growth Impact Study design and procedures are similar to those used in previous and current Maine Forest Surveys, though the sample size is smaller. Field data were collected annually starting the summer of 1975. A description of the Growth Impact Study is given by Ashley et al. (1976).

Spruce and fir mortality estimated for 1976, 1978, and 1979 were reported by Lawrence et al. (1979). The mortality estimates were fairly constant over the 3 years. The annual mortality per acre of spruce and fir was 11.4 and 27.6 cubic feet (ft^3), respectively.

We calculated annual mortality rates for spruce and fir during 1959-71 from Maine forest survey remeasured plots data. The 1971 Maine forest survey design and methods are described in Ferguson and Kingsley (1972).

Three causes of mortality were recorded in 1971 Maine survey remeasured plots: cutting (C), other removals (R), and natural (N). Table 1 gives the 12-year (1959-71) probabilities of mortality from cutting (P_C), other removals (P_R), and natural causes (P_N); and 12-year conditional probabilities of natural mortality (M). The latter is defined as the probability that a tree will die from natural causes given it is not cut or "removed." A discussion of mortality from a specific cause in the presence of multiple mortality factors is

Table 1. — Twelve-year crude probabilities of mortality from cutting, other removal, or natural causes, and 12-year net probabilities of natural mortality in spruce-fir region of Maine, 1959-71.

Diameter class (inches)	Number of sample trees		Crude probabilities						Net probability of natural mortality	
			Cut		Other removal		Natural mortality			
	Red spruce	Balsam fir	Red spruce	Balsam fir	Red spruce	Balsam fir	Red spruce	Balsam fir	Red spruce	Balsam fir
6	1,044	1,733	0.110	0.079	0.000	0.002	0.070	0.101	0.08	0.11
8	481	675	.213	.170	.000	.001	.054	.132	.07	.16
10	386	422	.241	.158	.000	.000	.056	.195	.07	.23
12	199	181[a]	.288	.205[a]	.000	.000[a]	.046	.296[a]	.06	.37[a]
14+	175	—	.436	—	.000	—	.057	—	.10	—

[a]Diameter class is 12+.

found in Kimball (1969). The relationship of M, P_C, P_R, and P_N is

$$M = P_N/(1.0 - P_C - P_R).$$

In this paper, P_C, P_R, and P_N are called crude probabilities, while M is the net probability of natural mortality or net mortality rate. The annual net mortality rate (M_1) is calculated from the 12-year rate (M_{12}) by taking the geometric mean of the survival rate. The results are

$$M_1 = 1.0 - (1.0 - M_{12})^{1/12}.$$

Stock tables for the spruce-fir inventory (Table 2) were calculated from the 1975 Growth Impact Study data by the Resources Evaluation unit of the Northeastern Forest Experiment Station. Multiplying the volume in the stock table by the annual net probabilities of natural mortality provides estimates of the volume of spruce and fir that would have died in 1976 had the mortality rates remained at prebudworm outbreak levels.

Results

The predicted annual mortality per acre is 4.49 ft^3 for spruce and 10.97 ft^3 for balsam fir (Table 2). Compared with the reported annual mortality per acre of 11.4 and 27.6 ft^3, it appears that mortality has increased since the 1960's by a factor of 2.53 for spruce and 2.52 for fir.

The mortality of spruce-fir attributed to the spruce budworm is estimated as the difference between the estimated actual volumes and predicted volumes. The mortality of spruce attributed to the budworm epidemic in 1975-78 is estimated at 6.90 ft^3 per acre per year; that is, 61 percent of the natural mortality is due to budworm. For fir, the mortality attributed to the budworm epidemic is 16.63 ft^3 per acre per year; that is, 60 percent of the natural mortality is due to budworm.

What has been the effect of the increased mortality on the spruce-fir inventory? The drain on the inventory depends on how many of the mortality trees were included in the harvest. Cutting should favor the removal of high-risk trees. Ideally, all of the trees that would die naturally should be cut. The actual situation is between these extremes. One possibility is that the trees were cut randomly from the inventory.

Possible values for the drain on inventory can be calculated from statistics in this paper. The estimated 1975 inventory of spruce-fir (Table 2) is 1,382.57 ft^3 per acre. In recent years, the annual cut from Maine's Spruce-Fir Protection District has been about 225 million ft^3, which is 32 ft^3 per acre or 2.31 percent of the 1975 stock. The annual net mortality per acre of spruce-fir in Maine was 39.0 ft^3 or 2.82 percent of the 1975 inventory according to Lawrence et al. (1969). Dividing the cut and mortality percentages by 100 gives approximate values of the probabilities of trees being cut (0.0231) and the net probability of natural mortality (0.0282).

Suppose the only trees harvested were those that would have died naturally. Since the mortality exceeds the cut, the drain on inventory would have been the net mortality, or 2.82 percent of the 1975 stock. If none of the mortality trees was

Table 2. — The 1975 spruce-fir inventory, annual net probabilities of natural mortality, and predicted annual mortality in 1975 assuming no change inmortality rates from 1959-71, spruce-fir region of Maine.

Diameter class (inches)	1975 inventory		Annual net probability of mortality		Predicted annual mortality in 1975	
	Red and white spruce	Balsam fir	Red and white spruce	Balsam fir	Red and white spruce	Balsam fir
	-------- *ft³/acre* -------				-------- *ft³/acre* --------	
6	194.79	290.19	0.0069[a]	0.0097	1.34	2.8
8	159.91	226.29	.0060	.0144	.96	3.2
10	132.65	116.41	.0060	.0215	.80	2.5
12	94.00	63.50[b]	.0051	.0378[b]	.48	2.4
14+	104.83	—	.0087	—	.91	—
Total	686.18	696.39			4.49	10.9

[a] values based on red spruce only.
[b] diameter class is 12+.

included in the harvest, the drain on inventory would have been the cut plus the net mortality, or 5.13 percent of the 1975 stock.

If every tree had the same probability of being cut, the mortality rate would be the probability of a tree not being cut times the net mortality rate, or 2.75 percent of the inventory. The drain on the inventory would be the cut plus the crude mortality, or 5.06 percent of the 1975 stock.

Changes in the other growth components must be estimated to determine the total effect of the budworm epidemic on the spruce-fir inventory. We have estimates of survivor growth before the budworm outbreak from the 1971 remeasured plot data. For balsam fir (n = 2474), we found that the annual growth was independent of the initial diameter. The annual diameter growth can be estimated from the sample mean which was $\bar{g}$ = 0.0896 inch. The sample standard deviation was 0.0609 inch.

For red spruce (n = 2099), we found that there was a statistically significant linear relationship between the annual diameter growth and the initial dbh. The annual growth of spruce can be estimated from the equation.

$$\hat{g} = 0.0688 + 0.0035 \text{ dbh}.$$

The standard error of regression was 0.0627 inch. The sample R^2 was only 0.024, which suggests that the annual diameter growth of red spruce be estimated by the average, which was $\bar{g}$ = 0.0967 inch. The sample standard deviation was s = 0.0635 inch.

Fourth-year Results

Since the completion of this study, Lawrence and Houseweart (1981) have reported the results from the fourth year of the Maine Spruce Budworm Growth Impact Study. The average annual diameter growth for 1975-79 was 0.059 inch for red spruce and 0.053 inch for balsam fir. These averages can be compared to the average growth rates in 1960-70. It appears that there has been a growth loss (in dbh) of 39.0 percent for spruce and 40.8 percent for fir.

In 1979, the mortality of fir increased to 34.96 ft^3/acre. Spruce mortality was 10.94 ft^3/acre, which is about the same as the average annual mortality in the 3 previous years.

Discussion

Estimating the amount of mortality attributed to the budworm as the difference between predicted values based on past data and current values is comparable to the procedure used by Baltzer (1973) to estimate net mortality in balsam fir due to budworm defoliation. He estimated the mortality as the difference in mortality between sprayed and unsprayed plots. We used statistical controls rather than experimental controls to estimate the mortality due to budworm.

Lawrence et al. (1979) also presented data on the percentage mortality by causal agent. They estimated that the average mortality due to budworm was 5.3 percent for spruce and 23.9 percent for fir. Our estimates of the mortality due to budworm are higher than the values reported from the Budworm Impact Study. The major source of mortality reported by Lawrence et al. (1979) was blowdown. But some of the blowdown may be "due to budworm." How much of blowdown is due to budworm and how much is natural blowdown cannot be determined.

We feel that with the current state of knowledge it is not feasible to assign a cause of mortality to dead trees. One approach to estimating mortality due to an insect outbreak is to use past data. Forest Survey is one source of such data.

Our estimates of the volume of mortality due to the current budworm outbreak are based on mortality in the presence of a large-scale spray program. How long the budworm epidemic will last and what the total mortality will be are major unknowns which bar a determination of the long-term effect of budworm on the spruce-fir inventory.

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