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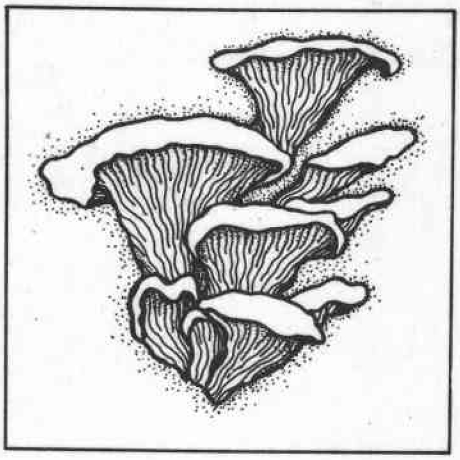
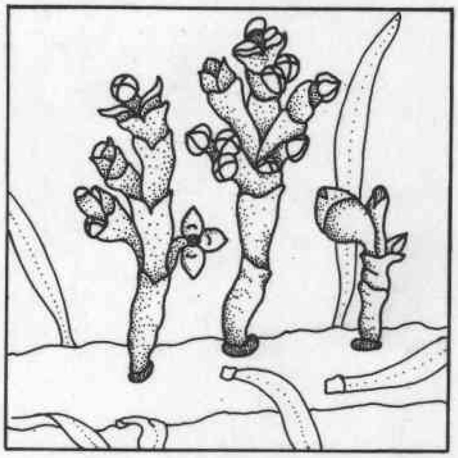
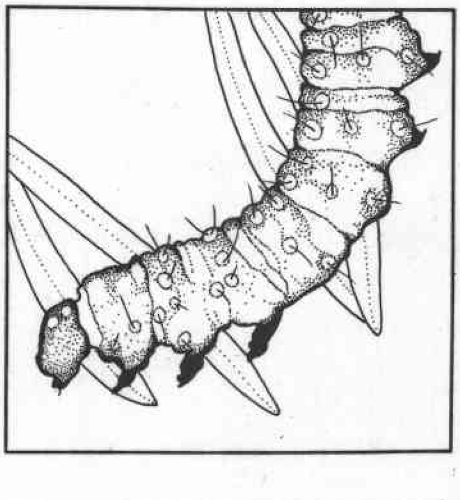
WESTERN SPRUCE BUDWORM DEFOLIATION TREND RELATIVE TO WEATHER

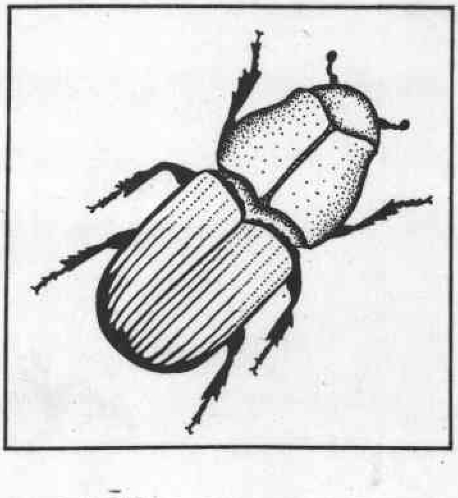
in the Northern Region, 1969-1979

by J. Hard, S. Tunnock and R. Eder









WESTERN SPRUCE BUDWORM DEFOLIATION TREND RELATIVE TO WEATHER IN THE NORTHERN REGION 1969-1979

By

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and Robert Eder, Statistical Assistant

ABSTRACT

Western spruce budworm defoliated area in the Northern Region has differed significantly across three discrete geographic zones during the past decade. Aerially visible defoliation in northern Idaho increased from 1.7 million acres in 1969 to a high of 2.2 million acres in 1974, and declined to none in 1979. Defoliated area in western Montana increased from 1.8 million acres in 1969 to a high of 2.8 million acres in 1972 and declined to 0.6 million acres in 1979. Conversely, defoliated area in eastern Montana fluctuated at low levels between 0.1 and 0.7 million acres between 1969 and 1974, and then rose to a high of 1.6 million acres in 1979. Analysis of defoliation trend, the ratio of acres defoliated in the current year by acres defoliated the prior year, and weather during budworm larval and pupal periods during the past decade revealed the following relationships: Defoliation trend in all three geographic areas varied (a) directly with mean maximum temperature during May, June, and July of the year before, and (b) inversely with frequency of measurable precipitation during May, June, and July of the year before. Based on warm, dry conditions throughout the Region in 1979, we predict a general increase in budworm populations in the Northern Region in 1980.

INTRODUCTION

The western spruce budworm [1] has often defoliated millions of acres of coniferous forest in Idaho and Montana during the past several decades, but outbreak centers have been displaced geographically across three discrete geographic zones (Johnson and Denton 1975). The zones are separated by major mountain ranges (figure 1), and average elevation increases from west to east with abrupt changes occurring along the Bitterroot and Continental Divides. Climates are dissimilar, and budworm outbreak history differs on opposing sides of these major divides.

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[1] *Choristoneura occidentalis* Freeman.

Northern Idaho is the warmest and wettest zone, and is largely influenced by moist air masses from the Pacific Northwest resulting in a milder climate than latitude and altitude indicate (USDA 1941). Acres of budworm defoliation increased gradually from 1969, peaked at 2.2 million acres in 1974, and declined sharply to no acres in 1979 except for a few small areas in the Idaho portion of the Bitterroot National Forest (table 1, figure 2).

Western Montana is characterized by a transition climate cooler and drier than northern Idaho. It is influenced considerably by moist air masses from the West and less so by drier air masses from east of the Continental Divide (USDA 1941). From 1969, budworm defoliation increased to 2.9 million acres in 1972, declined gradually until 1977, and then sharply to about 600,000 acres in 1979 (table 1, figure 2).

Eastern Montana is coolest and driest of the three zones and is strongly influenced by continental air masses from Canada and the Arctic (USDA 1941). Acres of budworm defoliation remained relatively low there between 1969 and 1974, but have increased to about 1.6 million acres in 1979 (table 1, figure 2).

Weather, in addition to biotic factors such as host defoliation, parasites, predators, and disease, is suspected of causing change in western budworm numbers and acres of visible defoliation. Wellington (1952), Greenbank (1956, 1963), and Ives (1974) discuss the relationship between dry, sunny weather and eastern spruce budworm 2/ population increases. Miller (1972) showed that outbreak areas extended during successive warm, dry summers, and the most recent outbreak in Newfoundland peaked during a period of consecutive warm, dry summers (Otvos and Moody 1978). Since the eastern and western budworms are closely related and have very similar life histories, weather probably influences the two species similarly, although the western budworm occupies a more arid region.

Because of differing budworm outbreak histories and dissimilar climates among the three geographic zones, we compared budworm defoliation trends with weather by geographic zone. This type of analysis could be used by researchers to develop a predictive tool for western spruce budworm defoliation trends in western Regions based on weather, and to promote identification of additional weather variables that may improve predictions. Use of appropriate weather variables to delineate discrete climatic provinces within geographic zones could help explain observed differences between the occurrence of budworm outbreaks and the range of budworm host type (figure 3). Such knowledge could improve the precision of budworm prognosis models, and would be useful to land managers in selecting alternatives for budworm management in specific areas.

2/ *C. fumiferana* Clemens.

METHODS

Acres of budworm defoliation in the Northern Region before 1975 were measured on aerial survey detection maps using an inaccurate dot-grid system. In addition, the Helena and Deerlodge reporting areas straddle the Continental Divide which separates western and eastern Montana, so budworm-defoliated areas in each geographic zone were remeasured using an electronic planimeter.

Area figures used in our analysis are not confused by the effects of large-scale operational control programs against the budworm because none have been conducted in the Northern Region since the mid-1960's. Despite some inaccuracies and omissions in acres of budworm defoliation (see footnotes, table 1), areas reported here are the most accurate available and supersede areas listed differently in earlier reports.

We believe that the acreage data are adequate to reveal existence of broad, true relationships although trees must be about 25 percent defoliated before they are visible from the air. Defoliation intensity was not considered in our analysis because degree of defoliation was often not recorded on aerial detection maps.

We selected seven permanent weather stations distributed among forested areas to represent each geographic zone (table 2, figure 1). Weather reported at these stations does not reflect precise weather in nearby budworm-infested forests because temperature usually decreases and humidity increases as elevation increases (Cramer 1961). However, relative changes in major weather patterns at the weather stations parallel changes in nearby forests.

We chose indices of relative humidity as the weather variables for analysis because saturated air in eastern budworm larval shelters inhibits or halts feeding which results in slowed larval development and reduced adult fecundity (Greenbank 1963). Large larval survival is low during seasons with infrequent warm, dry days (Miller 1972), and wet weather is directly related to larval fungus infection (Otvos and Moody 1978).

Since weather stations do not report relative humidity, we chose mean maximum temperature and mean frequency of measurable precipitation for the months of May, June, and July as indices of relative humidity during the budworm larval and pupal periods for our analysis. Precipitation frequency was chosen instead of amount because infrequent heavy rain may often result in shorter periods of air saturation than frequent occurrences of light rain. Mean frequency of precipitation was determined by counting the number of days that measurable precipitation was recorded in May, June, and July at all selected weather stations in a geographic zone and dividing the sum by the number of selected weather stations.

Defoliation trend was computed for each geographic zone and year by dividing acres defoliated in the current year by acres defoliated the year before. We constructed a Chi-square contingency table to test whether direction of defoliation trend in the current year was contingent on weather during the larval and pupal periods of the year before.

Scatter diagrams of defoliation trend over each weather variable were constructed by geographic zone and we computed simple and multiple linear regressions of numerical defoliation trend over mean maximum temperature and mean frequency of measurable precipitation during the larval and pupal periods the year before for each geographic zone. We also computed regressions of defoliation trend over deviations from (a) average maximum temperature, and (b) average frequency of precipitation for all three zones combined in order to determine equilibrium values for the two weather variables.

Technically, the Model I regression computations used here are inappropriate because the independent variables were not measured without error; consequently, the regression coefficients are likely to be biased slightly toward zero (Sokal and Rohlf 1969, Daniel and Wood 1971). Therefore, Bartlett's 3-group Model II regression technique (Sokal and Rohlf 1969) was applied to regressions where all three zones were combined to show equilibrium weather values.

RESULTS

Graphed weather trends of the three geographic zones appear quite similar (figures 4 and 5). However, comparison of annual weather deviations from the 1969-78 10-year averages shows that northern Idaho became substantially colder and wetter than average during the latter half of the decade, and western Montana followed a similar trend but with less deviation from its 1969-78 average. Eastern Montana was the coolest and wettest geographic zone during the first half decade, and warmest and driest during the second half decade when compared with 10-year zone averages.

A Chi-square test to determine whether direction of defoliation trend is contingent on type of weather the year before was highly significant (Chi-square sum = 13.77, table 4). Probability of such a high value occurring due to chance alone is less than 5 times in 1,000, which supports the hypothesis that direction of defoliation trend is contingent on type of weather the year before during the larval and pupal periods.

Correlation matrices (table 5) of dependent (Y) and independent (X_1 and X_2) variables used in the multiple linear regression analysis showed the following relationships: defoliation trend was directly related to maximum temperature and was inversely related to frequency of rain in all three geographic zones, but was consistently better correlated with frequency of rain. Maximum temperature was inversely related to frequency of rain in all three geographic zones but least so in western Montana. Defoliation trends based on questionable acreage figures (footnotes, tables 1 and 3) were not used in the correlation and regression analyses.

An unexpectedly low defoliation trend occurred in western Montana in 1974 and was not used in regression computations for that zone, but was used in computations when zones were combined. Only the Flathead, Lolo, and Bitterroot areas within the entire Region experienced a budworm decline in 1974 despite an unusually warm, dry season in 1973. Weather records revealed no instances of prolonged, extremely hot weather in the summer of 1973 that could have adversely affected budworm fecundity (Sanders 1967), or hard frosts in May or June of 1974 that could have killed new foliage or young budworm larvae (Fellin and Schmidt 1972). However, Watt (1963) showed a parabolic relationship between eastern budworm larval survival and temperature-humidity index, and very high indices were associated with reduced larval survival. This may partially explain the situation in western Montana in 1974.

Multiple correlations between defoliation trend and the two weather variables were numerically higher than single correlations between defoliation trend and either weather variable except in eastern Montana (table 5). There, the multiple correlation was numerically equivalent to the single correlation between defoliation trend and precipitation.

Analyses of variance of multiple linear regressions for the three geographic zones yielded nonsignificant F-ratios at the 5 percent level of probability, but the F-ratio for regression was significant at the 6.4 percent level for northern Idaho, was significant at the 13.5 percent level for western Montana, and was significant at the 8.5 percent level for eastern Montana (table 6). Regardless, the multiple linear regressions show that by linear analysis weather variables combined accounted for 55 to 67 percent (R^2's) of the variation in defoliation trend from 1970 to 1979 (table 5).

The regressions of defoliation trend on deviations from (a) average maximum temperature and (b) average frequency of precipitation for all three zones combined were significant (figures 8 and 9), but even more important were the equilibrium values $\overline{E}_t$ and $\overline{E}_p$. These are the computed values where defoliation trend is equal to 1, and there is no change in defoliated acres from the previous year. In the Northern Region $\overline{E}_t$ equals -0.1°F, and closely approximates the 10-year average maximum zone temperatures (figure 8). $\overline{E}_p$, the equilibrium precipitation frequency deviation, equals +0.8 day and closely approximates the 10-year average zone frequencies of precipitation (figure 9).

DISCUSSION

Curves shown in figures 6 and 7 are "least squares" fits computed by a "Select Best Fit" simple regression program. They should not be misconstrued to represent all outbreaks in each geographic zone because they could be inappropriate depending on whether epidemic populations are increasing or collapsing.

Our purpose was to portray differences in the relationships between weather and rising or falling budworm populations. The relationship between defoliation trend and either weather variable follows less steep curves for northern Idaho and western Montana than similar plotted curves for eastern Montana.

If weather influences the western budworm directly, as we hypothesize here, differences in the apparent slopes of relationships in figures 6 and 7 may be explained as follows: rising budworm populations in eastern Montana in the late 1970's had much healthy, nondefoliated host type to expand into. Fecundity was probably high, and starvation, parasitization, predation, and disease were probably low. Conversely, populations in northern Idaho and western Montana that peaked in the early and mid-1970's had relatively less area of undefoliated host type for expansion, average fecundity was probably lower, and was probably accompanied by higher incidence of parasitization, predation, and disease.

Ability of a vigorous budworm outbreak population to respond to favorable weather is probably greater than for a low vigor population, whereas response of a heavily parasitized or diseased population to adverse weather is probably greater than for a vigorous population. We don't have the data to test these assumptions for the budworm in the Northern Region, but believe that they are true based on our understanding of the variable influences of natural controls on pest populations.

We suspect that an indepth computer analysis of weather records (Nicholson and Bryant 1972, Powell and MacIver 1977) and budworm history in the western United States could reveal substantially more than we have shown. Perhaps much weather analysis relevant to the relationship between western budworm and weather has already been done by forest fire meteorologists. Preparation of forest fire risk rating maps requires knowledge of specific weather variables that indicate fuel moisture levels. Fuel moisture levels are influenced by mean relative humidities within timber stands (Cramer 1961).

PREDICTION FOR 1980

We predict a general increase in budworm populations in 1980 because weather during May, June, and July of 1979 was warmer and drier than average in all three geographic zones. Deviations from average maximum temperatures were +0.9°, +2.1°, and +1.5°F respectively for northern Idaho, western Montana, and eastern Montana, whereas deviations from average precipitation frequencies were -7.2, -9.0, and -8.7 days respectively. Unforeseen circumstances such as a late hard frost in the spring of 1980 could minimize such an increase, however. In addition, defoliation is not visible by aerial observers until about 25 percent of new needles are destroyed so visible response to 1979 weather could be delayed.

CONCLUSIONS

Records of the 1970's in the Northern Region show that western budworm defoliation trend varies with (a) mean maximum temperature for May, June, and July of the previous year, and (b) mean frequency of measurable precipitation during the same period in all three geographic zones. These two weather variables are indices of relative humidity which probably influence change in defoliation trend if weather truly regulates western budworm as it does eastern budworm. Either weather variable may suffice to predict direction of defoliation trend in the following year, but we believe that frequency of precipitation is the better predictor because correlation coefficients between defoliation trend and precipitation frequency are consistently greater (table 5). In addition, equilibrium weather values, $\overline{E}_t$ and $\overline{E}_p$, closely approximate average weather values for the three geographic zones.

We suspect that a large-scale computer analysis of weather records and budworm history within each Forest Service Region could refine the relationship shown here. We believe that such analyses should be done to improve predictions of the courses of budworm outbreaks, and to help explain why budworm outbreak populations have not utilized more budworm host type in the West. Such knowledge could perhaps be incorporated in future budworm prognosis models and stand risk rating systems so land managers responsible for managing budworm host type could make better decisions in dealing with budworm outbreaks on discrete land management units.

RECOMMENDATIONS

We believe that the following direction, if taken, could improve our understanding of why budworm outbreaks occur when and where they do, and could ultimately provide guidance for land managers to act effectively in minimizing adverse effects of budworm outbreaks.

1. Conduct a broad-scale computer analysis of the relationship between budworm outbreaks and weather in the western U.S.

2. Identify specific weather variables that are significantly correlated with budworm defoliation trends within discrete geographic zones. Relative importance of weather variables may change across the spectrum of latitude and longitude in the western U.S.!

3. Use the important variables to construct climatic zones within the range of budworm host type using principal components or factor analysis.

4. Construct a map of high and low hazard budworm outbreak areas in the West based on budworm outbreak history and climate defined by important weather variables.

5. Use the important weather variables isolated by computer analysis to predict directions of current outbreaks in discrete geographic zones.

6. Attempt to refine the relationship using defoliation intensity as well as defoliated area and weather.

7. Develop predictive methods for budworm defoliation trends on management units as small as National Forests if enough recording weather stations as well as seasonal fire weather recording stations are available.

8. Analyze the relationship between weather and budworm egg mass survey data collected in western Regions in the mid-1970's to determine whether egg mass surveys could be reduced in scope and intensity and partially replaced by weather summaries for predicting budworm trends.

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Table 1.--M acres 1/ of aerially visible western spruce budworm defoliation by reporting area 2/ and year

N. IDAHO	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
PANHANDLE	18.1	37.8	44.1	75.2	154.3	202.5	189.6	190.6	176.4	7.4	0.0
CLEARWATER	327.9	378.5	440.3	495.4	476.8	596.4	634.8	358.1	286.4	8.1	0.0
NEZPERCE	1,370.6	1,330.9	1,415.2	1,403.7	1,015.4	1,359.9	7.0 3/	107.1	184.3	4.6	0.0
SUBTOTAL	1,716.6	1,747.2	1,899.6	1,974.3	1,646.5	2,158.8	831.4	655.8	647.1	20.1	0.0
W. MONTANA											
KOOTENAI	-- 4/	--	--	--	--	--	3.6	9.7	20.0	14.6	1.4
FLATHEAD	131.2 5/	212.0	399.7	515.0	283.2	154.3	216.9	168.0	183.9	65.7	5.3
LOLO	1,051.7	1,353.6	1,394.1	1,574.5	1,063.7	1,024.6	1,000.6	820.3	947.9	281.2	335.3
BITTERROOT	439.1	409.1	126.2	346.1	352.6	240.6	402.5	413.6	451.5	379.1	95.3
DEERLODGE 6/	33.4	102.4 7/	165.8	257.5	34.7	102.4	120.1	29.5	24.1	125.2	115.1
HELENA 6/	133.6	0.0	137.1	177.0	8.8	64.3	74.0	25.1	14.1	31.4	76.4
SUBTOTAL	1,789.0	2,077.1	2,222.9	2,870.1	1,743.0	1,586.2	1,817.7	1,466.2	1,641.5	897.2	628.8
E. MONTANA											
DEERLODGE	75.7	102.4	144.8	226.2	51.8	170.8	151.6	194.1	159.1	257.6	287.5
HELENA	254.5	11.0	280.6	411.7	49.0	201.0	400.0	288.1	448.9	543.8	386.8
LEWIS & CLARK	53.5	--	--	--	0.4	18.4	7.4	5.9	116.5	176.3	211.5
BEAVERHEAD	22.5	-- 8/	6.7	21.1	22.5	38.8	241.0	250.4	173.3	223.7	349.9
GALLATIN	69.3	--	13.9	31.9	22.3	53.7	337.9	286.3	428.0	293.3	325.9
CUSTER	1.4	--	--	2.9	--	--	--	5.2	7.4	3.6	5.4
YELLOWSTONE	26.7	1.9	52.5	48.4	19.2	39.4	112.0	114.6	79.3	104.7	75.5
SUBTOTAL	503.6	115.3	498.5	742.2	165.2	522.1	1,249.9	1,144.6	1,412.5	1,603.0	1,642.5
REGIONAL TOTAL	4,009.2	3,939.6	4,621.0	5,586.6	3,554.7	4,267.1	3,899.0	3,266.6	3,701.1	2,520.3	2,271.3

1/ Acres shown here may differ from acres reported earlier. Acres reported here are based on new planimetric area measurements and are the most accurate estimates available.

2/ Reporting area includes private, State, and Federal ownership other than National Forest. For example, the Flathead reporting area includes the Flathead Indian Reservation.

3/ Only a small area of the Nezperce was flown in 1975, but we know that area of defoliation was much greater.

4/ A dash indicates that the area was not necessarily flown, but ground observations indicated little or no noticeable defoliation occurred.

5/ Defoliation on the Indian reservation was not included in 1969.

6/ Both the Deerlodge and Helena reporting areas straddle the Continental Divide.

7/ The 1970 aerial detection map of the Deerlodge was missing, so we divided the reported area equally for tern and eastern Montana.

8/ Map missing.

Table 2.--Weather stations used in the analysis

NORTHERN IDAHO

NAME	INDEX NO.	ELEVATION
DIXIE	2,575	5,610
FENN RANGER STA.	3,143	1,585
GRANGEVILLE	3,771	3,355
KELLOGG	4,831	2,320
OROFINO	6,681	1,027
RIGGINS	7,706	1,800
SAINT MARIES	8,062	2,220
		MEAN = 2,560

WESTERN MONTANA

NAME	INDEX NO.	ELEVATION
HAMILTON	3,885	3,529
KALISPELL	4,563	2,971
LINCOLN RANGER STA.	5,040	4,540
MISSOULA WSO AP	5,745	3,190
PHILIPSBURG RANGER STA.	6,472	5,270
SEELEY LK. RANGER STA.	7,448	4,100
THOMPSON FALLS PH	8,211	2,380
		MEAN = 3,711

EASTERN MONTANA

NAME	INDEX NO.	ELEVATION
BOULDER ST. SCHOOL	1,008	4,904
BOZEMAN MT. ST. UNIV.	1,044	4,856
DILLON WMCE	2,409	5,228
ENNIS	2,793	4,953
LIVINGSTON	5,076	4,485
TOWNSEND	8,324	3,833
WHITE SULPHUR SP.	8,927	5,160
		MEAN = 4,774

Table 3.--Mean weather variables and defoliation trends by geographic zone and year

Year	Max. temp. (°F.)	Days precip.	Weather type[1]		Defoliation trend[2]	
					Direction	Numerical
	(May, June, and July)			NORTHERN IDAHO		
1969	78.3	20.5	Warm, dry	1969-70	+	1.018
1970	78.7	26.7	Warm, dry	1970-71	+	1.087
1971	75.8	27.3	Cold, dry	1971-72	+	1.039
1972	77.1	28.1	Warm, wet	1972-73	-	.834
1973	79.4	14.5	Warm, dry	1973-74	+	1.311
1974	77.1	23.8	Warm, dry	1974-75	-	.385[3]
1975	74.0	33.2	Cold, wet	1975-76	-	.789[3]
1976	75.4	30.9	Cold, wet	1976-77	-	.987
1977	75.4	36.4	Cold, wet	1977-78	-	.031
1978	73.9	33.6	Cold, wet	1978-79	-	.000
	Mean=76.51	Mean=27.50				
				WESTERN MONTANA		
1969	74.6	21.8	Warm, dry	1969-70	+	1.161[3]
[illegible]0	75.8	31.5	Warm, wet	1970-71	+	1.070
1971	73.8	27.3	Cold, dry	1971-72	+	1.291
1972	73.5	29.0	Cold, wet	1972-73	-	.607
1973	76.2	16.9	Warm, dry	1973-74	-	.910[4]
1974	74.7	26.1	Warm, dry	1974-75	+	1.146
1975	71.8	31.3	Cold, wet	1975-76	-	.807
1976	74.1	29.4	Warm, wet	1976-77	+	1.120
1977	73.7	34.2	Cold, wet	1977-78	-	.547
1978	71.9	33.6	Cold, wet	1978-79	-	.701
	Mean=74.01	Mean=28.11				
				EASTERN MONTANA		
1969	73.3	29.7	Cold, wet	1969-70	-	0.229[3]
1970	74.9	35.1	Warm, wet	1970-71	+	4.324[3]
1971	73.3	22.7	Cold, dry	1971-72	+	1.489
1972	73.2	30.3	Cold, wet	1972-73	-	.223
1973	75.0	17.7	Warm, dry	1973-74	+	3.160
1974	75.8	21.3	Warm, dry	1974-75	+	2.394
1975	70.8	35.7	Cold, wet	1975-76	-	.916
1976	74.9	25.7	Warm, dry	1976-77	+	1.234
1977	73.7	33.2	Cold, wet	1977-78	+	1.135
1978	72.1	36.2	Cold, wet	1978-79	+	1.025
	Mean=73.71	Mean=28.76				

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[1] Warm, dry weather type is weather warmer and drier than the 10-year mean, etc.

[2] Defoliation trend is computed by dividing acres defoliated in the current year by acres defoliated the year before.

[3] Numerical values of defoliation trend are questionable because of incomplete aerial surveys, etc. Inaccurate area of defoliation in a single year affects two consecutive defoliation trends.

[4] The reduced trend is an unexplained anomaly.

Table 4.--Chi-square test of relationship between western spruce budworm defoliation trend in all three zones and type of weather the year before

NULL HYPOTHESIS: THERE IS NO RELATIONSHIP BETWEEN DEFOLIATION TREND AND TYPE OF WEATHER THE YEAR BEFORE

ALTERNATE HYPOTHESIS: DEFOLIATION TREND IS CONTINGENT ON TYPE OF WEATHER THE YEAR BEFORE

CONTINGENCY TABLE

Weather type 1/	Increased trend		Decreased trend	
	N	Chi-square	N	Chi-square
Warm and dry	8	1.34	2	1.53
Warm and wet	3	.36	1	.40
Cold and dry	3	1.23	0	1.40
Cold and wet	2	3.51	11	4.00

Sum Chi-square = 13.77, d.f. = 3, P <0.005

CONCLUSION: REJECT NULL HYPOTHESIS AND ACCEPT ALTERNATE HYPOTHESIS

1/ Descriptive weather types are relative to 10-year averages 1969-78, of mean maximum temperature and mean frequency of precipitation by geographic zone.

Table 5.--Correlation matrices of multiple linear regression analyses by geographic area, 1969-1979

I. NORTHERN IDAHO (excluding 1974-75 and 1975-76)

	Defol. trend (Y)	Max. temp. (X_1)	Days precip. (X_2)
Defol. Trend (Y)	1.0000	0.7631	-0.8007
Max. Temp. (X_1)		1.0000	-0.8472
Days Precip. (X_2)			1.0000

Multiple - R = 0.8164 $R^2 = 0.67$

II. WESTERN MONTANA (excluding 1969-70 and 1973-74)

	Defol. trend (Y)	Max. temp. (X_1)	Days precip. (X_2)
Defol. Trend (Y)	1.0000	0.5033	-0.6932
Max. Temp. (X_1)		1.0000	-0.3701
Days Precip. (X_2)			1.0000

Multiple - R = 0.7423 $R^2 = 0.55$

III. EASTERN MONTANA (excluding 1969-70 and 1970-71)

	Defol. trend (Y)	Max. temp. (X_1)	Days precip. (X_2)
Defol. Trend (Y)	1.0000	0.6384	-0.7915
Max. Temp. (X_1)		1.0000	-0.8063
Days Precip. (X_2)			1.0000

Multiple - R = 0.7915 $R^2 = 0.63$

Table 6.--Analysis of variance tables of multiple linear regression analyses by geographic area

I. NORTHERN IDAHO

	Sum of squares	Degrees of freedom	Mean square	F ratio	P
Regression	1.146	2	0.573	4.996	0.064
Residual	.573	5	.115		

II. WESTERN MONTANA

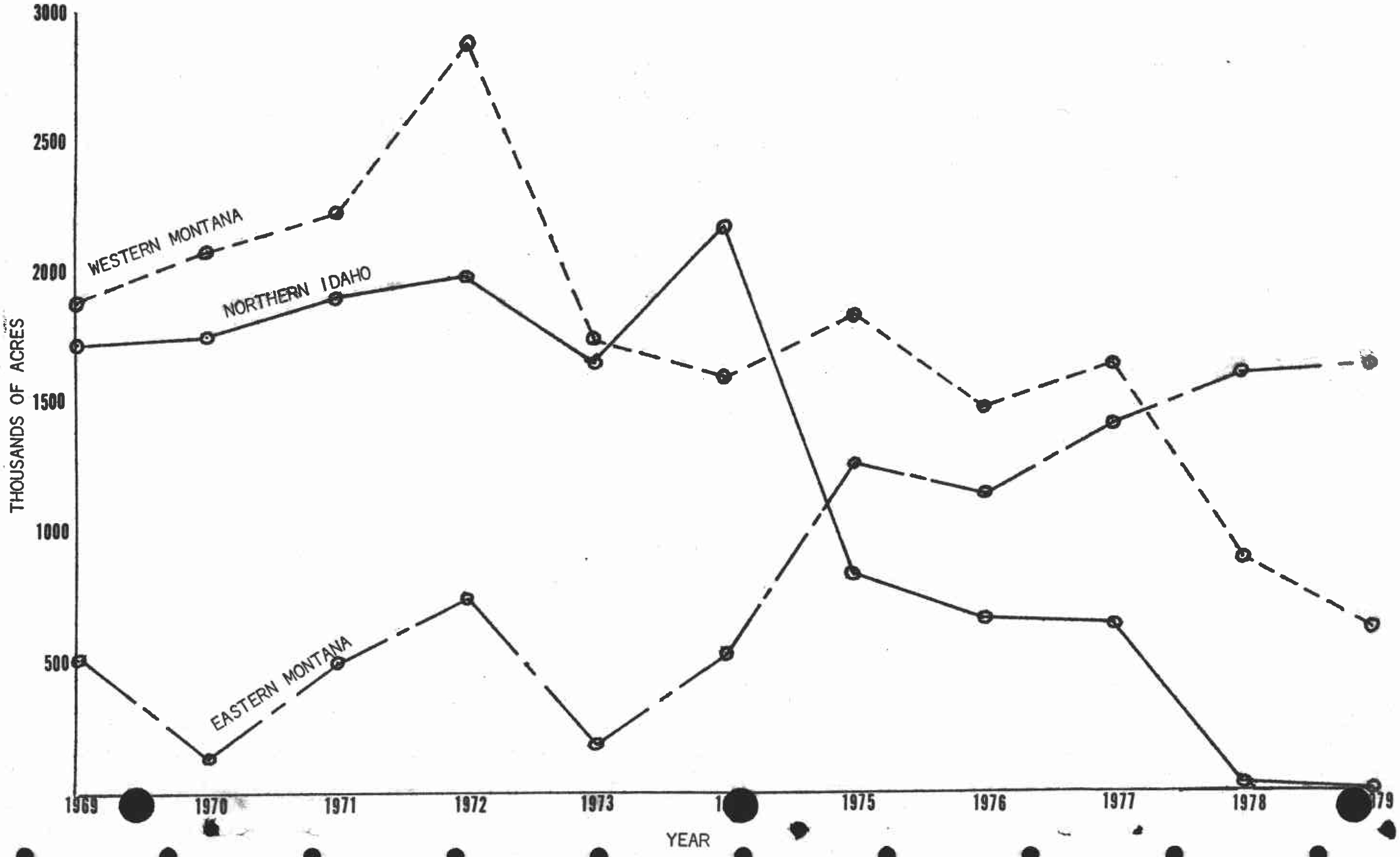
	Sum of squares	Degrees of freedom	Mean square	F ratio	P
Regression	0.282	2	0.141	3.069	0.135
Residual	.230	5	.046		

III. EASTERN MONTANA

	Sum of squares	Degrees of freedom	Mean square	F ratio	P
Regression	3.720	2	1.860	4.192	0.085
Residual	2.219	5	.444		

Figure 1.--Geographic zones in Region 1 and locations of selected weather stations

Figure 2.--Acres of western spruce budworm defoliation detected by aerial observers in the Northern Rocky Mountains (Region I), 1969 - 1979



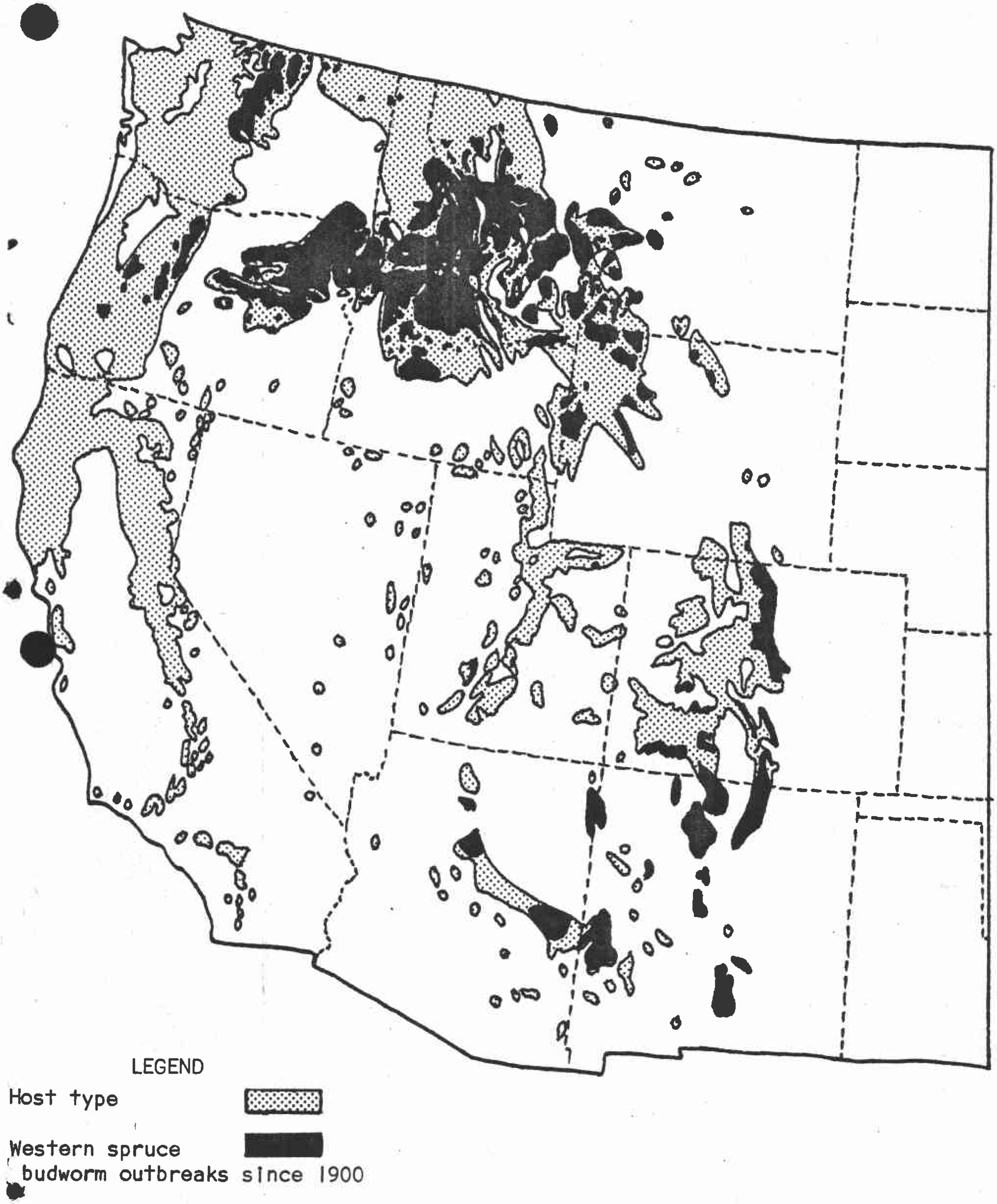


Figure 3.--Distribution of western spruce budworm host type and known budworm outbreaks in the western United States. (Prepared by Larry Stipe, CANUSA ntomologist, Region I)

Figure 4.--Mean maximum temperature in May, June, and July by geographic zone, 1969 - 1978

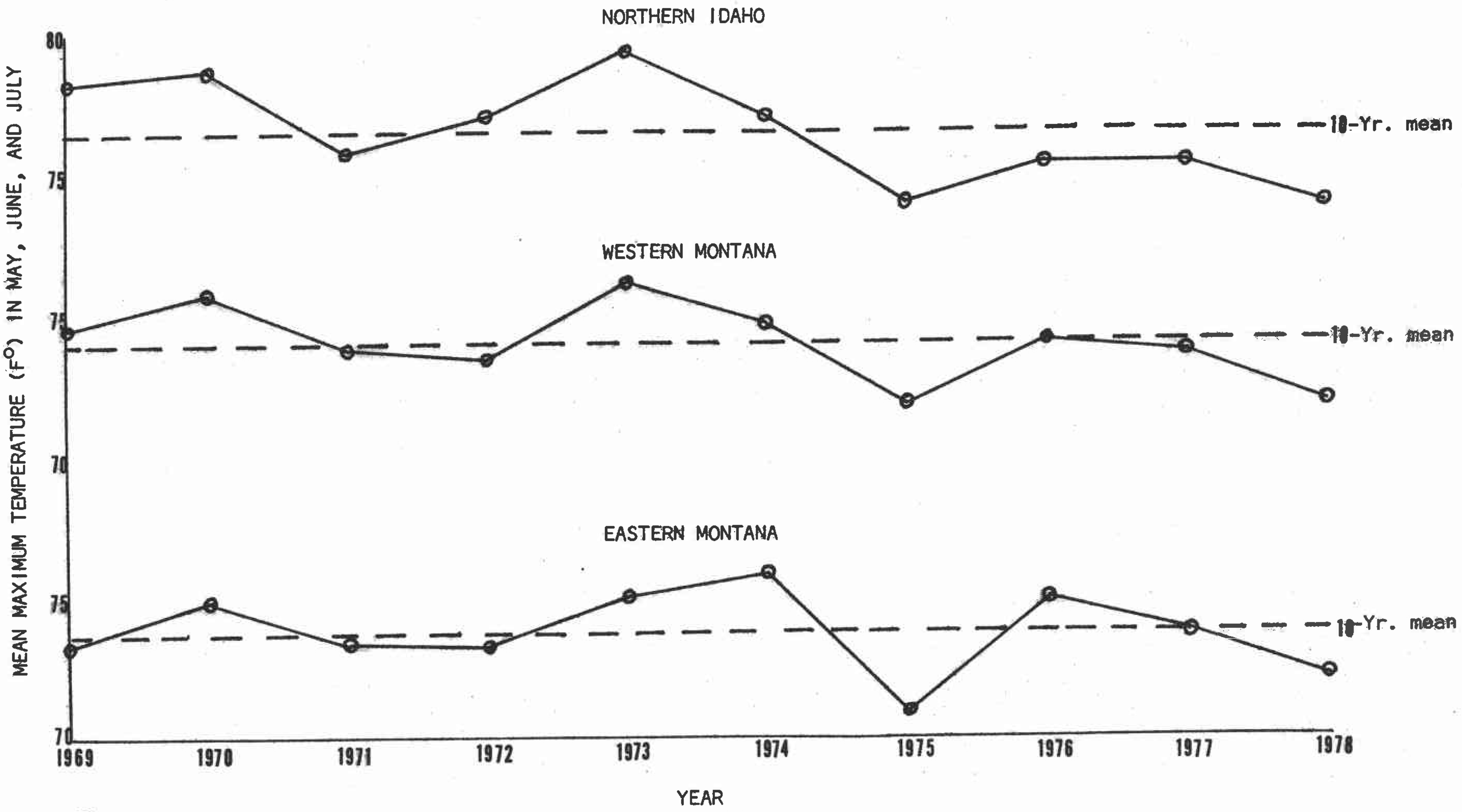


Figure 5.--Mean number of days with measurable precipitation in May, June, and July by geographic zone, 1969 - 1978

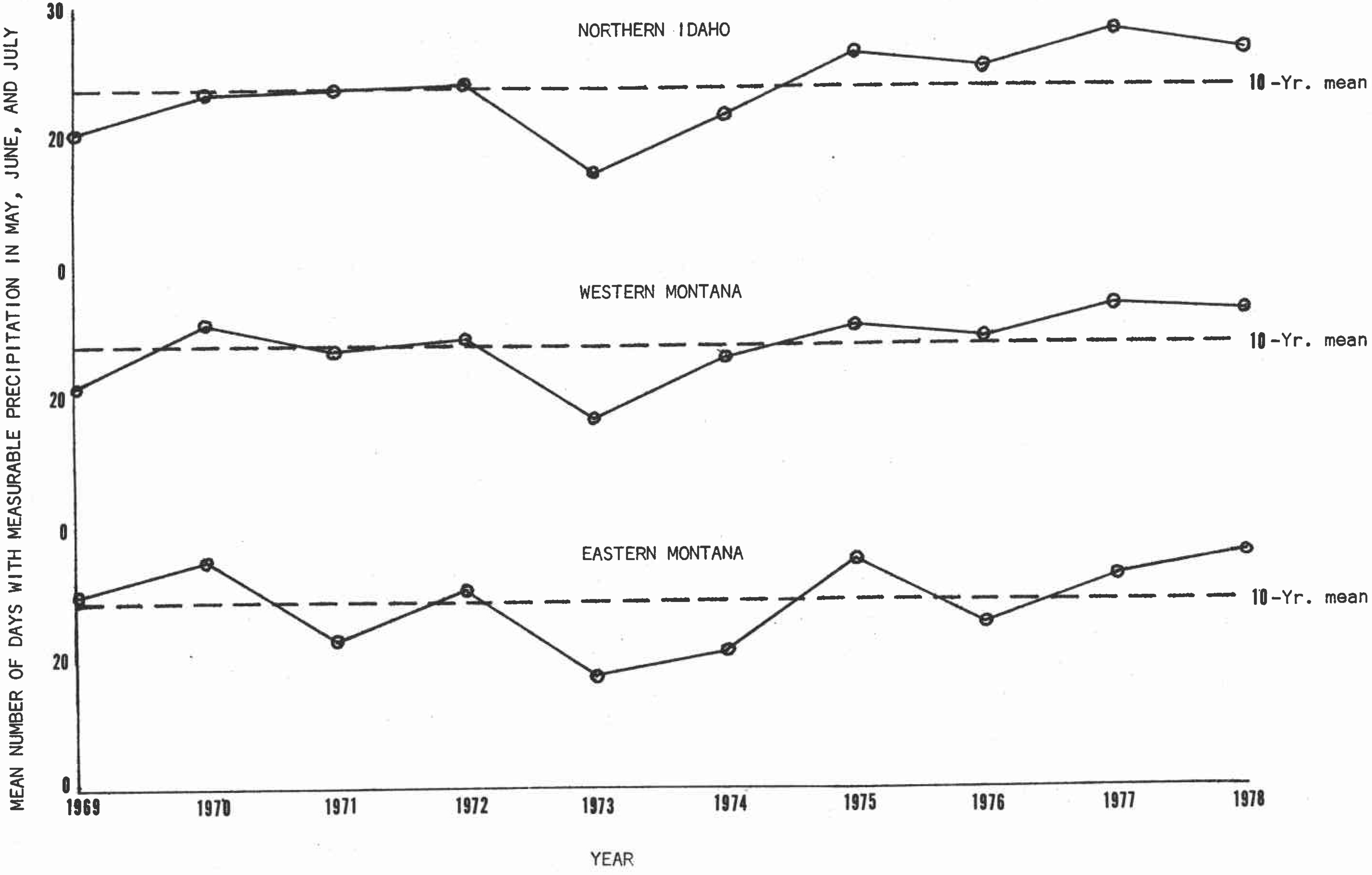
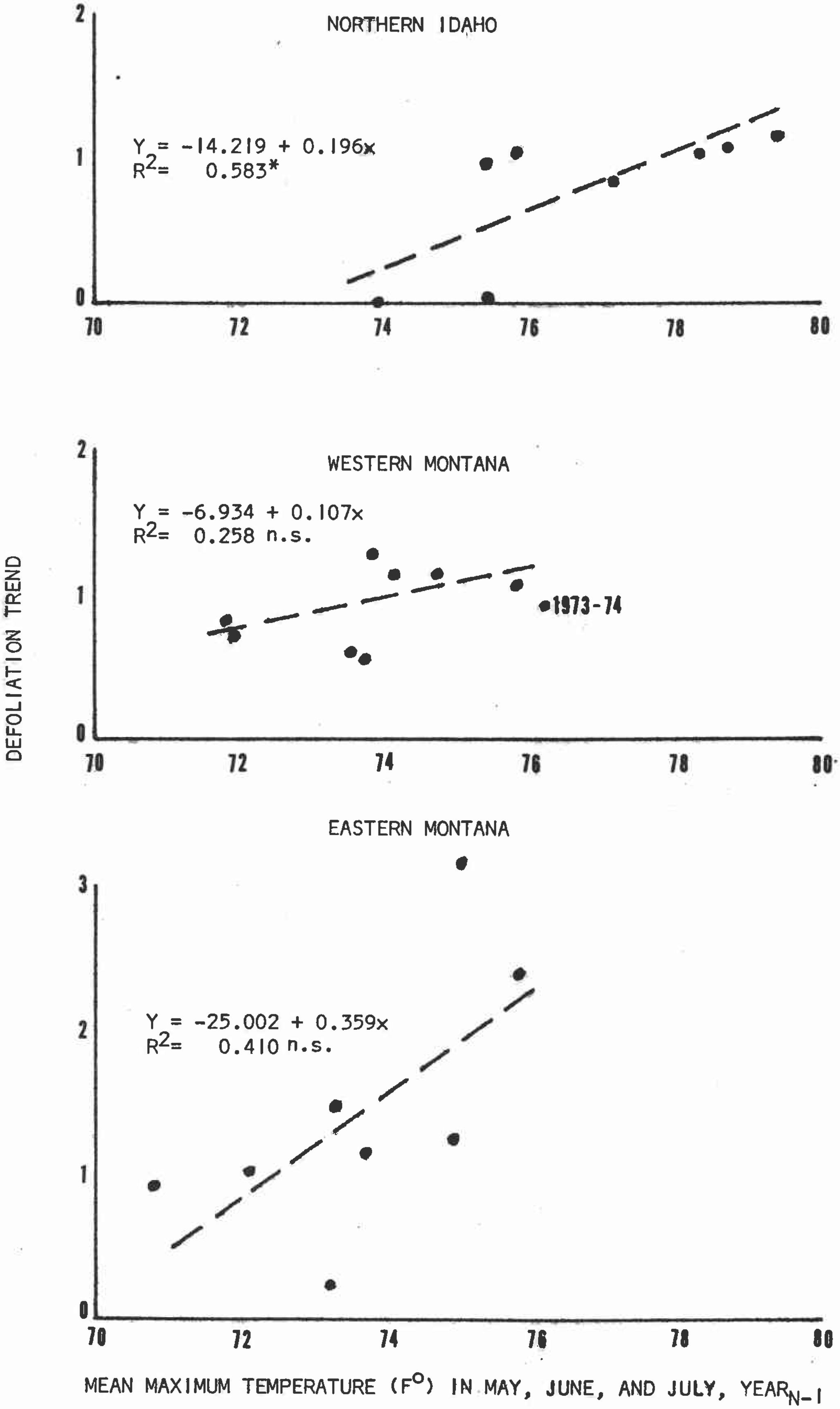


Figure 6.--Relationship of defoliation trend to mean maximum temperature during budworm larval and pupal periods the year before



NORTHERN IDAHO

WESTERN MONTANA

EASTERN MONTANA

Figure 7.--Relationship of defoliation trend to mean frequency of measurable precipitation during budworm larval and pupal periods the year before

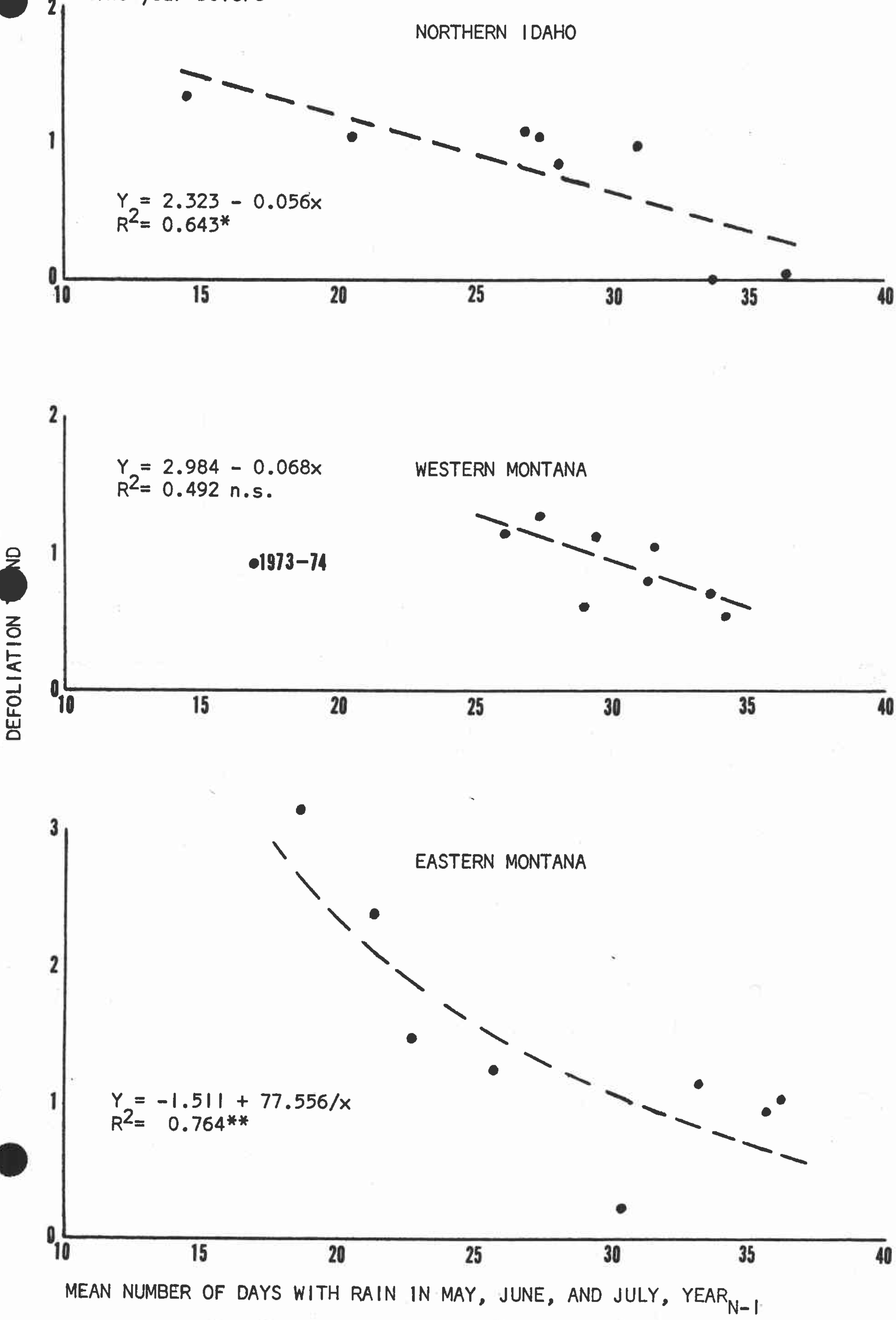


Figure 8.--Relationship of defoliation trend to deviation in °F from 10-year average maximum zone temperatures throughout the Northern Region, showing equilibrium temperature, $\bar{E}_T$.

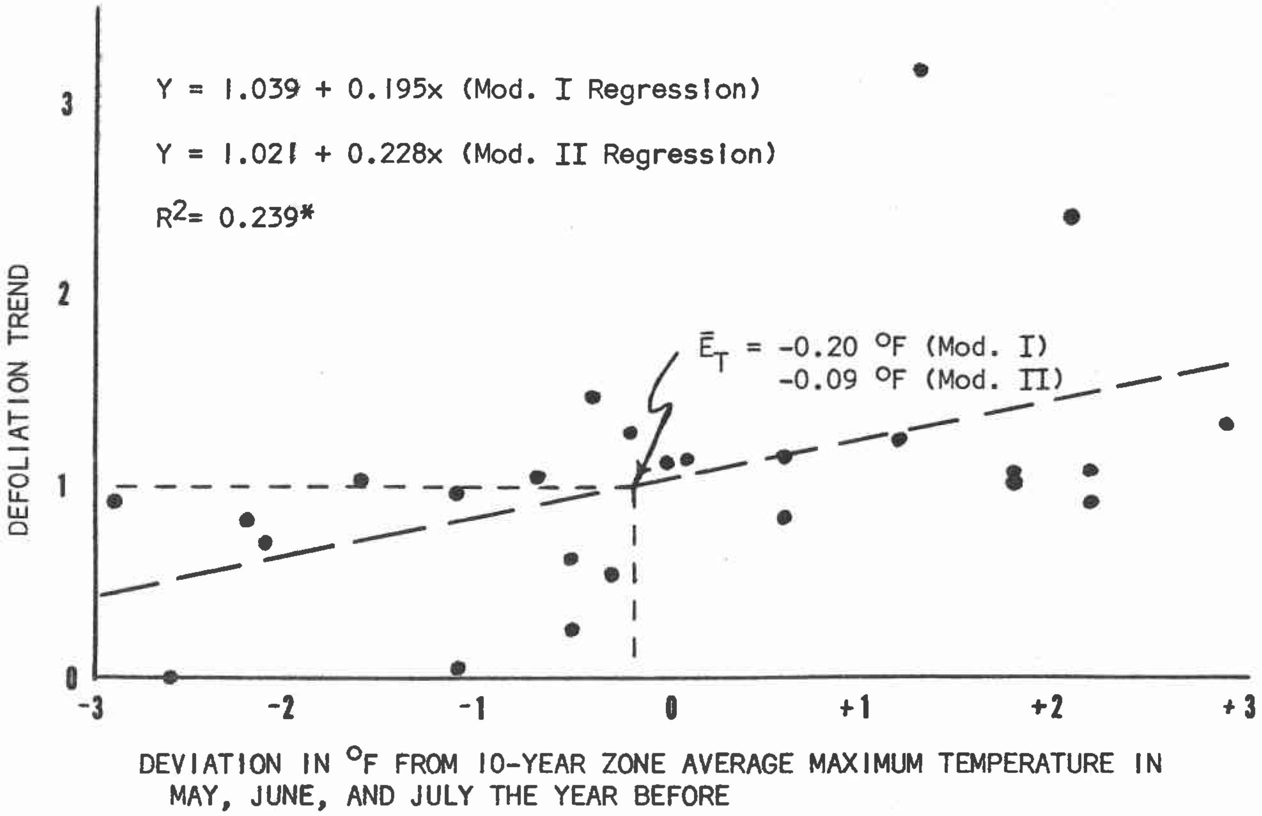


Figure 9.--Relationship of defoliation trend to deviation in days from 10-year average zone frequencies of precipitation throughout the Northern Region, showing equilibrium frequency, $\bar{E}_P$.