Budworm In Coastal Alaska

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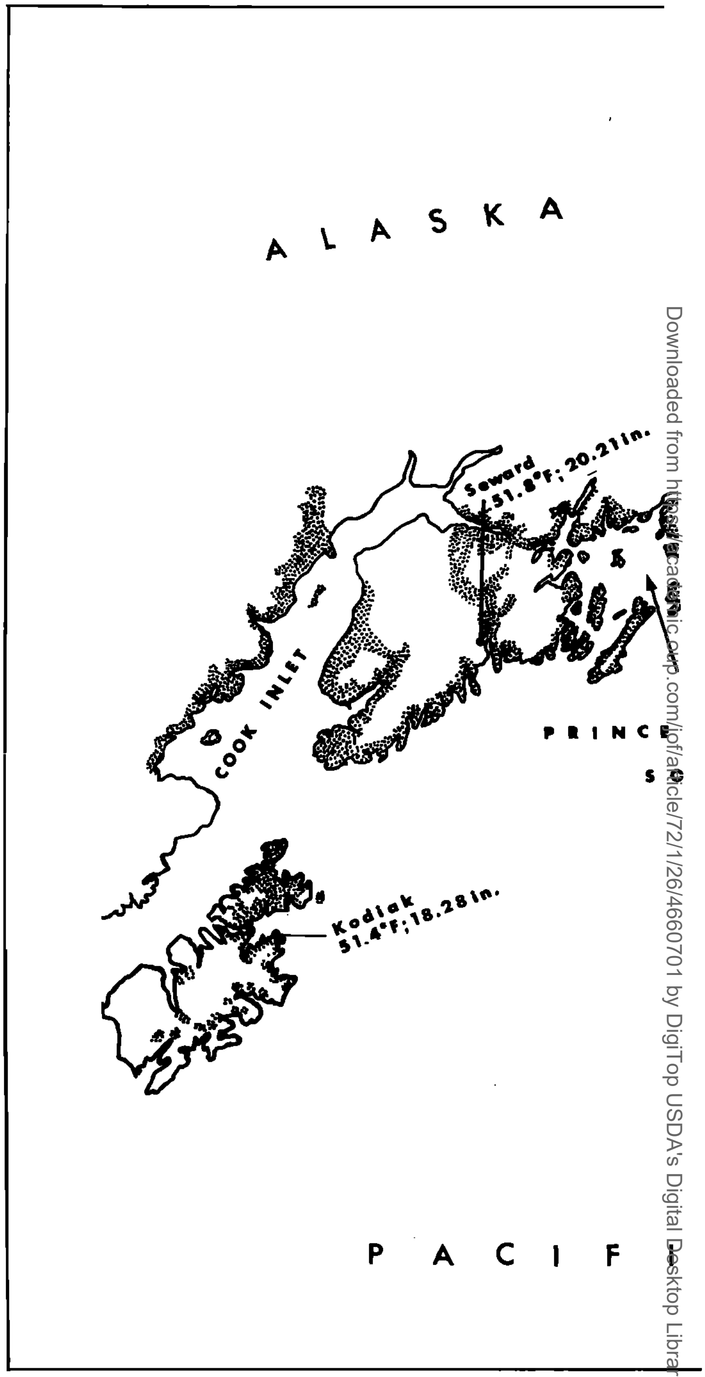
ABSTRACT—Periodic outbreaks of black-headed budworms have been reported in southeast Alaska and on Prince William Sound since 1917. The 1950's outbreak caused severe defoliation of mature hemlock and almost one-third of net volume was lost in some stands. The defoliation trend—ratio of acres defoliated in a given year to acres defoliated the year before—was directly related to regional Temperature Index. Since virgin stands have recovered from past outbreaks, widespread defoliation need not be viewed with alarm.

The black-headed budworm, *Acleris gloverana* (Wals.), periodically defoliates vast areas of the western hemlock-Sitka spruce forest, causing reduced tree growth, tree top-kill, and some whole-tree mortality. Its primary diet consists of western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) buds and current year's needles. Older hemlock needles and Sitka spruce (*Picea sitchensis* [Bong.] Carr) foliage are eaten less readily. Since budworm and western hemlock phenologies are closely synchronized, recently emerged larvae can feed within the protection of unopened hemlock buds. Spruce budburst precedes budworm egg-hatch by several weeks, so young larvae on spruce are not afforded a similar protected feeding site. This may account for differences in host preference (*12*).

The budworm has probably caused periodic defoliation of western hemlock and Sitka spruce in Alaska for centuries. Following several years of relative inactivity, it is increasing again. Surveys in 1971, 1972, and 1973 show growth within a 50-mile radius of Ketchikan, one of the warmest places in southeast Alaska, and noticeable defoliation occurred in 1973. Successive, discontinuous outbreaks northwest to Prince William Sound, near the extremities of the host type (*Figure 1*), have been noted since 1900, often following epidemics on the Olympic Peninsula and Vancouver Island. Hemlock scarcity probably accounts for the lack of reports on budworm activity in forests west of Prince William Sound, on the Kodiak-Afognak Island group, and on the west side of Cook Inlet (*7*).

History of Alaskan Epidemics

Widespread black-headed budworm defoliation occurred in southeast Alaska between 1917 and 1921, followed by an infestation on the Chugach National Forest in 1925 (*6*).[1] Defoliation was not reported again until 1948, in a small area south of Wrangell. Apparently no noticeable damage occurred in 1949, but defoliation became more widespread in 1950 and extended to Yakutat in 1953. By 1955, nearly every forested acre in southeast Alaska had been defoliated to some extent (*8*). The most recent outbreak in southeast Alaska appeared near Ketchikan in 1958, spread without causing much damage, and collapsed in 1965. It was followed by budworm defoliation of 29,000 acres on western Prince William Sound between 1968 and 1970.



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[1] In the preparation of this paper file reports of R. F. Taylor, G. L. Downing, F. T. Hutchison, and especially W. F. McCambridge, have been drawn upon freely by the author.

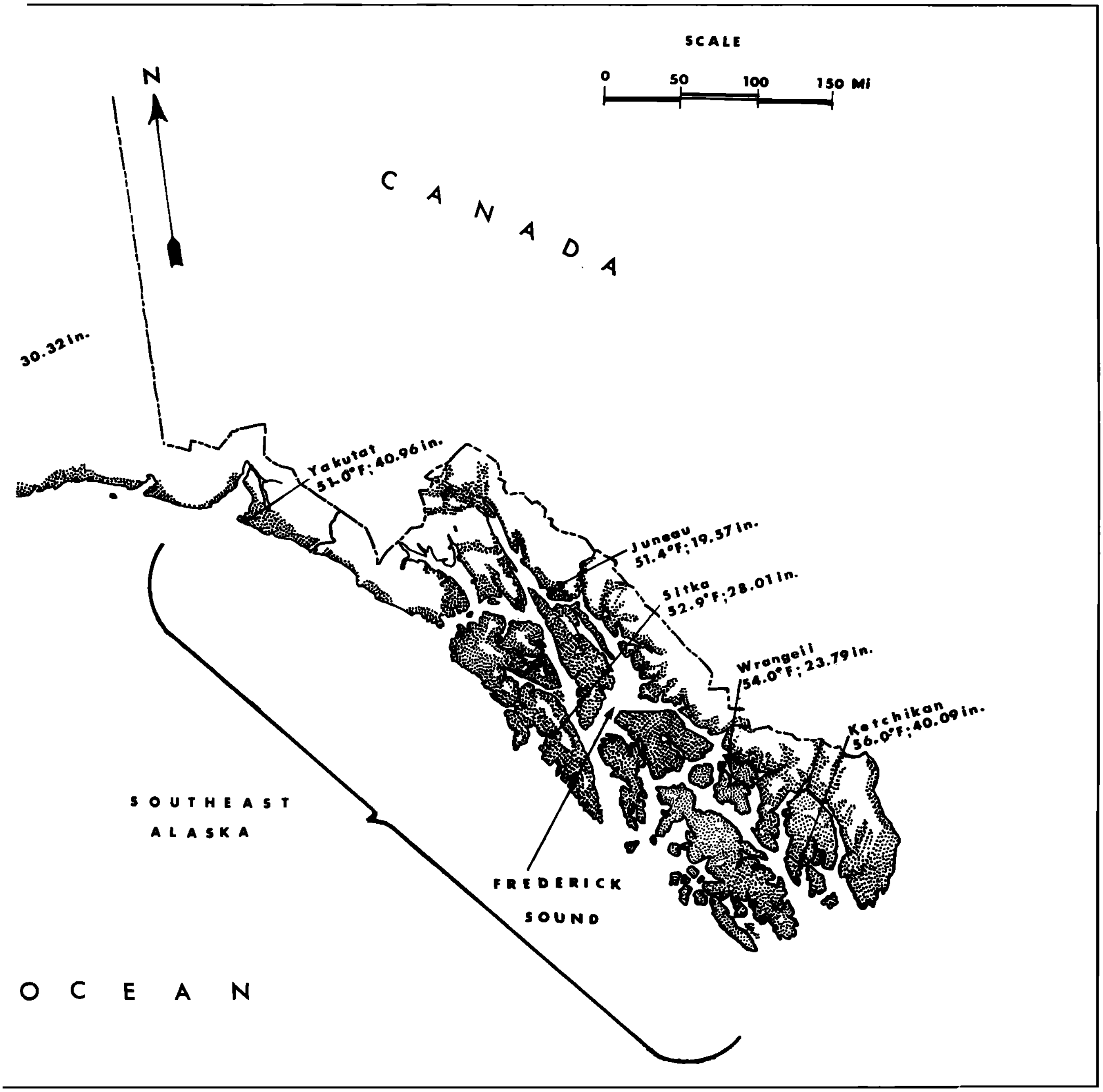

Figure 1. Range of the hemlock-spruce type (stippled areas) in Alaska, with major weather stations showing long-term mean (1931-60) (a) Temperature Index, and (b) precipitation for June, July, August, and September combined.

Loss Appraisals

An aerial appraisal was made in 1953 of two selected budworm-defoliated hemlock stands in southern southeast Alaska. One mapped area of 6,600 acres had a gross volume of 105 million board feet of hemlock with *50 percent or more* dead crown length. The volume loss, although not estimated, was substantial; moreover, stand deterioration was expected to increase due to entry of heart rots through dead tops.

Ground appraisal of a mature hemlock stand damaged by the budworm was made on Admiralty Island in 1956, the year following collapse of the 1950's epidemic. The 800-acre surveyed area contained 33,600 trees 11 inches or greater in diameter; 14,000 were damaged, of which 4,640 were killed. Net volume loss was approximately 7,300 board feet per acre, roughly one-third of estimated net live stand volume before defoliation. Of the damaged trees, 75 percent were in the overstory and 25 percent in the understory, which closely approximated the structure of the live stand before budworm attack.

A 30-year-old, heavily stocked, second-growth hemlock stand and a 40- to 45-year-old, open, second-growth spruce stand were appraised in 1954 to determine the effects of a single year of heavy feeding by the budworm on young stands (*8*). In the hemlock stand, upper crowns in 40 percent of all hemlocks were completely defoliated; tops were killed in 25 percent. In the spruce stand, 74 percent of all spruce

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stems and 50 percent of hemlock were top-killed. In both stands the injury was primarily in the dominant and codominant crown classes. Spruce top-kill was confined mostly to new growth, whereas hemlock top-kill extended beyond new growth.

Weather and Budworm Population Change

Species such as the budworm are characterized by periodic spectacular increases followed by rapid declines, and individuals are rarely seen for years between outbreaks. The rapid declines are caused by a variety of factors, biotic and abiotic. Watt (*15*) stressed the varying degree of importance of these two types of mortality factor in restricting a species throughout its range:

> . . . near the central part of the range of a species, climate will probably be optimal and weather will rarely be an important regulator . . . [Here] the population will be regulated by . . . competition for food, disease, parasitism, and predation. At the edge of its range, the weather will only be good enough to support population increase in, say four years of every 10, and the population will never become dense enough for density-dependent factors to regulate it. . . .

Since the budworm reaches the extremities of its range in coastal Alaska, adverse weather there may be a more restrictive factor than it is in milder climates farther south. Compared with continental weather that occurs beyond the range of coastal mountains, coastal Alaska has a maritime climate with warm, wet winters and cold, wet summers. Most coastal stands occur within a few miles of salt water (*Figure 1*), whose cool, tempering influence prevents wide temperature variation. Resultant low temperatures during the growing season appear to limit tree growth and development, since mean temperatures and site index diminish from south to north (*1*).

Parasites and disease caused high budworm mortality in some areas during Alaskan budworm outbreaks, but no evidence shows that they caused widespread outbreak collapses. The budworm parasite complex in Alaska is limited — only 16 known species — whereas 48 species occur on budworm in coastal British Columbia (*13*). Budworm eggs, overwintering on host needles, are often lost due to sliding ice and snow (*10*). This is not considered a primary mortality factor since a high incidence of eggs showed up in surveys conducted in spring 1970 at several locations in Prince William Sound, an area with heavy snowfall.

Recent Alaskan budworm population trends were associated with temperature trends. From 1953, the year when the 1950's outbreak peaked, to 1955, the year of the outbreak collapse, the cumulative temperature above 42°F for May through September diminished. By September 30, 1955, less than 50 percent of the moths had emerged (*Figure 2*). October was severe — the mean monthly temperature of 25 southeastern weather stations was 4°F colder than average. The summer of 1956 was also colder than usual (*Figure 3*). Therefore it appears that abnormally cold temperatures contributed to the collapse of the outbreak.

Comparison of temperature and precipitation data during the larval period with survey records shows a direct relationship between budworm population trend and regional mean temperature, but none between population and regional mean precipitation (*Table 1*). Upward and downward trends occurred throughout the range of precipitation. All downward trends occurred when mean temperature was colder than normal, and most upward trends coincided with years warmer than normal. However, precipitation may be limiting during critical periods of larval development, or indirectly through its effect on relative humidity in the larva's microhabitat (*16*). Temperature's apparent effect may also be largely due to its influence on relative humidity.

Table 1. Relationship between black-headed budworm population trends and weather during the larval period in southeast Alaska, 1948-66.[1]

TEMPERATURE ($\frac{\text{JUNE + JULY + AUGUST}}{3}$)

PRECIPITATION ($\frac{\text{JUNE + JULY + AUGUST}}{3}$)

	Hot >56.1°	Warm >55.1° to 56.1°	Normal 55.1° F.	Cool <55.1° to 54.1°	Cold < 54.1°
Very Dry <4.4 in.	+ (1953, peak of outbreak)	+	+	- - - (1954, outbreak decline) (1965, outbreak collapse)	
Dry <5.4 in. to 4.4 in.	+ (1948, outbreak begins)	0		+	
Normal 5.4 in.				+	
Wet >5.4 in. to 6.4 in.	+ (1958, outbreak begins)	+	+	- - +	- (1955, outbreak collapse)
Very Wet >6.4 in.		+			-

[1] A plus sign represents an upward population trend for a given year, a minus sign represents a downward trend, and a zero represents no apparent change.

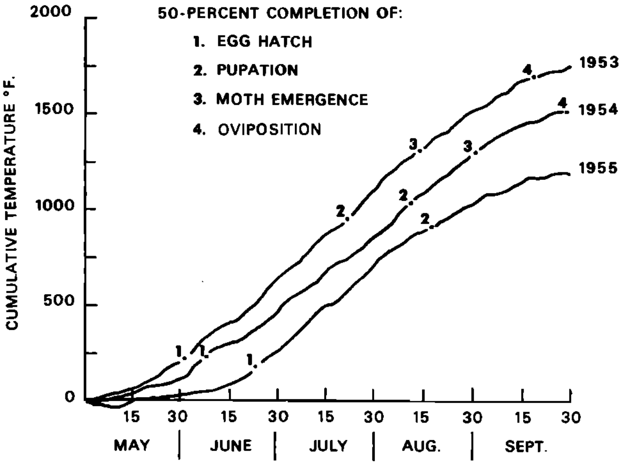

Figure 2. Relation between black-headed budworm development and cumulative average daily temperatures above 42°F. (Source: W. F. McCambridge, 1955. Studies of the biology and control of the black-headed budworm in Alaska. USDA Forest Serv. Alaska Forest Res. Cent., Juneau. Progr. Rep.)

Black-headed budworm studies at Green River in eastern Canada, with a warmer and drier growing season, related rate of population change directly to accumulated degree days in June, July, and August, the larval period, but not to rainfall (*9*). Environmental conditions during both larval and adult periods can each restrict population growth, regardless of conditions during the other. Poorly nourished larvae resulting from adverse conditions will not produce prolific adults, even if environmental conditions favor adult activity. Conversely, highly fecund moths from healthy, well-nourished larvae can be hindered by adverse environmental conditions. But the relative importance of conditions may change from year to year depending on how far they deviate from optimum. Here, conditions during both periods are given equal weight for purposes of analysis.

Analyzing Temperature Deviations

Mean temperatures, June through September, for southeastern Alaska, were extracted from U.S. Weather Bureau Annual Reports 1945-1971.[2] Mean temperatures for the same months, 1960-1971, were extracted for the stations at Cordova Airport, Cape Hinchinbrook, and Seward, to represent weather conditions in Prince William Sound. Weather data from other stations in this area were incomplete and therefore not used.

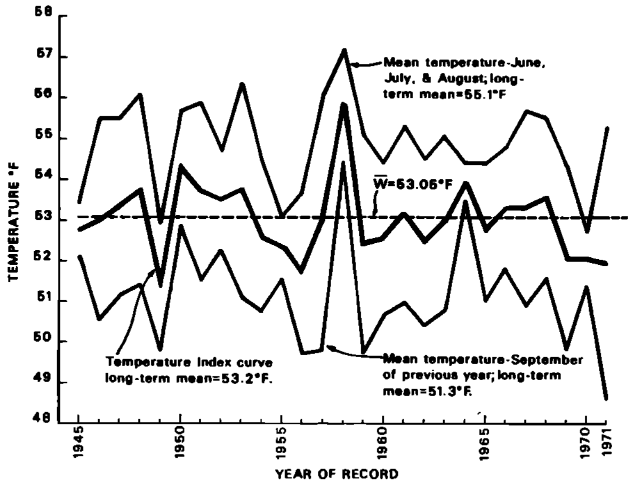

Figure 3. Mean temperature by year during selected months for all weather stations in southeast Alaska. Long-term means from U.S. Weather Bureau (*14*); Temperature Index curve calculated from means for upper and lower curves.

A single mean temperature was computed for the larval period of June, July, August, for each year, 1945-1971, from the Southeastern Division monthly means (*Figure 3*). The division monthly mean temperatures during the adult period in September, 1944-1970, were also graphed (*Figure 3*), but the entire graph for September was plotted one year to the right. Thus the mean temperature of September 1969 falls directly below the mean temperature for June, July, August 1970. This was done to ease comparison of temperatures during the two periods of budworm activity and to aid in plotting a single mean temperature, henceforth referred to as the Temperature Index or TI.[3]

Since quantitative budworm population data on the 1950's outbreak in southeast Alaska were not available, but maps and descriptions of extent of defoliation[4] were, these data were chosen for correla-

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[2] Monthly mean temperatures from all reporting weather stations were used to compute the monthly division mean for the years 1945 through 1955. Since then, monthly means by division were printed in the annual reports and are based on the same calculations.

[3] Temperature Index equals the mean temperature for the period of June, July, and August plus the mean temperature for the prior September, all divided by two.

[4] Defoliation, as used in the analysis, refers only to defoliation that occurred during the current year and was noticeable from the air.

tion analysis with regional temperature. Gross acreages of defoliation reported on the 1950's outbreak included much land that was nonforested. Reported acreages were adjusted to acres of defoliated forest (*Table 2*) using defoliation maps and unpublished forest inventory reports that list the acreages of forested and nonforested land by working circles in southeast Alaska.

Table 2. Estimated acreage of forest land defoliated by the black-headed budworm in southeast Alaska, 1951-1956.

Year	Estimated acres defoliated	Trend (A_{t+1}/A_t)	Temperature index
1951	4,588,250	—	53.70
1952	6,939,450	1.51	53.50
1953	9,175,800	1.32	53.75
1954	3,595,900	0.39	52.60
1955	3,073,750	0.85	52.35
1956	0	0.00	51.70

Defoliation trend — the ratio of acres defoliated in a particular year over acres defoliated the previous year (*Table 2*) — is an index of budworm population change. However, zero acres of defoliation noticeable by an aerial observer does not equate with a "zero" or endemic budworm population. Individual tree crowns may each contain hundreds of feeding budworm larvae, but defoliation will not be apparent even to an experienced observer except from the ground. Defoliation trend plotted against TI (*Figure 4*) showed a significant relationship, but data were scarce. The interpolated equilibrium TI or $\overline{W}$, where trend equals one and defoliation neither increases nor decreases, equals 53.05°F. This closely approximates the long-term mean TI for the Southeast Alaska Division of 53.2°F. (*Figure 3*) and suggests that southeast Alaska's climate may be marginal for optimum budworm development.

Defoliation was reported as more widespread in 1950 following the cold season of 1949, yet budworm populations did not rebound as rapidly after the cold season of 1956 (*Figure 3*). A probable low incidence of biotic mortality agents such as parasites and disease among rising budworm populations in the late 1940's, and a much higher incidence of biotic agents in the mid-1950's following the peak budworm population in 1953, might be responsible for differences in rapidity of recovery.

A resurgence of budworm damage appeared in 1958, a very warm year. Populations were not monitored closely, and only partial aerial surveys were made. Reported acreage of defoliation first occurred in 1962 and peaked in 1964 (*3*); the outbreak collapsed in 1965. The reported acreages, which never exceeded 50,000 acres, were too small to compare with a regional TI. Also, precise locations of the defoliated areas were not reported; therefore, local weather stations could not be identified for comparing temperature with defoliation trend. However, TI's were generally low during the 1960's. A rising trend began in 1962 and peaked in 1964 (*Figure 3*).

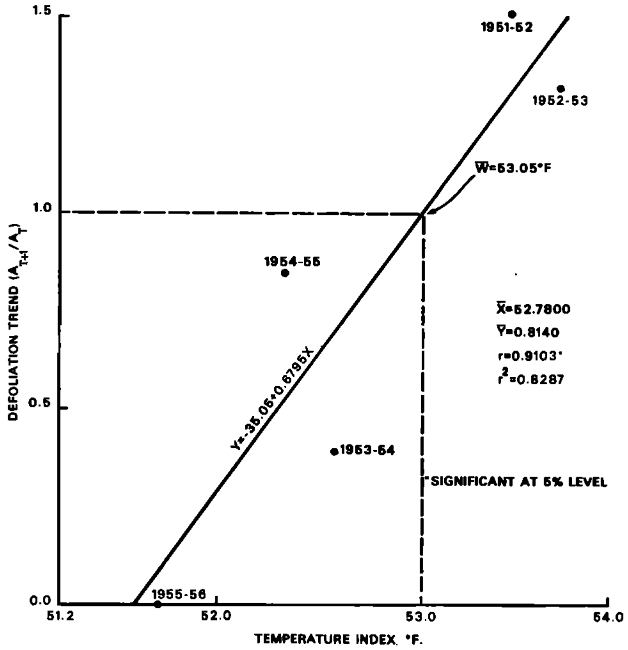

Figure 4. Relation between black-headed budworm defoliation trend and Temperature Index during the 1950's outbreak in Alaska.

The collapse in 1965 was associated with a very warm, dry period in July (*11*) preceded by an unusually cold June; many young larvae died while still feeding in expanding shoots. A possible contributor to the 1965 collapse was the suspected but not proven presence of a cytoplasmic polyhedral virus in late larval populations (*4*).

Between 1965 and 1970, budworm populations remained endemic in southeast Alaska but flared up in forests of Prince William Sound in the late 1960's. A localized budworm population was reported there in 1963 (*2*), and an outbreak in 1969 (*5*). This outbreak was expected to continue in 1970 because of very high egg populations. However, early larvae were retarded in development, and late larval populations were drastically reduced. Laboratory analysis of dead and unthrifty larvae revealed no evidence of major disease.[5] Live larvae were characteristically small relative to head-capsule size, and few pupae were formed. An egg survey in the spring of 1971 conducted in seven areas yielded four budworm eggs, compared with

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[5] Personal communication, Kenneth M. Hughes, insect pathologist, Pac. Northwest Forest and Range Exp. Sta., Corvallis, Ore.

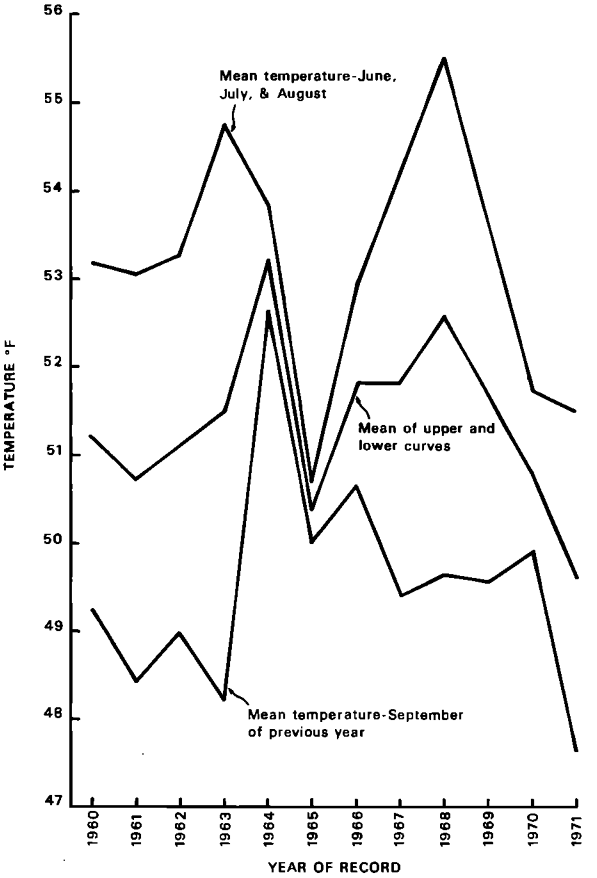

Figure 5. Mean temperature by year during selected months for Prince William Sound (Cape Hinchinbrook, Cordova Airport, and Seward weather stations only).

thousands found in the spring of 1970. Thus, the rise and fall of the most recent budworm outbreak in Prince William Sound is attributed at least partially to warm temperatures from 1966 to 1969 and cold temperatures in 1970 (*Figure 5*).

The hypothesis that TI, as defined in this paper, is a good climatic indicator of population trend needs further testing. Beginning in 1971, larval populations in over 150 locations in coastal Alaska are being sampled annually. We hope that comparison of larval population fluctuations over the next few years with various weather factors will determine which weather trends are most closely associated with budworm population trends.

Discussion and Conclusions

Circumstantial evidence suggests that temperature during the growing season may be a major factor restricting growth of budworm populations in coastal Alaska. If so, it can be assumed to be most restrictive in Prince William Sound's cool forests, and least restrictive in southern Alaska's warm forests. Most damage to hemlock-spruce forests by defoliating insects has occurred south of Frederick Sound, or about 57° north latitude, where it is warm and trees grow faster.

Budworm outbreaks will probably not become a serious threat to the forests of Prince William Sound because of inclusion of many vulnerable stands in a proposed Wilderness Area, probable short life of future outbreaks, an educated public that can accept forest defoliation as a recurrent natural phenomenon, and low commercial timber values.

Outbreaks may well be more frequent and more severe in southeast Alaska. Much forest land has been logged in the past 20 years, especially south of Frederick Sound, and extensive young even-aged stands occur there. We don't know whether damage is greater to young stands or to mature stands for a given degree of defoliation, but discoloration due to defoliation on North Vancouver Island is most severe in regeneration and second growth.

The budworm is not an intruder to Alaska's virgin forest ecosystem but a natural and perhaps beneficial component. Defoliation may cause dead trees and unsightly stands for a few years, but the energy and nutrients stored in the host needles are released during the rapid recycling process of an outbreak for use by surviving trees and other plants and animals. Increased solar radiation and precipitation reach the understory and soil surface until the crown canopy closes again. Therefore, large-scale defoliation in virgin stands should not necessarily be viewed with alarm, since stands have recovered from past epidemics. Outbreaks in managed stands are of more concern.

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