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FINAL ORAL EXAMINATION

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

of

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B.ScF. University of Toronto
M.A. University of Toronto

IN ROOM 187A, BIOLOGICAL SCIENCES BUILDING

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ABSTRACT

The lodgepole needle miner, *Recurvaria starki* Free. has been studied intensively since 1948. Until 1953, this insect was referred to in publications as *Recurvaria milleri* Busck. The life history and taxonomic position of *R. starki* are reviewed briefly and an historical review of the research carried on since 1948 is given.

A full description is given of the procedure of applying life table techniques to needle miner studies since 1954 and examples are given for selected study areas. Six sampling intervals, one egg, four larval and one pupal are deemed suitable to assess the course of the population of a single generation from the time of oviposition to moth emergence.

The life tables and survivorship and death-rate curves show clearly that there are five periods in the two-year life cycle of the lodgepole needle miner during which extensive mortality may occur: (1) between egg formation and oviposition; (2) between oviposition and larval establishment; (3) during the first larval hibernation; (4) during the second larval hibernation; (5) during the spring of moth emergence. Population success is also undoubtedly affected by conditions during the adult life.

Population sampling shows that the outbreak has declined since 1948 and defoliation and increment studies show that the period of greatest defoliation occurred from 1940 to 1944 and that the outbreak probably began in the late 1930's. It is shown that winter temperatures, probably those of the coldest month, were responsible for the decline. It is estimated that the needle miner populations in Banff National Park can have a high survival if extreme minima of —30°F. to —40°F. do not persist long enough to depress the mean monthly temperature close to or below the zero mark. Parasitism was not an important factor in the outbreak decline and it was shown that this was probably due to a greater mortality in parasite populations due to winter temperatures. Other natural control factors are discussed as well as the possible effects of climatic factors on oviposition and fecundity.

From a detailed survey of records since 1920 and yearly averages since 1885, it is postulated that the origin of the needle miner outbreak was due to a warming trend in the climate of the region. This began in

the late 1930's, reached a peak in the mid-1940's and has declined since that time. The warming trend has been noted by other authors for northern latitudes and is substantiated by the weather records of this region. From these data it is further postulated that the climate of this part of Western Canada is generally too severe for an outbreak of the lodgepole needle miner, *Recurvaria starki* Free. to be prolonged.

PUBLICATIONS

Stark, R.W. Sequential sampling of the lodgepole needle miner. For. Chron. 28(2): 57-60, 1952.

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Stark, R.W. Distribution and life history of the lodgepole needle miner *(Recurvia* sp.) Lepidoptera: Gelechiidae) in Canadian Rocky Mountain Parks. Canad. Ent. 86(1): 1-12, 1954.

Stark, R.W. The effects of defoliation by the lodgepole needle miner *(Recurvaria starki* Free). In Press. Forest Science.

Graham, K. and Stark, R.W. Insect Population Sampling. Ent. Soc. Brit. Col. Proc. 1954.

GRADUATE STUDIES

Field of Study: Forest Entomology

Forest Insect Ecology .... K. Graham
Climatology .... J. D. Chapman
Experimental Zoology .... W. S. Hoar
Forest Associations .... V. J. Krajina

Other Studies:

Forest Research Methods
Biological Methods
Forestry Seminar

POPULATION DYNAMICS OF THE LODGEPOLE NEEDLE MINER,

RECURVARIA STARKI FREE. (LEPIDOPTERA: GELECHIIDAE)

IN CANADIAN ROCKY MOUNTAIN PARKS.

by

RONALD WILLIAM STARK
B.Sc.F.,(1948), M.A.(1951) University of Toronto.

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY IN FOREST ENTOMOLOGY

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Forestry and Zoology

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

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ABSTRACT

The lodgepole needle miner, Recurvaria starki Free. has been studied intensively since 1948. Until 1953, this insect was referred to in publications as Recurvaria milleri Busck. The life history and taxonomic position of R. starki are reviewed briefly and an historical review of the research carried on since 1948 is given.

A full description is given of the procedure of applying life table techniques to needle miner studies since 1954 and examples are given for selected study areas. Six sampling intervals, one egg, four larval and one pupal are deemed suitable to assess the course of the population of a single generation from the time of oviposition to moth emergence.

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Population sampling has shown that the outbreak has declined since 1948. Defoliation and increment studies have shown that the period of greatest defoliation occurred from 1940 to 1944 and that the outbreak probably began in the late 1930's. The major cause of the decline was winter temperatures, probably during the coldest month. From laboratory experiments and population sampling compared with weather records it is estimated that needle miner populations can have a high survival if extreme minima of $-30^{o}F$ to $-40^{o}F$ do not persist long enough to depress the mean monthly temperature to near $0^{o}F$.

Parasitism was not a particularly important factor in the outbreak decline probably because of a greater depressant effect on parasite populations by winter temperatures. Other natural control factors are discussed as well as the possible effects of climatic factors on oviposition and fecundity.

From a detailed survey of weather records since 1920 and yearly averages since 1885 it is postulated that release of the needle miner population was due to a warming trend in the climate of the region. This began in the late 1930's, reached a peak in the mid-1940's and has declined since that time. The warming trend has been noted by other authors for northern latitudes and is substantiated by the weather records of this region. It is further postulated that the climate of this part of western Canada is generally too severe for an outbreak of the lodgepole needle miner, <u>Recurvaria starki</u> Free. to be prolonged.

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my Department or by his representative. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Zoology

The University of British Columbia,
Vancouver 8, Canada.

Date December 30, 1957

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T.N. Freeman, Systematics Division, Division of Entomology, described and named this species of needle miner and to him my thanks are due.

POPULATION DYNAMICS OF THE LODGEPOLE NEEDLE MINER, *RECURVARIA STARKI* FREE. (LEPIDOPTERA: GELECHIIDAE) IN CANADIAN ROCKY MOUNTAIN PARKS

by

R.W. STARK

1. INTRODUCTION

The lodgepole needle miner is a defoliating insect which attracted attention because of its increase to outbreak abundance in the Canadian Rockies during the 1940's. The forests attacked by this insect cover a vast western watershed and are the main forest stands in four National Parks. The stands are adjacent to the extensive lodgepole pine stands of the Eastern Slopes of the Rocky Mountains in Alberta which are a major source of revenue to the forest industry of Alberta.

These considerations made it of paramount importance to analyse the factors responsible for the increase in numbers in the region, to explain zones of abundance within the outbreak and to determine the factors which may limit outbreaks to the region recently affected. Since the mid-1940's needle miner populations have declined until at the present time (1957) outbreak conditions do not exist. This leads to the question whether the outbreak may recur. No evidence exists that any previous outbreaks occurred in this region.

The purpose of this thesis therefore, is to analyse the factors responsible for the decline in the outbreak since the mid-1940's and to formulate an hypothesis for the origin of outbreaks of this insect.

1.1. The organism

1.1.1 Taxonomy. When the outbreak was first discovered in 1942, adult specimens were compared with the description of a species with a similar life cycle occurring on lodgepole pine in Yosemite National Park, California, (50,52,93). It was concluded that they were the same species, *Recurvaria milleri* Busck of the family Gelechiidae, Lepidoptera (12). The use of this determination persisted until 1953 when T.N. Freeman of the Systematics Unit, Division of Entomology, Science Service, Department of Agriculture, Ottawa, indicated doubt that they were the same species (Freeman, T.N. pers. comm.). At his suggestion the insect was then referred to as *Recurvaria* sp. in publications.

In 1954 a total of 1,962 needle miner adults from many points within the outbreak areas and from several elevations were submitted to Freeman to assist him in unravelling the complex (125). In 1957 the species occurring in the Canadian outbreak was described by Freeman and named *Recurvaria starki* (30). His description follows:

Recurvaria starki Freeman, new species

"*Recurvaria milleri auct.* (in part) *nec* Bsk.; Hopping, 1945, Proc. Ent. Soc. British Columbia 42: 1-2; McLeod, 1951, Canadian Ent. 83: 295-301. *Recurvaria* sp., Stark, 1954, Canadian Ent. 86: 1-12.

Antenna alternately marked with ocherous-white and black bands. Palpus rather short, not tufted in the male. Second joint of palpus whitish inwardly, ocherous-fuscous outwardly; third joint white with ocherous-fuscous base. Face and vertex shining white. Thorax and forewing light grey, the latter with somewhat obscure blackish patches crossing the wing at the basal third, at the outer two-thirds, and near the apex; the post-median band bordered outwardly with white and appearing to be sharply angled outwardly at its middle. The patch near the apex extending obliquely inward almost to the posterior margin. Apex of wing mostly white, and with an obscure, blackish central area. Hind wing pale smoky. Fringes of all the wings shiny, light, ocherous-grey. Under surfaces of all the wings, dull white. Male with a long ocherous hair-pencil arising from beneath the anal angle at the base of the hind wing. Fore and mid tibiae and tarsi alternately banded with black and white scales. Hind tibia whitish, with long hairs above. Each segment of hind tarsus grey, with a white tip. Wing expanse: 12 - 13 mm. Moth in the latter half of July.

Male genitalia. Uncus rooflike, Gnathos with three hooklike processes, the median one slightly the longest. Caudo-lateral projections of tenumen asymmetrical, flaplike. Claspers asymmetrical, tubular twisted; the right clasper much larger than the left. Aedoeagus pistol-shaped. Vinculum produced apically into two somewhat asymmetrical hooklike sicae.

Holotype. - Male, Mt. Eisenhower (near Banff), Banff National Park, Alberta, July 19, 1954. Reared from Pinus contorta Dougl. by officers of the Forest Insect Survey, Forest Biology Division. No. 6298 in the Canadian National Collection, Ottawa.

Paratypes. - Twenty males and 16 females, Mt. Eisenhower, Banff National Park, Alberta, July 17 and 19, 1954. Eleven males and five females, Cascade Mountain (near Banff), Banff National Park, Alberta, July 18 and 19, 1954. Two males, Lake Louise, Banff National Park, Alberta, July 20, 1954. Two females, Mt. Edith Cavell (near Jasper), Jasper National Park, Alberta, July 15, 1954. All paratypes reared from Pinus contorta, and No. 6298 in the Canadian National Collection, Ottawa.

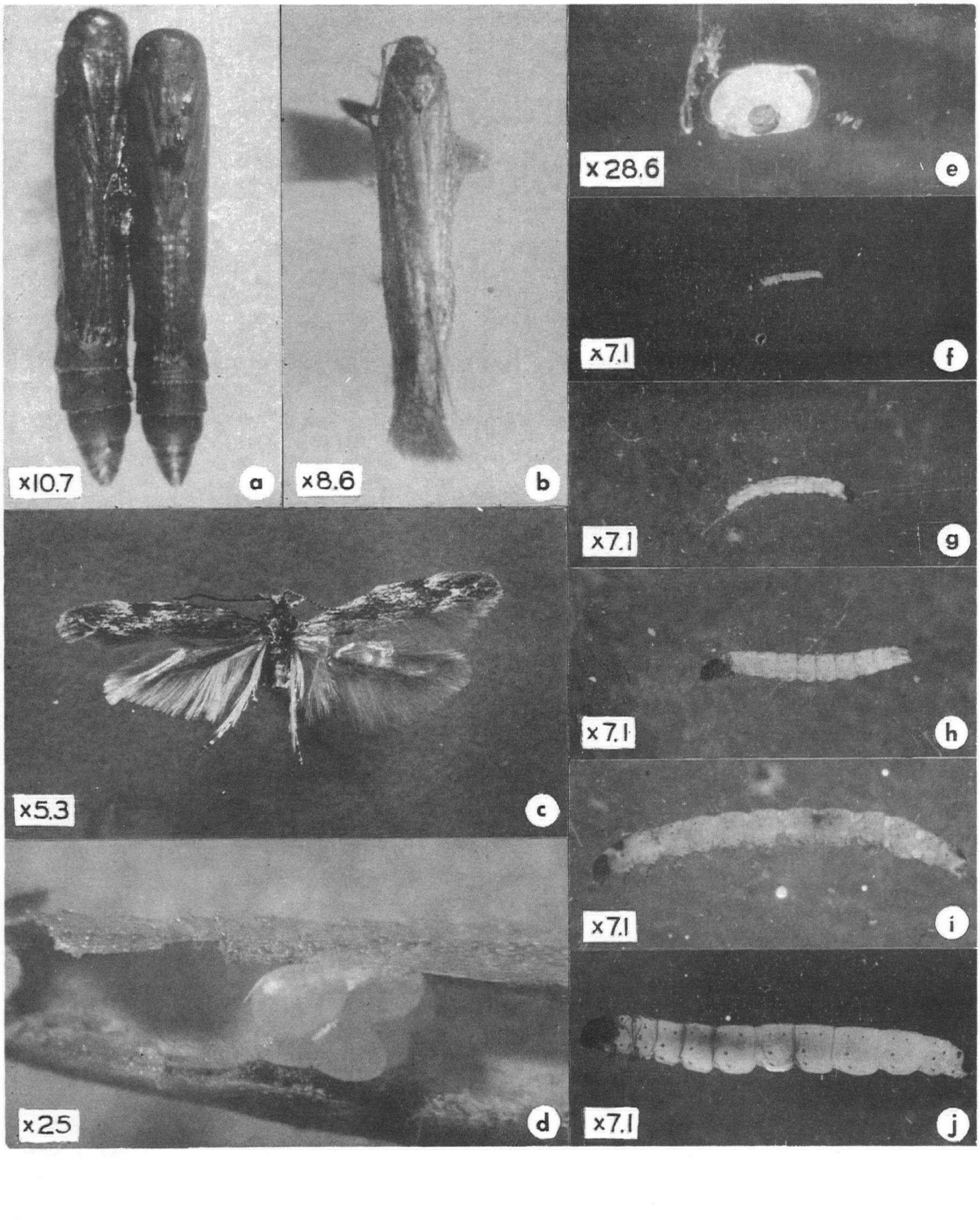
Food plant. - Pinus contorta Dougl.

This species is closely allied to and has been confused with R. milleri Bsk. The male genitalia appear to be identical with those of that species and of R. moreonella Heinr., a species described from a single male reared from Pinus scopulorum (Engelm.) Lemmon at Cheyenne Mountain, Colorado. R. milleri is somewhat larger, mainly white with black longitudinal streaks or distinct irregular spots. R. moreonella has a narrow irregular line of white scales extending longitudinally through the middle of the wing, from the end of a sub-basal black streak to near the apex. R. starki and R. milleri are needle miners that require two years to complete their life cycles in the type localities.

There is some evidence to suggest that R. milleri, R. moreonella, and R. starki, as well as some allied species, do not belong to the genus Recurvaria Haw. The male genitalia of R. nanella Hbn., the genotype of Recurvaria, are bilaterally symmetrical. The male genitalia of the group of species under consideration are asymmetrical. There is also a difference in the shape of the sugnum in the bursa of the female. Further studies are necessary to elucidate the generic significance of these characters."

1.1.2 Life history. A photograph of the major life stages is presented in Figure 1 and a schematic illustration of the life cycle

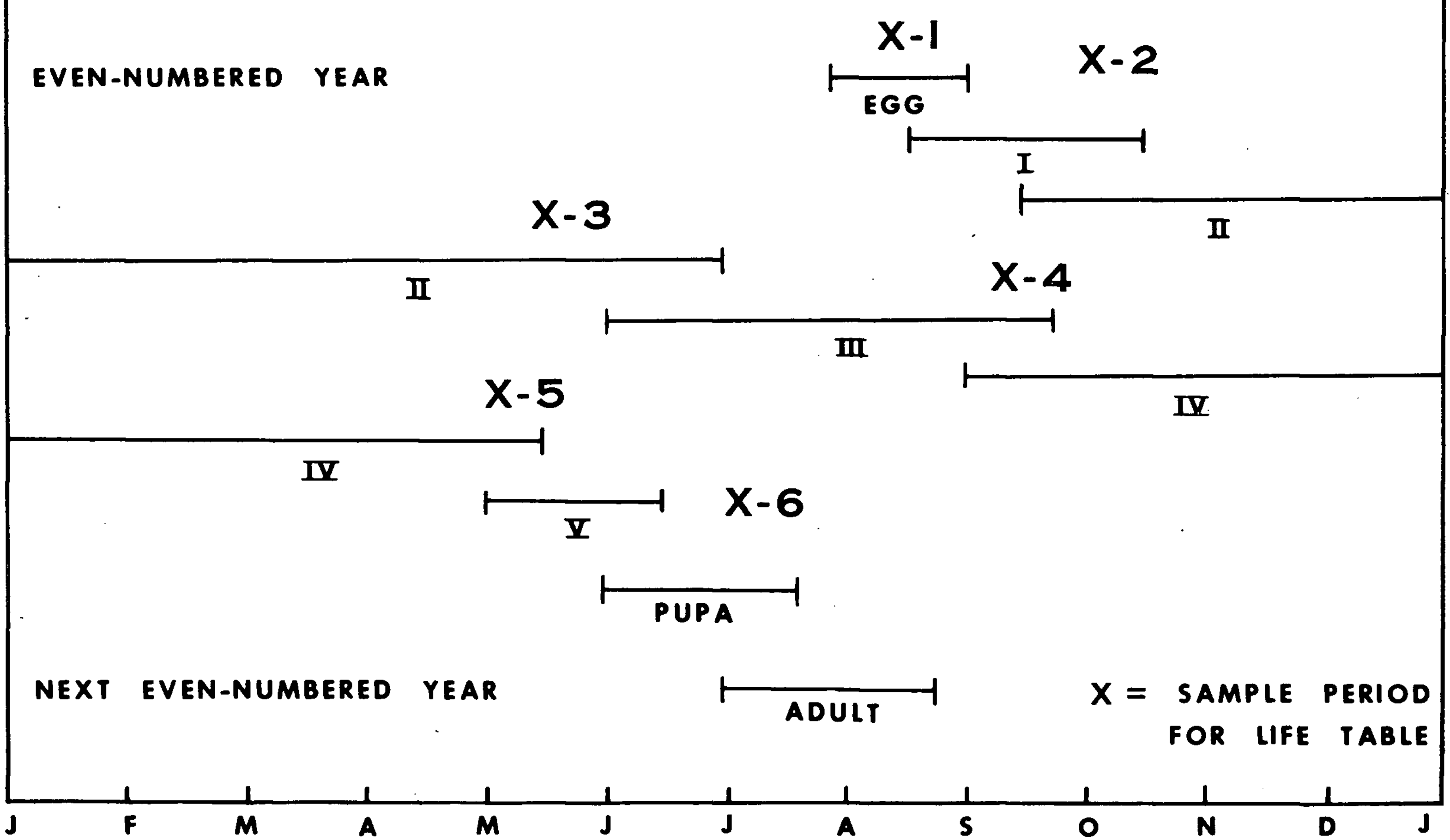
Figure 1. Stages in the life history of *Recurvaria starki* Free.



x10.7
a
x8.6
b
x28.6
e
x7.1
f
x7.1
g
x7.1
h
x5.3
c
x7.1
i
x25
d
x7.1
j

Figure 2. Schematic illustration of life cycle of the lodgepole needle miner and sampling periods for life-table studies.

SCHEMATIC ILLUSTRATION OF LIFE CYCLE OF THE LODGEPOLE NEEDLE MINER, RECURVARIA SP.



in Figure 2. The needle miner in the Canadian Rockies has a two-year life cycle. In the even years the adults emerge in July; eggs are laid in late July and August and hatch in August and September. Each larva immediately enters a needle in which it spends the first winter. The following spring the miner commences to feed in late April or May, depending on spring weather and completes mining the first needle. Transfer to a second needle takes place in mid-summer; climatic conditions affect the time and duration of the transfer period considerably. The larva over-winters in the second needle and the following spring, again an even year, transfers to a third needle. It completes mining by early June, pupates and the moth emerges three to four weeks later. Details of the life history have been published (123).

1.1.3. Unsynchronized population phenomena. There have been two instances of off-year maturation of the needle miner. Discussion of these has deliberately been omitted from the main thesis as it was felt that it would only lead to confusion. The first occurred in the Bow Valley of Banff National Park in 1949 (32,34) and was restricted to an area from Mount Eisenhower to the town of Banff. Only a small portion of the total population was involved, a maximum of less than 30 per cent in any one location (32). Parasitism of this off-cycle population averaged 20 per cent (34). The second occurred in the Kickinghorse Pass of Yoho National Park in 1951 and was very restricted in extent; maturing larvae and pupae were found in an area of less than one acre (123). The first indication that this might occur was noticed in the winter of 1950. Larvae brought into the laboratory in September continued to feed until by November 20 these larvae were three times the size of larvae in the field. Larvae collected in November resumed feeding under laboratory conditions and increased in size (103). Sampling in July showed an average of two to three 'precocious' larvae per tip, the average of all larvae per tip was about 20. A total of 305 advanced larvae were collected and reared. Parasitism proved to be high; of the 305 larvae collected 300 were parasitized (114).

There are three possible explanations for this off-cycle occurrence of adults. The first is that there is another species involved. Unfortunately no specimens were preserved for identification. However, were another species present we would expect recurrence of adults in the odd-numbered years, progeny of those found. Careful watch has been kept since 1949 and other than those found in 1951 in another area, no further occurrence of the phenomenon has been noted.

The second is that possibly part of the needle miner population possesses an obligatory diapause factor which automatically interrupts development regardless of environmental conditions. The remainder may lack a diapause factor and become sufficiently abundant in the two locations found to be noticed (34). Although the numbers found were relatively small, there were enough that we would expect to have individuals occur in the winter sampling which would show this diapause factor. All experiments made in breaking diapause tend to discount this theory.

The third theory is that the small portion of the population affected were individuals which were in particularly favorable niches and developed more quickly than their neighbors. They cannot be regarded as 'stronger' than those which did not mature in the off-year as it is difficult to conceive of parasitized larvae being capable of more rapid development than unparasitized larvae in the same location. As no progeny of either example were found in following years, no further work could be done. The fact that no progeny were found makes any of the three explanations difficult to support. We can only regard it as a chance occurrence where development was accelerated in certain individuals by some unknown factor but that they were incapable of reproduction.

The effect of this phenomenon on the epidemiology of the total population was negligible, although had it occurred later it would have been listed as a mortality factor, as those individuals were lost to the normal population. In 1949, this would have averaged 20 per cent, in 1951 about 10 per cent in the areas where the phenomenon occurred. Had offspring of this off-cycle population become established, we would have had to consider it as a separate population.

1.2. The host

Lodgepole pine is found from lower California to Alaska and the Yukon Territory and from sea level to an elevation of 11,000 feet in the Rocky Mountains. Some botanists recognize coastal and inland forms of lodgepole pine. The former is sometimes designated as *Pinus contorta* Dougl. whereas the inland form from north to south is known as *Pinus contorta* var, *latifolia* Engelm.(76). In the outbreak area of *Recurvaria starki* Free., *Pinus contorta* var. *latifolia* Engelm. (= *P. contorta* Dougl. of Freeman) is the sole host.

The distribution of lodgepole pine in Alberta is shown in Figure 3 (82). The Alberta distribution given by Moss follows closely that given by Halliday and Brown (39) except for the region between Edmonton and Peace River.

1.3. Description of the region.

Needle miner populations were found in four national parks; Banff, Yoho, Kootenay and Jasper. The outbreak dealt with in this thesis was more extensive and severe in Banff Park than in any of the others (Figure 4 and flyleaf).

The terrain is mountainous, the mountains being steeper and more rugged on the east side than on the west. The parks are similar in that there is a relatively narrow valley in each with steep, high sides formed by the mountain ranges, often up to 10,000 feet in height. In Banff the direction of the valley is west-north-west; in Kootenay south, in Yoho, west. Timberline varies from about 6,500 feet in some areas to 8,000 feet, being around 7,200 feet in the Banff area (83). Valley bottom varies in altitude from about 4,000 feet at the eastern approaches to almost 5,000 feet at the Continental Divide.

The outbreak areas fall within Halliday's sub-alpine forest region SA-1 (East Slope Rockies section). His description reads (38): "A characteristically coniferous forest covers the eastern slope of the Rockies from around the 4,000 foot elevation to the tree line. The sub-alpine dominant engelmann spruce forms the bulk of the forest cover, the subclimax lodgepole pine being mixed with this species following fires and often forming large areas of stands of varying degrees of purity. Alpine fir enters toward the tree line, together with white-bark pine and, in the south, alpine (Lyall's) larch. Along the lower slopes, in the southern parts, there is some intrusion of Douglas fir from the Montana forest region and a fringe of aspen occurs where the section comes into contact with the Grassland formation."

Figure 3. Alberta distribution of lodgepole pine, _Pinus contorta_ var. _latifolia_ (After Moss, 1955).

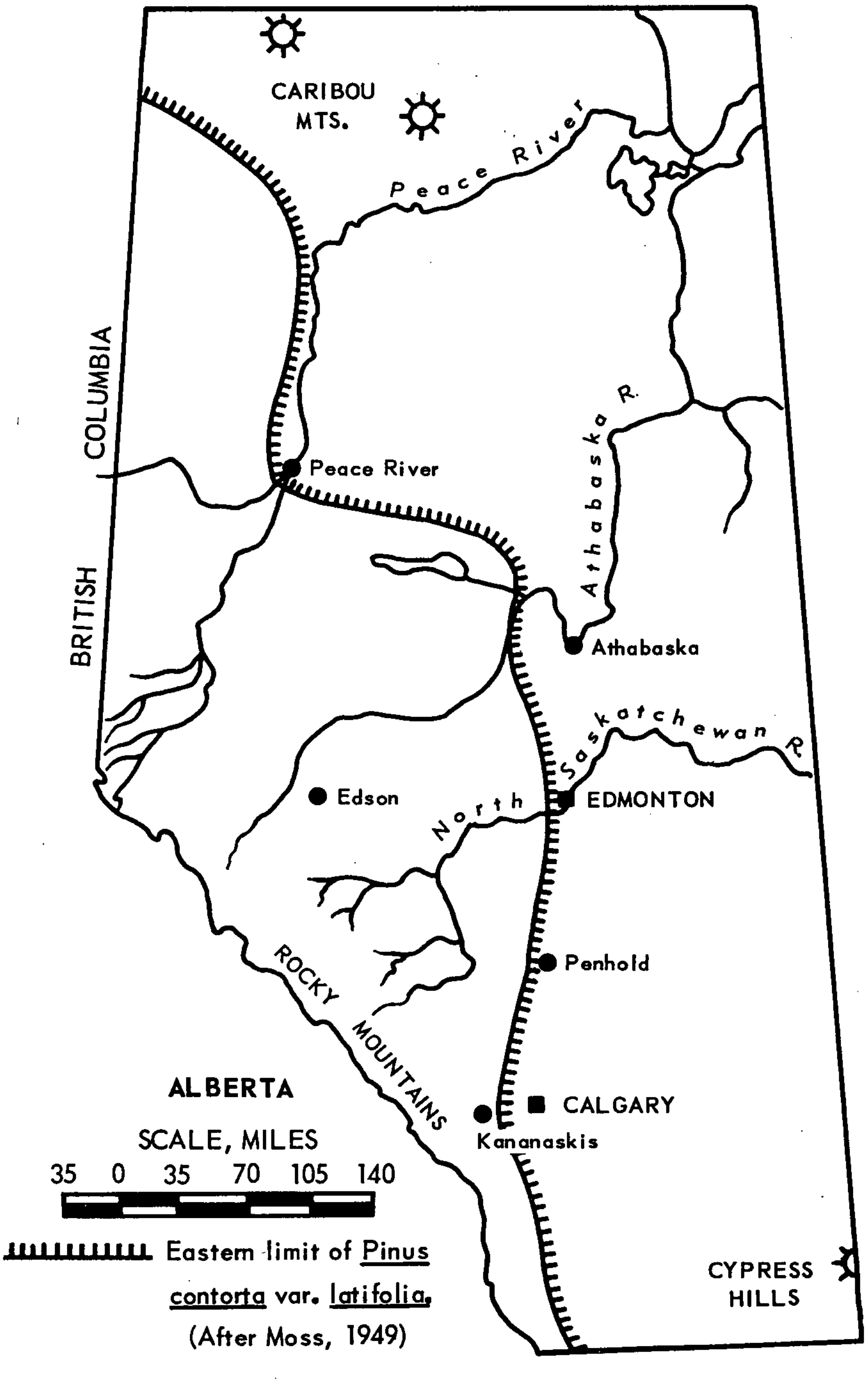
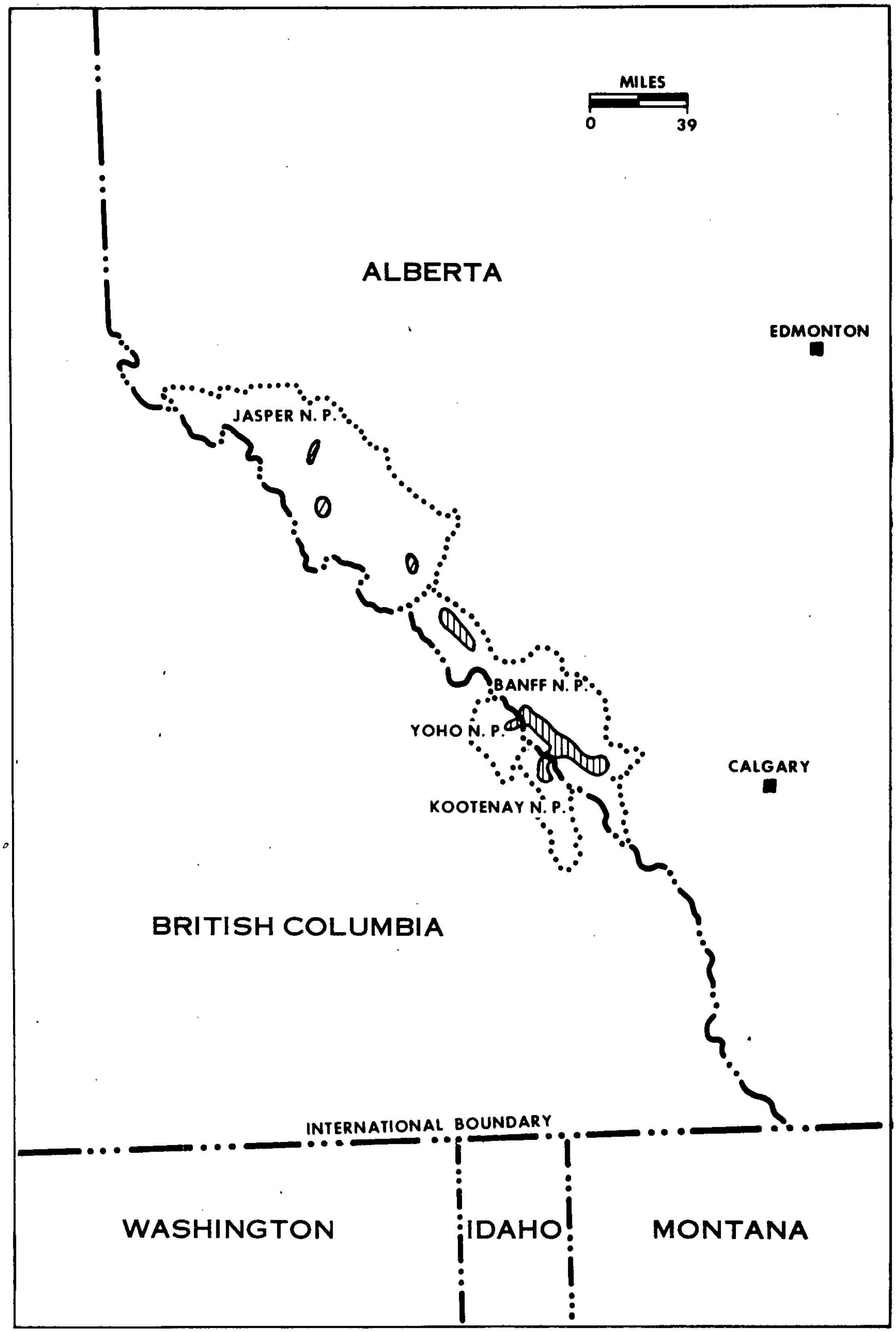

CARIBOU
MTS.
Peace River
Athabaska R.
Peace River
Athabaska
BRITISH
COLUMBIA
North Saskatchewan R.
Edson
EDMONTON
Penhold
ROCKY MOUNTAINS
ALBERTA
SCALE, MILES
35 0 35 70 105 140
CALGARY
Kananaskis
Eastern limit of Pinus contorta var. latifolia.
(After Moss, 1949)
CYPRESS
HILLS

Figure 4. Map of western Canada showing location of needle miner outbreak (circa 1948). Hachured area represents the outbreak.


MILES
0
39
ALBERTA
EDMONTON
JASPER N. P.
BANFF N. P.
YOHO N. P.
KOOTENAY N. P.
CALGARY
BRITISH COLUMBIA
INTERNATIONAL BOUNDARY
WASHINGTON
IDAHO
MONTANA

Horton (59) describes the area as the "subalpine division" corresponding closely to Halliday's SA-1 section. He, however, states: "the characteristic tree species is engelmann spruce but subclimax stands of lodgepole pine predominate. White spruce replaces engelmann in the lower valleys and hybrid forms of the two species are common in the intermediate zone. Black spruce is present in this division only north of the north Saskatchewan River and then only at lower levels, presumably as a result of intrusion from the foothills along the low Athabasca valley. Alpine fir is a frequent component, particularly in older stands. Douglas fir occurs spasmodically in the three main mountain passes, which distribution suggests intrusion from British Columbia. The poplars attain fairly good development in protected valley sites but seem incapable of competing with the coniferous species on the mountain slopes."

Horton divides the Eastern Slopes area, adjacent to the outbreak area, into two divisions, High Foothills and Low Foothills both of which lie in Halliday's B19 or Foothills Section of the Boreal Forest Region. The High Foothills division is "a long narrow strip of country typified by high wooded hills and deep valleys, usually between the altitudes of 4,000 and 6,000 feet." Lodgepole pine is again preponderant but white and black spruce are the major species. Alpine fir is less prevalent than in the mountains and poplar is relatively unimportant. The Low Foothills Division is comprised of low hills and plateaux from 2,000 to 4,000 feet elevation. The main difference between this and the High Foothills Division is the prevalence of mixedwood types. Aspen and balsam poplar are able to compete with lodgepole pine as post-fire pioneers. White and black spruce are common but alpine fir is rare.

Hopping (54) recognizes six distinct timber types in the Canadian Rocky Mountains (none of) which disagree essentially with the descriptions given by Halliday and Horton.

The main forest cover in the outbreak area consists of lodgepole pine stands of varying ages but largely mature (80 years or over) with a spruce understory. The extensive stands of lodgepole pine resulted from a series of fires late in the nineteenth century. Horton (59) suggests that succession from pine to engelmann spruce-alpine fir is indicated for the sub-alpine region and the High Foothills region, with the substitution of white spruce for engelmann and the addition of black spruce. Such successions may be completed in periods ranging from 225 to 325 years. Moss (83) reviewed the literature on succession in lodgepole pine in Alberta and his views regarding the successional position of lodgepole pine agree with those of Horton.

1.4. Historical review.

The outbreak was first noticed in June, 1942, on an area of approximately 50 square miles in Banff National Park where it joins Kootenay National Park at Vermilion Summit (11). The attack was largely confined to elevations between 5,000 and 6,500 feet from Vermilion Pass east to Brewster Creek on the south side and only four miles eastward on the north side of the Bow River. It was practically non-existent at valley bottom (45). A slight decrease was noticed in 1943 (47,48,62) but in 1944 it had spread into Yoho and Kootenay Parks for short distances. No marked altitudinal change was observed (63). In 1945 the area of the outbreak was estimated as 200 square miles in Banff, Yoho and Kootenay Parks, largely in the first (64). This estimate was revised to 300 square miles in 1946 (65). Surveys indicated that the outbreak had spread eastward almost as far as Banff, south into Kootenay Park as far as Hawk

Creek, north along the Banff-Jasper Highway to Hector Creek and for several miles westward into Yoho Park from Wapta Lake (52). It was also noted that the population had increased in stands below the 5,000 foot levels, that is, in valley bottom stands (51).

In 1947 D.K. Campbell of the Vernon Forest Insect Laboratory spent some time studying the outbreak. He attempted to determine the populations present and experimented with chemical control. His results were inconclusive (13,14,15).

The fourth generation of needle miner under observation (1946-48) increased in distribution to 400 square miles in the outbreak region (69). A second outbreak, centred in Jasper National Park, was reported. This was entirely separate from the more southerly outbreak occurring on the slopes below Mount Edith Cavell (70,108), and was thought to be autochthonous (35).

The Calgary Laboratory of Forest Zoology (later Biology) was established in May, 1948. One of its original projects was the lodgepole needle miner and the writer was assigned as project leader that year. Main objectives included the determination of the life history, precise sampling methods and possible controls (53).

In 1949, K. Graham of the University of British Columbia was assigned seasonally to the project with the author. Considerable data were gathered on life history and sampling procedures (32,34,110,111).

The distribution in 1949 included areas adjacent to the Eastern Slopes forests. In Jasper the infestation was continuous throughout the upper Sunwapta and Athabasca valleys on the forest floor but confined to the higher altitudes in the northerly sections of Jasper Park. The outbreak was generally light but two areas were more seriously infested (36,71).

Results of experiments conducted by Graham and Stark in 1949 (35,112) indicated little hope of success in chemical control.

During the winter of 1949-50 there was high mortality of lodgepole needle miner larvae. The region particularly affected was from the Great Divide eastward to the eastern limit of the outbreak. Populations were practically eliminated in stands at valley bottom (56,57,113). Additional information on natural controls and life history was obtained (55,103).

During 1950-51 further studies were made on the effects of winter temperatures on larvae and diapause was found to be facultative (58). Temperature was found to have a profound effect on larval feeding behaviour (129). From material collected during the moth flight year in 1950 a clearer picture of the parasite complex began to emerge (33,114).

In 1952 the number of larval instars was determined (120) and a precise sampling technique was perfected. The average number of larvae per branch tip (including five years' needles) was accepted as the sample unit; four branch tips were taken from two crown levels in each tree and the average number per branch tip per tree calculated for each crown level (115,116). This system was established by sampling 40 trees at valley bottom, 35 at the 750 foot elevation and 30 trees at the 1,500 foot elevation (from valley bottom) on Cathedral Mountain in Yoho National Park and has since been tested in all sampling areas. For practical purposes the lower crown samples could be eliminated and the measure of the outbreak taken as the average number of larvae per tip in the more vital upper crown. Since this technique was established it has been modified slightly. Samples are now taken from the upper third of the crown with an extension pole pruner (78) from several trees, until the accuracy desired is obtained. Conversion of population estimates by this method to a per tree basis or per acre basis was made possible by the determination of the relationship of number of branch tips per tree to tree height (33). A sampling technique designed for rapid population estimates was derived on the sequential plan. In this system the outbreak was classified as light, medium-low, medium-high or heavy. Sampling was continued until the estimate fell into one of the four classes (116,121).

Ecological studies were made on the effects of solar radiation on temperatures within the needle mines, by Henson and Shepherd (42). Their results showed that orientation and aspect of the needle, extent of the mine, and the presence or absence of wind modified the heating effect of radiation. On clear nights the mine temperatures were below air temperature, on clouded nights slightly higher. At the highest radiation level mine temperatures exceed air temperatures by as much as 6.8 F.°.

In 1953, there was a reduction in populations throughout the outbreak areas. Intensive studies were commenced on the damage done by the lodgepole needle miner in collaboration with J.A. Cook.

Curves were prepared from which it was possible to predict the amount of defoliation expected from a given needle miner population. Increment and growth studies based on the work of Duff and Nolan (27) were begun by Cook (84).

In 1954 the life history and distribution data were integrated and published (123) and a tentative theory was advanced for periods of high winter mortality observed since 1948 (43). Beginning that year, a systematic approach to population dynamics was begun. The method proposed was that of the life table - a systematic tabulation of a measureable portion of the population throughout its life cycle (125). The studies presented in this thesis cover the period from 1953 to 1957 during which the author was enrolled at the University of British Columbia. Distinct from the population dynamics studies to be presented, however, are two publications resulting from intensive growth studies. The first summarizes the damage done to lodgepole pine in the outbreak area (128) and the second deals with critical growth studies of lodgepole pine in the outbreak region (84). These studies permit certain deductions to be made concerning past population history. Portions of the authors' summary of the paper on needle miner damage will give some indication of the potential importance of this insect in forests.

"1. It was demonstrated that the lodgepole needle miner caused as much as 80 per cent defoliation of lodgepole pine in Banff National Park. The defoliation did not, except in a few overmature trees, reach 100 per cent. The period of greatest defoliation probably occurred from 1940 to 1944. Since 1945 there has been a decrease in defoliation varying in location with differences in needle miner populations, until at the present time (1956), maximum defoliation in any part of the outbreak is not above 40 per cent. Had the outbreak continued at levels present from 1940 to 1944, mortality of trees would have occurred, probably by 1960.

2. A method is presented whereby it is possible to estimate percentage defoliation, expected tree mortality and approximate time to tree mortality from population estimates obtained by survey sampling.

3. Terminal and lateral growth were significantly reduced by a defoliation of 40 per cent with negligible reduction at 10 per cent.

6. Analysis of many (tree rings) in the course of these studies clearly showed a lag in effect of defoliation on increment between the upper and lower bole."

2. LIFE TABLES FOR THE LODGEPOLE NEEDLE MINER

2.1. Review of life tables in entomology

The importance of life tables in epidemiological studies has become increasingly important since the review by Pearl and Miner (94). Their recognition of the necessity of following a statistically acceptable cohort of an organism throughout its life cycle to achieve this was perhaps the beginning of the intense interest which has since been generated. The extensive review by Deevey (24) focussed ecologists' attention on the transition of demographic life tables to ecological life tables. The limiting factor to their use in ecology has been the development of suitable techniques for measuring natural populations. Prior to Deevey's review the use of life tables was recognized in few textbooks. Leopold (66) gave a comprehensive review of ecological life tables which he called "life equations". Bodenheimer (9) discussed the concept at some length for insects as well as mammals and birds. Since Deevey's review at least three major ecological texts have devoted considerable space to discussions of life tables. These are: Allee, Emerson, Park, Park and Schmidt (2), Odum (92), and Andrewartha and Birch (3).

The use of life tables in forest insect population dynamics has lagged behind that for other organisms. Again, this is largely due to the lack of suitable sampling techniques. A form of life table for insect populations has been in use in Europe since at least the 1930's. Schwerdtfeger, in his concise text "Fundamentals of Forest Pathology" presents what is intrinsically a life table: that is, the graphic presentation of the "intracyclic change" for a generation of Panolis flammea Schiff ((Panolis griseovariegata (Goeze), pine beauty, of Varley (146)). These are linked for many successive generations to compile "Gradation" or infestation curves (102). Varley, in 1947, published his intensive studies on the Knapweed gall-fly where he followed the reduction of populations as a result of natural mortality factors. His sampling periods were at short intervals and he was able to describe the action of natural control factors in some detail (145). His methods were essentially the life table approach. Morris and Miller, in 1954, presented the first detailed example in North America of a life table designed specifically for a forest insect, the spruce budworm (81). This excellent paper introduced a series which follows the development of techniques with the objectives of compiling life tables for long-term studies of population dynamics. When completed this series should stand as a model for future workers for a long time to come.

2.2. <u>The preparation of life tables</u>.

The life table is a continuous quantitative record of the abundance of an insect throughout its life and as such is dependent upon suitable techniques for measuring changes in population level. It is of fundamental importance in the study of population dynamics but only if records are kept for successive generations and the mortality factors determined.

The method used in formulating life tables for the lodgepole needle miner is that used in standard demographic tables but with the inclusion of a column for listing and separating mortality factors and the elimination of the column giving "life expectation" (81). Andrewartha and Birch (3) define the life table (lx table) as: "the age-schedule of survival. For any particular age-group of pivotal age x, lx is the proportion of individuals alive at the beginning of the age-interval." However, life tables as are commonly used also include their "dx table", or that giving the age-schedule of mortality. The terms and columns used are best defined by Allee et al. (2).

"Conventionally, a life table is a series of columns each of which describes something about the mortality relations within a population when ages of the components are taken into account. Conventionally also, a life table starts with a certain sized group....at its time of birth and tabulates the events to which that cohort is subjected.....This tabulation takes the following form:

x - Age in appropriate units stated as an interval.

lx - the number surviving at the beginning of the age interval stated in the x column.

dx - the number dying <u>within</u> the age interval stated in the x column.

qx - the number dying in the age interval divided by the number of survivors at the beginning of the intervals. The rate of mortality.

ex - life expectation. Mean length of life remaining to each organism alive at the beginning of the age interval."

In demographic life tables age intervals are generally equal, beginning at age zero or birth. In some cases age at fertilization is considered (24) but this obviously is often impractical in studies other than demographic. In forest entomology the egg stage is generally considered as age zero. Also, with insects it is often impractical to sample at equal intervals because it may not be possible to sample certain life stages in the same manner as others and sampling may be prohibited by seasonal behaviour. Therefore age intervals appearing in the x column generally represent major stages in the life cycle or "susceptible stages". These will be described in greater detail in the following section.

The origin of the life table conventionally starts with a certain-sized group, usually 100,000 or 1,000 (2,24). In forest entomology, an important objective is to determine how mortality factors are affected by population density changes of the insect from generation to generation. Therefore, as recommended by Morris and Miller (81), lx is given as an actual population estimate, the number of individuals per five-year branch tip (117). When populations are low this necessitates the use of fractions so that for convenience the figure is taken as 100 lx or the number of larvae per 100 tips.

Similarly qx is usually expressed as rate per 1,000 population or 1,000 qx (24) whereas for our purposes it is more convenient to use 100 qx, i.e., percentage mortality (81). No immediate value for inclusion of the "life expectation 'ex' column" in needle miner work could be seen and so was discarded.

The value of a column describing mortality factors responsible for the corresponding mortality (dx) is obvious (81) and so is incorporated in needle miner life tables.

2.3 Life tables for the lodgepole needle miner

Graham (31) pointed out the suitability of the needle miner as an insect for critical population studies. He recognized a number of "crucial trials" through which any insect must pass if it is to survive and by implication "succeed" in the sense of great abundance. For the needle miner he mentions the following "trials":

(a) The obtaining of adequate food reserves for the maturing larvae
(b) Successful pupation and öogenesis
(c) Successful fertilization in the adult stage
(d) Oviposition
(e) Eclosion
(f) Establishment in the needles
(g) Larval growth from establishment in the fall of an even year to the spring of the next even year.

Each of these trials includes many environmental factors which may affect the insect at that particular stage. A discussion of these must wait for a later section. However, the relation of the stages listed above to the sampling stages decided upon merits some discussion here. The sampling stages chosen for the needle miner were based upon practical considerations as well as theoretical. They were chosen with a view to obtaining as much critical information as possible within the limits of practicality.

The development of sampling techniques for the needle miner was not faced with as many difficulties as are many other forest insects, like the larch sawfly (142) or the spruce budworm (79). The former presents the difficulty that the pupal stage is spent in a different sampling universe than the larvae; the latter, among others, that the larvae are subject to wide-spread dispersal. Eggs of the needle miner are deposited in old, mined needles (103,123). The larva spends its whole existence within three mined needles except for the short time taken for transferring from one needle to another, and pupates within the last mine. Consequently, the only truly mobile or dispersable stage of the needle miner is in the moth stage.

The sampling intervals for needle miner life tables are illustrated in Figure 2 along with a schematic illustration of the life cycle. Described in detail, they are:

X-1 The egg stage. The distribution of needle miner eggs in lodgepole pine trees is similar to that of the larvae (126). Oviposition is greatest in the upper crown, least in the lower crown. Upper crown samples give the maximum population estimate for a tree, mid-crown samples a reasonable average (117). Variability between trees arises from differences in crown length and stand density. The larva upon hatching usually mines a needle in the same tip if available, within a few hours of eclosion. For egg and larval sampling therefore, mid-crown samples are taken where time does not permit sampling all crown levels. Distribution of the eggs within oviposition sites (empty mined needles) is relatively constant for any one area and the five-year branch tip samples are therefore convertible to a "per tree" basis and from that to a "per acre" basis if required (33).

The time of sampling of this stage is naturally dependent upon completion of oviposition. Generally, this is about mid-August, but as the weather during the summer affects both moth emergence and oviposition the progress of these events must be checked before intensive sampling is done. Hatching usually commences within one to three weeks after the completion of oviposition, leaving a limited period to make the sample. The sampling technique is necessarily slow and painstaking. Careful dissection of the needles is required for an accurate egg count. They are usually laid within a few millimetres of the moth emergence hole (103) (Figure 1) but with disturbance frequently fall to lower levels in the needle. The eggs are large enough to be counted by the naked eye or with a low-power hand lens. Sampling is usually continued on a per tip basis until a mean number per five-year-branch tip within set error limits is reached (standard error less than 10 per cent of the mean).

Egg sampling was attempted on a large scale for the first time in 1954. Three areas were sampled, Mount Eisenhower (5,400 feet), Brewster Creek and Baker Creek on four separate days, August 9, 10, 17 and 19th. On the last date the three samples were taken at the same time of day by three separate workers from the mid-crown of the trees. A total of 1500 mined needles was opened and eggs counted. Eggs were laid singly and in bunches up to as many as 23 in one needle. One needle contained 46 eggs in two clusters. Table 1 presents a summary of these data (124).

TABLE 1
EGG SAMPLING - 1954

Area	Elevation	Mean number needles containing eggs (in groups of 50)	Mean number eggs per needle
Mount Eisenhower	5,400	15.8	4.95
Brewster Creek	5,700	12.2	3.97
Baker Creek	6,000	11.8	2.79

No significant difference between means for the utilization of oviposition sites (empty, mined needles) was found. As populations prior to moth flight were comparable, this was to be expected. However, the mean number of eggs laid at Baker Creek was significantly less than on the other two areas.

In 1956, egg sampling was carried out in the four areas chosen for continuous life table sampling, Mount Eisenhower, Mount Girouard, Massive Mt. and Cathedral Mt. in Yoho National Park. Three hundred branch tips from mid-crown of several trees in each locality were examined. Table II presents a summary of the results of this examination.

TABLE II
EGG SAMPLING - 1956

Area	Elevation	Total No. Mined Needles	Number containing eggs	Total No. eggs found	Average per needle	Average per tip
Mt. Eisenhower	5,400	3423	441	1133	2.6	3.8
Girouard	6,000	2287	390	1151	3.0	3.8
Massive	5,500	1380	105	228	2.2	0.8
Cathedral	4,700	953	42	89	2.1	0.3

Some interesting comparisons may be made between the results of this and the 1954 sample but as these have a bearing on natural mortality and epidemiology, discussion will be left to a later section.

The estimates made in 1956 were on a comparable basis to the first larval examination made in September, 1956. These are compared in Table III.

TABLE III
COMPARISON OF EGG SAMPLING AND FIRST LARVAL ESTABLISHMENT
1956

Area	Average number of eggs per tip (Table II)	Average number of larvae per tip
Eisenhower	3.8	3.1
Girouard	3.8	4.0
Massive	0.8	1.9
Cathedral	0.3	0.6

In two areas therefore, established larval populations were double those expected from the egg sampling. Two explanations bearing equal weight are responsible for this and, fortunately, both are susceptible to correction in the future.

(a) Time did not permit the usual practice of sampling until estimates were equally accurate and sampling was therefore limited to 300 tips per area. At the Massive and Cathedral stations populations are much lower than in the other two areas and these areas should have been more intensively sampled.

(b) During the egg sampling period a total of five assistants were used. These included one other research officer, one laboratory technician and three student assistants. This variety of help was at its peak when sampling the two areas, Massive and Yoho. In an attempt to ascertain the source of the error involved an analysis of variance was made comparing the workers' efficiency. It was found that two of the workers were unsuited for the critical work of finding and counting eggs.

The combination of these two sources of error thus led to low estimates for the two areas and must be taken into account prior to future egg sampling. The occurrence of this error does not permit any speculation concerning the progress of the population from oviposition to larval establishment.

More time and space have been devoted to describing this sampling interval as the results of this work have not yet been published in detail.

X-2. First larval sample. This sample is taken in late September or early October and can be done without dissection of the needles. The new mines are thread-like and careful examination of the tips is necessary for accuracy. Entrance into the first needle is almost invariably in the distal quarter of the needle and from the curved surface. The needle epidermis over the fresh mine is a pale green in contrast to the dark green of the unmined portion of the needle. Often the larva is visible under the epidermis of the mined portion. Unsuccessful mines are also detectable without dissection but these are usually checked.

The larva present may be first or second instar depending on the time of sample; ecdysis usually occurs before winter hibernation. The advantage of sampling at this time is that it determines the established starting population and the loss of needle miner larvae between eclosion and establishment.

New mines per branch tip are counted from as many tips as necessary to achieve the desired accuracy. This procedure is followed for all larval and pupal sampling.

X-3. Second larval sample. This is done after diapause is broken the following spring and fresh feeding is noticeable. Past studies have indicated that winter mortality is one of the major factors in population reduction (43,123). If the sample is left too late the larvae killed during the winter period dry and shrivel and are hard to find. A fairly accurate estimate can be made by counting the mines showing fresh feeding and obtaining the mortality estimate by subtraction from the first larval sample (X-2). However, if time permits, greater accuracy is obtained by actual counts of dead larvae. This permits a precise check of the previous autumn's sampling.

A portion of the dead larvae are examined for incidence of disease. This work is now performed by Miss M.E.P. Cumming of the Calgary Laboratory. Disease examinations prior to 1954 were made by members of the staff of the Forest Insect Disease Laboratory, Sault Ste. Marie, Ontario.

X-4. Third larval sample. This sample determines the population which will hibernate during the second winter. Again, it is possible to do this without dissection of the needles by inspecting and counting the fresh mines. Third-and fourth-instar larvae are present in the autumn of the second year and are large enough to be seen in the mined needle. The population reduction over the summer can be determined by substraction from the spring sample (X-3). Mines in which the needle miner have been killed during the summer are characteristic, the pale green resulting from feeding being absent and previously mined portions drying to a straw color. As long as the larva lives, fresh feeding can always be distinguished.

Experience has shown that this sample may be omitted without much loss in accuracy. Mortality during the summer of the larval years, even though a transfer from the first to the second needle is effected in mid-summer, has always been extremely low.

X-5. Fourth larval sample. This is an extremely important sampling period as it shows the second winter's mortality and the larval parasite complex. Sampling must be done after mid-May as prior to this the parasites have not developed sufficiently to be visible. Mass insectary rearings are necessary to check parasitism estimates and to obtain pertinent information on parasite biologies. Parasitism is not generally evident prior to this time except by larval sectioning or dissection. Again, a portion of the larvae found dead is examined for incidence of disease.

X-6. Pupal sampling. After moth emergence, careful examination of pupal cases will yield information on pupal parasitism, mortality from other causes, moth population and the sex ratio. However, it is much simpler and more in keeping with the principles of life tables to obtain this information from mass insectary rearings and to check these results with limited field samples. It is possible at the time of the last larval sample (X-5) to differentiate the status of each miner examined without undue disturbance of the larva. Once recorded for the purpose of that sample, the specimens are then placed in a field insectary for rearing. Field checks are necessary to avoid any artificial effect which may arise from insectary rearings.

These sampling intervals, one egg, four larval and one pupal, are the ones deemed suitable to assess the course of the population of a single generation from the time of oviposition to moth emergence of the needle miner. The emphasis on sampling of the larval stage is understandable from the life cycle. Approximately 89 per cent of the life cycle of the needle miner is spent in the larval stage, covering the most adverse climatic periods, 4.3 per cent is spent in the pupal stage, 4.3 per cent in the moth stage and slightly more than two per cent in the egg stage. Whenever possible, extra samples are taken, as the oftener the population is sampled the more information on population dynamics is obtained.

However, these facts do not detract from the importance of the pupal, moth and egg stages in population ecology. In many, perhaps most instances, one of these may be the determining factor in population rise and fall. To fully understand long-term fluctuations of the population in succeeding generations it is necessary to link together the life tables of each generation through the reproductive stage. The comparison of established larval populations will give the trend of the outbreak but will not yield any information on reductions which occur in the critical reproductive stage. The adult stage cannot be sampled by any of the means described and other study methods must be used.

Two methods have been used in attempts to determine moth fecundity: controlled matings and moth dissections. The conditions for successful mating of needle miner moths have never been met as attempts to mate moths in captivity have been singularly unsuccessful. Perhaps flight is necessary prior to copulation. Moth dissections were made in 1950, 1954, and 1956. When the 1956 results of moth dissections were compared with actual numbers of eggs found and larvae established the counts by dissection were found to be too inaccurate to use. Until the problem of mating the moths in captivity and inducing them to lay their eggs can be surmounted we can only speculate from observations made by dissection and in the field on oviposition behaviour. Indications are that there has been a reduction in fecundity, at least since the 1954 generation. The evidence for this, and implications of it, will be discussed in the natural controls section.

2.4 Examples of needle miner life tables.

Life tables are presented for needle miner populations from four localities in the outbreak area. These are:

(a) Mount Eisenhower, Banff National Park. The sample area is located 22 miles northwest of the town of Banff, Alberta, on the east side of the Bow Valley. Two altitude levels are represented: Valley bottom (4,800 feet a.s.l.) and 5,400 feet. Partial life tables based on actual samples are presented for three generations for the valley bottom and four for the higher elevation. Only the tables for the 1954-1956 generation follow the system described for their formulation.

(b) Massive Range, Banff National Park. This area is located about eleven miles northwest of Banff on the west side of the Bow Valley. The altitude level sampled is approximately 5,500 feet. Only the life table for the 1954-1956 generation is presented.

(c) Mount Girouard, Banff National Park. This area is located about nine miles northeast of Banff on the south side of Lake Minnewanka parallel to the opening of the Cascade Valley. The elevation is approximately 6,000 feet. Only the 1954-1956 generation is presented.

(d) The Kickinghorse Pass, Yoho National Park. This area is located on a north-facing slope of Cathedral Mountain about 250 feet above valley bottom (elevation 4,700 feet a.s.l.). Only the 1954-1956 generation is tabulated.

Example 1. Mount Eisenhower - valley bottom. These are presented in Tables IV to VI. Life tables for the 1948-1950 (Table IV) and the 1952-1954 (Table V) generations are incomplete but the sample periods are so timed as to show the major mortality factors. The life table for the 1954-1956 generation (Table VI) shows that there was no measurable population after the winter of 1955-1956.

The number of larvae present per 100 tips in the lx column is based upon actual samples statistically evaluated and indicates estimated numbers within plus or minus 10 per cent of the mean (117). The established larval populations following the 1948-1950 and the 1952-1954 generations agree fairly well with the expected number of eggs.

What is demonstrated clearly by these tables is the existence of three periods, when natural control factors may drastically reduce the larval population. These are the two overwintering periods and the spring of the last year of the life cycle when parasitism becomes effective. The winter of 1949-50 accounted for 78 per cent of the population (Table IV). In the winter of 1953-54, between December 16 and February 5, almost 95 per cent of the population was killed (Table V). During the winter of 1955-56 the whole measureable population died (Table VI). The data from valley bottom show that climate (the specific effect will be described in the following section) during all three generations represented, was the factor which in effect "controlled" the established population in this area from 1948 to 1956.

The life table lends itself readily to graphic presentation. Usually three graphs are derived from the table: the survivorship (lx) curve, the death (dx) curve, and the death-rate (qx) curve (24). As the death curve is merely the complement of the survivorship curve its value is questionable and in this presentation only the survivorship and death-rate curves are given for each area. The death-rate curve emphasizes the periods of high mortality with respect to the life stage affected. An addition to the conventional death-rate curve is the bar to the right of the curve. The solid portion represents the total mortality of the starting population.

Survivorship and death-rate curves are presented for the 1952-1954 and 1954-1956 generations from Mount Eisenhower, valley bottom in Figures 5 and 6. Figure 5 also presents the curve for the 1952-1954 generation from the 5,400 foot elevation.

TABLE IV

LIFE TABLE FOR THE 1948-1950 GENERATION OF NEEDLE MINER
MOUNT EISENHOWER - VALLEY BOTTOM

x	lx	dxF	dx	100qx
Sept. 1948 - June, 1949 I and II instar	3015	Climate	932	30.91
June 4, 1949 III and IV instars	2083	Climate Parasites	1622 459 2081	77.87 22.03 99.87
May 3, 1950 IV and V instars	2			
Pupae-no sample, assumed emerged	2			
Moths SR 50:50	M 1 F 1			
GENERATION			3013	99.93

Expected no. eggs per 100 tips = 24
Actual not measured.
Established larval population per 100 tips = 25
Population trend (larvae) = 0.8%

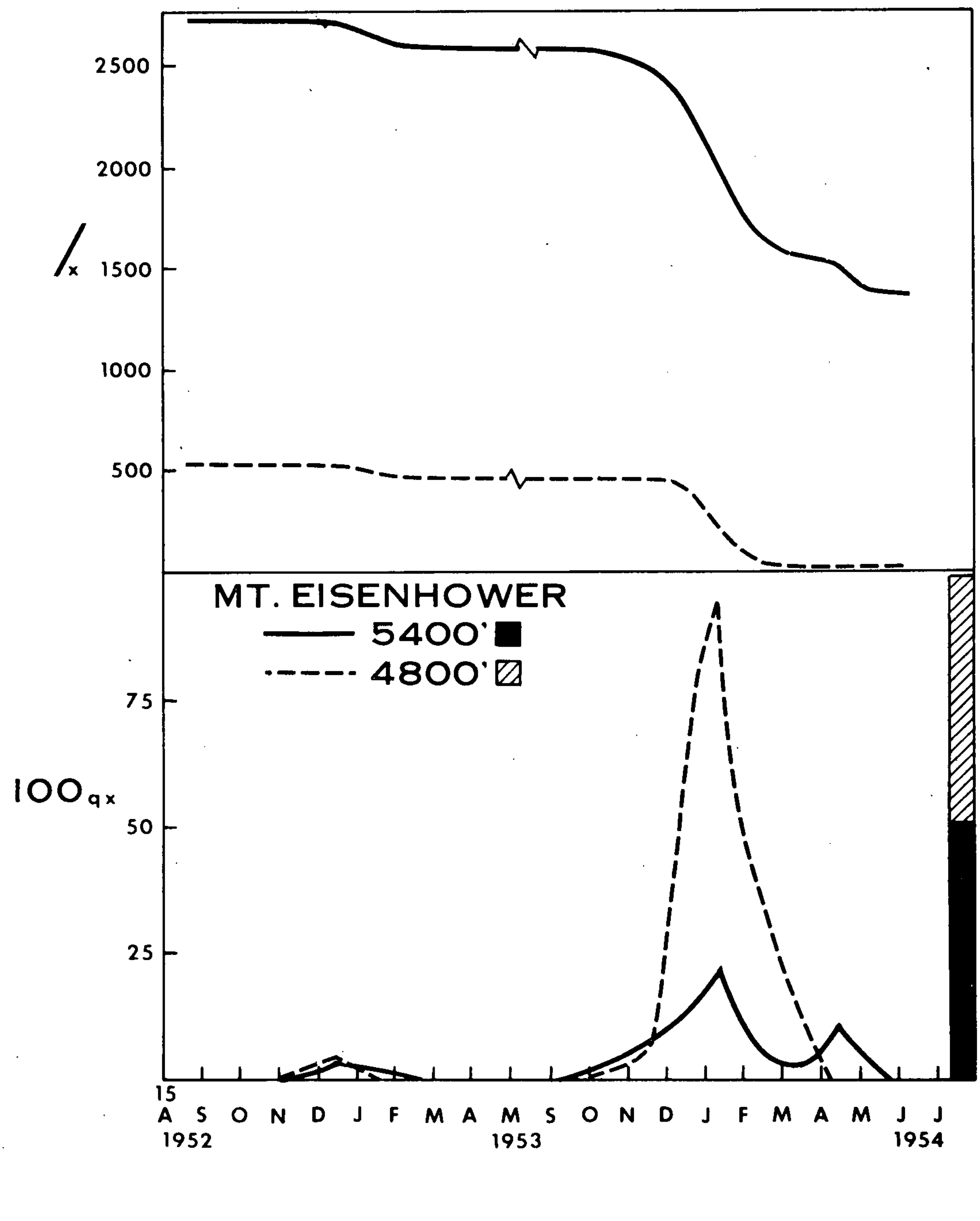
TABLE V

LIFE TABLE FOR THE 1952-1954 GENERATION OF NEEDLE MINER
MOUNT EISENHOWER - VALLEY BOTTOM

x	lx	dxF	dx	100qx
From eclosion to May 12, 1953. I and II instars.	505	Climate	26	5.2
May 12, 1953. II, III and IV instars.	479	Climate	21	4.3
Dec. 16, 1953. III and IV instars.	458	Climate	434	94.69
Feb. 5, 1954. III and IV instars.	24	Climate	19	79.17
June 2, 1954. V instar and pupae.	5			
Moths SR 50:50	M 2.5	F 2.5		
GENERATION			500	99.01

Expected eggs per 100 tips = 60
Actual not measured
Established larval population = 98 Population trend (larvae) = 19.40%

Figure 5. Survivorship and death-rate curves for Mount Eisenhower, valley bottom (4,800') and 5,400' for the 1952-54 generation of needle miner.



2500
2000
1500
1000
500
l_x
MT. EISENHOWER
5400'
4800'
75
50
25
100_{q_x}
15
A S O N D J F M A M S O N D J F M A M J J
1952
1953
1954

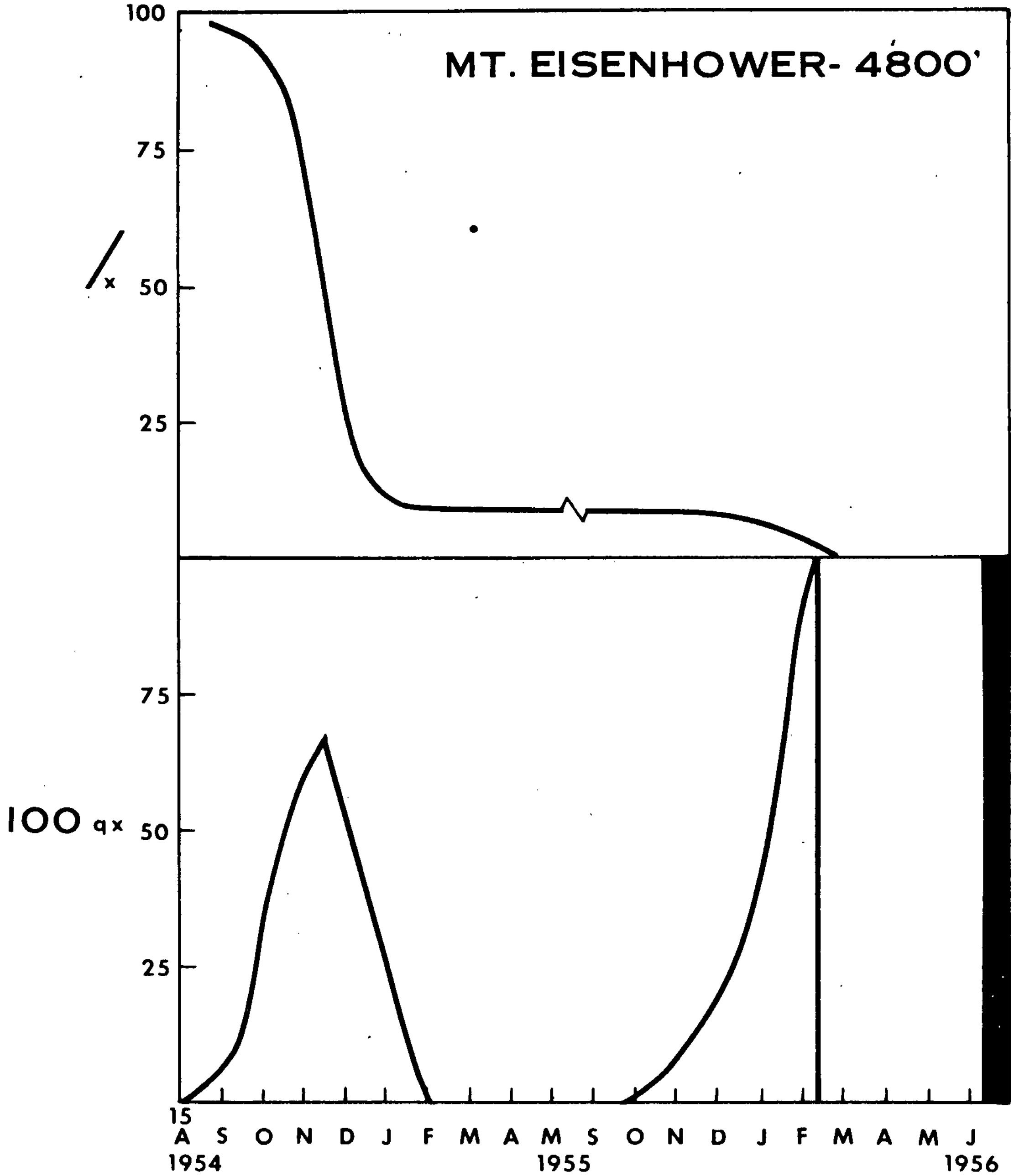
TABLE VI

LIFE TABLE FOR THE 1954-1956 GENERATION OF NEEDLE MINER
MOUNT EISENHOWER - VALLEY BOTTOM

x	lx	dxF	dx	100qx
Eclosion to Dec. 13, 1954 I and II instars	98	Climate	83	84.23
Dec. 13, 1954. II instar	15	Climate	7	46.67
Summer, 1955	8	Climate	8	100.00
June 26, 1956	0			
GENERATION			98	100%

Expected number of eggs - none

Figure 6. Survivorship and death-rate curves, 1954-56 generation. Mount Eisenhower, valley bottom (4,800')



MT. EISENHOWER- 4800'
100
75
l_x
50
25
75
100 q_x
50
25
15
A S O N D J F M A M S O N D J F M A M J
1954
1955
1956

TABLE VII

LIFE TABLE FOR THE 1948-1950 GENERATION OF NEEDLE MINER
MOUNT EISENHOWER - 5,400 FOOT ELEVATION

x	lx	dxF	dx	100qx
Eclosion to 1949. I,II and III instars.	3990	Climate	927	23.23
June 1, 1949. III, IV and V instars	3063	Climate Parasites	2199 450 2649	71.80 14.68 86.48
Pupae	414			
Moths SR 50:50	M 207 F 207			
GENERATION			3576	89.62

Expected no. eggs = 4968
Actual not measured
Established larval population = 2500

Population trend (larvae) = 62.7%

Figure 7. Survivorship and death-rate curves, 1954-56 generation. Mount Eisenhower, 5,400'.

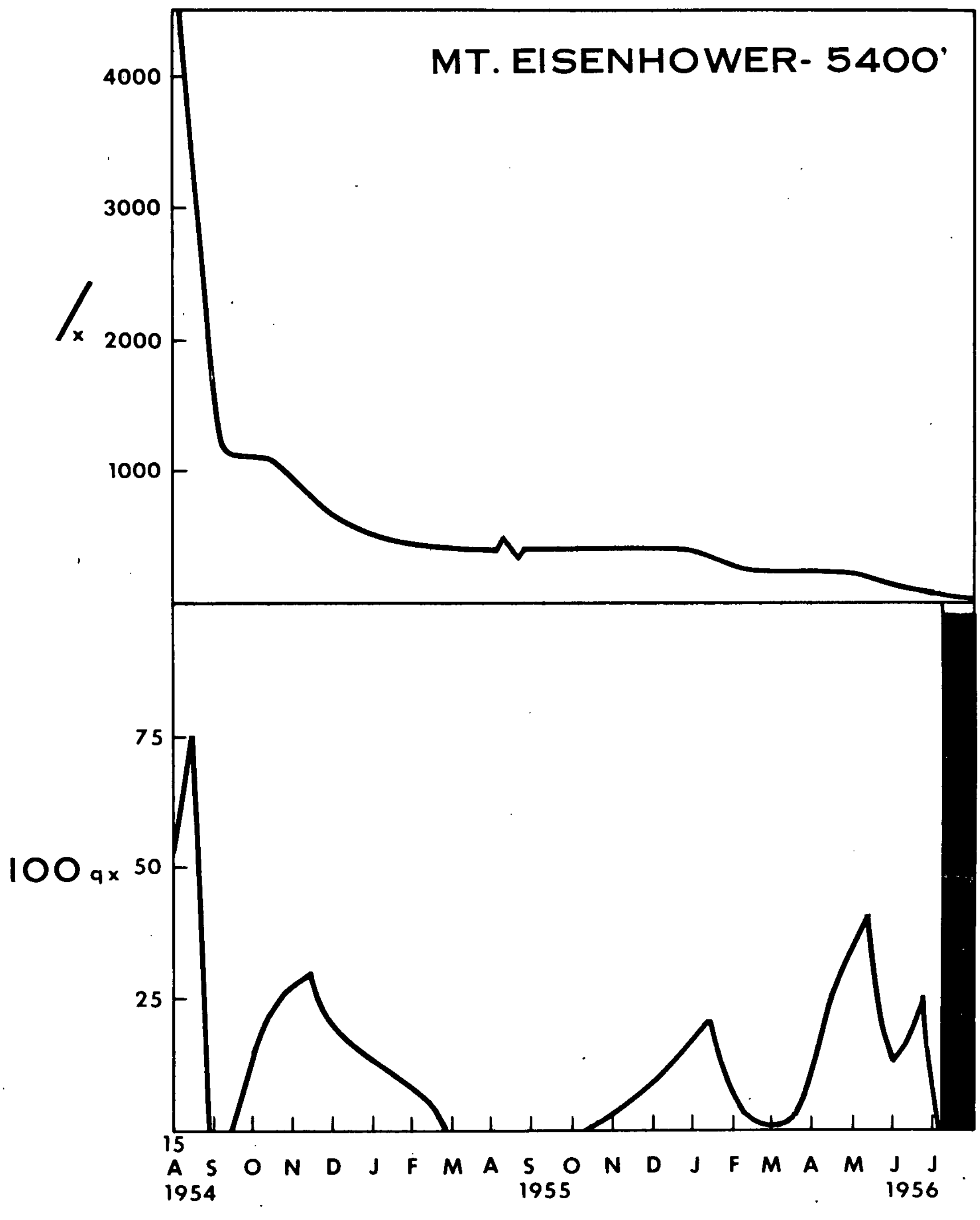

MT. EISENHOWER- 5400'
4000
3000
2000
1000
l_x
75
50
25
$100 q_x$
15
A S O N D J F M A S O N D J F M A M J J
1954
1955
1956

TABLE VIII

LIFE TABLE FOR THE 1950-1952 GENERATION OF NEEDLE MINER
MOUNT EISENHOWER - 5,400 FOOT ELEVATION

x	lx	dxF	dx	100qx
Eclosion to summer, 1951 I, II and III instars.	2500	Climate	500	20.00
Summer 1951 to spring 1952. III, IV and V instars	2000	Climate Parasites	315 85 400	15.77 4.23 20.00
Spring, 1952	1600			
Pupae, no sample, assumed emerged.				
Moths SR 50:50	M 800	F 800		
GENERATION			900	36.00

Expected number of eggs - 19,200
Actual not measured
Established larval population = 2709

Population trend (larvae) = 108.0%

TABLE IX

LIFE TABLE FOR THE 1952-1954 GENERATION OF NEEDLE MINER
MOUNT EISENHOWER - 5,400 FOOT ELEVATION

x	lx	dxF	dx	100qx
Eclosion to summer, 1953 I, II and III instars	2709	Climate	152	5.6
June 9, 1953. II, III and IV instars	2557	Climate	219	8.55
Dec. 16, 1953. III and IV instars	2338	Climate	604	25.81
Feb. 2, 1954. III and IV instars.	1734	Climate Parasites	248 236 484	14.30 13.60 27.90
May 25, 1954	1250			
Pupae not sampled, assumed emerged.				
Moths SR 50:50	M 625	F 625		
GENERATION			1359	50.17

Expected number of eggs = 15,000
Actual number of eggs 4,700
Established larval population = 1114

Population trend (larvae) = 41.1%

TABLE X

LIFE TABLE FOR THE 1954-1956 GENERATION OF NEEDLE MINER
MOUNT EISENHOWER - 5,400 FOOT LEVEL

x	lx	dxF	dx	100qx
X-1 -eggs	4700	Needle drop & unknown	3586	76.30
X-2 Instars I and II	1114	Climate	409	36.68
Extra- Dec. 14, 1954 II instar	705	Climate (winter (spring)	219 70 289	31.06 9.93 40.97
X-3 July 1, 1955 X-4 III and IV instars	416	Climate Parasitism Unknown	143 142 8 293	34.37 34.09 1.98 70.44
X-5 IV and V instars	123	Parasites	18	14.55
X-6 Pupae	105	Unknown Parasites less	26 than 1 26 +	24.76 0.45 25.21
Emerged	79			
Moths SR 48:52	M 38 F 41			
GENERATION			4621	98.32

Expected number of eggs = unknown
Actual number of eggs = 378
Established larval population = 308
Population trend (eggs) = 8.04%

Example 2. Mount Eisenhower, elevation 5,400 feet. This example is more complete than the first, as, following the severe winter of 1949-50 when it appeared that the higher elevations offered "refuge" areas for the needle miner (43) sampling was continued more intensively there than at the lower level. The life tables for this location are presented in Tables VII to X for the 1948-1950, 1950-1952, 1952-1954 and 1954-1956 generations. Survivorship and death-rate curves for the two later generations are presented in Figures 5 and 7.

The first three tables also demonstrate the importance of the two winter periods and of parasitism in the final year of the life cycle. The egg sampling, begun in 1954 and repeated in 1956 (Tables IX and X) indicates possibly two additional periods in the life cycle where natural control factors may effect drastic reductions in the egg stage. These are; between egg formation and actual oviposition and/or between oviposition and establishment of the larvae in the needles.

Again, climate is the predominant controlling factor, parasitism remaining low throughout the four generations indicating that the parasites are equally or slightly more susceptible to adverse climatic factors. Table XI presents the percentage parasitism based on the established larval population for the four generations (Tables VII - X). The heaviest larval kill was during the winter of 1949-50 and from the above this would appear to be equally true for parasites. Since that time however, where a residual larval population has remained, parasitism has increased. This will be discussed in greater detail in a later section.

TABLE XI

PERCENTAGE PARASITISM OF THE TOTAL ESTABLISHED LARVAL POPULATION

Year	Percentage Parasitism
1948-50	10.13
1950-52	3.40
1952-54	8.71
1954-56	14.36

<u>Example 3. Massive Range, Banff National Park</u>

A life table is presented for the 1954-56 generation only (Table XII). The survivorship and death-rate curves are presented in Figure 8.

<u>Example 4. Mount Girouard, Banff National Park</u>

A life table is presented for the 1954-56 generation only (Table XIII). Survivorship and death-rate curves are presented in Figure 9.

TABLE XII

LIFE TABLE FOR THE 1954-1956 GENERATION OF NEEDLE MINER
MASSIVE RANGE - 5500 FEET

x	lx	dxF	dx	100qx
X-1 Not measured				
X-2 Fall, 1954	1257	Climate		
I and II instar		(winter)	737	58.60
		(spring)	55	4.38
			792	62.98
X-3 Summer, 1955	465	Climate		
X-4 III and IV instar		(winter)	94	20.22
		(spring)	2	0.43
		Parasitism	123	26.45
		Bird predation	124	26.67
			343	73.77
X-5 Spring, 1956				
IV and V instar	122			
X-6 Pupae	122	Climate	30	24.84
Moths SR 45:55	92			
M 41		F 51		
GENERATION			1165	92.68

Expected number of eggs = unknown
Actual measured number = 76
Established larval population = 190
Population trend (larvae) = 15.11%

Figure 8. Survivorship and death-rate curves, 1954-56 generation. Massive Range, 5,500'.

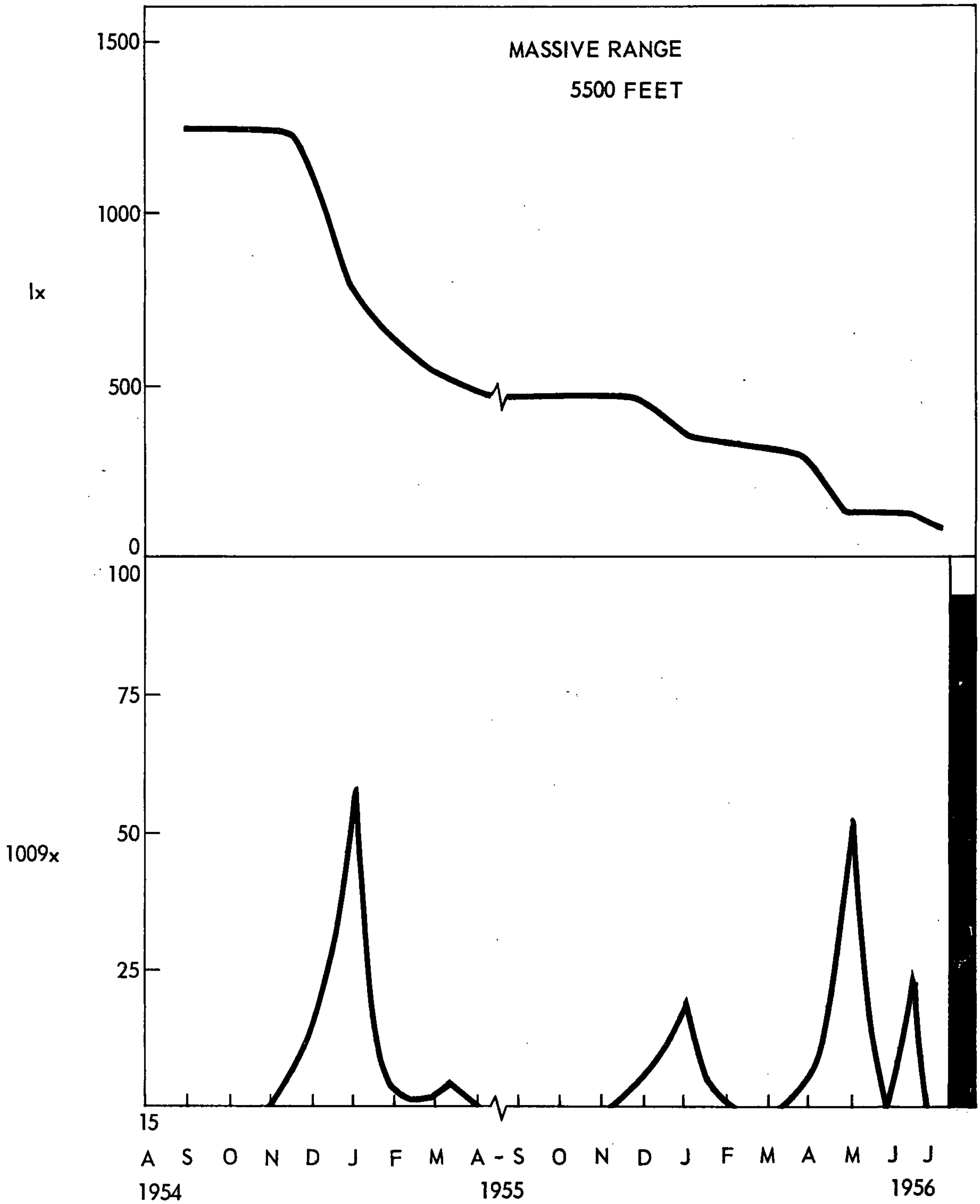

MASSIVE RANGE
5500 FEET
1500
1000
lx
500
0
100
75
50
1009x
25
15
A S O N D J F M A - S O N D J F M A M J J
1954
1955
1956

TABLE XIII

LIFE TABLE FOR THE 1954-1956 GENERATION OF NEEDLE MINER
MOUNT GIROUARD - 6000 FEET

x	lx	dxF	dx	100qx
X-1 Not measured				
X-2 Fall, 1954	2633	Climate		
I and II instar		(winter)	1593	60.50
		(spring)	144	5.46
			1737	65.96
X-3 Summer, 1955	896	Climate		
X-4 III and IV instars		(winter)	213	23.77
		(spring)	15	1.67
		Parasitism	281	31.39
		Bird Predation	76	8.50
		Unknown	41	4.60
			626	69.87
X-5 June 4, 1956				
V and pupae	270	Larval parasitism	7	2.59
X-6 Pupae	263	Climate	56	21.29
		Parasitism	2	7.60
			58	28.89
Moths SR 47:53	205			
M 96		F 109		
GENERATION			2428	92.21

Expected number of eggs = unknown
Actual measured number = 385
Established larval population = 395
Population trend (larvae) = 14.60%

Figure 9. Survivorship and death-rate curves, 1954-56 generation. Mount Girouard, 6,000'.

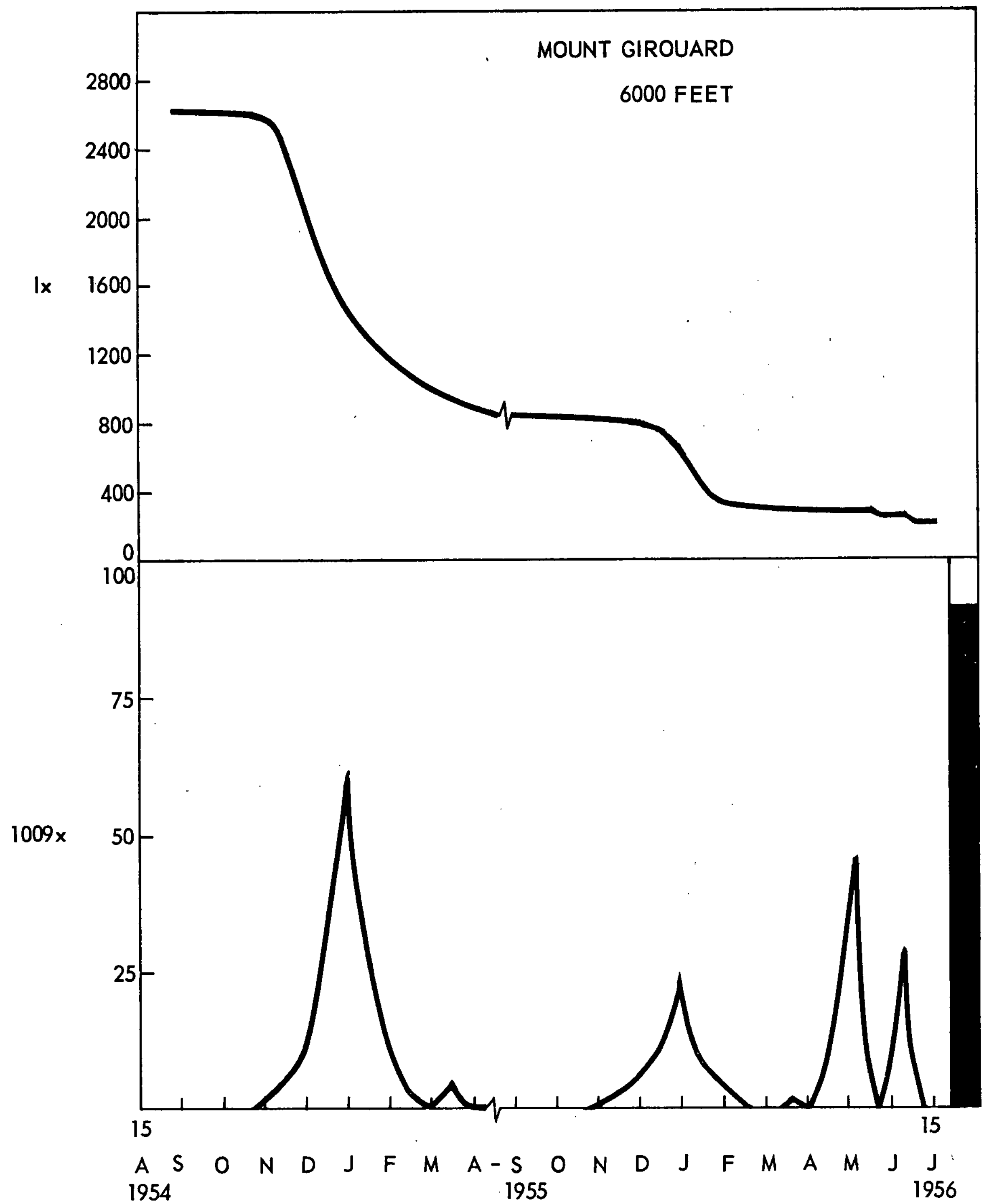

MOUNT GIROUARD
6000 FEET
lx
2800
2400
2000
1600
1200
800
400
0
100
75
50
25
1009x
15
15
A S O N D J F M A - S O N D J F M A M J J
1954
1955
1956

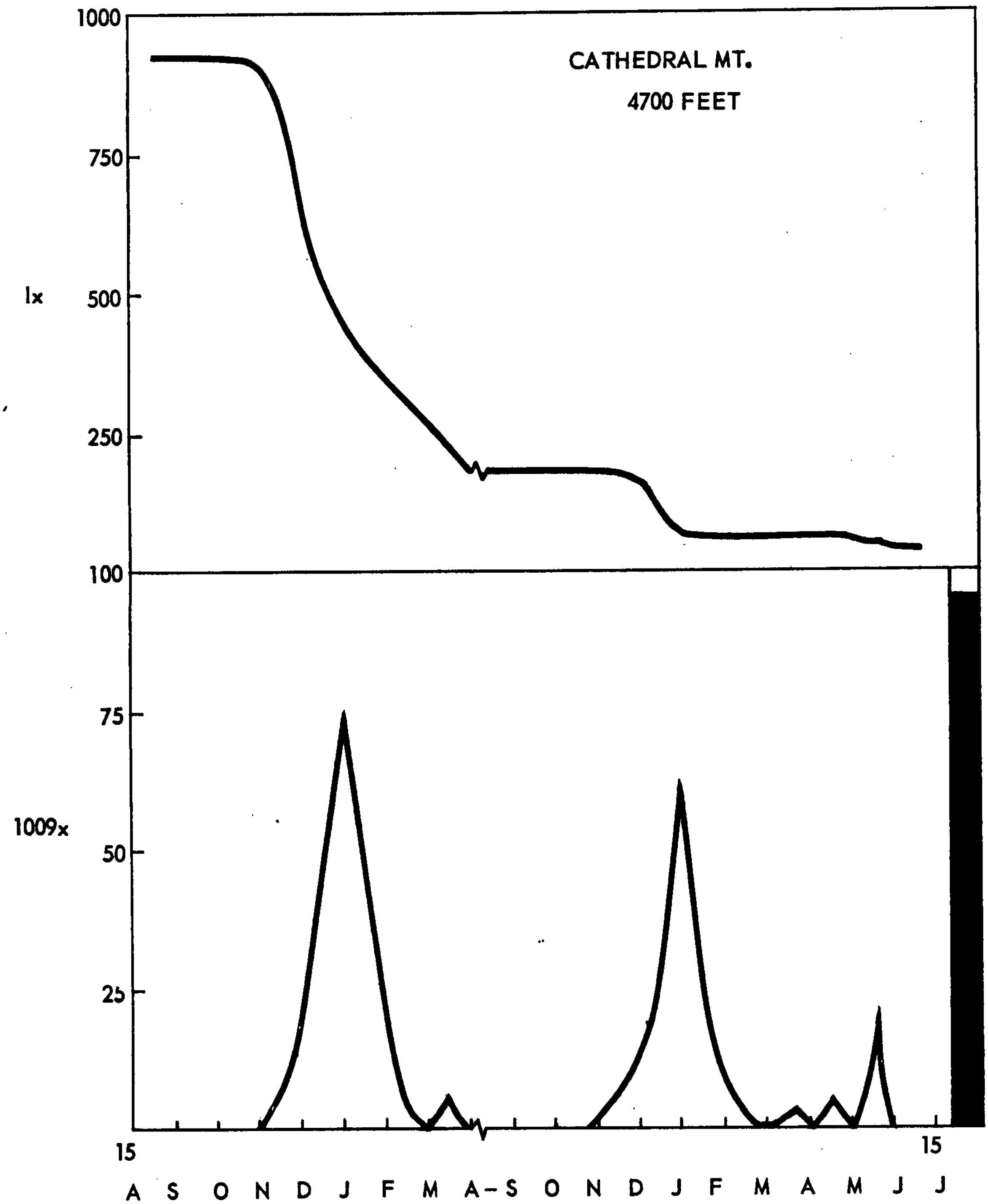
TABLE XIV

LIFE TABLE FOR THE 1954-1956 GENERATION OF NEEDLE MINER
CATHEDRAL MOUNTAIN - 4700 FEET

x	lx	dxF	dx	100qx
X-1 Not measured				
X-2 Fall, 1954	924	Climate		
I and II instar		(winter)	687	74.4
		(spring)	56	6.02
			743	80.42
X-3 Summer, 1955	181	Climate		
X-4 III and IV instar		(winter)	111	61.33
		(spring)	6	3.31
		Parasitism	11	6.08
			128	70.72
X-5 May 27, 1956	53	Parasitism	11	20.75
V instar				
X-6 Pupae	42			
Moths SR 51:49	42			
	M 21	F 21		
GENERATION			882	95.45

Expected number of eggs = unknown
Actual measured number = 30
Established larval population = 60
Population trend (larvae) = 6.49%

Figure 10. Survivorship and death-rate curves, 1954-56 generation. Cathedral Mountain, 4,700'.


CATHEDRAL MT.
4700 FEET
1000
750
500
250
100
lx
100
75
50
25
1009x
15
15
A S O N D J F M A-S O N D J F M A M J J

Example 5. Cathedral Mountain, Yoho National Park.

As in the two preceding examples only the 1954-56 generation is presented. The data are given in Table XIV and Figure 10.

The life tables given above present a tabulated record of mortality and survivorship from four localities and two altitude levels. Additional data are available from other areas and altitude levels but these were taken in a manner unsuited to presentation in life tables. However, they will be referred to in the discussion of natural control factors.

The life tables show clearly that there are four and possibly five periods in the two-year life cycle of the lodgepole needle miner during which extensive mortality probably occurs:

(1) between egg formation and oviposition.

(2) between oviposition and larval establishment.

(3) during the first larval hibernation.

(4) during the second larval hibernation, and

(5) during the spring of moth emergence.

3. DISCUSSION OF NATURAL CONTROL FACTORS

3.1 Climatic factors

3.1.1 Winter mortality

Larval mortality caused by extreme winter conditions is without a doubt the primary cause of the decline in populations of the lodgepole needle miner since 1944. As was stated earlier, the outbreak was very heavy in 1942 and continued to spread and generally increase (45-50). The first major check was observed in 1946 (51) but populations were still high until the winter of

1949-50 (53,113). Following this year the populations have retreated to the area where they were first noted, at the intermediate levels on the mountain slopes, and at much lower levels of abundance. This will be discussed in greater detail in a later section but mention here serves to introduce the discussion of the factor which caused this to come about. (See Figures 11 and 12).

(1) Theories of cold resistance and death in insects.

Our knowledge of the process of insect death by cold temperature is far from complete but certain fairly well substantiated conclusions may be made. Uvarov (144) summarized the early work and from his review came to several conclusions:

(a) There is a seasonal variability in cold resistance, the greatest resistance being found in winter and least in summer.

(b) Cold-hardiness of an insect is affected by desiccation, starvation, type of food, developmental stage and sex.

(c) Degree of cold-resistance depends on the balance of easily freezable water and fat present in the body and is not therefore constant even within individuals of a species.

(d) Two problems are involved, designated as "quantity factor" (prolonged moderate cold) and "quality factor" (degree of cold).

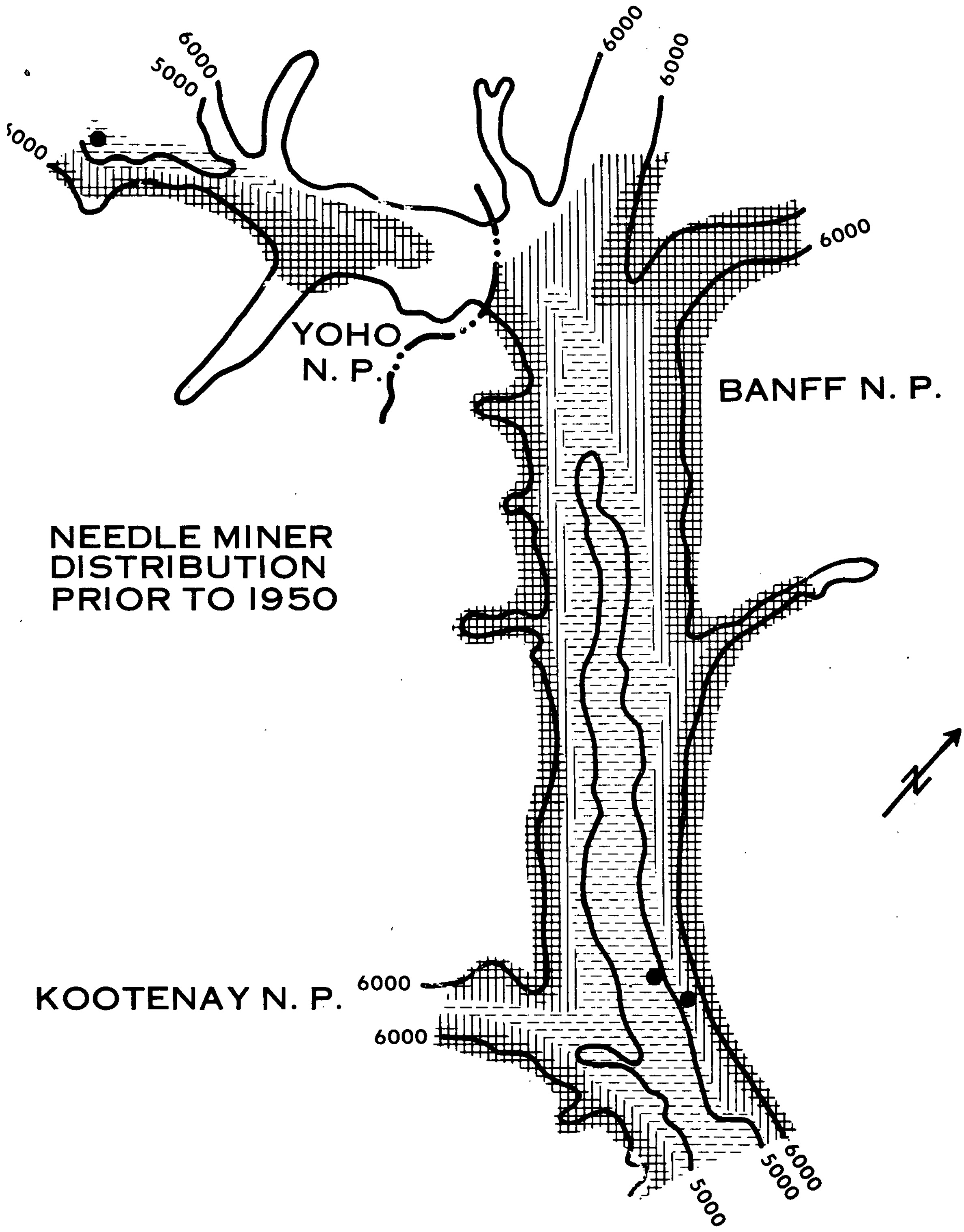
(e) The lethal temperature is apparently dependent on velocity of cooling, stage of insect development and sex, physiological state of insect, repetition of cooling,

Figure 11. Needle miner distribution prior to 1949-50.

Horizontal lines - heavy

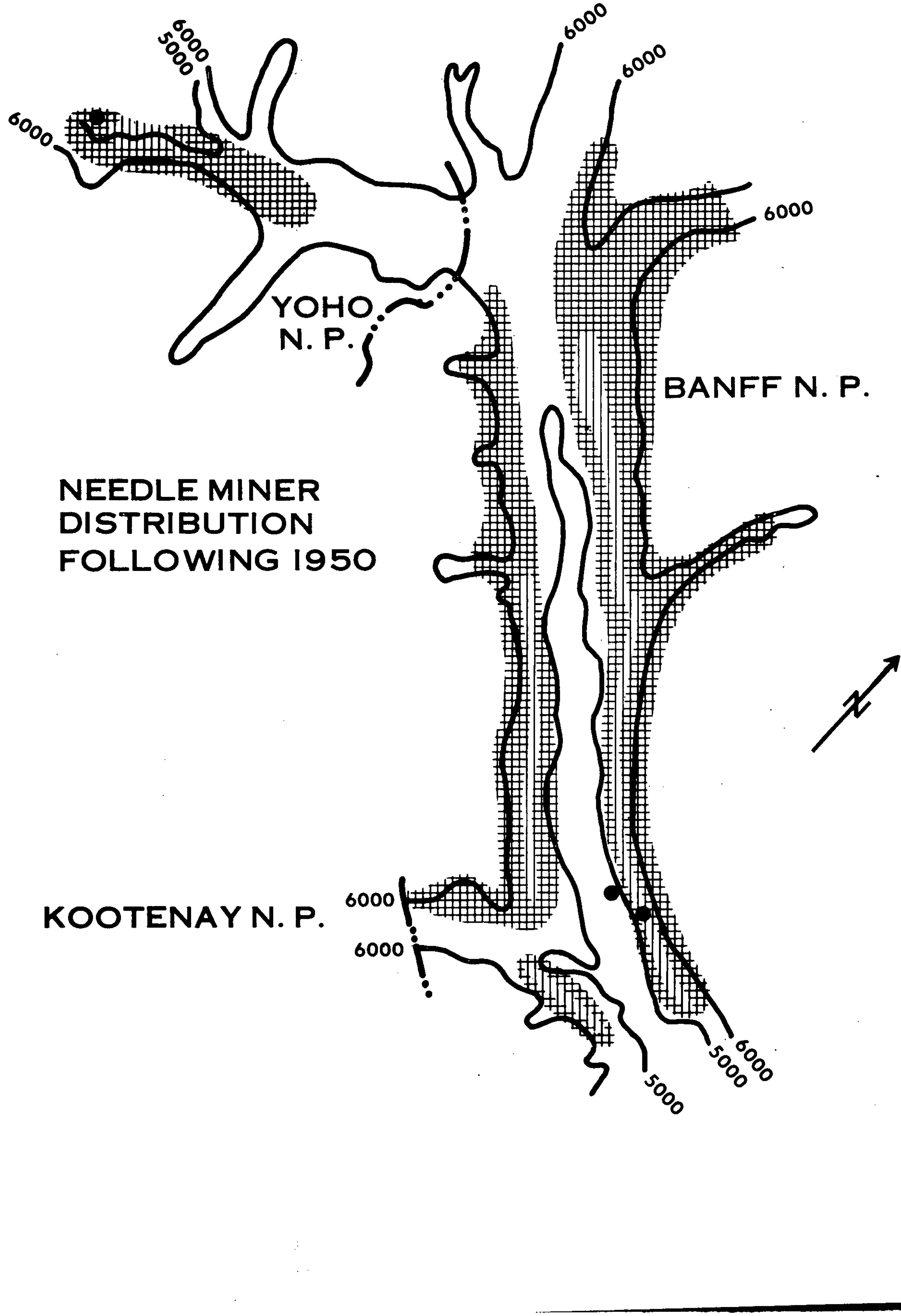
Vertical " - medium

Crossed " - light



NEEDLE MINER
DISTRIBUTION
PRIOR TO 1950
YOHO
N. P.
BANFF N. P.
KOOTENAY N. P.
6000
5000

Figure 12. Needle miner distribution following 1949-50


NEEDLE MINER
DISTRIBUTION
FOLLOWING 1950
YOHO
N. P.
BANFF N. P.
KOOTENAY N. P.
6000
5000
6000
6000
6000
6000
6000
6000
6000
5000
6000
5000

time of exposure and the constitution of the body fluids.

More detailed works since Uvarov's review have verified the basic truth of the above conclusions and have added information regarding them. It is now believed that a very small portion of the insect fauna can withstand actual freezing of tissues. (2,28,99). However, the type of freezing, whether intra- or extra-cellular has an important bearing on the survival of most insects at low temperatures. Generally insects which hibernate in an active developmental stage can survive a high degree of extra-cellular freezing but intra-cellular freezing results in damage to organs and/or death (4,98,99,100,101). Various protective mechanisms against intra-cellular freezing are known. These include: dehydration and contraction of tissue cells; hydrophilic colloids in condensed blood layers forming a mechanical barrier against penetration of tissues by ice crystals; and the formation of gels rich in hydrophilic colloids which depress the freezing point (4,41). The temperatures above which such insects can survive are not constant for any one species, stage, or sex. Many factors, extrinsic and intrinsic, have a modifying influence. The lowest lethal limit that it may be safe to generalize about lies between -40°F to -50°F, or its equivalent in time x temperature (2,3).

Limited tests of cold-hardiness made on lodgepole needle miner larvae in the laboratory indicate they are extremely cold-hardy, even in the immature stages.

Cold temperature tests were made on first-instar needle miner in the fall of 1950 before establishment. It was determined that they could withstand temperatures of 21°F for periods up to 24 hours.

Temperatures of $10^{o}F$ caused about 25 per cent mortality of larvae in 24 hours. Temperatures of $0^{o}F$ caused no mortality in 1 hour but almost 100 per cent mortality in 24 hours (113).

Further tests were conducted on larvae removed from the field in November, 1951. Examination of the gut disclosed no food material suggesting that feeding had ceased and the larva hibernates with no food in its' gut. No significant mortality was observed at temperatures down to $-8^{o}F$ of 24 hours duration (125).

Comparison of the mortality which has occurred in the field with the low winter temperatures associated with periods of mortality gives a better conception of the ability of the needle miner to resist cold temperatures (see sections (3) and (4)).

(2) Winter temperatures as a controlling factor in populations.

Uvarov takes the extreme view that "the mortality of insects caused by winter cold is probably the main factor in controlling the abundance of most insects in the temperate latitudes" and cites many examples to support his statement (144). This may be taken as the opposite end of the scale to the various "biotic" theories (90). More realistic are the recent "comprehensive" theories (102,106) which allow that under certain circumstances any environmental factor may act as a check on insect abundance.

It is the intention in this section to show, by example, that reduction of insect abundance by winter temperatures is not uncommon.

All overwintering larvae of the brown-tail moth are reported to have been destroyed by temperatures approximating $-25^{o}F$ in the northeastern United States. Low winter temperatures are apparently a barrier to this insect's northward spread (74). Similar conclusions have been reached for the European pine shoot moth in Michigan (5). Percentage mortality approached 100 per cent with exposure for 14 days to temperatures of -4°F and increased progressively with time of exposure. At -13°F mortality approached 100 per cent in 72 hours; at -22°F over half succumbed after an hour's exposure and all were dead after eight hours.

Nolte (91) reviewed the theories then current for control of the rape flea beetle in Germany. It had been commonly accepted that extreme cold winters were the major controlling factor. Nolte found that this was not always so, that it was not always winter temperatures. Low temperatures from mid-August on, and in March, were equally successful in preventing outbreaks of this agricultural pest. The insect population studied overwintered in every developmental stage which would contribute to different population effects from severe environmental factors.

The California oak moth, Phryganidea californica Pack., overwinters in an actively feeding larval stage. Exhaustion of available food supply is the most common biotic cause of mass mortality in oak moth populations; natural enemies, parasites and predators, are not usually the cause of crash declines in populations. Crash declines of Phryganidea populations in central California usually are due to factors associated with severity of winter weather. Populations fluctuate only moderately in southern California where the physical environment is essentially "benign". They are more violent in Central California and in northern California the climate is too severe to allow more than temporary summer colonies to survive (40). This is an example of an insect with apparently very narrow limits of cold tolerance.

Hutchinson (60) as well as several other authors (23,25,60) have shown that populations of some scale insects are dependent upon winter temperatures for their increase (or lack of it). Thus the California Red Scale numbers remain low in areas of low temperature but increase in areas of mild winter temperatures resulting in large spring populations. Hutchinson found that population density of the California Red Scale was inversely correlated with the number of winter nights when temperatures dropped below freezing.

In summary, it appears that the temperature environment of insects, like that of most organisms may be divided into several "zones". These are termed: "the zone of lethal high temperature; zone of favorable temperature; and zone of lethal low temperature." The zone of lethal low temperature may be further divided into two sub-zones: "the zone of freezing temperatures", chiefly important in those species that spend some time in dormancy and "the zone of non-freezing lethal low temperatures" (3). The needle miner is particularly subject to the zone of freezing temperatures as the larval stage spends two winters of approximately five months duration when freezing conditions persist.

(3) Winter mortality in lodgepole needle miner populations.

The importance of winter mortality as a control factor is clearly shown in the life tables presented earlier (Tables IV - XIV). Table XV shows the percentage winter mortality of the total population in the two-year cycle.

TABLE XV

PERCENTAGE WINTER MORTALITY OF ESTABLISHED NEEDLE MINER POPULATIONS IN FOUR LOCATIONS

Area	Per Cent Mortality of total established population Generation 1948-50	1950-52	1952-54	1954-56
Mount Eisenhower Valley bottom	85	-	99	100
Mount Eisenhower 5,400'	78	33	45	70
Girouard, 4,700'	-	-	-	68
Cathedral, 6,000'	-	-	-	86

These figures of percentage mortality for the whole generation based on the established larval population are more significant, if less striking, than those based on yearly estimates of the population present before the effect took place. This is another advantage of the life table that such a comparison is easily obtained. To determine the winters which have had the greatest effect yearly estimates are necessary. These are presented for all areas and estimates made from the beginning of the study in Tables XVI to XXIII. The reliability of the estimates varies, those beginning with the 1948-49 estimates being statistically acceptable. The comments arising from perusal of these tables are best dealt with together.

TABLE XVI

RECORDED WINTER MORTALITY
MOUNT EISENHOWER, Bow Valley, Banff National Park

Year	Altitude 4800	5300	5800	6300
1943-44		9		
1944-45		-no estimate-		
1945-46		50		
1946-47		1		
1947-48		20		
1948-49	31.65	27.58	20.04	23.92
1949-50	99.9	78.8	64.8	61.9
1950-51	low	25.0		
1951-52	low	15.8		
1952-53	5.2	5.6		
1953-54	98.4	17.7	6.3	1.5
1954-55	91.84	48.1	67.6	
1955-56	100.0	34.4		

TABLE XVII

RECORDED WINTER MORTALITY
MASSIVE MOUNTAIN, Bow Valley, Banff National Park

Year	Altitude 4600	5100	5600	6100
1948-49	9.8	16.6	11.8	28.3
1949-50	100.0	91.0	92.6	87.0
1950-51	no estimate			
1951-52	"	"		
1952-53	"	"		
1953-54	79.8	6.7	0.5	2.9
1954-55		51.0	58.6	
1955-56		20.2		

TABLE XVIII

RECORDED WINTER MORTALITY
CATHEDRAL MOUNTAIN, Kickinghorse Canyon, Yoho National Park

Year	Altitude 4500	5000	5500
1948-49	14.0	14.3	44.6
1949-50	24.6	43.4	30.8
1950-51	21.4	43.2	12.6
1951-52	2.4		
1952-53	5.3		
1953-54	11.2	7.0	3.7
1954-55	74.4		
1955-56	61.3		

TABLE XIX

RECORDED WINTER MORTALITY
LAKE LOUISE, Bow Valley, Banff National Park

Year	Altitude 5050	5550	6050	6550
1948-49	23.0	18.5	16.1	8.9
1949-50	100	61.1	41.3	63.4
1950-51		no estimate		
1951-52		" "		
1952-53	6.1			
1953-54	99.5	15.8	17.4	6.8
1954-55		85.2 (90.3)		
1955-56		no estimate		

TABLE XX

RECORDED WINTER MORTALITY
MOUNT NORQUAY (EDITH), Bow Valley, Banff National Park

Year	Altitude 4700	5200	5700	6200
1948-49	34.8	17.7	13.4	17.8
1949-50	97.8	93.5	88.0	82.4

TABLE XXI

RECORDED WINTER MORTALITY
BANKHEAD, Bow Valley, Banff National Park

Year	Altitude 4800	5300	5800	6300
1948-49	23.9	16.9	7.0	38.9
1949-50	91.0	89.5	87.8	84.0

TABLE XXII

RECORDED WINTER MORTALITY
HAWK CREEK (SNOW CREEK) Kootenay National Park

Year	Altitude 4400	4900	5400	5800
1948-49	23.2	13.9	15.5	9.9
1949-50	56.9	75.8	81.2	60.7
1953-54	23.8			

TABLE XXIII

RECORDED WINTER MORTALITY
MISCELLANEOUS AREAS - Banff National Park

Year	Location	Altitude	Mortality
1951-52	Baker Creek	6000	15.8
	Stoney Creek	5500	6.9
	Upper Cascade	5750	9.4
1953-54	Baker Creek	6000	1.7
	Stoney Creek	5500	11.9
	Brewster Creek	5200	8.9
	Saskatchewan Crossing	4700	11.2
	Eisenhower Junction	4676	91.3
1954-55	Baker Creek	6000	77.7
	Stoney Creek	5500	73.7
	Cascade Valley mouth	5500	73.4
	Mount Coleman	5000	87.6
	Brewster Creek	5700	83.2
	Brewster Creek	5200	64.1
	Mount Girouard	6000	60.5
1955-56	Mount Girouard	6000	23.73

The conclusion drawn from the above tables is that five winters since 1943 were significant in their effects on larval populations. These are: 1945-46; 1949-50; 1953-54; 1954-55; and 1955-56.

The regular occurrence of comparable results at similar elevations led to the formulation of Table XXIV where mortality estimates of comparable elevations were combined.

TABLE XXIV

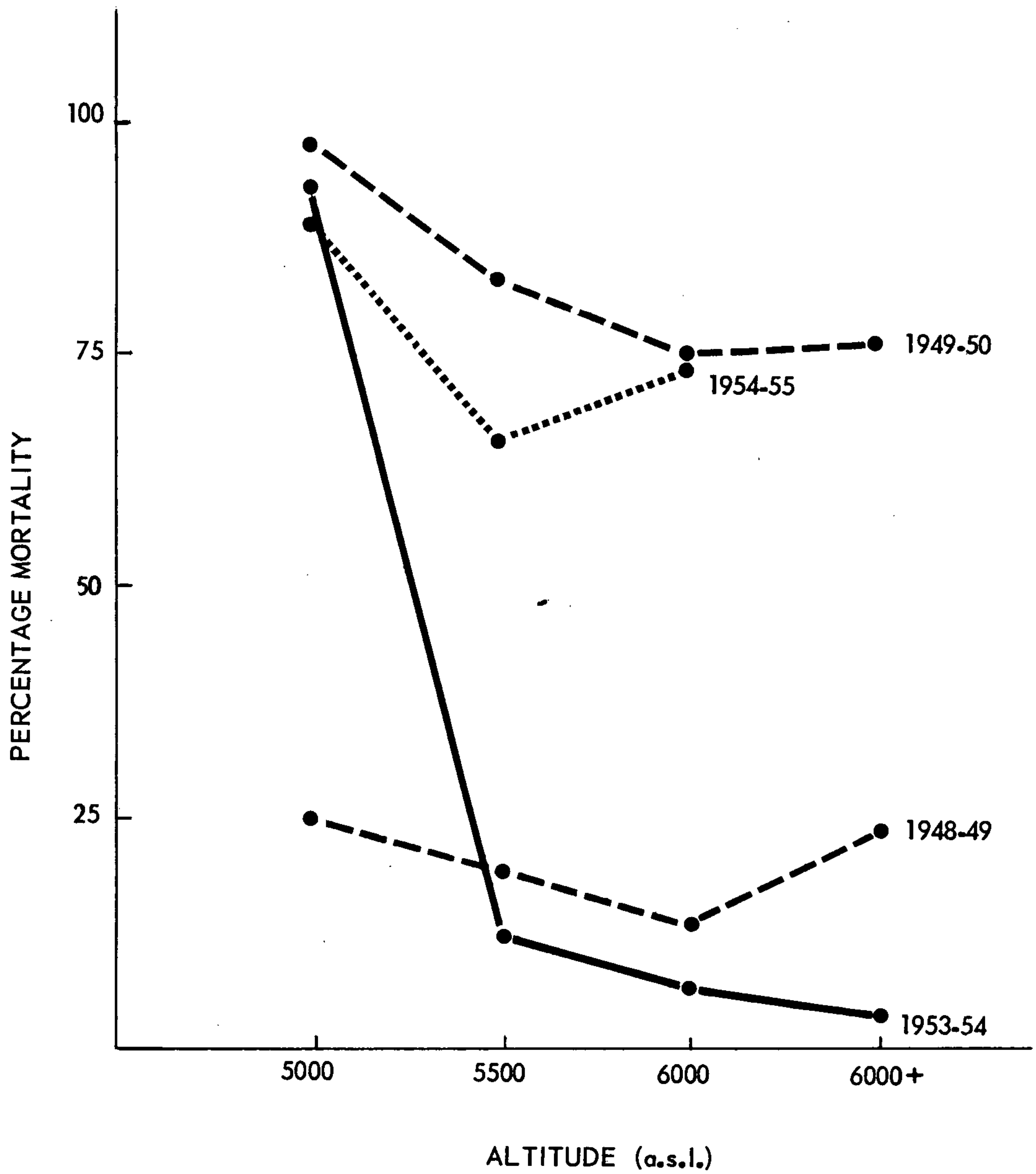
RECORDED WINTER MORTALITY BY ALTITUDE - ALL AREAS

Year	Altitude up to 5000		5000		5500		6000	
	% Mort.	N	% Mort.	N	% Mort.	N	% Mort.	N
1943-44	-		9.0	1	-		-	
1944-45	-		-		-		-	
1945-46	-		50.0	1	-		-	
1946-47	-		1.0	1	-		-	
1947-48	-		20.0	1	-		-	
1948-49	24.6	5	19.4	5	13.7	5	23.6	5
1949-50	97.7	5	82.8	5	74.9	5	75.7	5
1950-51	-		25.0	1	-		-	
1951-52	-		11.3	2	12.6	2	-	
1952-53	5.6	2	5.6	1	-		-	
1953-54	92.2	4	12.2	5	6.5	4	3.7	3
1954-55	89.7	2	65.9	6	73.0	6	-	
1955-56	100	1	27.3	2	23.7	1	-	

N = Number of mortality estimates at each altitude.

The data for four of the significant years are plotted in Figure 13. Averaged in this way, the decreased mortality with increase in elevation is less significant but in years when heavy mortality does

Figure 13. Mortality of lodgepole needle miner at different elevations in four selected years.



100
75
50
25
PERCENTAGE MORTALITY
1949-50
1954-55
1948-49
1953-54
5000
5500
6000
6000+
ALTITUDE (a.s.l.)

not occur (1948-49 particularly) the decrease in mortality is slight and that at the highest elevation is greater than at valley bottom.

(4) <u>Climatic conditions causing winter mortality observed in lodgepole needle miner populations</u>.

In 1954, it was postulated that the weather of the coldest month of the winter was the major factor causing winter mortality of the lodgepole needle miner (43). This work compared the winters of 1948-49 and 1949-50 in relation to mean monthly temperatures (November to March) and demonstrated that although mortality was far greater in 1949-50 than in 1948-49 (See tables XVI - XXII and Figs. 11-12) the mean monthly temperatures were higher in 1949-50 than 1948-49 with one exception, January. The lower mortality observed at the Cathedral sampling area did not conform to the rest of the area and it was pointed out that more complex relationships between air masses occur on the western side of the Great Divide separating the areas. The general conclusions of this study were:

"1. In the main part of the Bow Valley, the vertical distribution of temperature is a function of the predominant type of general circulation. Thus during a month characterized by frequent, but rapid, invasions of polar continental air, the upper slopes are more often colder than the valley floor. On the other hand, stagnating air of any type produces extremes of cold on the valley floor, and these are much more severe when the air is of polar continental origin. (Invading maritime air warms the upper slopes so that effectively, the valley bottom is colder than the upper slopes at such times. Thus effects are produced that are similar to, but more moderate than, the effects of stagnating polar continental air).

2. In the Bow Valley, winter mortality seems to be distributed in the same way as the zones of extreme cold that occur during the coldest winter month. Because the dominant type of circulation

during this month may be different in different years, the zone of most extreme cold may occur either at valley bottom or at the tops of the slopes. Consequently, greatest mortality should occur in either of these locations, although it should occasionally be exceptionally great at valley bottom. Best survival should occur most consistently along the middle of the slopes.

3. This middle zone then, should constitute the most persistent reservoir for re-infestation of the other zones and, therefore, the most serious attempts to control the insect should be concentrated in it.

4. In or near the major passes that enter the Bow Valley from the west, the air flow is more complicated and, therefore, the vertical distribution of mortality is much less predictable than it is in the rest of the valley."

Two major postulates were susceptible to testing: that pronounced inversions in the lower air were produced by stagnating cold air masses in the Bow Valley, and that the bulk of larval mortality occurred during the coldest month. During January, 1956, Fuess hygrothermographs in Stevenson screens were set out at valley bottom and valley bottom + 750 feet on Mount Eisenhower and attended from January 2 to February 14. Air-mass analyses for this period were made by W.R. Henson from charts supplied by the Dominion Meteorological Office, Calgary (Appendix 9). Even in this short period temperature inversions were common.

On January 7, after a day and a half of cold polar continental air there was an inversion from 0700 to 1100 MST with a peak difference of 12 F^{o}. This was due to a weak invasion of maritime polar air whose warming effect was felt first on the upper slopes, five hours earlier than in valley bottom. This is reported to be a common phenomenon noticed by skiers in this area. Leaving the town of Banff in sub-zero weather they find it near the freezing point on the ski slopes.

The next inversion occurred on January 13th. Polar continental air had invaded the Bow Valley late on January 11th but as circulation was weak, the air mass could not displace the warm maritime air completely. This inversion undoubtedly resulted from the cold cP air displacing the warm mP air at valley bottom first.

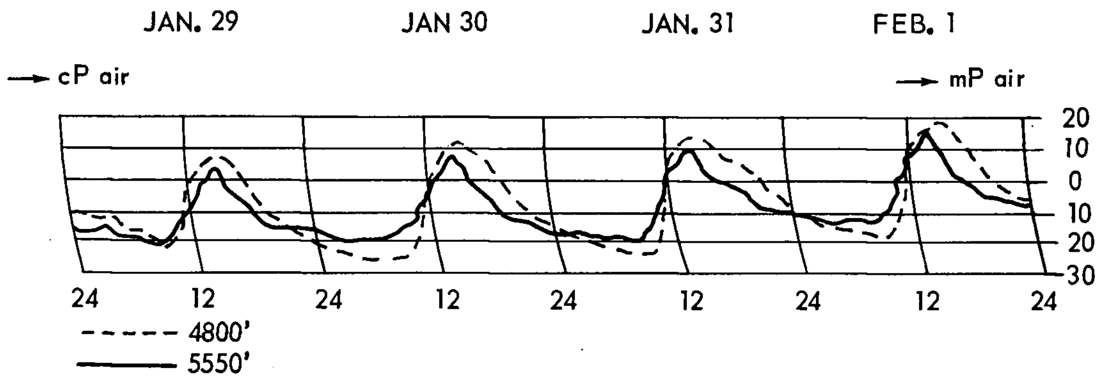
Another short inversion occurred on January 18th when mP air entered the valley replacing cP air and in the same day itself was replaced by cP air. The cP air remained in the valley from January 24th to February 2nd, becoming increasingly colder. The conditions approached those postulated by Henson et al. (43) for 1949-50 but to a lesser degree. The nightly inversion began on January 28th and was repeated each night until February 1st. The effects on valley bottom and slope temperatures are illustrated in Figure 14 which is a tracing of the actual thermograph chart. Figure 15 shows a four-day period following the period illustrated in Figure 14 after polar maritime air had finally supplanted the colder polar continental air.

The total temperature difference from 0100 to 1100 on the three successive days showed valley bottom to be 59,53, and 45 F° colder than the upper slopes. Not only was the temperature more severe at valley bottom, but it was much more variable. The diurnal ranges for the three days at valley bottom were: 9°F to -25°F; 11°F to -23°F; 13°F to -18°F compared to: 5°F to -19°F; 8°F to -19°F; and 10°F to -13°F on the upper slopes. Conditions such as these were responsible for the differential mortality observed in 1949-50 and 1954-55 and possibly also for the mortality being restricted to valley bottom in 1953-54 and 1955-56 (See Table XVI and others).

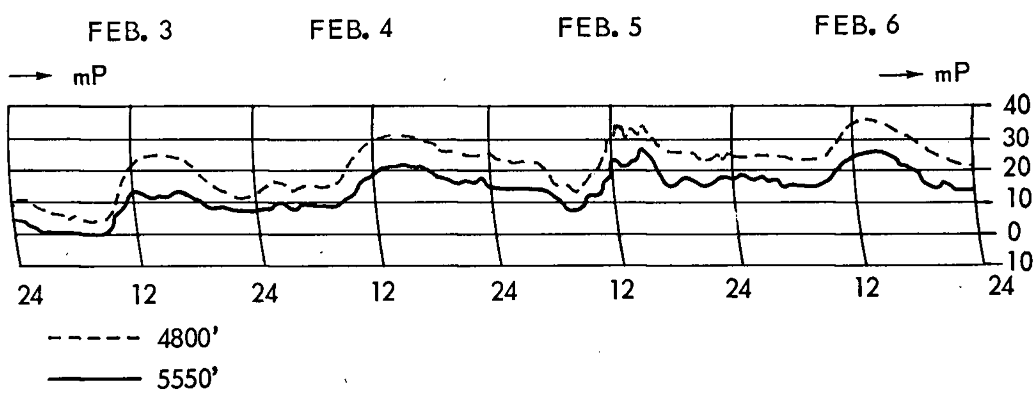
Figure 14. Hygrothermograph tracing showing temperature conditions at valley bottom (4,800') and 5,550' on Mount Eisenhower from January 29 to February 1, 1956, when area was in polar continental air.

Figure 15. Hygrothermograph tracing showing temperature conditions in the same locations from February 3 to 6, 1956, when area was in polar maritime air.

CONDITIONS UNDER POLAR CONTINENTAL AIR



CONDITIONS UNDER POLAR MARITIME AIR



The second postulate was tested in 1953-54. Winter sampling was carried out on three of the sample areas, Mount Eisenhower, Cathedral Mountain and Lake Louise (See life tables V and IX). The first samples were collected December 10 and 16 and examined from the 15 to the 20th.; the second samples were collected February 2 to 5 and examined from the 3rd to the ninth. The usual spring sampling was done in 1954, the results of which are presented in the mortality tables above. The summarized results of the three samples are presented in Table XXV.

TABLE XXV

PERCENTAGE WINTER MORTALITY - 1953-54

Location	Elev.	Dec. 1953 High	Dec. 1953 Low	Feb. 1954 High	Feb. 1954 Low	Spring 1954
Mount Eisenhower	4800	8.6	4.3	95.0	94.6	98.4
	5300	2.6	2.4	19.4	18.1	17.7
	5800	13.7	6.2	17.0	15.6	6.3
	6300	4.3	-	9.9	9.1	1.5
Cathedral Mountain	4500	7.3	-	17.4	18.4	11.2
	5000	7.1	-	29.2	31.3	7.0
	5500	9.0	3.8	6.8	7.5	3.7
Lake Louise	5050	10.0	5.4	94.1	91.7	99.6
	5550	69.9	43.5	12.5	11.3	15.8
	6050	17.0	13.0	39.0	20.6	17.4
	6550	19.7	-	13.9	8.7	6.8

There is considerable discrepancy between the mortality estimates in the winter months (particularly February) and the final spring estimate. This is largely due to the fact that the larvae brought in in February were less easily roused from dormancy (58) and when they failed to respond in any way they were classed as dead. The great differences between December and February at Mount Eisenhower and Lake Louise and the close agreement between the February and spring samples for the low elevation at least leaves little doubt that the bulk of the mortality found occurred between December 16 and February 5th. The fact that the high mortality found was restricted to valley bottom indicates a weather phenomenon similar to that described above. Examination of weather records of two stations, Banff and Lake Louise, both on the valley bottom and approximately equal distances in opposite directions from the sampling area should give some inkling of the mortality-producing agent.

The only period of prolonged cold between the sampling dates was from January 10 to 29th. The maximum and minimum temperatures for this period are presented in Table XXVI (See appendices 1 and 2).

It is reasonable to assume that temperatures at valley bottom Mount Eisenhower would lie somewhere between the temperatures given at the two stations. If we assume that the inversions which occurred so commonly in January, 1956, also occurred during this period, then it is likely that temperatures at the sampling stations above valley bottom were considerably warmer. As a comparable mortality pattern was observed in 1955-56 it is likely that the causes were the same. The air mass summaries (Appendix 9) show that during the winter of 1953-54, the area was in polar continental air for 22 days. This is only three days less than in 1949-50 but the important difference was that in 1950 there were only two polar continental fronts in January with a total number of

3 fronts of all types whereas in 1953-54 there were eight cP fronts with a total of 20 of all types. This means that there was less stagnation of polar continental air during the winter of 1953-54 and temperatures throughout the whole valley had less chance of becoming as extreme as in 1949-50.

TABLE XXVI

DAILY MAXIMUM AND MINIMUM TEMPERATURES, JANUARY 10-29, 1954
BANFF AND LAKE LOUISE

	Temperature of			
	Banff		Lake Louise	
Date	Max.	Min.	Max.	Min.
Jan. 10	17	- 1	18	- 26
11	21	8	26	- 8
12	17	- 5	15	- 23
13	18	9	16	7
14	5	- 15	- 8	- 16
15	- 22	- 26	- 21	- 35
16	1	- 39	- 3	- 52
17	4	- 13	- 2	- 8
18	6	- 19	8	- 31
19	- 9	- 18	- 15	- 32
20	- 11	- 33	- 12	- 47
21	- 18	- 26	- 14	- 23
22	- 16	- 23	- 6	- 25
23	- 15	- 25	- 14	- 22
24	- 12	- 21	- 12	- 19
25	- 1	- 20	- 7	- 20
26	1	- 14	15	- 12
27	17	- 24	14	- 21
28	27	10	19	7
29	18	- 3	17	- 21

Comparison of 1953-54 winter temperatures with those for 1948-49 shows a more severe and prolonged cold period in 1953-54. In 1953-54 the maximum was below zero eight days and the minimum 18. In 1948-49 the maximum was below zero on only four days and the minimum 17. Also, in 1953-54 the maximum was below zero for seven consecutive days, the minimum for 14 consecutive days. In 1948-49 the maximum was below zero for only two consecutive days, the minimum for only eight consecutive days. Thus, the comparison of these three winters shows that the winter of 1953-54 was intermediate; conditions were not severe enough to cause the extreme mortality at all altitudes as in 1949-50, but were severe enough to cause high mortality at valley bottom.

The general heavy mortality of 1954-55 was comparable to that of 1949-50 although slightly less severe on the upper slopes. The air-mass summaries (appendix 9) do not show the large number of days in which the area was under polar continental air as in 1949-50, but frontal activity was reduced and stagnation over the 12-day period could have occurred. Calgary weather records show that, generally, 1954-55 was a mild winter (1) so this appears to be a slightly different case. The air-mass summary shows that during March the area was under the influence of cP air for 16 days. This is a high number for March, being exceeded only three times since 1920 and equalled twice. It is possible, therefore, that March was the 'coldest month' of 1954-55 and winter mortality occurred at that time. If temperatures in Banff corresponded to those observed at Calgary the extremes of temperature to which the needle miners were exposed could have been the mortality factor involved.

Daily maximum and minimum records are not yet available for Banff and Lake Louise for the winter of 1955-56. However, the records of Calgary, Alberta (84 miles East of Banff and out of the Rocky Mountains), for this interval show several periods when this mortality could have occurred (1) (see appendix 3). However

Calgary records are not always applicable to the outbreak area, as the eastern ramparts of the Rocky Mountains protect that portion of the Bow Valley in Banff National Park from many invasions of cold continental arctic air from the east and northeast. As will be seen later this keeps the Eastern Slopes of the Rockies colder, on the average, than the outbreak area. We cannot, therefore, with any degree of confidence, pinpoint the period when mortality occurred in 1955-56 until figures are available for Banff and Lake Louise.

During the winter of 1945-46 mortality was apparently high, although the degree of mortality is not certain. Examination of the daily temperatures for this winter at Banff and Lake Louise (Appendices 1 and 2) shows that in general it was a mild winter but the mild periods were separated by sharp cold periods. Thus a minimum of -35°F at Lake Louise and -26°F at Banff was recorded on November 8, whereas on November 3 the maximum was 51°F and the minimum 31°F. Similar cases, though less extreme, occurred throughout the winter. The air-mass summary (Appendix 9) shows that the area was in cP air for 12 days in November. This amount has been exceeded only once (1927-28) and equalled once (1935-36). The only safe conclusion is that the mortality was perhaps overestimated, although the comments made above still may obtain. As samples made were small and localized it would be unwise to generalize.

The five winters during which heavy mortality occurred have been discussed in detail and when mortality is compared with that of other years it should be possible to come to some general conclusions as to what temperature limits the needle miner can withstand. For this we use principally Table XIV. Thus the years 1943-44, 1946-47, 1947-48, 1948-49, 1950-51, 1951-52 and 1952-53, were years of low mortality (i.e. highest 31.6) and the years discussed above were years when mortality was extreme in some locations.

Air-mass summaries are available for only three of the low-mortality winters 1946-47, 1948-49 and 1952-53. These show no long-term invasions of cold polar continental air except for 1948-49, but the high frontal activity pointed out earlier (43) reduced the opportunity for stagnation of air. Table XXVII summarizes the low temperature information for the winter months of six of the 'low mortality' winters. Extreme minima alone signify little, time and variation of temperature may be equally important (See section (1)). Mean maxima and minima and mean monthly temperature give some indication of extent and variation of temperature. In particular cases however, a careful scrutiny of daily temperatures would probably be required.

Table XXVIII presents comparable information for the years when mortality was high; 1945-46 (?), 1949-50 and 1953-54.

Comparison of these two tables year by year reveals certain differences which could contribute to differences in mortality. We may, therefore, generalize that the lodgepole needle miner populations in the outbreak region in Banff National Park can have a high survival if extreme minima of -30°F to -40°F do not persist long enough to depress the mean monthly temperature close to or below the zero mark. This generalization must be considered with respect to the month in which low temperatures occur and the

TABLE XXVII

SUMMARY OF WINTER TEMPERATURE DATA - YEARS OF LOW MORTALITY
BANFF, ALBERTA.

Year	Month	Extreme Minimum	Mean Maximum	Mean Minimum	Monthly Mean
1943-44	Nov.	4	38.5	19.5	29.0
	Dec.	- 8	28.0	10.7	19.4
	Jan.	- 8	29.1	11.0	20.0
	Feb.	- 13	28.8	5.9	17.4
	Mar.	- 15	35.8	10.4	23.1
1946-47	Nov.	- 27	27.2	9.0	18.1
	Dec.	- 31	25.6	7.2	16.4
	Jan.	- 41	24.0	5.8	14.9
	Feb.	- 34	30.3	5.2	17.8
	Mar.	- 31	39.8	8.5	21.6
1947-48	Nov.	- 9	31.5	14.3	22.9
	Dec.*	- 15	26.4	5.0	15.7
	Jan.	- 21	30.8	11.1	21.0
	Feb.*	- 29	23.8	- 6.0	8.9
	Mar.	- 23	33.6	7.5	20.6
1948-49	Nov.	0	33.9	18.6	26.2
	Dec.	- 28	16.9	- 1.8	7.6
	Jan.	- 44	15.3	- 7.4	4.0
	Feb.	- 39	21.7	- 2.9	9.4
	Mar.	- 19	38.8	15.5	27.2
1950-51	Nov.	- 28	28.4	11.0	19.7
	Dec.	- 20	28.5	14.3	21.4
	Jan.	- 41	16.2	- 4.2	6.0
	Feb.	- 23	26.7	1.3	14.0
	Mar.	- 41	28.1	5.4	16.8
1951-52	Nov.	- 13	33.3	17.5	25.4
	Dec.	- 39	14.5	- 1.6	6.4
	Jan.	- 34	17.8	0.1	9.0
	Feb.	- 15	29.3	9.5	19.4
	Mar.	- 13	35.0	10.3	22.6

* Lake Louise - Banff not complete.

TABLE XXVIII

SUMMARY OF WINTER TEMPERATURE DATA - YEARS OF HIGH MORTALITY
BANFF, ALBERTA.

Year	Month	Extreme Minimum	Mean Maximum	Mean Minimum	Monthly Mean
1945-46	Nov.	- 26	27.4	8.8	18.1
	Dec.	- 15	22.8	7.6	15.2
	Jan.	- 13	28.7	12.7	20.7
	Feb.	- 15	31.8	11.2	21.5
	Mar.	3	40.3	20.6	30.4
1949-50	Nov.	11	45.1	28.6	36.8
	Dec.	- 18	17.0	0.9	9.0
	Jan.	- 51	- 5.2	- 26.7	- 16.0
	Feb.	- 18	31.9	12.1	22.0
	Mar.	- 29	31.2	11.9	21.6
1953-54	Nov.	6	38.4	24.9	31.6
	Dec.	0	29.6	17.2	23.4
	Jan.	- 39	11.1	- 4.1	3.5
	Feb.	- 6	35.9	21.7	28.8
	Mar.	- 22	33.1	9.1	21.1

duration of cold cP or cA air in the region. Thus, in November or March a higher minimum may be lethal, particularly if alternated with warm periods. It is unlikely that extremes of temperature of short duration are a major cause of winter mortality.

It would be unwise to generalize on the mortality in populations in a region such as was encompassed by the past outbreak from a few samples at one altitude or from the weather records of a single station such as Banff, or even from the reasonably comprehensive sample coverage given to populations in Banff National Park. The comments made above do not obtain to mortality conditions found in Yoho or Kootenay National Parks, at least not to the degree found in Banff Park.

The lack of temperature data from Yoho and Kootenay Parks and, as yet, a lack of understanding of the complex relationships of air masses in the trans-Divide area do not permit more than speculation. That the populations in these areas have subsided at an equivalent rate to those in Banff Park is certain but the causes for this are less certain. That it is attributable to weather factors we are reasonably certain, as neither parasites nor disease have ever figured prominently in the control complex. In the Yoho area climatic conditions are much more variable, if less extreme, than in the Banff area and while these conditions have not resulted in excessive mortality except in later years (Table XVIII) it is likely that they have affected the population in other ways, through development, fertility and fecundity, although there is no material evidence for this hypothesis. In the Kootenay area, mortality differences are not as great (Table XXII) and the remarks pertaining to Banff Park probably are pertinent but to a lesser extent. Altitude and orographic differences probably are influential in causing the variations noted.

With increased use and refinement of air-mass and frontal analytical techniques and consideration of local fluctuations in climate in the Bow Valley such as discussed above it is now possible to develop a predictive system for use in mortality and population studies. From the above studies we now know that the heaviest persistent infestations are likely to be centered on the mid-slopes in the Bow Valley of Banff National Park because although populations may increase above and below this favorable zone during a few favorable years they will eventually suffer 'catastrophic' mortality during the types of winter weather noted above (152).

3.1.2. Spring mortality.

A small percentage of larvae killed after feeding in the spring, has been found since detailed sampling for life tables studies began in 1954 (see life tables). This mortality never exceeded six per cent of the larval population entering hibernation. That spring mortality can be an important factor has long been recognized, particularly in open-feeding insects (144). The tent caterpillar has suffered 'catastrophic' mortality from spring temperature extremes in Ontario (8) and spring frosts shortly after hatching were credited with a high degree of control in one outbreak in Minnesota (44).

Early studies on the needle miner indicate that commencement of feeding in the spring is largely dependent on spring temperatures. Generally, it appears that feeding ceases in the fall when maximum temperatures fall below 45°F and the minimum temperature is commonly below freezing. These conditions in reverse are associated with commencement of feeding in the spring (110,128). Spring frosts, common during this period, may be severe enough to cause the mortality observed. Lack of knowledge of the precise time of occurrence and the low incidence of the mortality precludes intensive discussion of the temperature fluctuations for this period.

3.1.3. Other climatic factors possibly involved in the reduction of populations.

(1). Effects of weather on egg and first instar larvae.

No mortality of eggs in the field has been observed. They are apparently able to endure any field conditions which occurred in the two years that egg sampling was carried out. However, that large reductions in populations between oviposition and larval establishment may occur periodically is evidenced by 1954 sampling when a count of 4700 eggs per 100 tips was made and larval establishment was only 1,114 larvae per 100 tips. No such loss was observed in 1956. That this loss is not due to a factor acting directly on the eggs is reasonably certain. All eggs kept for rearing and experimentation (without extensive handling) hatched and no dead eggs have ever been found in the field.

In 1954 limited tests were conducted on the effects of humidity and temperature on egg development. While these experiments were not precise enough nor extensive enough to report in detail they did indicate that eggs of the needle miner are capable of withstanding extremes of humidity and temperature not found in the field for any length of time. However, development may be delayed by adverse conditions which may have an effect on successful establishment of the larvae (109). Two sources of loss have been observed in the field but techniques have not been designed by which they can be evaluated except by subtraction from present sampling stages. One cause of loss is the drop of mined needles containing eggs. The other cause is the prevention of larval establishment by adverse weather factors.

That drop of mined needles containing eggs does occur has been substantiated by examination of the needle litter at the base of trees. No estimate of loss has yet been made but it is reasonably certain that such eggs would be lost to the population. Morgan (77) estimated this loss to be 18 per cent in the California needle miner. As loss of eggs by needle casting did not occur in the Bow Valley in 1956, it is probably only an occasional phenomenon, perhaps resulting from strong gusts of wind during the time of egg development.

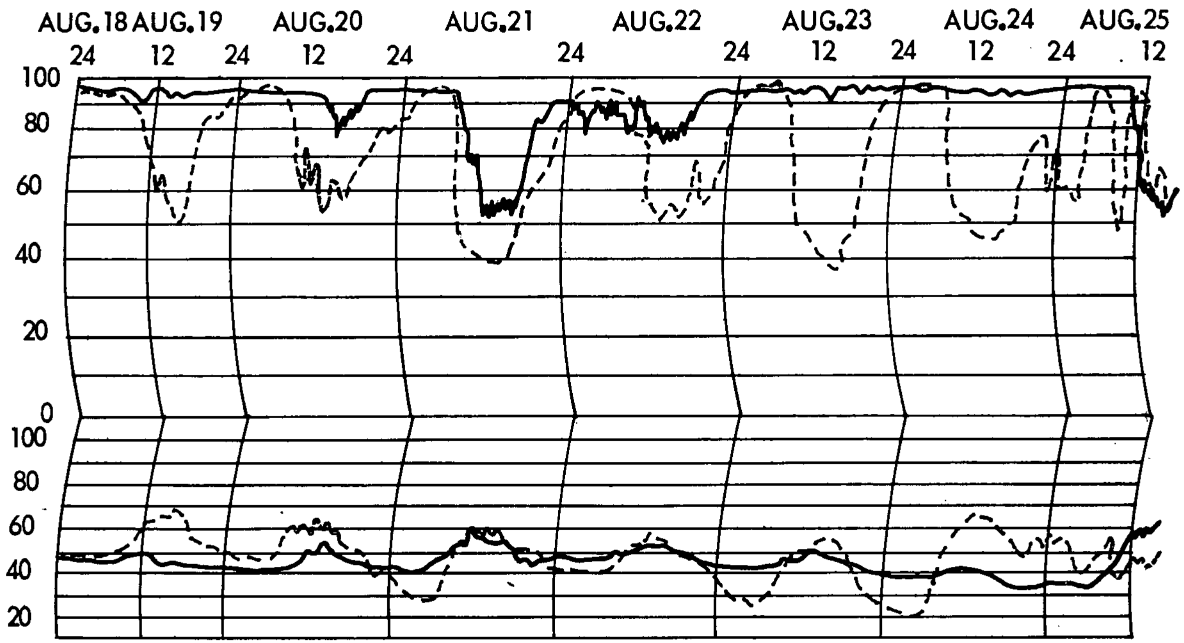
No measurement has been made of loss of hatching larvae but it is recognized that it could be an important factor in population reduction. Experiments by Shepherd (103) indicated that the threshold of activity of newly emerged larvae is rather high (59 - 65°F) and the limited experiments on eggs noted above indicated that high humidities (usually accompanied by cool weather) restrict first-instar larval activity. Examination of hygrothermograph records maintained on Mount Eisenhower in 1954 indicates a cold, wet period from August 18 to August 24th which corresponds closely to the beginning of the hatching period. Temperature and humidity conditions for this period are shown in Figure 16. Again, no measurement of loss is possible except by interpolation from the life table but it is reasonably certain that the combination of low temperature and high humidity is responsible for the loss noted in 1954 between oviposition and larval establishment. Humidities were above 90 per cent for most of this period, except for a short time on the 20th, 21st, and 22nd. The temperature, except for the mid-day period on the 20th (61°F) went to 55°F only once and was about 50°F or less for the remainder of the period. As this loss between oviposition and larval establishment did not occur in 1956, comparison of conditions for the same period should be markedly different if the above suppositions are

Figure 16. Hygrothermograph tracing showing humidity (upper) and temperature (lower) conditions on Mount Eisenhower, 5,550' from August 18 to 25, 1954 and 1956.

Solid line - 1954

Broken line - 1956

HYGROTHERMOGRAPH TRACING - 2400 AUGUST 18 - 1200 AUGUST 25 (MST).
MOUNT EISENHOWER - 5,550'



correct. The dotted line in Figure 16 shows the hygrothermograph tracing for the same period but from a thermograph maintained at Eisenhower Field Station a few miles away. Conditions in 1956 were more favorable for larval establishment than in 1954. The lower night temperatures in 1956 were not severe enough to cause mortality.

(2) Effects of climatic factors on larvae during the summer.

Morgan (77) has suggested that larvae of *R. milleri* Busck may be forced from their mines by excessive heat and that this may be an important factor in control. It has been established that temperatures of mines may be increased by as much as 11°F under optimum radiation conditions (42) but the behaviour suggested by Morgan has never been observed in the Canadian needle miner.

Although actual mortality does not occur during summer when only larvae are present, adverse climatic factors during this period may have a long-term effect on the population by affecting larval development. The only occasion observed when this may have happened to a marked degree was in Yoho National Park in the summer of 1951. This summer was cool and wet and the larval transfer from first to second needle lacked any semblance of order. Transferring began about June 20th and on August 23rd some larvae were still transferring. Approximately 90 per cent had completed transfer by the 30th of July but this process is usually completed in two to three weeks in July (123). This could be a contributory factor to reductions in populations by long-term effects on winter survival and possibly on fecundity. As this phenomenon was observed only in the Cathedral Mountain sampling area it is also possible that this, rather than excessive winter mortality was one of the factors which caused reduction of Yoho populations.

(3) Effects on pupae.

As shown in the life tables, in all areas except Mount Cathedral in Yoho Park mortality of pupae was estimated at from 20 to 25 per cent in 1956. No other factor is evident for this mortality except climate. As there was no apparent mortality of pupae in 1954 comparison of weather records during pupation should show a difference. Examination of hygrothermograph charts from Eisenhower Field Station for June in both years gives little basis for speculation. The mean maximum temperatures differed by less than 1°F, the mean minima were almost identical. The considerably higher relative humidity in 1956 than in 1954 eliminates the possibility of desiccation as an explanation. There occurred in June, 1956, a four and a six day rainy period, separated by only one day, which were characterized by temperatures averaging 42°F. On five of these ten days the minimum was below the freezing point. There was an equivalent number of days in June, 1954, with minima below the freezing point but in 1954 these were not usually associated with low maximums. Thus on five consecutive days in June, 1954, when the minima fell below freezing, the maxima were all 60°F or above, with an average daily temperature of 45.4°F for the five day period.

It is unlikely that high temperatures are involved although it has been demonstrated by the work of Henson and Shepherd (42) that needle mine temperatures may be increased by as much as 11°F in the most intense radiant conditions (see also 150). If this were the factor involved we should have found equal or greater mortality in 1954 as the month of June, 1954, was generally warmer and sunnier than

June, 1956.

As pupal development was retarded and this pupal mortality did occur, it is therefore postulated that in 1956, developmental conditions were sub-optimal and the period described above (June 5 - 8; 11 - 16) may have been a contributory factor to the mortality.

(4) Effects of various factors on moth behaviour in respect to needle miner abundance.

All moth activities relating to insect abundance, flight, copulation, and oviposition are dealt with together, as well as fecundity and fertility, for the same factors have some effect on them all. Detailed information on this extremely important stage is scarce and we have data from only two generations when the population from 'potential' to actual has been assessed, viz; 1954 and 1956. The estimate of potential population is extremely crude and only indicative.

Dissections by several workers have shown that egg potential in the needle miner approaches 100 eggs per female (35,125, unpublished data). The number of apparently mature eggs in captive females was found to be 16 to 30. Whether this number is ever exceeded in nature is not known. Field samples in 1954 and 1956 indicated a reduction in egg potential or in ability to lay eggs. The average number of eggs laid per female (from life tables) was nine and eight respectively. It is therefore possible that we have been overestimating the potential egg capacity of the needle miner and part of the egg losses discussed above does not actually occur.

The apparently low fecundity of the females in 1954 and 1956 may be the effect of adverse climatic factors acting on developmental stages (see Section 3.1.1.). Conditions during the 30-day pupal period could have a drastic influence on oögenesis of females. The low temperatures during pupal development may have interrupted development enough to be detrimental to eventual egg development (102,144). Pradhan (97) found that development of _Earias fabia_ Stall was quicker under variable than constant low temperatures but slower under variable than under constant high temperatures. If this were true of the needle miner, a month characterized by high maxima (70°F) and low minima (about freezing), or short periods of cold weather followed by warm to hot weather could have a delaying effect on pupal development and a resultant adverse effect on moth fecundity. Yet another factor which may effect fecundity is the presence of non-fatal disease in the moth population (86).

There are many factors which may affect successful oviposition. Possibly greater inhibition of oviposition in 1956 than in 1954 was indicated by egg samples. Fewer large egg masses were found in 1956 than in 1954 and the number of single eggs found in proportion to the total number was far greater.

Greatest flight activity occurs at sunset. This is believed to be due to diminishing light. Diminution of light (or radiation) such as occurs prior to heavy clouds passing over, caused increased activity during the day. At sunset, if there is no wind or rain,activity is at a peak, the moths flying upward to the tops of the tree crowns, which gives rise to the distribution of eggs and larvae described earlier. If the temperature is not too low this flight occurs even when the sky is overcast but is less than when the sky is clear. The moths are quiescent at winds above 5 m.p.h. and during rain storms. On calm days there is general excitability at high humidities but as these were usually associated with cloudiness the precise factor involved is not certain (35).

Fluctuations in barometric pressure cause increased flight activity in some insects (131,148). However, as great flight activity of the needle miner occurs at sunset on calm, reasonably warm days, changes in pressure cannot be particularly significant. Pressure could be a minor factor during daylight hours when associated with changing weather conditions (16).

On hot, sunny days, when the humidity is low, needle miner moths seek shaded locations and display a minimum of activity. On cloudy days activity occurs in spurts, associated with passing clouds.

Cold, windy, or rainy weather during the moth flight could have a profound effect on the success of oviposition and result in a wide discrepancy between the potential number of eggs and the actual number laid.

3.2. Parasitism

Parasites have long been upheld as the major influence in so-called "biotic control" and many instances have been cited where economic control of insect pests has been effective, largely through the introduction of new parasites. Sweetman (132) subjected many claimed examples to intense scrutiny and came to the conclusion that many of the 'controls' claimed to be due to biological factors, parasites and predators, were in fact, due to other factors. However, he concluded that parasites can be a controlling influence on insect populations.

Andrewartha and Birch (3) quote Elton who states "It is becoming increasingly understood by population ecologists that the control of populations i.e. the ultimate upper and lower limit set to increase, is brought about by density-dependent factors, either within the species or between species. The chief density-dependent factors are intra-specific for resources, space or prestige, and inter-specific competition, predators or parasites." They, however, take strong exception to this statement and claim there is little evidence to support it. Indeed, they go so far as to call it dogma rather than a conclusion (p.19).

Milne (75) claims that there has been no proven case of control of an insect population by it's natural enemies but abundant evidence exists that they are unable to do so.

However, it is not the intention here to enter into this philosophical argument but merely to point out that one does not need to apologize for the failure of a parasite complex to control the host; there are as many people decrying the inefficiency of biological control as support it. However, the tendency towards control by parasites is recognized and for the proper understanding of the dynamics of an insect population one must analyze and explain the reasons for failure of biological control.

As has been partially shown in the life tables presented above and will be shown in greater detail below, the parasite complex of the lodgepole needle miner, *Recurvaria starki* played no major role in the striking declines of population already described.

3.2.1. Description of the parasite complex of *R. starki*.

Table XXIX is a list of the known parasites of the lodgepole needle miner. The list is compiled from the Annual Reports of the author, the Calgary laboratory of Forest Biology, the Biological Control Laboratory, Belleville, Ontario, and numerous short publications (48,57,72,114,118,122). The determinations were made by the Systematics Unit, Division of Entomology, Ottawa. It is impossible to indicate some of the parasites as larval or pupal as they were obtained from mass rearing and are extremely rare. The order of listing is taken from Muesebeck et.al., (85).

Three of the species listed comprise 90 per cent or more of the total number of parasites present in field populations. These are Copidosoma n.sp. and the two Apanteles species. Most of the parasites are rare and little information is available on these but it may be of value in discussing their abundance and dynamics to summarize what is known about them. These will be dealt with in the order given in Table XXIX and not in the order of their importance.

1.2. Apanteles californicus Mues. and Apanteles sp. As there is no apparent difference in the behaviour or life cycle of these parasites they are discussed together. Muesebeck states that all species of this subfamily seem to be internal parasites of lepidopterous larvae (85). A. californicus is described from Oregon and California and Recurvaria milleri Bsk. is given as it's host.

The life cycles of the parasites follow that of the host although there is a greater variability in emergence dates. Emergence records for 1954 show that the parasites emerged about the same time as the needle miner, in early July. In 1956, parasite emergence was markedly earlier and there was a tendency towards two emergence peaks, the 23rd and 28th of June. This may be due to a species difference but it is thought in this instance to be due to climatic influences.

After the first peak of emergence, cold, rainy weather set in and did not let up until June 27th, the day before the second emergence peak. Emergence was high up to the end of the first week in July. McLeod (72) records emergence of Apanteles in late July and August but this was not the case in 1954 or 1956.

It is not known for certain which stage of the needle miner the Apanteles species attack but from the emergence dates and the length of life of the parasites (approximately three weeks) it is presumed to be the egg stage. Morgan (77) states that this is the case with Apanteles in California whose life span is fifteen days, but his belief is also based on circumstantial evidence.

The parasite is internal and does not affect feeding behaviour until the fourth or fifth instar. Upon the death of the needle miner larva the parasite emerges from the skin of its host and spins a white, opaque, silken cocoon within and near the base of the mined needle. Emergence is effected by cutting off a circular cap from the cocoon and crawling out of the exit hole prepared by the needle miner larva. The parasites are not visible until they leave their hosts, in mid-May (See Figure 17).

At least two species are hyperparasitic on Apanteles one of which is likely Alegina pinifoliae (Cush.), the other is not known. The hyperparasites are either polyembryonic or multiple parasites since Apanteles cocoons have been found with up to four emergence holes. The effect of the hyperparasites on the numbers of Apanteles has been slight to date.

3. Eubadizon gracile (Prov.). Very little is known of the subfamily to which this parasite belongs. E. gracile is listed from Canada

TABLE XXIX

PARASITE COMPLEX OF RECURVARIA STARKI FREE

Superfamily	Family	Species
ICHNEUMONOIDEA	Braconidae	1. Apanteles californicus Mues.
		2. Apanteles sp.
		3. Eubadizon gracile Prov.
		4. Meteorus n.sp.
	Ichneumonidae	5. Alegina pinifoliae (Cush.)
		6. Gelis tenellus (Say).
		7. Itoplectis obesus Cush.
		8. Phaedroctonus sp. near epinotiae Cush.
		9. Phaeogenes sp. near epinotiae Cush.
CHALCIDOIDEA	Eulophidae	10. Dicladocerus sp.
		11. Derostenus sp. (?)
		12. Euderus sp.
		13. Neoderostenus n.sp.
		14. Sympiesis sp.
		15. Tetrastichus sp.
		16. Zagrammasoma americana Gir.
		17. One unknown.
	Encyntidae	18. Copidosoma n.sp.
	Pteromalidae	19. Amblymerus sp.
		20. Habrocytus sp.
		21. Pachyneuron sp.
	Chalcididae	22. Spilochalcis sp. prob. albifrons (Walsh).

(no specific locality) and Maine. The only host given in Muesebeck is Recurvaria piceaella Kearf (85). Prebble (pers. comm.) found it on the black-headed budworm in British Columbia.

Little is known of its behaviour. The parasite is internal and leaves the host carcass in late May and spins a tough, brown, translucent cocoon midway between the base of the mine and the exit hole within the needle. The needle miner is unaffected until early May. Emergence has occurred as early as June 18th and as late as July 10th. Specimens were too few to postulate a peak emergence period. Specimens in captivity lived only a few weeks. A Eubadizon sp. is listed from Recurvaria milleri Bsk. (77). (See Figure 17).

4. Meteorus sp. Nothing is known of its life cycle or behaviour as it was obtained from mass rearing and is rare. All species are described as internal parasites (85).

5. Alegina pinifoliae (Cush.). This and the next species Gelis tenellus (Say) are of the same subfamily. The only other host recorded for A. pinifoliae is an eastern needle miner Exoteleia pinifoliella (Chamb.). This is one of the suspected hyperparasites of Apanteles species. Members of the same tribe are described as occasional or habitual secondary parasites. Many hosts are recorded for G. tenellus but of particular interest are three species of Apanteles and four of Meteorus (85). Neither species is recorded from California (77).

7. Itoplectis obesus Cush. Members of the tribe to which this belongs are parasites of a great variety of pupae and prepupae of Lepidoptera.

There is little host specificity and adults have a corresponding variability in size. The species of Itoplectis may also be secondary parasites (85). It is not recorded from California (77).

8. Phaedroctonus sp. The tribe includes many important parasites of economic pests. Most species attack lepidopterous larvae (85). A Phaedroctonus sp. occurs on R. milleri Bsk. (77).

9. Phaeogenes sp. The members of the subfamily to which Phaeogenes belongs are described as internal parasites of Lepidoptera. They oviposit into either the host larva or pupa, but always emerge from the pupa (85). The only note made on this relatively rare species is that it was observed emerging from the needle miner pupa on August 4th and was extremely active. Depending on the length of adult life it could either parasitize needle miner eggs or first instar larvae. There is some evidence to suggest that it may have a one-year cycle.

10. Dicladocerus sp. This internal larval parasite was not found in 1951 by McLeod and was one of a number of species of parasites liberated in the Banff area. The presence of it in later rearings may indicate establishment of this species. It is very rare, however. Morgan lists it along with three other Eulophids, Sympiesis sp., Derostenus sp. and Tetrastichus sp. as occurring in third- and fourth-instar larvae of R. milleri in the larval year (77). Such a phenomenon has never been recorded in the Canadian outbreak.

11. Derostenus sp. Other members of the same subfamily are Euderus sp., and Neoderostenus n.sp. Nothing is known of the first two except that they are very rare. Neoderostenus n.sp. was recorded as

an important parasite in Alberta by McLeod in 1951 (72) but sampling since this time indicates that it is relatively rare. It completes its development in the host pupa and may parasitize the larva in the same year carrying over on alternate hosts. It forms the naked black pupa typical of Eulophids. There are usually four to six parasites per pupa but whether this is due to polyembryony or multiple parasitization is not certain. It is also recorded as a secondary parasite of Copidosoma sp. (72).

14. Sympiesis sp. This is believed to be an external larval parasite and was relatively abundant in Alberta (72). This is not the situation now. Parasites believed to be Sympiesis sp. have been recovered from needle miner larvae and pupae and also from the important parasite, Copidosoma n.sp. Morgan records it as an external parasite on late instar larvae of R. milleri (77).

16. Zagrammasoma americana Gir. This was one of the earliest recorded parasites from Alberta. It was found emerging from host larvae and also from cocoons of Copidosoma n.sp. Since that time it has regularly appeared in mass rearings but in small numbers. It also is listed as a parasite of R. milleri (77).

18. Copidosoma n.sp. This Chalcid parasite was first thought to be taxonomically near C. nanellae Silv. However, in 1954, Miller (pers. comm.) stated: "A further study of the male genitalia of specimens from (Alberta, British Columbia, Idaho and California) has made it possible for me to state that there is but one species of Copidosoma attacking lodgepole needle miner in Western North America." This includes Recurvaria milleri, R. starki and possibly several other

Recurvaria species.

It is a polyembryonic species of which as many as 14 adults emerge from a single host larva. The average in *R. starki* is about seven per host. Emergence occurs over a relatively short period. In 1956 this period extended from July 11 to July 30 with the peak occurring about July 19. This was slightly earlier than in 1954 when emergence began about July 15 and extended into the first week in August. This corresponds with the oviposition period of the needle miner adults.

Recently emerged adults were placed in a vial containing a mined needle containing needle miner eggs. The parasites seemed capable of determining where the eggs were in the needle by tapping the needle with their antennae. Once found, the adult investigated the egg cluster repeatedly by inserting her head into the exit hole. If the egg cluster was too far from the hole for the parasite to reach with her antennae or ovipositor the female would either leave the needle or investigate the surface of the needle around the egg cluster. As they were found ovipositing through cracks in the dried needles it is possible that this condition is what they were searching for. Many unsuccessful attempts at oviposition were observed, the ovipositor repeatedly slipping off the egg surface. When several adults were placed in the same vial with only one egg cluster, they were seen to parasitize the same eggs. Individual females were seen ovipositing into the same egg several times.

Larval sectioning has established that this parasite has a life cycle corresponding in length to that of *Recurvaria starki* Free. (See Figure 18).

Figure 17. Parasites of _R_. _starki_ Free.

(a) _Apanteles_ spp. cocoon.

(b) Cocoon of _Eubadizon_ _gracile_ Prov.

(c) Unidentified pupal parasite.

(d) _Spilochalcis_ sp. poss. _albifrons_ (Walsh).

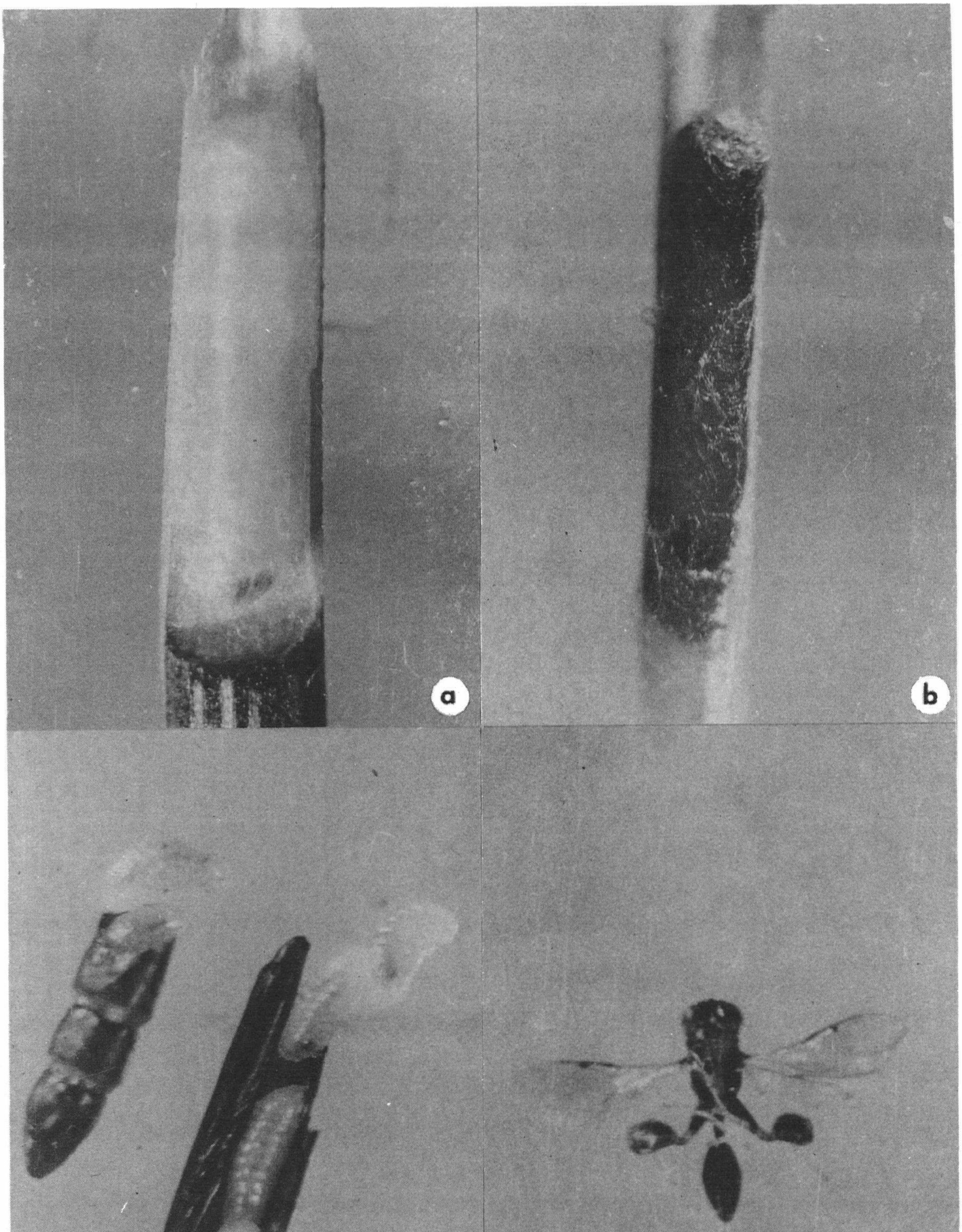
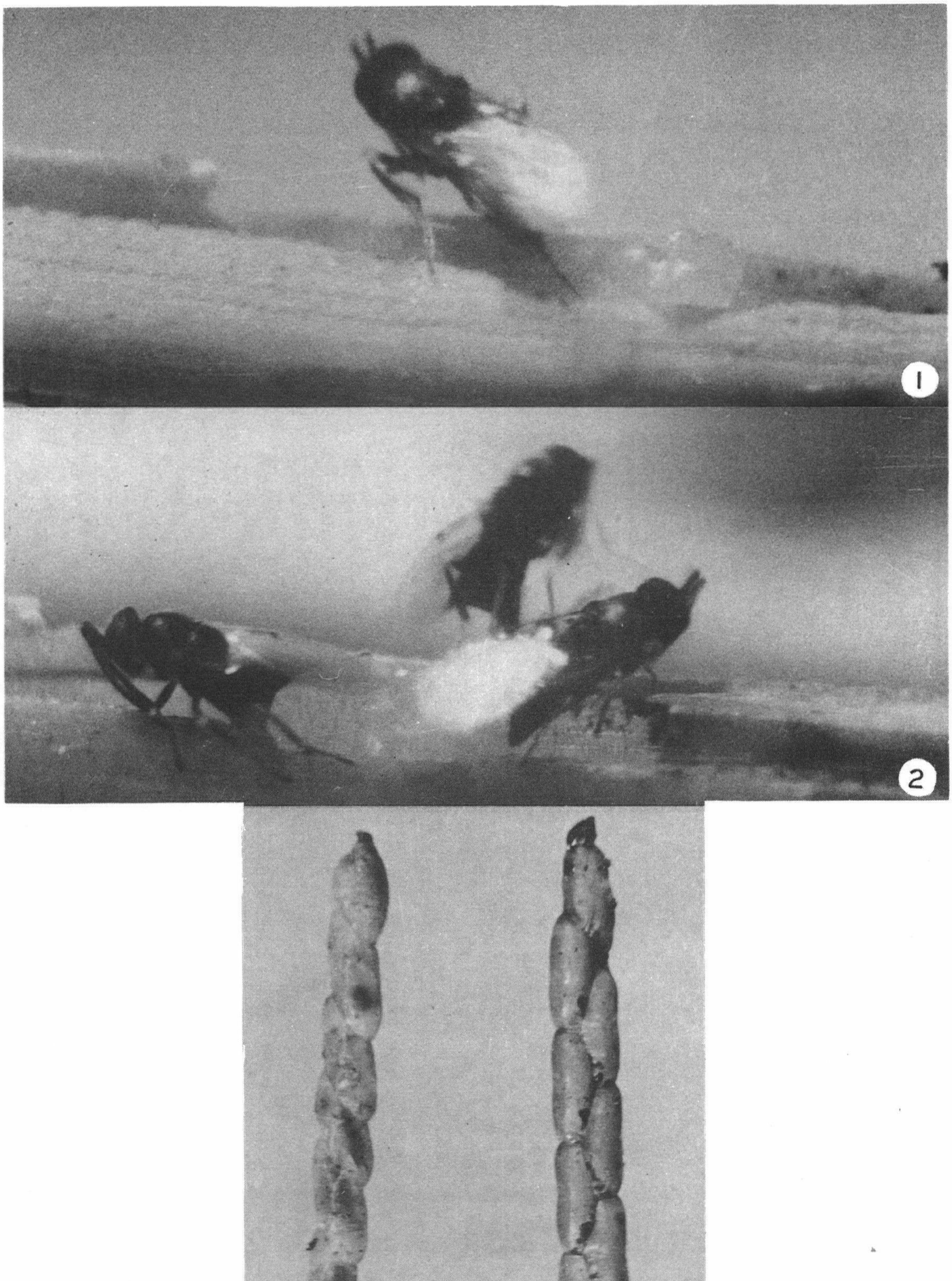

a
b
c
d

Figure 18. Parasites of _R. starki_ Free.

(1) _Copidosoma_ n.sp. ovipositing in needle miner egg cluster.

(2) Multiple parasitism by _Copidosoma_ n.sp.

(3) Needle miner larvae parasitized by _Copidosoma_ n.sp. Parasites almost mature.



3.2.2. Population dynamics of needle miner parasites.

One of the advantages of the life table method is that it is possible to isolate any period or stage in the life cycle covered by the life table itself and examine it in greater detail (73). Inclusion of such detail in the original life table would make it unwieldy. The spring of the moth flight year when parasitism becomes evident, is of particular interest. Information gained from a more detailed examination will be of greater value if we can reconstruct what has happened to the numbers of the parasite complex since the beginning of the investigative period.

The first estimate of parasitism, based on a limited number of samples, was in 1944 (40). Scanty estimates are also available for 1946 (51), and reasonably precise estimates were made in 1948, 1950 and 1952 (112,113,122). More precise estimates with better understanding of the species complex were made in 1954 and 1956. The proportionate abundance of parasitized hosts is presented in Table XXX for all areas. The estimates in these tables are based upon the populations present just prior to the winter before the moth flight year. The percentage parasitism is thus only the percentage of parasites which reached maturity. Except for the small fraction which die after they become evident there is no way of determining the mortality of parasites except by sectioning of dead needle miner larvae. Practical considerations do not permit such sampling at present.

Two values are shown for the spring of 1950. Twelve per cent is the degree of parasitism evident in the spring, two per cent is the actual per cent parasitism which survived the winter of 1949-50.

TABLE XXX

PERCENTAGE PARASITISM IN MOTH FLIGHT YEARS
- ALL AREAS -

Year	Parasitism per cent	Most important parasite species (in numbers)
1944	11	*Copidosoma* n.sp.
1946	10	- - - - - - - -
1948	10	- - - - - - - -
1950	12 to 1.7	*Copidosoma* n.sp.
1952	10	*Copidosoma* n.sp.
1954	18	*Copidosoma* n.sp. *Apanteles californicus* Mues. *Apanteles* sp.
1956	30	*Apanteles californicus* Mues. *Apanteles* sp. *Copidosoma* n.sp.

Partial records are available for several areas which demonstrate the variability of parasitism within the general outbreak area. These are summarized in Table XXXI for areas selected to conform with the four areas now being continuously studied. Two estimates are given for the 1950 samples in this table also.

TABLE XXXI

PERCENTAGE PARASITISM IN MOTH FLIGHT YEARS FOR FOUR AREAS NOW UNDER CONSTANT INVESTIGATION

Area	1950	1952	1954	1956
Mount Eisenhower	19 - 3.7	4 +	20	39
Bankhead	11 - 1.9	17	16	
Girouard				32
Massive	13 - 0	-	10	26
Cathedral	0	22	14	12

The population data for all areas other than Mount Eisenhower were not complete enough for the formulation of life tables. To make the data comparable therefore, supplementary tables were not prepared for any other than the 1954-56 generations. However a comparison of the species composition of parasites in the spring of 1954 is of interest (Table XXXII). These data clearly show the importance of three of the parasite species.

Although it is not wholly consistent throughout the whole area of the outbreak *Apanteles* often appear to be more numerous in the valley bottoms than on the slopes. This may suggest that they are more cold-hardy than *Copidosoma* n.sp. or that there is a fundamental difference in conditions required for oviposition.

Supplementary tables for the critical spring period of the moth flight year for the four areas on a continuous study basis are presented in Tables XXXIII to XXXV which relate to Tables X, XII, XIII and XIV.

It is clear from the life tables presented earlier and their supplements above that parasites have not played the major role in the population reductions observed since 1948.

It is generally accepted that population growth follows a logistic curve where density increases until a point is reached at which the trend will be reversed and the rate of increase will begin to decline. Finally a more or less constant density is reached. It is also generally assumed that this phenomenon is brought about in two ways: through new and more severely unfavourable processes coming into play at successively higher levels of density and by an increase in the intensity of action of various individual

TABLE XXXII

SPECIES COMPOSITION AND PERCENTAGE PARASITISM IN ALL AREAS SAMPLED IN 1954

Location	Elev.	Per cent Parasitism	By species-per cent of total parasitism Copidosoma	Apanteles spp.	Others
Mount Eisenhower	4800	-	-	-	-
	5300	11.0	39.0	59.0	2.0
	5800	18.7	86.0	13.5	0.5
	6300	20.3	83.0	16.5	0.5
Massive	4800	1.5	-	100.0	-
	5300	7.8	47.4	52.6	-
	5800	12.2	48.4	51.6	-
	6300	9.4	21.0	79.0	-
Cathedral	4500	13.6	6.2	92.2	1.6
	5000	10.7	53.9	45.1	1.0
	5500	28.5	40.4	58.6	1.0
Lake Louise	5000	-	-	-	-
	5500	8.6	81.0	18.5	0.5
	6000	12.9	95.3	4.2	0.5
	6500	6.4	92.6	3.6	3.8
Brewster Creek	5200	69.5	37.9	61.9	0.2
Baker Creek	6000	61.2	30.8	69.2	0
Cascade Valley	5500	16.2	60.0	39.7	0.3
Saskatchewan Crossing	4700	1.6	11.3	88.7	-
Hawk Creek	4000	14.9	83.4	16.6	-

TABLE XXXIII

SUPPLEMENT TO TABLE X FOR MOUNT EISENHOWER SHOWING MORTALITY OF LATE INSTAR LARVAE AND PUPAE

x	lx	dxF	dx	100qx
Instars III - IV (1955 - 1956)	416	Climate-winter mortality	143	34.37
Instars IV - V May, 1956	273	Parasitism		
		Copidosoma n.sp.	86	31.50
		(Apanteles californicus Mues. (Apanteles sp.	68	24.90
		Eubadizon gracile (Prov.)	5	1.83
		Undetermined species	1	0.38
			160	58.61
		Unknown	8	2.93
			168	61.54
Pupae	105	Unknown-poss. climate	26	24.76
		Parasitism		
		Phaeogenes sp. and others less than	1	0.45
			26 +	25.21

TABLE XXXIV

SUPPLEMENT TO TABLE XII FOR MASSIVE MOUNTAIN SHOWING MORTALITY OF LATE INSTAR LARVAE AND PUPAE

x	lx	dxF	dx	100qx
III - IV instars (1955 - 1956)	465	Climate - winter mortality	94	20.22
		spring mortality	2	0.43
			96	20.65
IV - V instars May, June, 1956	369	Predation by birds	124	33.60
		Parasitism		
		(*Apanteles californicus* Mues. ((*Apanteles* sp.	66	17.89
		Copidosoma n.sp.	52	14.09
		Eubadizon gracile (Prov.)	3	0.81
		Undetermined species	2	0.54
			123	33.33
			247	66.94
Pupae June, 1956	122	Climate - desiccation?	30	24.84
Emerged	92			

TABLE XXXV

SUPPLEMENT TO TABLE XIII FOR MOUNT GIROUARD SHOWING MORTALITY OF LATE INSTAR LARVAE AND PUPAE

x	lx	dxF	dx	100qx
III - IV instars (1955 - 1956)	896	Climate - winter mortality	213	23.77
		spring mortality	15	1.67
			228	25.44
IV - V instars May - June, 1956	668	Predation by birds	76	11.38
		Parasitism		
		(*Apanteles californicus* Mues. / *Apanteles* sp.)	228	34.13
		Copidosoma n.sp.	50	7.48
		Undetermined species	10	1.50
			288	43.11
		Unknown	41	6.14
			405	60.63
Pupae June, 1956	263	Climate - desiccation?	56	21.29
		Parasitism - unidentified species	2	7.60
			58	28.89
Emerged	205			

TABLE XXXVI

SUPPLEMENT TO TABLE XIV FOR CATHEDRAL MOUNTAIN SHOWING MORTALITY OF LATE INSTAR LARVAE AND PUPAE

x	lx	dxF	dx	100qx
III - IV instars 1955 - 1956	181	Climate - winter mortality	111	61.33
		spring mortality	6	3.31
			117	64.64
IV - V instar May - June, 1956	64	<u>Parasitism</u>		
		(<u>Apanteles</u> <u>californicus</u> Mues. (<u>Apanteles</u> sp.	17	25.56
		<u>Copidosoma</u> n.sp.	4	6.25
		Undetermined species	1	1.56
			22	24.37
Pupae June, 1956	42		0	
Emerged	42			

density-dependent factors or processes (106).

Klomp (61) in reviewing the major theories of host-parasite interaction is of the opinion that the work of Tinbergen supports the theories of Nicholson and the limiting or 'damping' of population oscillations is brought about in three ways. The first is based on Nicholson's theoretical model where the density of the other than the regulated host is independent of the activity of a given parasite and remains constant. This is not realized in nature but it must be considered that the fluctuations of the numbers are not caused by the parasite, the influence of the parasite being compensated by the regulating mechanism of the host. However at high densities of the parasite due to large numbers of the regulated host it is unlikely that the regulating mechanism of the alternate host is able to compensate for the high mortality. This does not appear to obtain in populations of the needle miner. First, there is known no alternate host of sufficient numbers to create the problem, and second the numbers of the parasite have never reached "high densities" in spite of the large numbers of the host, or in other words the host has never been regulated in the true sense of the word.

The second way in which population oscillations are limited is by a density-dependent reproduction of the host. Examples are given by Klomp where fecundity of the host is reduced at high levels of abundance which permitted the parasite population to overtake the host population in numbers. This also does not appear to apply because the parasite population has not to date come near 'over-taking' the needle miner populations, and although it has been shown in the section on climatic control that there is a strong indication of a reduced fecundity in the needle miner population this is obviously not a result of density-dependence in the sense used by Klomp since it has occurred at low populations.

The third damping mechanism is a density-dependent mortality of the host. In theory, a density-dependent mortality, like reproduction, would have a damping effect, provided the factor played a considerable part in mortality at intermediate stages. No such factor is operative in the needle miner populations. The factor which has caused the decline by means of catastrophic mortality showed no partiality.

From Tables XXX to XXXVI it can be seen that the parasites of the needle miner have never taken much advantage of their 'environment', certainly never in the manner assumed in the theoretical models briefly reviewed. The proportion of parasites to the host population has remained more or less constant since 1944. Only the last two generations, 1952-54 and 1954-56 have shown a significant increase. On the basis of this we may postulate a similar sequence of events prior to 1944 which kept the parasite populations at a low level. The climatic analyses presented in an earlier section apply equally well to the parasite population. Indeed, to explain the lack of success of the parasites we must postulate an effect which limited their population growth more than their host and kept it more or less constant.

The first effect considered was that there was a differential mortality of parasites from severe winter weather. That is, the parasites suffered heavier mortality in the severe winters and/or that their survival rates from 'normal' cold winters is lower than the needle miner. Unfortunately we have no concrete evidence to support this claim. The only measurement of parasite mortality (all species) was made in 1956 and was not significantly different from needle miner mortality.

There is considerable evidence in the literature to support this hypothesis however. Clausen (19) recognized, particularly with introduced parasites, that differential mortality of parasites can be a limiting factor to parasite success. The introduced species may not be able to withstand as low temperatures as its host. Dowden's work (25) is an outstanding example of this effect.

Control of the oyster-shell scale by Aphytis mytilaspidis is usually effective in the mild-wintered Annapolis valley in Nova Scotia but is inneffective in New Brunswick where winter temperatures fall to - 20°F or lower (68). Success of parasites of scale insects in California was limited by low temperatures and extreme temperature fluctuations in the winter (20,23).

Uvarov (144) reviews several studies which show a differential mortality of parasites at low temperatures. Some internal parasites are more sensitive to low temperatures than the host in which they exist. However, he also gives examples which show that low temperatures can favor parasite populations where the parasitized hosts are less susceptible to temperature extremes than non-parasitized. Blais et al. (8) found this to be true for parasites of the forest tent caterpillar. Unseasonably warm weather in May followed by several days of freezing temperatures caused high mortality of larvae but its principal parasite was unaffected.

In the needle miner population the major parasites are internal and not evident until spring of the larval year. In sections of dead larvae made in 1949 and later years the percentage parasitism was in some cases higher than that observed in late instar larvae. However, we have the observation of parasitism made in 1956 to offset this evidence. It appears then that differential mortality may be a factor which aided in keeping the parasite population of the lodgepole needle miner at a low level but the evidence does not permit its unqualified acceptance.

A second limitation to parasite success is thought to be the differential effect of weather on developmental rates. Uvarov (144) gives ample evidence to show that host and parasite are very often unequally adjusted to normal climatic conditions and will react to disturbances in different ways. Slight differences in rate of development may have a profound effect on the success of a parasite particularly when the stage attacked is short-lived and the period of oviposition of the parasite is equally short. Thus DeBach, et al. (23) found that winter temperatures affected the rates of development of the parasite of a scale insect which disrupted the synchronization of parasite emergence and the stage attacked resulting in markedly reduced parasitism. It has been shown above that the emergence dates of two of the major parasite species of the needle miner were markedly different in two different generations. If the assumption is correct that these species are parasites of the egg stage, then the numbers of these species may be expected to be less in 1958.

Another possible factor, based solely on example and speculation, is that cold temperatures may reduce the fecundity and fertility of the parasite to a greater degree than its host. There is ample evidence to indicate that fecundity and fertility of insects are affected by external factors. In this thesis we have dealt largely with winter extremes but these effects may occur at any time during the life cycle (144). DeBach et al. found that the fecundity of a parasite of the California Red Scale was markedly reduced by detrimental effects of winter weather (23).

Thalenhorst (134) states that in nature, parasites and predators rarely attain their theoretical maximum efficiency and gives as a major reason for this that the hosts are rarely dispersed uniformly over an area, even under outbreak conditions. Differences in mobility and the 'searching ability' of the parasite may place the parasite at a distinct disadvantage. Environmental conditions during adult parasite activity may seriously limit their ability to search out the habitat of the stage attacked by them. So many variables are involved in determining the success of parasitism in comparison to that of the host that it is not surprising that parasites may be ineffective in controlling populations of the host insect.

We have reached the general conclusion that the parasite complex of the lodgepole needle miner, R. starki has been kept at low levels of abundance during the past outbreak through a combination of factors which acted in a differential manner to the detriment of parasite success. The conclusions of Bodenheimer and Schiffer (10) seem so pertinent to this discussion that a portion of them will be quoted in full.

"The fact that no accumulative summation of the parasitic effect in successive generations[1] is observed in nature, means in other words that the parasite is, as a whole, always more sensitive to decimating factors than the host. This rather mystical statement is, however, accessible to quantitative analysis. This analysis shows that this higher sensitivity is just what had to be expected:

a). In addition to the hosts and parasites killed directly by the catastrophe, there survive always a number of parasites within hosts which have been killed by the catastrophe. In endoparasites which have not yet finished their growth, this must lead to an almost 100 per cent mortality of these survivors. Ectoparasites and predacious larvae will be found to leave the dead host and to go in search for another suitable prey. It may be safely assumed that never 100 per cent of these migrants will reach their goal, but that usually - especially at the low host density which prevails just after the catastrophe, a very important percentage of them will die of starvation.[2]

b). In many cases, the parasitized hosts will certainly be more sensitive towards the catastrophic factor, increasing thus the host mortality as well as the type of mortality just described.

c). In a considerable number of cases the direct mortality of the parasite must actually be larger than that of the host. This has a priori to be expected for a good number of cases if the relative sensitivity of hosts and parasites are distributed at random........it is probably correct that the relation of host- and parasite- sensitivity towards the catastrophic factor (s) is not at random, but that in the majority of cases it actually works to the unfavor of the parasites. From these reasons which are fully confirmed by the mathematical analysis, we come to the conclusion that either the natality of the parasites must be very high or its mortality rather low as compared to that of the host, in order to overcome this unfavorable effect. If we assume an equal and at random sensitivity for host and parasites, the latter will, by reasons a) and b) always be decidedly more reduced than the host. The main operative modus is an ecological one independent of the higher physiological sensitivity under c). This analysis seems to give sufficient reasons to explain the absence of an accumulative effect of parasitism ..... or - in other words - why the parasite is always more "sensitive" than the host."

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1. Referring to the Thompson theory that if certain premises are fulfilled the parasite will cause the extinction of the host by accumulative increase from generation to generation. Thompson recognizes that such does not occur in nature but considers the hypothetical case of artificial introduction of a parasite into an hitherto unparasitized population.

2. This is apparently what happened in the spring of 1949-50. The two mortality estimates given in Tables XXX and XXXI indicate that the parasites comprising the higher estimate must have completed their development to a stage where they were visible in hosts which were killed by the severe temperatures in January, 1950, before themselves succumbing.

3.3 Predation

3.3.1 Types of predation.

Predation was not an important mortality factor in the outbreak until 1956. No significant loss in eggs or larvae could ever be attributed to predation of any kind. Repeated field observations have never led to suspicion of predation of eggs but in the detailed sampling carried on since 1949 during the larval stage an insignificant number of shredded needles have been found, which were suspected of having been shredded by birds. In 1956, in two areas, Mount Girouard and Massive Mountain, there was found a large number of shredded needles such as could have been done only by flocking birds. Tables XXXIV and XXXV show that the extent of the predation was 11.38 per cent at Mount Girouard and 33.60 at Massive. No definite information is available but from a limited knowledge of the bird fauna the suspect predators were narrowed to three. These are:

(1) The Black-capped chickadee, _Penthestes atricapillus septentrionalis_, or possibly Gambel's chickadee, _P. gambeli_. Although no actual feeding has been observed chickadees are very common in the Bow Valley at times and have been seen flocking in mid-winter around Banff and Mount Eisenhower. Their habits and the high percentage of insect food they are accredited with needing (133) made them a logical suspect.

(2) Canada Jay or Rocky Mountain Jay, _Perisoreus canadensis capitalis_. This species is also very common in the outbreak area, as many as eight at one time congregating around the field station. They have actually been observed pecking at mined needles and shredded needles have been recovered from their perching trees. As most of the establishments throughout the National Parks are closed during the winter and as the Canada Jay is supposed to shun larger centres of habitation (133) it is possible that insects may be one of their winter staples. The Jay is omnivorous (133) so is a less likely suspect for mass predation than the chickadee.

(3) Less likely to be involved in needle miner predation than the other two is the Junco, probably the Slate-colored Junco given the name _Junco hyemalis connectens_ by Taverner (133). Taverner's description fits the species observed by the author but no specimens have been taken for identification. Although feeding primarily on weed seeds Juncos have been known to eat insects. This has been included as a doubtful suspect because it has been seen in fairly large numbers in Banff National Park in early spring and late fall.

3.3.2. <u>Importance of predation in dynamics of needle miner populations</u>.

This is very difficult to assess. As has been noted it has been immeasureable until 1956 and then was very localized. The extent and importance of such predation over the whole outbreak area, or as a factor in causing population reduction is likely very small. It could however, assume an important role where needle miner numbers are low and restricted to fairly distinct "refuge areas" such as was discussed in the climatic controls section.

The importance of bird predation either during an outbreak or during endemic periods must, however, be treated with caution. Unless the birds actually discriminate between parasitized and unparasitized larvae their effect is liable to be more harmful than beneficial. With the needle miner the possibility of discrimination is very remote as the important parasite species are internal and are not visible as parasites (to external human observation at least) until late in the needle miner development. The long-range effect of reducing the parasite population in equal proportion to that of the needle miner could conceivably cause an increase in needle miner numbers as it removes from the control complex a more prolific control agent.

That birds are continuous predators in many insect communities is well understood (2) but it is also admitted that most bird predators are generally indiscriminate in their choice of prey species. It is unlikely, therefore, that the needle miner is the sole food at any time for any of the birds mentioned above or the visible evidence of predation would be more common. It has been shown that in an outbreak of a forest insect where insectivorous birds are present the birds will eat a substantial and significant number but no estimate was made of the effects of indiscriminate predation of parasite and host alike (26). Such predation as has been observed in the needle miner outbreaks would have a greater depressant effect on parasite populations than the host i.e. in the manner discussed by Bodenheimer and Schiffer above (10). No estimate of predation of adult needle miner has yet been made.

3.4 Disease

Disease has not been an important factor in the needle miner outbreak. An early report of "disease" larvae between 1945 and 1946 (51) is now believed to have been winter mortality, a view in which the originator of the first report concurs (Hopping, G.R.- pers. comm.). Samples submitted to the laboratory of Insect Pathology at Sault Ste. Marie, Ontario, prior to 1952 showed no incidence of any disease. In 1952, workers at the Insect Pathology Laboratory succeeded in isolating a virus disease from the California needle miner, R. milleri Bsk. At the suggestion of J.M. Cameron, Officer-in-Charge of that laboratory, an attempt was made to introduce the virus disease into the Canadian infestation (117).

The supply of the capsule virus in suspension was very limited. Three concentrations were used:

a) full strength, with an appropriate amount of a wetting agent (methocel).

b) diluted 1 in 10 of 1 per cent methocel.

c) diluted 1 in 100 of 1 per cent methocel.

d) 1 per cent methocel was used as a control.

The location chosen for the experiment was in the Cathedral Mountain sampling area. Five trees were selected, all of which were heavily infested. Twenty-five tips on each of three trees and 25 in the remaining two trees were chosen on the basis of the number of available egg-laying sites i.e. abandoned, mined needles. A large number of these were desirable to guarantee a satisfactory experimental population. Later, needles containing eggs were picked from surrounding trees and interlaced among the treated tips. Every tip to be treated on each tree was stripped of needles for several inches back of the 1950 or 1951 foliage limiting the larvae to the desired part of the tip. The stripped portion was painted an identifying color for each treatment. The capsule material was then applied by brushing it onto the green needles with a camels-hair brush. Only the top half and the convex surface of the needles were painted to conserve virus material, since the first instar larvae almost invariably enter into the needle in this portion. A further precaution taken was to do the control first, to avoid contamination, and working up the scale of concentration, rinsing the brush after each treatment. This was done for two reasons, to avoid alteration of the concentration and to perfect the technique so that when the full strength was applied, waste would be at a minimum.

Two samples of the treated material were submitted to the Laboratory of Insect Pathology at Sault Ste. Marie, one taken in

December, 1952, and the other taken in April, 1953.

In addition to the experiment described above samples of live and dead needle miner were submitted to the insect Pathology Laboratory in 1953 and 1954. Since 1954 Miss M.E.P. Cumming has kindly examined a portion of the needle miner population for disease each year.

The first application was begun July 31 and completed August 9th. Larvae began to emerge in the field within a few days of completion. During the nine days of application there were a few light showers and on the night of August 13th a very heavy rainfall. As eclosion and larval establishment were not yet complete this may have affected the results.

Results of the first sample of the treated tips were encouraging. The tips treated with the highest concentration showed the greatest number of larvae with 'many' capsules present. This was the only concentration however which showed a significant increase. At the time of this sample,specimens from other locations in the outbreak area were also submitted. Capsule virus was found there for the first time (Cameron, J.M.- pers. comm.).

The second sample from the treated area in April, 1953, was less encouraging. There appeared to be a slight tendency for increase in incidence in the full strength treatment but an almost equally high incidence was found in the control and in samples taken upwind and downwind from the treated area. There was a noticeable decrease in the occurrence of the capsule virus from the first sample. However, there were indications that incidence of the virus in the experiment was in fact due to the introduction of the virus. The incidence of disease elsewhere was much lower.

It must be pointed out that although the incidence of the disease was rather high in the treated area it did not increase the actual mortality. The "dead" larvae examined by the Insect Pathology Laboratory were likely killed by dehydration of the needles or other artifacts owing to the relatively long period between submission and examination at Sault Ste. Marie (April to July). The actual mortality in this locality at that time was about 12 per cent, which is largely attributable to winter kill.

Examination of material collected in December, 1953, and January, 1954, indicated a high occurrence of capsule virus but again mortality was felt to be due to winter conditions rather than the disease. Results of investigations since this time indicate low occurrence throughout the outbreak area and probably very little mortality, if any, can be attributed to it. There is little evidence to suggest that the capsule virus disease isolated from the California needle miner is actually lethal to the larvae infected (Struble G.R.-pers. comm. (77)).

Steinhaus (130) reviewed in considerable detail the knowledge of insect diseases. He outlines nine categories of relationships between micro-organisms and the main body of the treatise deals with the field we are interested in:

> "9. Insect as a definite host of microbial agents to which it is susceptible.
>
> In other words, the microbe-insect relationship may be that in which the microbe is a pathogen whose activity causes disease and frequently death in the insect host.
>
> The principal groups of microbial agents responsible for infectious diseases in insects are: viruses, bacteria, fungi, protozoa and nematodes. Examples of diseases caused by these

> agents abound....The regular or periodic occurrence of disease among insect populations itself constitutes an ecological factor of great importance from the practical standpoint as well as from that of insect ecology generally. The insect ecologist in particular should not lose sight of the fact that infectious disease is a manifestation of parasitism. It represents the reaction of the insect to invasion of the animal's tissues by a micro-parasite. It is simply a form of the struggle of living beings for food, shelter and propagation as expressed in the host-parasite relationship."

It has been assumed since a virus disease was isolated from the California needle miner and later from populations of R. starki that we are dealing with such a relationship. The evidence does not support this assumption but on the other hand does not entirely refute it. In the relatively long history of the outbreaks of Recurvaria milleri Bsk. in California (since 1911 at least) (93) there has been no indication that the disease caused any of the several population declines. These were thought to be rather the effect of overpopulation resulting in "ghost forests" (Struble, G.R.-pers. comm.). Yet the incidence of the virus in California needle miner populations is high enough to extract relatively large amounts of it. Thus it is possible that the occurrence of the virus is actually one of Steinhaus' other types of relationship not necessarily detrimental to the host. However, the general concensus of opinion is that the viruses are usually disease-causing and may become lethal.

Even if we continue to accept the assumption there is some doubt that the virus present in the needle miner population could become an effective control agent. A conclusion reached by Steinhaus was:

> "if the proportion of resulting disease in the total population is not great and satisfactory adaptation occurs, the mutant may thrive in the susceptible population and gradually the insect may develop a high degree of tolerance to the pathogen that initially exploited it."

Yet another consideration which makes the success of virus disease in needle miner populations unlikely is the insects' behaviour. It is difficult to conceive an efficient method of dissemination for an insect which spends most of its life cycle (certainly the most susceptible stages) inside a protective needle. There is little gregarious contact between needle miners, even in the same branch tip. The only times when 'bodily contact' could serve as a means of dissemination would be immediately after eclosion before the larvae had separated from the egg cluster to find their respective needles; during the second year larval transfer when contact would be rare except in the case of extremely high populations; and during the final larval transfer in the spring of the moth flight year.

No examination of adult needle miner for disease incidence has yet been made. A protozoan and polyhedral disease have been isolated from the abdomen of spruce budworm moths (86) and it is possible that occurrence of disease in adults may cause reduced fecundity in females and lower fertility in males.

As it appears certain that disease outbreaks are an "overpopulation phenomena" (130) and that diseases have a "threshold" of host density before they become effective it is further possible that the populations of Canadian needle miner never reached a high enough degree of population density for the virus disease to reach outbreak levels. The virus disease present in R. starki populations has apparently remained at the "enzootic" level throughout the course of the present outbreak.

3.5. Other natural control factors.

3.5.1. Resination. Behaviour of first instar larvae of *Recurvaria starki* Free. and *R. milleri* Busck is almost identical. Upon eclosion they seek a green needle and begin to mine, almost invariably on the convex or outer surface of the needle (77,93,123). The few that attempt to enter the needle from the concave or inner surface are usually killed. The abortive mine frequently has a small bubble of resin above it with the carcass of the larva in it. No measurement of larval loss in the Canadian population has been included in the mortality tables because mortality from this factor is not significant. In the California needle miner Morgan (77) states that "99 per cent of all first-instar larvae that entered needles on their concave (flat) surfaces were killed by an excessive flow of resin." However, less than 0.1 per cent of the larval population was affected.

The only other reference to this phenomenon found was on the pine needle miner, *Exoteleia pinifoliella* (Chamb.) which attacks jack pine, lodgepole and seven other species of thick-needled pines (6). Jack and pitch pine are its favored hosts in eastern North America but lodgepole pine is severely attacked when planted in the insect's range. Internal structure of the needle and susceptibility to injury by the pine needle miner were correlated. Number, position and size of the resin canals and possibly tree vigor were the main factors involved. Jack pine and lodgepole pine contain only two moderately sized resin canals, situated one in each corner of the needle. In these two hosts, larvae of *E. pinifoliella* were able to feed with "little, if any, interference from resin flow" (6). This does not agree with observations made on the two Recurvaria species on lodgepole pine in California and western Canada. One possible explanation, other than differences in tree vigor, lies in differences in mining behaviour. The Recurvaria species start their mine (whether on the concave or convex surface) in the distal third of the needle whereas first instar larvae of E. pinifoliella enter the needles commonly near the base of the needle in the mid-line. The Recurvaria species also usually begin their mine in the middle of the needle but are less select; mines are commonly found near the edges of the needles. We can only assume that the majority of those Recurvaria entering the flat surface do so in too close proximity to the resin canals. In any event, as noted above, the mortality from this cause is negligible.

3.5.2. Competition and 'Overpopulation' factors.

Competition, as discussed here, will only be concerned with the intra-specific level. In the history of this outbreak there has been no evidence to suggest that any other organism competes with the lodgepole needle miner for its food. 'Overpopulation factors' (106) have been credited by various authors with causing fluctuations in forest insect pests. Among the phenomena credited to overpopulation are reduced fecundity, increased susceptibility to disease, food shortage and increase of natural enemies. Disease susceptibility and increase of enemies were not important factors in the decline of the outbreak. One could assume, without real evidence, that the population declined due to reduced fecundity caused by overpopulation (106) or to a genetic collapse (29). However, the closely allied Californian needle miner, Recurvaria milleri

Busck has repeatedly reached the saturation point of its environment, causing large areas of forests to be killed without noticeable reduction in population prior to their own starvation and death. Survivors from those populations which destroyed their own environment have caused outbreaks in new locations (77,93).

Food shortage could conceivably be an important factor in population reduction but again in the Californian needle miner outbreak this has become a critical factor only upon the death of a large number of trees and populations continued to increase around these "ghost forests" (77). In the Canadian outbreak the population never quite reached the levels which would cause a critical food shortage. From intensive defoliation analyses begun in 1949 it was apparent that populations did not persist at high levels long enough to cause complete defoliation. However, populations from 1940 to 1948 were high enough to cause about 80 per cent defoliation in some localities and had these populations persisted, food shortage would have occurred in localized areas (128).

It is extremely unlikely that competition for food has ever been critical enough in the Canadian needle miner outbreak to have caused any fundamental population phenomenon to occur. However, a reduction in fecundity from a change in food quality as a result of intense defoliation may have occurred. There is little evidence to suggest any change in fecundity prior to the investigative period, 1948-1956, and only the evidence from inaccurate estimates based on dissection of female moths during this period. As stated above, the only apparent change was in 1954 and 1956. In this outbreak therefore competition is discounted as a significant population reduction factor.

4. EPIDEMIOLOGY

4.1. Epidemiology since 1942.

In the above sections we have discussed the population density and natural mortality of succeeding generations since 1942. It has been established that the population density was high when the infestation was first noted but was restricted to elevations between 5,000 and 6,000 feet. Following this year the outbreak spread to all altitude levels where lodgepole pine grows but did not increase appreciably in population density. In 1949-50 the population suffered a 'catastrophic' mortality which reduced the populations to low density (see Figs. 11,12). Most significant was the comparatively high populations which remained at elevations between 5,000 and 6,000 feet. The population was thus restricted to the altitude levels where it was first found. This indicates that the outbreak was probably 'young' in 1942, although numbers per tip were considerably higher then. It has also been shown from studies begun in 1948 that the reduction in numbers in 1949-50 was largely due to adverse climatic factors, chiefly winter temperatures. Other natural control factors, chiefly parasitism, could not have caused the declines noted. Subsequent population decline since 1949-50, while largely due to larval mortality during winter months, may have been accelerated in part by reduced fecundity in adult females, reduced fertility in males and/or other factors limiting oviposition. These considerations led to the speculation that the origin of the outbreak was due to climatic conditions less severe than those which occurred during the period under investigation or, the "theory of climatic release."

4.2. Origin of the outbreak

4.2.1. The theory of climatic release

The importance of climate in the epidemiology of insect outbreaks has been a subject of controversy for many years. Early "biotic" theories placed the emphasis on biotic factors but some authors recognized that weather factors may cause an "unbalance" which may lead to outbreaks (106). Later theories were more comprehensive (88,102,107,138).

Nicholson (88,89,90) has long held the view that populations are in a state of balance and the main controlling factors (of numbers) are "density-dependent" which include direct competition for resources or space, parasites, predators, and pathogens. Climate is "density-independent" and can never control populations.

Andrewartha and Birch (3) hold that the factors of environments controlling numbers are numerous but that climatic factors are of major importance. They conclude that all factors are "density-dependent" and attach no special importance to the biotic factors which are affected by host density.

Thompson (137,138,139) believes that natural control results from an organism living in a continuously fluctuating environment. Under favorable conditions, numbers increase; under unfavorable conditions, numbers decrease. Never do numbers increase indefinitely and, rarely ever, decrease to extinction. Variability in population abundance tends to be inversely correlated with the complexity of the "ecosystem" (137) a view held by many authors (2,3,54).

Milne (75) reviewed the theories mentioned above and proposes his own which he describes as a "modification of Thompson's." He objects to the Nicholson theory on the grounds that competing species, parasites, predators, and pathogens can not control because they are imperfectly density-dependent and to Thompson's theory that it underestimates the importance of density-dependence. The Andrewartha and Birch theory also suffers from their treatment of density-dependence. Milne's own theory is that competition between individuals of a single species is the only perfectly density-dependent factor in nature. This factor is seldom evoked and therefore the control of increase is the combined action of factors, density-independent and imperfectly density-dependent. The control of decrease of numbers is brought about by density-independent factors.

Ullyett (143) has called climate a "catastrophic" factor and thinks it can be a contributory cause to insect outbreaks. This is based on the assumption that "density-dependent" (biotic) factors are more adversely affected by such catastrophes than the insect in question. In the absence of these controlling factors the insect may reach destructive densities when the catastrophe is spent.

Thalenhorst (135) has presented several European examples of insect outbreaks attributed to weather conditions. From observational evidence, he shows that weather may influence an insect population in many ways. These are: acting directly on the population; by its effect on some other factor which is fundamental to population growth (or lack of growth); by acting on the other factor and the population simultaneously with a reciprocal effect between population and factor; or by a maze of interactions involving soil, host plant, population and its enemies simultaneously, with interactions between the factors affected. He summarizes his paper by paraphrasing Wellington (153):

> "So far it can be generally seen that weather factors (whether acting directly or indirectly) may play a decisive role in the origin of mass outbreaks, particularly (and possibly even only) when certain meteorological phenomenon are repeated in successive years."

The development of thought concerning weather in relation to insect outbreaks has slowly given more importance to weather as a causal effect. However Wellington (152) has pointed out that although the literature is studded with papers dealing with the effects of various meteorological factors on many phases of insect development and behaviour, only a few deal with those effects in terms of large scale weather processes and a very few follow through to the logical conclusion: prediction of the biological phenomenon with the aid of modern methods of weather analysis forecasting. Wellington has developed probably the first inclusive theory relating insect abundance and weather (152).

"Weather and climate are often considered simply as the broad framework within which the complicated biotic interactions take place. This viewpoint hastens the process by which numerous instances of the direct effect of meteorological factors are relegated to the limbo of density-independence so that the biological heart of the problem may be pursued without further distraction. Predictive systems lose a number of potentially valuable facts in this way. More important however, this viewpoint leads to total disregard of the indirect effects of meteorological factors on the equilibrium of a population by their action on its habitat, its parasites, its diseases, and the supply and quality of its food.

To assess climatic influences correctly it is necessary to examine climatic variations during the period immediately preceding or coinciding with the beginning of an outbreak of an insect that exhibits violent fluctuations in numbers instead of studying the climate while the outbreak exists. This follows from the concept of climatic release of a small indigenous population. That is, in a region where a species exists in small numbers, and in which biotic conditions already favor population growth no initial increase may occur until seasonal climatic control is relaxed. The important point to keep in mind, however, is that favorable weather may have to recur several years in succession before a major increase in population can develop. Once the enormous potential for increase that such a species possesses is realized, the population grows so rapidly that no combination of adverse physical or biotic factors can halt it immediately. Since it is usually during this period that the outbreak is studied, it is not surprising that effects of the various original governing factors are often obscured."

The application of the theory is best dealt with from concrete examples. There are three reasonably detailed examples in Canada.

Thus Wellington et al. (154) after distinguishing between those weather types favorable and unfavorable to the spruce budworm, related past outbreaks of the spruce budworm in central and eastern Canada to climatic changes. It was shown that outbreaks were preceded by reductions, during three or four consecutive years, in the annual number of cyclonic centers passing through the affected areas and by reductions in June precipitation. By later more refined weather analyses Wellington (151,152) has been able to show definite short-term latitudinal shifts in the movements of pressure centers over North America. Pressure centers are closely associated with known air-mass source regions and may be differentiated into groups depending on where they originate. When the tracks for each center are traced and studied independently, shifts in the principal courses from one period to the next frequently show up. A southward displacement of the tracks of those centers originating in the central States (Colorado lows) is associated with a corresponding southward displacement of the tracks of pressure centers originating over the polar region. Humid tropical air masses will be mostly barred from the Great Lakes region when such a southward shift of the circulation pattern occurs in the central part of the continent. The majority of air masses that pass over the region will then be of polar origin.

Thus Wellington concluded that in Northern Ontario the required physical conditions for spruce budworm increase tend to occur when the annual number of cyclonic passages in the late spring and summer is below average, and the majority of the air masses involved in these passages during these seasons are dry. They are of polar continental or polar maritime origin, because a southward shift of the circulation pattern holds invasions of more southern air masses to a minimum.

In the same study Wellington found that the required physical conditions for forest tent caterpillar population increase begin to occur with increasing frequency as the annual number of passing cyclones rises to a maximum. During this period of increase in cyclones, the number of passages during spring and summer is above average, and the majority of air masses involved are of southwestern origin because there is a northward shift of the circulation pattern which moves the more northern air masses to higher latitudes.

His final conclusion from these studies is that his findings place the problem of forecasting population increases of the spruce budworm and the forest tent caterpillar to possible outbreak levels on a meteorological basis that should fit into the techniques for long-range weather forecasting that may be developed in the near future.

The third example also concerns the spruce budworm in New Brunswick. Greenbank (37) considered outbreaks of the spruce budworm which occurred in 1912 and 1949 in relation to the theory of climatic release proposed by Wellington. His results were confirmatory. While considering these works it must be pointed out that the basis for the theory was not in the realm of abstract synoptic meteorology but from laboratory and field studies on the effects of meteorological factors on the behaviour of the adult, including mating and fecundity, on larval development and behaviour and its relationship to eventual fecundity, stand conditions, the effects of climatic factors on the flowering of balsam fir and others, eventually related back to the causal effect of the meteorological factors in operation - the over-all macro-climate of the region.

In summary, the theory of climatic release explains the time and place of outbreaks and its worth may be measured by its ability to predict outbreaks. It is not a theory to explain "regulation" of an insect population at levels of abundance comparable to comprehensive theories. The purpose of the theory is not to postulate regulation of population by climate. Studies on population dynamics in forest entomology during endemic periods are rare, although it is apparent that fluctuations in numbers without loss of balance are common and outbreaks the exception. Within the endemic period increase in population from one year to the next can result from physical conditions becoming favorable to the insect. Readjustment of the population after this increase may come through density-related processes although these may not be entirely effective until physical conditions become favorable again. However, years with unfavorable weather conditions cannot always be expected to follow years with favorable conditions and eventually the favorable weather conditions recur several years in succession. During such a period, as the climatic theory postulates, the endemic population may be released from the controlling influences of both physical and biotic factors (153).

4.2.2. The theory of climatic release applied to the outbreak of the lodgepole needle miner, Recurvaria starki Free.

(1) Climatic controls of the region. Weather for any particular location is described as the sum total of its atmospheric conditions (temperature, pressure, winds, moisture and precipitation) for a short period of time or "the momentary state of the atmosphere" (140). Climate, on the other hand is a compilation of day-to-day conditions related to a particular place or region with consideration given to variations of the various climatic elements (17,140). The weather of particular months related to particular mortality phenomena has been described. This weather, however, is related to specific climatic conditions peculiar to that region. Daily, monthly, or yearly weather in any region is determined largely by type and circulation of air masses. In preceding sections we have described climatic elements with reference to the air-mass predominant at the time. In Appendix 9 a summary of air-mass types is given for a considerable number of years for the outbreak region. When a mass of air remains stationary for some time over a region it acquires properties of temperature and water vapor that are characteristic for the area. In winter an air mass that remains for some time over the cold frozen area of north central Canada would become cold and relatively dry. When extensive differences in air pressure develop the air mass would begin to move from a high to a low pressure area. Air masses can be classified and the system used most extensively is the Bergeron classification. In this system,

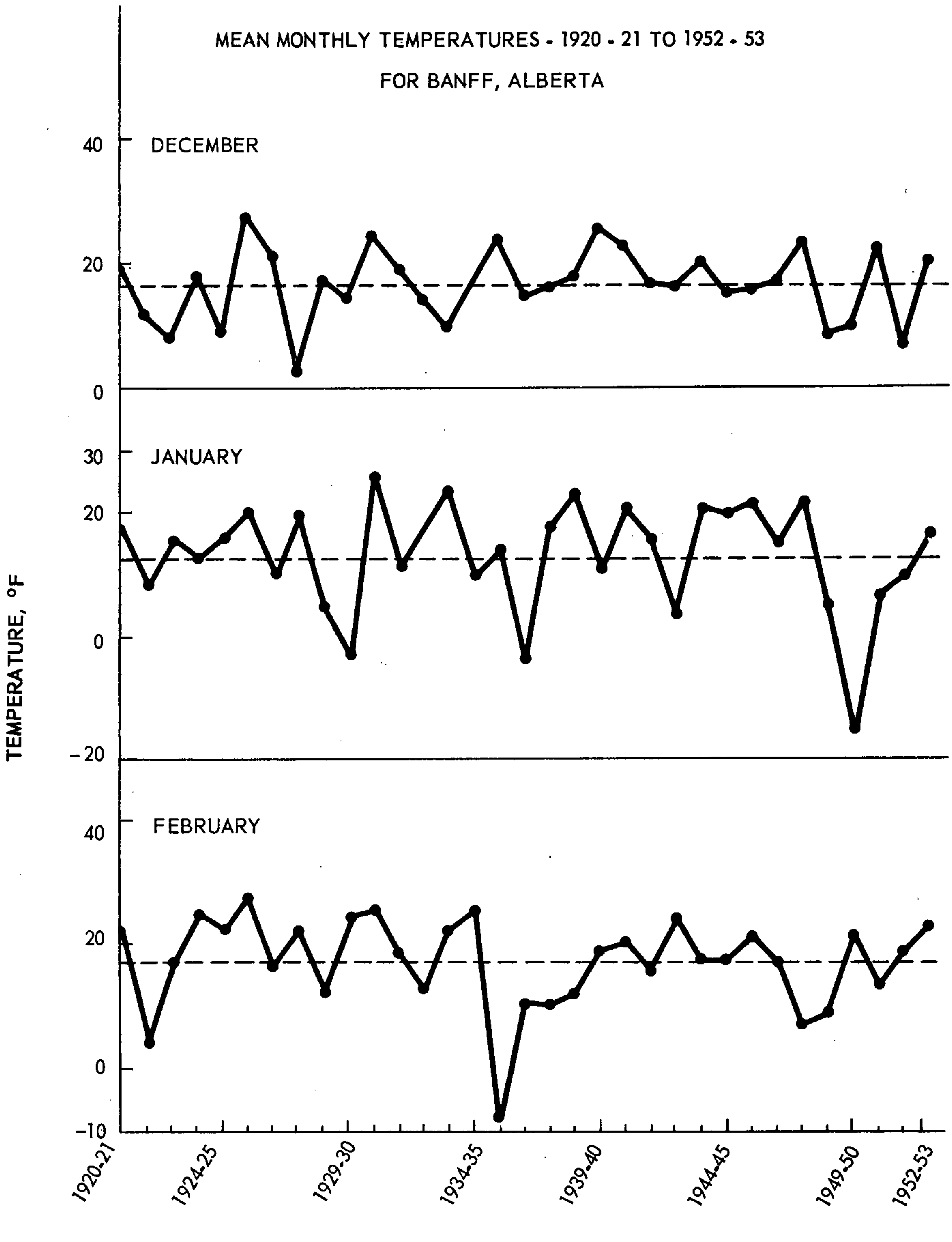
four principal source regions are recognized: polar, arctic, tropical and equatorial. These are known by capital letters P,A, T, and E. Lower case letters before the source letter further identify the air mass as originating over land or water and others may be used to describe a property such as temperature (140). Discrepancies in air-mass terminology arise from differences in opinion concerning source regions. Five main air masses have been used by most authors in describing the climate of western North America. This was the system used by Henson in his air-mass typing (43,141). There has been, however, a recent trend to consider fewer air masses as affecting the weather of western North America. Penner (95) has summarized the work of his colleagues in the Meteorological Service of Canada whereby for practical purposes, based on air-mass properties, four major air masses are recognized as affecting North America in the winter and three in the summer. The classification was based on thermal properties at various pressure levels within the air mass. The four air masses involved are tropical maritime (mT); polar maritime (mP); arctic maritime (mA) and arctic continental (cA). In summer, the arctic continental is modified to arctic maritime. The only way that adoption of this system affects us is that the polar continental air repeatedly referred to in the above discussions and in Appendix 9 must be considered equivalent to arctic continental. As we are largely dependent upon the Meteorological Service for our information and climatic analyses and as this new classification is becoming widespread in the various Meteorological offices it would seem advisable to adopt this system in our future work. If we are to understand climatic fluctuations and their relation to insect abundance synoptic concepts are essential whether we work from air-masses or air-mass properties. The chief advantage of a synoptic approach is that it will eventually be possible to place it on a long-range forecasting basis when more is understood of climatic variations.

The climate of the outbreak region is controlled by four main air-masses (mT,mP,mA,cA) in the winter and three (mT,mP,mA) in the summer. The main circulation is from the north and west which results in the predominance of mP and cA (mA) air. If we assume that the occurrence of the various air-masses is no more stable than weather and their variations are not necessarily random fluctuations about a mean it makes the assessment of climatic effects on insect populations simpler. The data given in previous sections in addition to that following give a reasonably clear picture of the general climate of the outbreak region.

(2) Climate and epidemiology of the lodgepole needle miner.

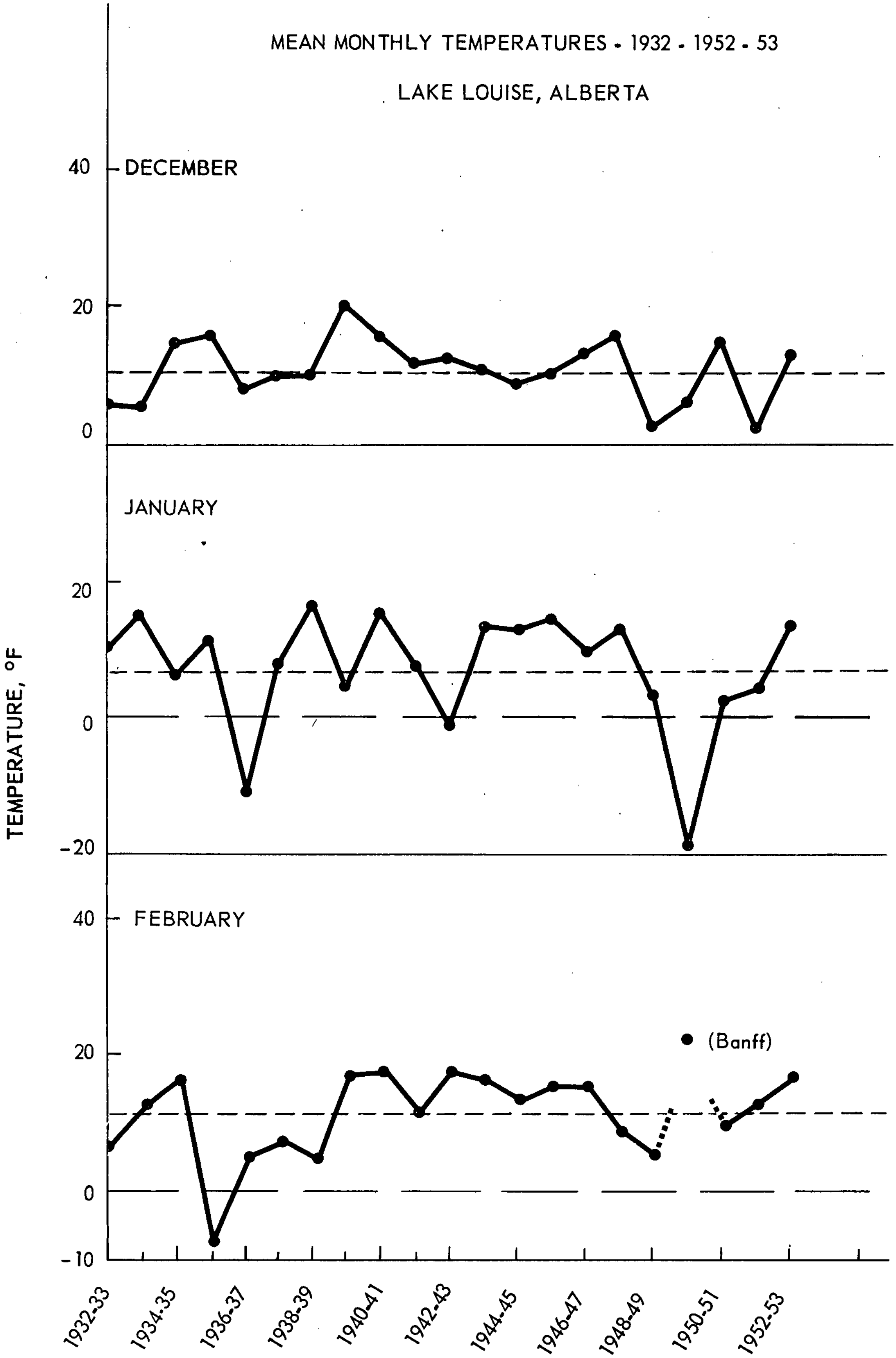
The effects of various winters on needle miner populations has been given in a previous section. Figure 19 presents the mean monthly temperatures for three winter months for Banff from 1920-21 to 1952-53. Mean monthly temperatures for the three months are shown for Lake Louise from 1932-33 to 1952-53 (Figure 20). It can be seen from these figures that conditions which caused heavy mortality in needle miner populations occurred with relatively high frequency. The largest gap between severe winters occurred from 1937 to 1950. As outlined above, the peak of the current outbreak was postulated to be from 1940 to 1944. The outbreak was found in 1942, confined to the

Figure 19. Mean monthly temperatures for December, January and February, 1920 - 1954. Banff, Alberta.



MEAN MONTHLY TEMPERATURES - 1920 - 21 TO 1952 - 53
FOR BANFF, ALBERTA
DECEMBER
JANUARY
FEBRUARY
TEMPERATURE, °F
40
20
0
30
20
0
-20
40
20
0
-10
1920-21
1924-25
1929-30
1934-35
1939-40
1944-45
1949-50
1952-53
YEARS

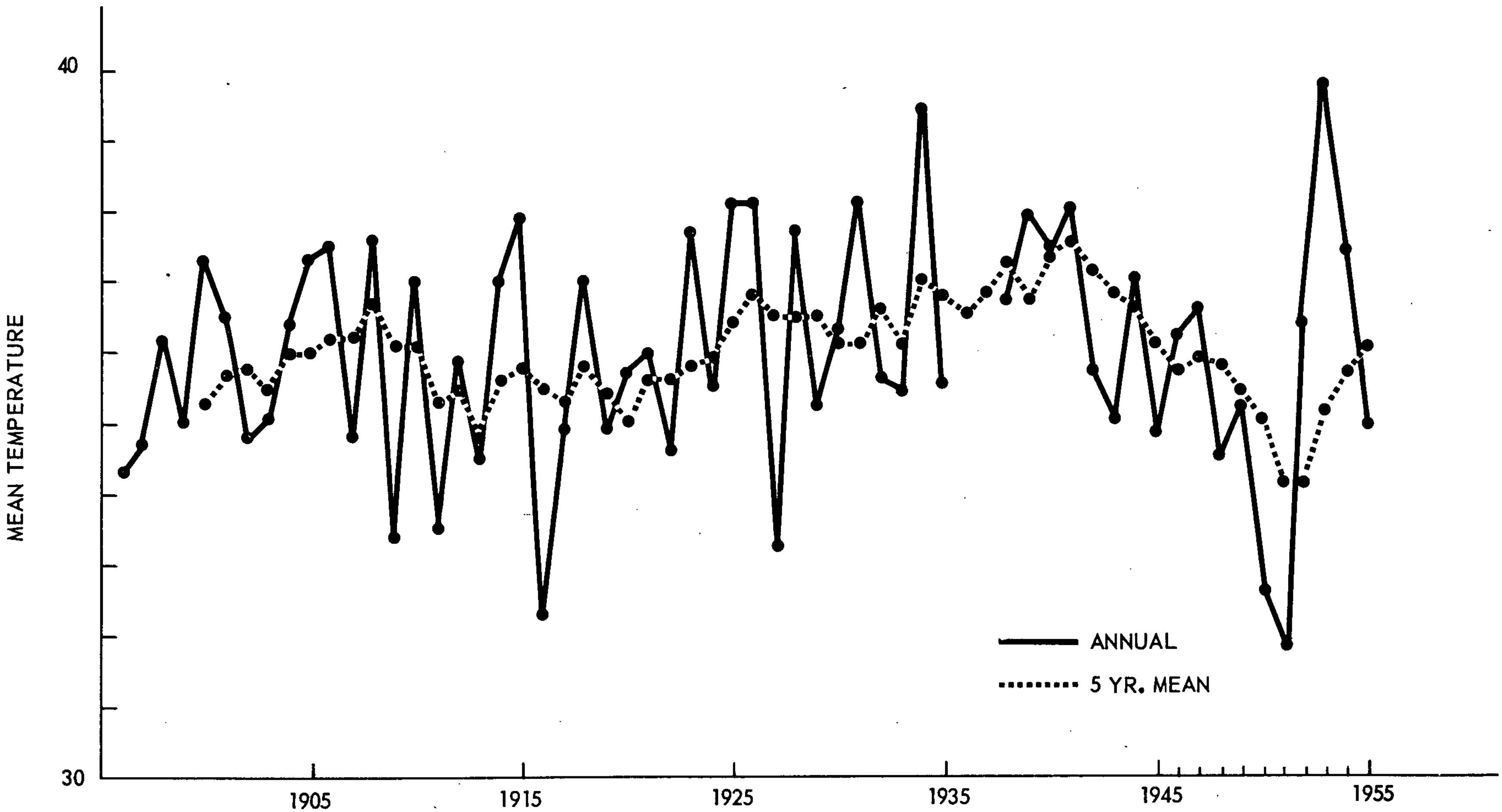
Figure 20. Mean monthly temperatures, December, January and February, 1932 - 1953. Lake Louise, Alberta.


MEAN MONTHLY TEMPERATURES - 1932 - 1952 - 53
LAKE LOUISE, ALBERTA
DECEMBER
JANUARY
FEBRUARY
(Banff)
TEMPERATURE, °F
40
20
0
20
0
-20
40
20
0
-10
1932-33
1934-35
1936-37
1938-39
1940-41
1942-43
1944-45
1946-47
1948-49
1950-51
1952-53

middle altitudes. The fact that large populations were found there indicates that the infestation was 'young'; in the process of building up. Empirical calculations show that build-up of the needle miner population to numbers far in excess of those found could occur in three generations (six years) with a few reasonable assumptions. If we assume one fertilized female per branch tip in the first year with an egg-laying capacity of 15 eggs and a series of mild winters where total mortality (including parasitism) did not exceed 20 per cent in any one year, the population in the sixth year would be greater than 100 per tip. Thus it is possible, beginning with the generation in 1938 that such a population growth could occur owing to the series of mild winters following 1936-37. The concentration of larvae per tip did not occur at the intermediate levels probably because of the dispersal throughout uninfested stands at other altitude levels and valley bottom (149). The series of winters described above, chiefly 1949-50, reduced the populations to levels which may have been present in 1938 or even earlier.

Such a series of mild winters should have an effect even on so gross a measurement as the yearly average temperature. The yearly average temperature for Banff was plotted with a calculated five-year running average. (Figure 21, after Longley (67)). The running average shows a definite warming period from about 1925 to 1948. As we have already seen however, there were several years prior to 1936-37 where the winters were comparable to 1949-50 which supports the assumption of the outbreak beginning about 1938. Evidence of a real climatic change not attributable to random fluctuations has been compiled and it was shown that the climate of northern regions of the

Figure 21. Annual mean temperature and five-year running mean, 1893 - 1955. Banff, Alberta.



40
30
MEAN TEMPERATURE
1905
1915
1925
1935
1945
1955
ANNUAL
5 YR. MEAN

world did become warmer about 1940 (152). From the weather records presented in the text and Appendices it is unlikely that an outbreak of comparable magnitude was able to occur prior to that time. Tree ring studies do not show any evidence of a previous outbreak (84,128). It would follow from these observations that in this region the 'normal' climate is too severe to permit outbreak populations of Recurvaria starki Free. to occur for any length of time.

(3) Geographical limitation of the needle miner outbreak.

The needle miner outbreak was restricted to the valleys in Banff National Park and adjacent areas in Yoho and Kootenay Parks. The restriction of spread east or west may also be explained from the severity of climate (22), but this is less certain in restriction of westward extension. In Appendix 8 the mean monthly temperatures from 1939 to 1953 (winter months) for selected stations is presented. The stations reported include three from the eastern slopes of the Rockies in Alberta and one from the Columbia Valley in British Columbia. The winter means show that the eastern slopes of the Rockies are generally colder than the outbreak area. This is also demonstrated in the Climatological Atlas for Canada (136). This is due mainly to the fact that the outbreak area receives most of its cold air from the north while the eastern ramparts of the Rockies protect the valleys from cold air originating in the east and north-east. Although the same circulation affecting the main outbreak areas in Banff Park affects Kootenay and Yoho Parks, winter extremes are often not so severe but fluctuations in climate are often more violent. Circulation is much more complicated west of the Great Divide (43). The cause for restriction on westward extension is probably violent fluctuations in climate affecting stages other than the larvae rather than severity of winter climate as in the east.

(4) General discussion of needle miner epidemiology with respect to future studies.

In the previous sections it has been shown that climate, principally winter extremes, has been the primary cause in the elimination of outbreak conditions of the lodgepole needle miner. It was further postulated, on the basis of climatological evidence that the outbreak developed during a warming period in the climate of the region. In studying the population the life-table approach - a quantitative one - has been used. However, no attempt has been made to apply any of the various theories of population growth or natural control "formulae" theories to the data. Natural or field demonstration of the various mathemetical theories or population "oscillations" has proved very difficult (90,106). To attempt to apply such theories on the basis of one short outbreak would be spurious, only continued investigation at the low endemic levels will lead to the formulation of sound theory. It has been cogently pointed out by various authors that very little in the field of population dynamics is beyond the hypothetical stage and a priori acceptance of mathematical concepts to describe short-term population studies, particularly when these are made at high levels of abundance only, will only lead to misuse and misinterpretation of valuable hypotheses (96,104,105).

In a symposium discussing the merits of mathematical models used in population studies, Neyman et al. (87) state:

"The focal objective of population ecology is the understanding of those processes responsible for census-trends of species-populations living in natural habitats. Owing to the inherent complexity of the processes this is an objective far easier to state than fulfill. Superimposed on this is another complication. The environment is characteristically variable and varying. The populations respond slightly, or markedly to this variation and, in so doing, may modify its environment. Such variation is not under the control of the investigator although he may systematically record it by initiating in the field a sustained program of census, and environmental measurement - a program leading to an impressive accumulation of physical and biotic information. But the information is likely to be difficult to analyze and even more difficult to generalize conceptually. Despite such handicaps however, this approach must remain the central one in the study of natural populations for the self-evident reason that it, of all others, directly comes to grips with conditions and responses as they occur in nature. No implication is intended that the direct approach lacks power; or indeed that its power cannot be increased. More judicious collection of relevant data, greater utilization of multivariate analysis, and in some cases, actual experimentation in the field, are valuable extensions that must find further perfection and adoption."

Morris (80) has pointed out that many of the difficulties found in assessing population trends are due to inadequate interpretation of mortality data. Mortality and variations in individual mortalities must be studied from the aspect of population trend rather than by generation. He shows that variations at high levels of mortality are potentially more important than variations at low levels, although variable low mortalities may be more important than constant high mortalities. Thus a variable low mortality contemporaneous with a relatively constant high mortality may be the determining factor in population trend.

From the study of the past needle miner outbreak it is felt that we do not have sufficient information at the present time to merit an attempt at 'fitting' the data to any mathematical theories of population fluctuations now extant. Continued sampling of the now endemic population from the life table approach is felt to be neces sary before this can be done. There is much to be learned yet about the relative effects of different environmental factors on the regulation of needle miner populations. This can be achieved by determining the population density as frequently as possible (7). Continued sampling studies compared with continuous life history and behaviour studies are therefore equally as essential as determining only fluctuations in population density (21). Perhaps the most important consideration is that critical research must be carried out on the needle miner populations in advance of, or between outbreaks (18). Studies at low populations densities are of fundamental importance in determining the origin of needle miner, or any other insect, outbreaks.

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6. APPENDICES

Origin of weather data[1]

Broadly speaking, weather reporting stations fall into two main categories: (a) those stations which report hourly, 3-hourly, or 6-hourly, for forecast purposes and are generally equipped with instruments for recording the various meteorological elements, and (b) those climatological stations where observations are taken once or twice daily and reports submitted to the district office at the end of each month.

Instruments at all official weather reporting stations in Canada under the supervision of the Meteorological Branch are supplied by that organization. Every effort is made to ensure that the observers are supplied with good quality instruments and the accuracy of the instruments is checked from time to time by meteorological inspectors, or in the Instrument Division of the Meteorological Branch.

The three stations used in the extensive analyses above are classified as follows:

Banff	(a) Synoptic	Founded in 1887
Calgary	(a) Synoptic- Aviation forecast	" " 1876
Lake Louise	(b) Climatological station.	" " 1915

The other stations used, Golden, Rocky Mountain House, Edson and Exshaw are all type (b) stations.

1. Personal Communication, C.C. Boughner, Acting Director, Air Services Branch, Department of Transport. September 12, 1957.

APPENDIX 1

DAILY MAXIMUM AND MINIMUM TEMPERATURES FOR WINTER MONTHS

BANFF, ALBERTA. 1920 to 1954.

BANFF, ALBERTA - 1920 - 21

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	44	14	37	22	29	20	34	19	39	32
2	41	31	38	29	33	26	33	22	37	21
3	36	30	38	31	29	14	32	21	42	29
4	35	15	38	28	23	12	26	2	40	26
5	34	15	29	13	30	12	19	- 9	33	12
6	31	5	28	12	24	14	22	- 8	35	26
7	35	8	29	20	20	10	35	17	32	2
8	33	12	25	6	30	12	35	30	41	12
9	30	4	28	10	28	11	36	21	38	17
10	28	13	32	23	22	6	36	28	18	5
11	18	- 6	29	21	16	- 6	37	26	6	-12
12	25	- 6	27	9	23	11	36	21	13	-28
13	22	- 3	26	22	27	18	21	14	17	-19
14	33	10	24	11	34	21	19	14	14	- 9
15	38	25	23	0	33	13	16	2	29	10
16	42	29	21	4	14	-13	17	-19	39	22
17	39	27	24	7	21	-12	19	-12	43	28
18	43	31	28	20	32	19	13	- 4	42	24
19	40	32	27	12	27	12	25	-14	34	7
20	39	30	15	1	25	5	30	0	26	-14
21	33	20	4	-12	22	8	30	- 4	38	2
22	34	25	- 5	-23	26	13	34	10	35	15
23	39	26	14	-16	24	8	45	28	41	24
24	37	26	24	11	27	- 2	48	33	38	28
25	38	29	19	4	28	16	45	39	36	25
26	33	22	15	-12	33	5	42	25	26	7
27	35	26	35	13	34	24	46	26	39	0
28	35	28	36	30	29	7	41	36	45	32
29	39	30	34	24	18	-13			40	24
30	40	30	39	29	26	5			43	15
31			33	20	31	10			45	25

BANFF, ALBERTA - 1921 - 22

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	45	34	26	2	24	12	15	-21	38	9
2	51	36	26	19	25	14	18	3	41	23
3	56	36	34	12	16	- 9	20	8	37	26
4	49	28	34	23	11	-10	21	7	34	19
5	49	40	26	15	17	- 6	22	- 5	31	14
6	43	27	32	12	20	4	28	13	31	- 2
7	28	19	29	12	20	3	25	2	31	8
8	34	12	32	19	39	16	3	-15	40	22
9	39	24	35	28	39	21	- 1	-11	41	31
10	42	31	39	29	26	7	- 7	-24	37	25
11	42	29	39	33	26	6	-15	-30	33	14
12	38	34	40	30	30	15	- 2	-31	29	23
13	36	29	41	27	32	12	18	-19	30	14
14	31	17	28	3	33	10	20	-16	35	0
15	27	15	13	- 2	19	- 1	24	- 3	38	9
16	16	6	14	- 7	18	0	34	17	36	13
17	10	- 6	14	- 5	2	-22	33	0	35	20
18	8	-14	9	-13	11	-28	30	0	38	9
19	4	-19	-11	-32	14	2	22	-21	37	28
20	3	-20	-17	-41	14	1	26	-11	36	5
21	- 5	-24	16	-27	15	3	22	- 2	32	24
22	7	-11	13	- 1	4	-16	4	- 8	30	8
23	25	-10	0	-23	15	-14	13	-27	24	10
24	22	1	8	-17	22	1	24	-24	30	8
25	33	9	8	-14	28	13	28	-16	24	0
26	34	23	5	-19	27	19	24	-25	12	1
27	34	28	22	- 3	27	8	32	-19	29	-21
28	31	21	24	3	9	-20	38	-12	35	-12
29	31	21	31	22	0	- 9			40	14
30	31	24	21	11	- 7	-35			41	10
31			14	-11	- 2	-36			42	13

BANFF, ALBERTA - 1922 - 1923

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	36	16	25	7	28	12	20	- 4	31	22
2	34	6	23	8	30	12	15	-21	23	14
3	35	5	11	- 3	34	24	26	2	27	-12
4	36	24	6	- 9	17	10	36	13	27	2
5	38	16	- 8	-29	26	5	38	25	31	6
6	36	6	- 2	-17	30	12	40	16	38	14
7	34	5	- 4	-25	33	23	37	21	38	25
8	38	20	- 4	-24	33	27	26	8	35	14
9	36	17	- 9	-16	33	25	24	11	31	9
10	31	5	-12	-19	30	22	13	-24	36	28
11	30	3	-13	-36	29	20	6	- 9	37	22
12	38	2	- 6	-29	25	4	- 5	-22	29	- 1
13	37	19	-14	-33	24	16	-14	-43	25	- 5
14	38	24	0	-32	22	2	-10	-41	30	- 8
15	40	23	3	- 9	30	17	26	-15	42	8
16	39	34	1	-27	36	25	37	- 7	37	23
17	38	27	3	-16	35	11	38	24	30	- 8
18	32	9	13	- 2	11	- 8	45	30	43	8
19	29	12	31	11	23	-10	42	13	42	31
20	33	9	37	26	27	19	42	12	35	21
21	33	23	40	31	11	2	22	5	31	6
22	36	22	39	34	16	15	26	13	39	11
23	38	16	39	38	17	3	42	32	39	5
24	39	20	38	32	20	- 3	40	29	43	26
25	41	26	38	31	18	- 3	36	16	43	18
26	42	33	35	27	21	4	42	17	50	34
27	38	28	39	28	19	- 9	50	25	54	24
28	32	16	37	27	3	- 2	54	32	54	28
29	17	- 1	32	20	- 2	-17			39	28
30	19	10	27	8	10	-21			60	26
31			26	12	11	-21			62	21

BANFF, ALBERTA - 1923 - 1924

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min
1	39	31	28	0	- 4	-35	40	30	43	20
2	38	31	30	20	- 5	-29	33	18	35	3
3	44	31	38	20	-11	-32	32	9	32	18
4	49	30	38	30	9	-12	34	10	40	10
5	48	27	30	25	22	4	38	26	47	27
6	48	17	31	23	29	21	36	13	46	17
7	47	16	30	24	34	26	35	16	45	10
8	47	17	23	4	32	15	30	13	44	4
9	45	21	26	15	25	4	34	4	40	13
10	44	22	36	20	28	20	39	22	40	18
11	41	17	31	22	24	8	36	30	38	16
12	42	18	22	- 2	19	- 2	40	32	42	15
13	42	22	24	- 5	25	10	37	21	41	8
14	45	26	32	17	27	11	22	4	37	28
15	42	23	40	28	25	1	18	3	34	7
16	40	24	41	33	2	-20	30	- 8	39	- 1
17	42	29	40	33	6	-12	36	2	41	14
18	37	23	39	33	3	-25	33	8	39	13
19	39	33	25	14	8	-24	16	- 6	36	8
20	28	20	24	5	16	1	34	-10	32	16
21	25	8	24	13	24	12	35	18	27	7
22	34	22	29	17	22	5	40	9	31	- 5
23	37	25	29	11	28	- 4	41	10	35	6
24	38	29	27	9	9	-10	44	23	34	9
25	35	23	20	6	28	- 1	45	20	37	2
26	33	20	14	2	36	17	43	29	32	24
27	36	17	22	5	38	26	47	29	37	14
28	34	27	13	0	39	29	42	27	40	9
29	32	22	-15	-18	40	30	42	20	35	21
30	24	7	-15	-27	41	32			33	6
31			-15	-40	45	34			39	11

BANFF, ALBERTA - 1924 - 1925

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	26	20	33	14	28	16	31	-12	45	28
2	36	22	30	13	28	23	36	27	43	34
3	39	24	34	15	25	13	41	32	38	30
4	23	18	34	22	25	16	36	23	38	30
5	22	1	25	13	29	17	36	27	38	12
6	22	5	9	1	25	14	36	17	35	5
7	37	9	18	- 1	21	11	33	12	39	- 3
8	17	- 1	14	- 7	19	- 2	30	0	39	- 1
9	11	-11	24	2	22	3	36	17	24	15
10	27	- 4	30	19	27	15	30	13	32	- 7
11	10	- 3	43	28	22	4	31	19	32	19
12	15	-15	39	32	19	6	34	0	14	1
13	26	10	35	25	4	- 9	31	- 1	30	-22
14	29	17	32	-14	5	-18	16	8	33	14
15	34	18	-12	-31	18	-12	19	-15	38	24
16	42	26	-33	-47	26	10	37	- 4	40	24
17	31	21	-34	-54	27	17	34	14	35	6
18	28	21	-10	-40	36	25	38	24	38	19
19	38	27	-10	-31	30	21	41	26	38	22
20	38	29	-21	-40	36	27	31	20	43	23
21	33	28	-18	-42	30	25	43	11	46	27
22	33	24	4	-22	42	23	42	13	38	34
23	34	21	9	-12	36	16	41	32	38	18
24	36	20	6	- 4	16	- 4	36	4	43	33
25	30	24	16	- 1	16	-14	12	-16	37	27
26	28	5	10	-14	22	- 1	37	- 3	41	21
27	30	18	5	-28	32	19	39	26	50	18
28	35	20	14	4	31	10	39	8	51	25
29	39	25	17	10	34	3			43	17
30	36	21	3	- 5	- 6	-14			45	27
31			26	- 1	-10	-20			50	27

BANFF, ALBERTA - 1925 - 1926

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Max.
1	40	17	47	35	26	15	27	3	52	24
2	37	13	39	24	24	17	27	1	57	24
3	22	16	30	21	23	6	37	12	55	21
4	32	1	37	26	18	8	41	28	42	29
5	41	29	42	30	25	15	38	28	38	26
6	41	19	43	34	34	15	37	27	42	10
7	38	15	39	29	36	26	36	27	44	16
8	34	18	38	31	33	17	41	30	46	11
9	39	30	32	23	26	19	43	27	50	14
10	38	22	36	25	21	10	43	28	50	14
11	42	27	43	30	26	9	34	28	44	29
12	38	26	41	25	26	11	29	24	44	20
13	38	17	32	12	33	16	27	10	50	24
14	35	15	30	14	24	17	32	- 1	53	16
15	36	24	33	24	32	20	35	10	59	23
16	39	26	32	28	29	23	23	14	42	25
17	41	32	35	21	31	23	34	1	45	24
18	45	31	34	22	14	2	36	19	43	30
19	46	37	31	10	21	1	39	29	48	25
20	31	20	19	7	22	7	41	20	50	33
21	25	6	17	- 1	16	- 5	38	15	47	33
22	37	15	31	17	27	3	37	26	54	39
23	36	29	31	22	24	16	32	18	40	32
24	37	27	38	19	26	4	37	22	36	22
25	33	28	42	34	31	14	38	22	39	15
26	29	12	39	17	35	18	44	32	38	23
27	20	- 2	27	16	27	20	47	28	33	8
28	23	7	27	12	30	17	45	22	37	13
29	29	11	29	10	28	14			42	23
30	37	18	27	13	36	22			34	11
31			27	8	31	7			34	15

BANFF, ALBERTA - 1926 - 1927

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	50	23	38	29	39	33	27	2	40	4
2	45	25	9	5	36	32	36	9	41	21
3	51	21	14	- 3	33	26	32	19	39	11
4	51	28	21	- 5	27	15	29	5	35	- 1
5	49	31	27	18	16	4	30	3	33	10
6	43	36	22	10	20	-10	28	1	37	25
7	45	29	28	5	30	16	22	-13	43	19
8	42	21	26	8	26	10	28	- 9	31	22
9	44	32	33	19	16	- 4	26	-10	34	12
10	47	32	41	25	24	2	32	7	32	4
11	44	34	30	9	17	- 8	31	18	36	2
12	45	34	- 5	-11	5	- 1	27	10	43	31
13	40	25	-20	-37	2	-20	31	3	38	28
14	40	28	- 7	-33	17	-19	1	- 6	27	11
15	36	25	7	-17	28	14	- 5	-14	30	15
16	34	14	17	1	21	- 3	- 7	-19	34	8
17	32	22	17	4	- 6	-14	27	-30	34	9
18	22	10	25	- 2	- 5	-29	31	7	32	- 6
19	10	0	31	20	- 8	-37	35	25	40	- 5
20	22	- 9	33	23	-11	-38	34	26	46	24
21	23	8	25	19	1	-27	37	27	41	33
22	33	13	7	- 7	5	- 6	36	12	40	22
23	25	20	19	-17	18	2	36	13	40	21
24	16	10	20	8	23	13	33	8	38	21
25	8	3	19	4	25	3	31	4	38	7
26	19	- 1	22	11	30	18	37	21	37	15
27	29	8	25	17	35	20	31	15	44	3
28	29	13	37	17	33	23	37	- 2	43	11
29	24	4	36	29	32	20			47	15
30	38	1	44	28	27	10			48	22
31			42	30	26	6			32	28

BANFF, ALBERTA - 1927 - 1928

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min	Max.	Min.	Max.	Min.
1	31	12	34	2	- 1	-31	30	2	39	4
2	42	27	34	8	16	-29	37	21	42	5
3	41	36	34	19	23	10	36	24	45	12
4	34	27	40	31	37	21	45	23	43	17
5	30	20	25	2	39	28	44	27	36	15
6	27	24	- 7	-22	38	30	43	31	39	7
7	24	11	- 8	-24	45	27	37	17	16	9
8	23	7	- 9	-24	49	35	35	13	24	3
9	28	8	- 6	-34	51	39	39	23	40	19
10	10	4	- 1	-27	42	38	47	28	40	27
11	9	- 9	10	- 4	39	33	36	26	38	25
12	7	- 5	7	- 3	35	30	30	8	35	13
13	7	1	-11	-26	25	15	32	13	32	9
14	5	- 3	2	-22	22	14	28	7	39	8
15	15	- 8	12	- 5	21	- 3	35	4	42	7
16	31	- 2	18	0	24	4	40	21	46	28
17	38	4	19	- 1	26	5	37	15	50	16
18	14	8	20	13	20	10	43	16	57	25
19	39	2	22	8	14	4	34	17	53	28
20	2	- 7	20	7	14	- 7	37	8	55	31
21	28	- 4	10	-10	19	1	14	6	54	32
22	31	17	12	- 9	20	2	15	-24	45	35
23	30	21	19	7	13	- 5	22	-20	42	28
24	32	24	22	7	19	- 4	30	-14	38	28
25	34	15	29	15	17	- 4	36	- 3	39	21
26	21	- 5	32	24	27	6	37	3	42	15
27	30	9	16	- 6	35	19	35	14	34	25
28	25	19	- 9	-17	35	27	30	12	39	22
29	27	- 2	- 9	-16	27	22	35	- 5	42	20
30	26	2	-20	-35	33	11			42	24
31			-22	-45	30	7			36	29

BANFF, ALBERTA - 1928 - 1929

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	39	5	25	15	23	10	0	-14	40	30
2	42	11	8	- 2	21	3	5	-11	41	29
3	43	12	0	-24	22	7	24	-20	43	33
4	43	34	11	- 7	9	- 2	20	-18	47	36
5	39	28	20	5	17	- 3	11	-11	35	16
6	42	27	22	7	26	14	15	-26	29	10
7	41	20	34	16	27	15	20	-13	35	20
8	36	20	38	30	28	17	26	-13	38	4
9	39	30	37	32	32	12	28	6	48	17
10	38	29	35	27	36	25	28	2	46	33
11	48	44	31	18	43	18	31	9	41	15
12	35	30	25	8	36	21	34	9	45	8
13	39	21	24	10	34	24	33	15	48	14
14	28	11	15	- 3	18	3	33	3	52	14
15	32	5	20	- 1	22	12	37	27	52	17
16	34	24	23	9	21	- 3	13	5	47	15
17	29	9	26	10	22	9	4	-15	42	29
18	30	8	17	4	6	- 8	12	-27	48	20
19	33	17	21	6	14	-14	25	4	49	24
20	40	31	27	13	10	- 1	27	13	43	32
21	50	36	24	15	6	- 2	26	1	47	24
22	45	33	27	18	- 6	-31	28	12	38	28
23	36	23	38	22	2	-32	34	13	26	14
24	33	12	29	14	1	-25	36	20	35	4
25	36	11	33	16	- 4	-18	28	18	37	15
26	37	23	29	15	-13	-21	27	1	42	30
27	30	16	23	13	-20	-31	32	7	45	30
28	35	6	15	-12	-20	-50**	35	1	45	31
29	31	19	26	8	- 9	-35			30	23
30	28	13	28	7	6	-27			30	8
31			25	8	0	-31			29	5

**-58 at Lake Louise

BANFF, ALBERTA - 1929 - 1930

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	49	29	23	11	25	8	38	27	18	-16
2	39	32	30	11	26	14	37	31	30	-14
3	39	15	33	15	25	7	31	9	38	2
4	43	32	35	17	- 5	-12	38	23	41	15
5	32	8	40	23	-14	-24	38	32	37	23
6	37	21	31	7	-10	-32	30	23	36	- 1
7	40	20	13	6	4	-22	38	5	36	12
8	46	27	5	0	2	- 6	23	19	36	20
9	40	33	- 4	- 8	- 7	-31	27	1	37	25
10	30	16	6	-12	- 2	-30	32	19	46	30
11	29	2	7	-14	- 6	-30	25	7	42	36
12	32	9	- 7	-16	- 5	-30	21	0	23	13
13	43	24	2	-20	4	-27	23	9	21	- 3
14	42	28	21	- 4	- 6	-12	29	-17	28	6
15	45	36	22	0	-19	-27	41	15	33	- 6
16	32	29	7	- 1	-21	-51**	43	33	41	- 4
17	30	23	4	- 5	2	-26	46	38	45	9
18	18	3	9	-16	8	- 9	37	34	51	27
19	19	-13	15	- 4	-10	-32	38	31	9	- 2
20	15	0	10	- 1	7	-34	41	27	31	-14
21	19	-11	22	- 5	10	-15	38	31	34	21
22	26	13	29	16	12	-12	36	8	39	27
23	27	6	33	24	17	-10	38	25	36	14
24	33	18	37	29	18	- 2	33	10	40	17
25	41	28	40	32	13	- 1	28	- 3	44	27
26	44	37	32	22	7	-17	25	15	43	29
27	43	37	27	19	14	-10	23	6	56	30
28	29	22	38	24	15	1	13	2	60	24
29	38	19	37	33	25	5			40	31
30	34	24	35	27	26	15			42	12
31			25	17	33	21			52	17

**-60 at Lake Louise

BANFF, ALBERTA - 1930 - 1931

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	51	31	33	24	28	20	42	12	44	30
2	54	33	37	29	30	19	41	15	47	30
3	50	36	37	27	33	25	41	14	47	34
4	43	32	37	28	33	18	36	7	25	18
5	50	26	33	18	35	23	37	16	35	6
6	46	27	30	24	32	25	32	25	35	21
7	50	29	33	23	22	8	27	-- 1	38	9
8	52	26	39	27	19	- 1	31	- 5	39	15
9	47	37	33	13	27	11	36	14	16	7
10	50	37	35	25	31	18	36	23	6	- 3
11	38	33	31	20	22	4	35	13	11	- 7
12	26	22	28	17	22	4	38	10	38	5
13	14	6	31	25	25	12	42	10	28	11
14	16	- 9	30	14	36	22	42	13	44	4
15	22	5	37	21	31	23	39	7	45	26
16	27	9	33	25	26	8	36	25	46	29
17	24	9	28	16	30	14	34	24	43	27
18	25	1	28	13	27	9	35	27	41	29
19	27	12	28	11	23	7	39	28	44	32
20	32	19	28	7	32	15	35	24	50	33
21	34	16	28	3	25	15	35	14	50	39
22	40	24	28	17	37	21	42	25	43	28
23	28	12	29	20	42	32	36	26	44	22
24	41	23	26	8	37	26	30	16	43	20
25	36	20	25	14	34	14	35	2	15	7
26	32	21	28	15	35	24	33	11	19	- 8
27	27	15	27	8	35	29	36	20	21	-11
28	28	15	27	15	47	33	39	15	42	- 4
29	33	20	26	10	51	41			41	19
30	35	28	26	11	44	26			43	22
31			29	15	44	16			50	33

BANFF, ALBERTA - 1931 - 1932

	November		December		January		February		March	
Day	Max.	Min	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	50	42	25	14	26	13	-11	-38	34	21
2	44	34	32	15	20	2	-13	-19	16	6
3	39	21	29	23	20	- 3	16	4	16	- 1
4	42	28	30	22	25	9	24	8	15	- 7
5	51	27	28	18	25	1	24	18	12	- 1
6	45	36	23	14	31	20	9	2	6	- 7
7	40	33	28	6	36	19	10	- 9	6	-15
8	32	18	18	8	38	27	29	- 4	17	-23
9	33	21	24	1	36	29	31	26	26	-14
10	33	16	21	11	35	21	28	15	34	-12
11	34	12	12	- 8	33	24	20	0	44	-11
12	37	27	16	- 4	- 5	-12	12	- 7	45	7
13	30	27	16	- 2	- 6	-26	16	-23	43	20
14	24	7	19	11	- 2	-22	24	- 1	48	28
15	5	- 8	24	11	11	-15	23	10	32	23
16	5	- 9	35	16	15	- 6	24	-14	38	14
17	13	- 9	33	25	16	- 8	35	8	43	29
18	20	- 5	40	29	23	10	33	9	42	26
19	23	11	38	31	29	12	32	15	44	24
20	14	6	34	22	28	5	29	13	40	25
21	14	-17	29	9	28	9	38	- 6	38	20
22	24	9	26	12	23	4	42	26	41	17
23	28	4	25	8	22	0	47	38	42	27
24	26	18	29	16	35	13	44	36	38	30
25	23	18	29	18	34	21	46	36	42	25
26	14	- 5	22	2	21	- 3	40	33	39	25
27	19	- 6	25	16	22	4	43	36	39	28
28	24	5	25	14	1	- 8	46	33	30	19
29	24	11	21	11	- 4	-28	33	20	38	8
30	23	10	16	- 5	-11	-22			42	28
31			21	9	-13	-25			43	33

BANFF, ALBERTA - 1932 - 1933

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	34	14	35	22	27	16	22	- 3	25	0
2	39	27	36	20	24	10	20	- 9	40	- 6
3	34	25	35	30	23	4	32	9	35	12
4	37	28	38	29	30	20	33	18	30	1
5	39	30	19	13	31	26	28	7	38	19
6	38	29	0	-11	31	25	0	-20	42	27
7	34	11	- 4	-29	33	26	0	-12	29	21
8	34	23	- 7	-23	35	26	- 4	-24	11	3
9	29	18	2	-18	35	30	2	-30	22	-16
10	26	7	5	- 7	24	14	7	- 8	25	- 5
11	29	9	8	-23	30	12	11	- 4	37	8
12	32	12	11	2	37	26	7	-12	39	29
13	32	- 4	11	1	40	25	9	-16	37	20
14	9	-12	11	- 7	32	26	18	- 7	37	7
15	11	- 5	17	- 1	5	- 4	24	7	39	4
16	32	0	18	- 1	8	-19	29	1	44	13
17	39	32	20	0	6	- 1	27	23	42	26
18	45	10	15	5	8	-17	27	3	39	10
19	42	27	24	11	11	- 5	29	19	39	16
20	30	16	31	26	19	7	35	25	42	32
21	30	18	29	20	23	6	35	28	36	25
22	33	25	32	25	22	12	33	22	32	19
23	40	25	33	21	26	14	31	19	31	19
24	40	31	26	14	27	9	29	15	34	10
25	29	7	26	11	22	3	37	25	37	6
26	41	32	29	18	22	- 3	33	25	40	4
27	44	37	26	16	20	13	26	15	42	19
28	46	36	26	18	20	- 7	13	5	43	29
29	38	33	25	19	18	- 7			42	26
30	37	26	25	7	21	0			43	35
31			29	20	21	1			39	27

BANFF, ALBERTA - 1933 - 1934

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	34	17	40	30	- 5	-15	42	34	40	30
2	32	25	44	29	35	-12	40	29	40	33
3	30	16	31	26	37	31	30	12	33	29
4	34	9	24	14	37	29	31	5	29	23
5	36	15	31	19	32	28	38	3	26	8
6	34	26	31	24	23	4	37	13	23	12
7	37	19	28	16	25	1	44	23	34	4
8	35	13	26	16	28	11	40	34	40	18
9	43	23	25	12	39	17	37	25	43	9
10	47	38	6	- 6	32	26	37	18	51	24
11	49	40	0	- 6	26	20	42	30	51	30
12	48	32	- 4	-11	28	2	43	25	51	35
13	57	41	- 2	-13	31	23	42	16	43	19
14	48	33	- 3	-14	24	20	41	16	45	34
15	45	27	- 4	-13	22	- 2	39	12	43	35
16	44	30	21	-23	35	17	43	11	27	14
17	36	28	31	12	34	21	35	20	40	16
18	44	31	6	-10	21	1	38	11	47	35
19	45	35	23	-12	32	10	34	7	46	37
20	40	33	39	- 7	33	24	22	14	41	28
21	44	33	28	5	33	25	17	- 3	33	21
22	47	34	13	- 7	31	24	19	- 8	32	8
23	49	41	- 3	-15	24	2	8	- 4	34	4
24	47	37	- 5	-31	22	-16	6	- 7	33	9
25	41	35	- 7	-44	23	14	15	-25	33	11
26	47	36	8	-35	42	21	24	- 8	48	7
27	26	18	6	-16	46	39	33	17	27	18
28	26	9	28	- 9	43	13	39	27	17	8
29	34	20	38	22	39	24			48	3
30	38	30	- 3	-15	41	20			53	31
31			- 6	-19	42	29			46	29

BANFF, ALBERTA - 1934 - 1935

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	47	38	32	25	37	19	46	32	39	27
2	37	31	28	16	13	- 5	47	34	38	28
3	38	30	29	16	34	- 6	46	29	37	13
4	41	30	29	6	29	26	41	25	7	- 2
5	44	30	30	17	27	-10	33	-13	13	- 8
6	43	35	32	12	30	21	30	18	28	-14
7	44	29	35	14	20	8	31	- 2	31	- 9
8	39	33	36	15	15	- 4	36	- 2	29	- 3
9	39	20	36	17	20	1	40	5	32	9
10	43	21	32	17	27	15	38	13	30	- 6
11	46	23	35	26	18	4	32	16	37	23
12	47	30	32	26	- 4	-14	33	16	41	30
13	53	33	37	28	- 7	-31	32	9	45	35
14	50	29	39	30	5	-26	36	18	40	30
15	52	36	33	25	9	-12	36	19	34	13
16	43	29	30	20	0	-14	40	14	35	27
17	41	26	33	26	-21	-29	43	29	38	21
18	39	24	32	24	-23	-42	37	19	36	17
19	33	20	35	26	-17	-43	28	12	36	21
20	29	15	32	24	- 8	-42	42	21	13	2
21	29	9	29	24	- 5	-17	40	26	28	- 5
22	38	23	24	4	16	-23	41	28	32	0
23	42	30	4	- 6	33	-12	23	14	34	19
24	37	27	-10	-30	40	28	28	0	34	28
25	37	29	-16	-42	42	3	32	- 2	30	17
26	31	20	0	-22	42	32	35	- 1	29	16
27	30	16	- 7	-30	44	36	35	0	30	4
28	25	8	9	-18	46	33	39	22	28	9
29	30	19	11	- 8	43	29			24	2
30	34	21	14	- 5	43	24			24	-10
31			32	- 6	43	29			17	- 4

BANFF, ALBERTA - 1935 - 1936

	November		December		January **		February **		March **	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	11	-19	31	14	32	21	8	-20	45	30
2	14	-20	30	11	35	18	6	-25	48	37
3	28	- 8	31	12	30	12	6	-24	43	18
4	32	17	30	13	26	0	4	-18	44	28
5	36	23	29	11	9	-18	- 4	-28	46	23
6	42	26	36	14	18	-12	-16	-28	43	24
7	44	32	39	29	32	13	-12	-45	40	26
8	37	14	38	34	32	21	1	-21	41	28
9	16	- 3	38	13	29	15	13	-17	34	23
10	24	0	39	32	24	5	15	- 2	32	6
11	29	17	37	28	22	10	0	-17	34	2
12	24	7	36	25	25	0	-10	-35	41	23
13	24	4	32	14	26	- 2	- 4	-38	37	26
14	30	1	28	13	16	- 1	- 5	-24	34	13
15	31	14	23	15	7	- 9	- 2	-38	38	13
16	38	26	24	15	4	-11	- 5	-36	39	21
17	34	24	25	15	5	-13	2	-36	39	19
18	26	0	19	2	1	-12	12	-28	38	20
19	34	11	30	3	21	- 4	20	-15	44	26
20	41	30	30	10	29	13	22	-10	40	23
21	38	26	34	15	38	21	21	- 6	36	23
22	27	17	32	22	41	30	16	0	31	30
23	35	15	24	- 6	39	28	4	-14	34	11
24	34	20	24	- 1	32	21	3	-19	32	- 6
25	38	27	31	16	22	- 9	4	-29	32	- 3
26	38	27	36	22	22	- 4	24	-11	33	7
27	43	32	34	22	20	4	39	19	29	9
28	44	33	36	27	19	-16	40	0	18	- 6
29	39	35	28	10	20	-11	44	28	15	- 5
30	33	19	25	14	22	7			17	-14
31			33	11	20	- 2			14	- 9

** Banff not recorded, readings from Anthracite.

BANFF, ALBERTA - 1936 - 1937

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	19	-9	36	27	3	-29	-6	-12	40	8
2	30	-11	28	-19	24	-17	-2	-13	45	17
3	31	22	16	5	26	1	8	-26	44	30
4	34	22	-5	-10	16	-2	3	-12	54	31
5	13	-1	7	-25	-4	-12	15	-14	49	34
6	18	-17	11	-25	-5	-40	18	-6	43	28
7	30	-5	28	1	1	-27	2	-8	46	12
8	41	19	26	8	13	-14	7	-33	48	12
9	40	20	26	3	7	-2	17	-7	49	18
10	40	27	31	14	15	-6	27	9	50	31
11	41	29	30	12	16	-4	29	19	37	26
12	52	33	30	24	20	5	25	18	34	19
13	56	44	35	24	-1	-10	28	-2	26	12
14	49	29	29	25	3	-28	30	11	30	-3
15	50	27	10	0	2	-16	30	17	37	21
16	46	26	33	-8	8	-25	34	22	43	10
17	48	31	32	25	12	-2	28	19	43	9
18	56	38	45	26	6	-11	24	8	40	12
19	59	44	34	20	-12	-33	19	4	35	20
20	38	22	35	13	-1	-33	18	-11	24	11
21	45	15	42	16	3	-14	23	5	29	-7
22	40	28	40	30	14	-4	37	3	33	7
23	43	18	26	17	12	4	34	3	39	8
24	39	14	16	4	10	-11	24	15	36	21
25	39	17	20	0	16	-3	24	10	38	20
26	41	12	13	2	2	-7	30	-11	46	2
27	29	12	7	-15	-5	-18	40	-14	48	5
28	37	11	-4	-21	-11	-26	37	2	37	13
29	38	23	10	-13	-3	-36			43	10
30	35	14	10	-2	10	-17			43	31
31			-2	-14	2	-14			44	23

BANFF, ALBERTA - 1937 - 1938

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	43	15	26	5	34	22	6	- 7	60	12
2	40	8	30	5	34	22	7	-14	33	26
3	45	28	23	13	33	7	30	- 9	25	19
4	41	21	27	2	27	5	34	16	26	9
5	44	26	36	22	22	7	7	- 9	29	18
6	36	29	33	22	24	0	7	- 9	41	4
7	36	24	5	- 8	28	2	9	-12	41	3
8	40	29	-10	-23	31	13	24	-23	42	3
9	36	30	9	-29	35	15	7	-25	41	15
10	29	24	29	-11	32	23	8	- 9	41	26
11	31	26	36	20	16	- 4	6	-19	40	32
12	23	13	20	7	28	11	- 5	-11	39	25
13	15	2	34	5	34	20	- 3	-16	50	27
14	11	0	37	25	34	27	- 3	-17	44	35
15	18	6	36	19	34	28	7	-28	40	28
16	20	5	36	30	23	3	25	-24	40	27
17	17	11	36	30	23	10	28	- 5	36	20
18	13	1	35	19	23	0	28	12	34	13
19	26	-18	33	10	27	6	34	- 5	33	25
20	33	12	39	20	30	- 9	34	5	32	3
21	35	21	28	16	35	23	40	21	31	5
22	35	15	18	8	33	21	39	5	33	8
23	40	28	0	-20	27	8	40	5	38	10
24	36	25	- 3	-15	23	6	46	9	44	19
25	37	30	8	-20	33	16	50	19	46	18
26	31	8	24	-20	29	20	53	24	44	29
27	28	- 2	6	-15	43	18	56	12	43	36
28	34	15	37	-11	7	0	54	11	37	27
29	30	11	36	31	- 6	-26			28	10
30	25	6	35	25	0	-33			37	20
31			33	24	7	-20			34	0

BANFF, ALBERTA - 1938 - 1939

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	36	24	41	32	36	32	19	-15	32	9
2	41	20	34	25	40	32	21	- 6	32	15
3	41	30	34	25	37	28	20	1	13	- 1
4	33	19	36	22	34	19	20	-12	27	-22
5	32	15	39	30	20	5	30	8	32	- 8
6	31	8	36	30	26	0	- 6	-14	36	13
7	40	26	40	32	37	21	-13	-24	36	17
8	33	26	47	32	35	24	-14	-29	36	- 1
9	33	10	28	22	32	15	4	-36	36	- 8
10	27	12	22	8	34	10	11	-30	34	2
11	23	- 5	18	-11	37	26	22	0	33	19
12	27	15	22	0	33	13	32	15	22	8
13	30	20	26	14	36	26	31	22	18	1
14	39	26	26	16	28	8	36	25	36	-18
15	39	31	17	3	28	18	33	10	33	0
16	38	26	25	1	28	9	37	7	36	- 3
17	35	22	22	4	30	20	42	30	47	4
18	40	30	21	5	33	22	34	21	50	35
19	35	26	18	- 4	37	28	25	- 4	51	40
20	28	8	18	- 5	30	15	25	- 7	56	46
21	21	1	21	- 1	19	-10	32	-11	60	46
22	14	- 8	24	0	27	14	39	4	62	35
23	20	- 6	41	19	31	18	38	21	61	47
24	27	14	41	32	30	21	40	13	56	46
25	26	- 2	12	- 1	27	18	32	24	42	20
26	28	11	- 2	-25	27	- 1	27	- 2	33	11
27	35	9	- 3	-18	30	17	30	1	48	6
28	35	17	-11	-22	31	12	28	2	54	18
29	34	12	29	-24	27	8			52	18
30	41	30	33	- 1	12	4			47	27
31			35	26	18	-10			50	39

BANFF, ALBERTA - 1939 - 1940

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	51	23	43	26	31	18	23	- 7		
2	49	21	44	31	35	24	20	7		
3	45	31	47	39	26	9	25	- 3		
4	41	31	47	38	18	11	38	15		
5	42	31	47	27	31	14	38	31		
6	41	31	42	33	22	3	26	22		
7	36	26	46	35	16	- 7	33	18		
8	36	27	45	37	9	-10	36	8		
9	34	26	34	32	21	-10	43	31		
10	39	28	38	27	25	15	35	28		
11	44	32	36	27	18	6	33	10		
12	52	37	34	24	19	-12	31	0	No	
13	48	26	36	15	24	10	35	6		
14	48	37	38	21	30	- 3	41	12		
15	50	41	40	29	33	- 1	33	- 4	record	
16	50	40	34	25	14	- 3	35	4		
17	49	35	28	20	12	- 5	38	23		
18	45	30	27	5	5	-22	28	21	for	
19	45	27	34	20	0	-24	30	10		
20	42	27	35	26	5	-24	31	9		
21	46	27	31	26	22	-10	21	13	March	
22	43	33	20	5	16	- 3	7	1		
23	40	24	8	- 5	2	-18	11	-18		
24	39	20	7	-14	- 2	-29	29	-14		
25	35	18	2	- 6	15	-30	11	0		
26	37	17	9	-14	26	3	6	- 7		
27	34	15	12	-16	38	19	40	- 6		
28	42	22	26	9	46	32	40	10		
29	45	36	36	5	49	28	44	20		
30	43	34	34	23	31	11				
31			27	1	27	- 1				

BANFF, ALBERTA - 1940 - 1941

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Min.	Min.
1	41	21	21	6	20	0	44	29	16	10
2	34	20	40	2	22	8	42	35	37	4
3	34	19	45	33	14	- 2	39	23	36	14
4	33	14	41	26	40	-11	42	21	44	16
5	28	5	39	31	12	- 5	40	15	45	9
6	21	10	36	29	22	2	39	4	44	22
7	9	3	36	30	24	- 5	37	2	49	34
8	3	-11	36	30	41	9	39	9	41	25
9	4	- 6	31	17	44	22	36	8	38	6
10	6	-18	19	6	51	38	39	21	41	4
11	4	-28	15	2	45	32	36	14	40	2
12	14	-17	15	-16	40	26	32	18	41	- 2
13	21	0	13	- 9	38	27	34	8	48	- 3
14	31	6	19	- 3	23	15	32	- 2	48	14
15	43	21	14	- 4	22	14	38	3	39	8
16	36	15	21	-10	15	- 1	38	3	46	1
17	36	15	33	-13	31	2	39	3	53	24
18	30	11	36	9	36	25	30	14	44	27
19	28	6	40	22	38	17	21	10	45	29
20	27	11	42	30	30	12	18	1	41	22
21	21	7	41	26	21	- 6	6	- 3	44	14
22	23	- 6	48	25	20	0	6	- 9	45	18
23	26	10	34	16	- 1	-11	11	-31	44	27
24	31	21	32	22	5	-21	19	-12	52	20
25	33	21	36	20	36	-12	27	0	52	25
26	32	18	36	26	36	2	37	2	47	32
27	32	18	30	16	43	27	43	30	54	19
28	35	18	31	16	44	34	45	32	54	20
29	32	23	29	11	35	16			53	23
30	34	18	25	10	46	27			54	27
31			24	14	41	25			44	31

BANFF, ALBERTA - 1941 - 1942

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Min.	Min.
1	41	27	43	28	10	-25	35	20	42	24
2	36	12	51	35	6	- 3	29	8	40	27
3	36	25	40	27	6	-22	36	10	35	23
4	44	28	27	22	- 6	-26	34	22	40	26
5	46	34	32	14	7	-21	26	16	34	24
6	43	25	36	27	- 8	-26	32	11	33	7
7	41	20	36	29	5	-24	33	10	42	21
8	49	27	34	28	4	-14	33	8	45	26
9	47	26	15	11	20	- 8	32	- 3	42	29
10	49	24	24	2	31	14	34	12	38	13
11	47	35	26	14	33	20	35	18	41	21
12	38	23	19	0	39	24	36	9	37	22
13	39	16	18	2	36	24	34	4	33	2
14	43	32	29	6	30	17	39	13	37	11
15	37	26	33	10	32	9	29	12	37	10
16	34	19	43	24	33	14	10	-16	37	14
17	25	10	30	24	31	8	23	-26	38	28
18	27	3	38	15	33	15	28	- 7	36	9
19	30	11	33	24	30	16	32	6	35	0
20	36	15	32	27	31	8	18	11	42	21
21	19	17	22	9	34	6	13	0	48	33
22	23	- 7	3[illegible]	9	36	2	10	-12	33	22
23	24	6	32	23	34	12	16	-21	24	6
24	38	15	25	21	-40	21	24	-11	29	- 5
25	42	29	15	5	38	24	28	-14	31	- 2
26	44	38	- 2	-21	38	21	30	- 6	36	- 4
27	40	20	32	-20	38	26	35	-13	44	- 3
28	44	18	15	-16	33	26	36	12	52	- 1
29	52	38	- 5	-18	26	0			51	8
30	44	40	- 1	-20	28	12			54	21
31			- 4	-38	27	- 4			57	25

BANFF, ALBERTA - 1942 - 1943

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	35	19	9	- 9	6	-13	24	10	25	- 8
2	33	7	14	4	6	-20	32	19	35	-10
3	27	20	19	- 4	10	-10	29	9	37	6
4	19	7	9	- 6	15	-10	30	17	6	- 5
5	21	- 1	3	-16	23	1	32	18	13	-28
6	29	2	10	-10	33	6	36	22	28	-14
7	29	- 2	7	-17	30	18	36	- 4	26	6
8	26	1	19	- 7	36	24	1	-29	27	4
9	28	- 2	23	6	41	22	19	-28	31	- 6
10	38	21	34	12	36	21	28	14	30	16
11	44	27	34	18	26	0	37	23	30	15
12	41	26	40	29	32	9	43	12	36	21
13	52	29	40	32	44	29	47	29	12	2
14	43	34	39	31	40	30	46	28	9	- 9
15	38	29	41	27	38	-12	47	24	13	-24
16	25	17	39	32	- 5	-30	43	22	19	-21
17	11	6	37	18	-14	-47	49	18	27	-21
18	19	- 4	30	3	- 9	-33	48	22	27	- 8
19	27	2	34	9	-21	-30	43	32	33	5
20	24	4	34	21	-26	-36	46	19	37	- 2
21	34	15	34	29	-23	-44	31	24	42	22
22	40	29	29	25	- 4	-32	41	4	44	30
23	30	27	12	1	- 4	-36	29	0	47	33
24	30	13	24	- 3	7	-35	34	- 1	45	39
25	23	6	24	- 3	4	-18	44	8	34	24
26	20	5	14	-10	20	- 7	45	10	30	20
27	12	- 5	19	-10	21	- 1	48	9	40	22
28	14	-10	32	2	28	8	39	22	35	26
29	23	- 6	30	- 3	18	- 8			26	22
30	28	6	24	- 2	21	-14			38	19
31			16	2	21	1			41	20

BANFF, ALBERTA - 1943 - 1944

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	32	4	32	16	26	12	32	9	31	-14
2	38	18	38	27	20	12	36	18	30	- 2
3	38	27	40	31	19	0	34	14	20	1
4	39	23	27	16	18	0	20	6	18	0
5	39	26	26	- 6	20	- 3	34	8	25	- 2
6	34	9	34	8	18	- 8	40	26	36	3
7	36	11	31	22	25	8	33	24	44	3
8	39	25	26	2	27	16	30	- 1	44	28
9	40	11	31	6	25	- 2	16	1	52	35
10	43	28	29	10	19	- 4	30	-13	48	20
11	41	22	29	19	24	- 3	31	18	29	5
12	42	16	21	- 2	28	16	30	0	28	10
13	42	23	27	7	35	25	28	14	23	- 5
14	42	23	30	10	40	24	21	11	40	0
15	42	20	32	8	38	29	28	- 5	46	15
16	46	23	29	14	40	28	28	16	47	33
17	45	30	34	17	40	34	29	- 4	44	32
18	34	16	33	28	38	31	32	7	40	20
19	40	25	13	- 8	50	36	31	- 5	39	26
20	40	19	21	- 4	38	28	28	8	38	18
21	45	31	26	9	33	10	20	7	34	7
22	36	22	26	6	41	15	28	-12	38	26
23	30	13	30	16	37	23	33	6	34	15
24	40	23	36	23	34	22	31	15	16	- 4
25	38	9	34	25	24	9	34	0	25	- 5
26	38	11	27	9	23	- 3	33	5	20	- 5
27	32	19	27	9	23	- 4	31	- 3	28	-15
28	32	10	23	10	26	- 6	15	8	45	6
29	34	25	10	- 3	23	2	20	- 7	53	23
30	38	25	20	- 1	21	- 6			51	25
31			25	6	30	1			47	25

BANFF, ALBERTA - 1944 - 1945

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	48	23	34	26	28	- 4	28	- 2	27	8
2	32	19	32	20	29	9	18	8	34	9
3	26	19	29	8	32	10	19	3	12	8
4	42	21	39	24	32	18	40	12	13	-24
5	48	32	44	25	36	26	28	14	25	-14
6	45	35	42	36	36	10	34	1	28	10
7	42	30	33	24	33	1	38	28	32	2
8	46	32	28	18	39	22	46	32	37	18
9	45	33	24	6	42	32	33	17	40	28
10	30	20	29	6	37	18	33	17	34	26
11	31	18	26	4	40	32	36	13	36	23
12	34	15	22	8	38	30	35	11	40	28
13	28	- 1	32	8	34	24	27	11	34	18
14	34	1	26	13	33	19	16	- 7	38	22
15	32	14	26	4	27	8	0	-11	38	20
16	40	12	24	10	31	16	15	-26	35	4
17	37	14	28	9	32	20	16	-25	37	5
18	32	10	23	10	18	13	27	-16	39	5
19	38	7	24	8	13	- 8	36	- 2	41	30
20	32	16	24	- 6	19	-12	32	14	44	34
21	38	24	20	6	28	2	31	2	40	27
22	42	31	0	-17	33	11	32	16	46	28
23	40	28	8	- 9	34	14	35	5	44	28
24	32	25	- 4	-17	27	34	39	19	43	27
25	28	10	11	-14	32	8	43	10	42	18
26	31	15	13	1	10	- 4	38	18	48	24
27	34	14	18	- 2	23	-10	31	22	46	17
28	28	6	30	10	23	3	35	4	44	30
29	28	7	21	4	20	-15			44	22
30	36	24	13	4	20	-14			44	37
31			0	- 9	11	-15			30	23

BANFF, ALBERTA - 1945 - 1946

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	32	19	27	6	33	25	26	3	38	28
2	35	18	30	10	35	14	23	2	41	30
3	51	31	39	11	36	22	13	- 4	40	19
4	36	25	40	26	36	26	21	- 7	38	14
5	15	8	36	28	32	19	20	-15	34	23
6	6	- 7	29	22	31	10	26	12	31	20
7	3	- 7	25	15	28	22	28	- 5	34	11
8	7	-26	4	- 3	30	12	29	14	38	24
9	15	- 7	15	-12	30	17	30	20	40	7
10	22	- 1	20	6	30	22	25	1	49	26
11	28	- 2	13	4	21	1	15	-14	41	32
12	19	7	2	-17	28	9	26	2	38	28
13	31	4	15	-14	34	21	34	19	37	18
14	24	8	14	0	32	13	44	26	36	8
15	33	- 2	16	4	40	20	36	27	34	18
16	31	- 2	15	2	32	8	34	2	36	6
17	33	14	11	- 4	37	26	37	9	46	3
18	30	22	11	-15	39	28	37	25	48	26
19	30	12	17	5	31	21	34	- 1	41	29
20	26	2	19	13	21	-11	40	9	50	12
21	23	- 3	0	- 6	30	11	40	15	57	15
22	31	14	2	- 9	33	20	39	26	50	20
23	35	16	31	- 2	28	17	40	25	41	28
24	36	21	31	21	25	16	45	30	39	24
25	37	22	31	21	9	- 3	38	28	40	30
26	32	24	31	10	16	-10	36	11	40	30
27	31	16	36	20	27	10	38	26	30	24
28	25	3	38	27	24	8	38	28	33	17
29	35	20	38	26	16	1			42	25
30	30	12	34	22	20	-13			44	28
31			34	22	24	11			46	14

BANFF, ALBERTA - 1946 - 1947

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	29	22	29	- 3	- 3	-19	11	-34	29	8
2	30	1	37	22	14	-13	- 2	-20	6	- 1
3	42	24	39	25	22	- 3	12	-27	6	- 9
4	47	21	44	27	24	11	36	8	13	-31
5	46	26	40	30	29	- 4	42	26	22	-26
6	45	30	38	27	32	3	24	8	26	-20
7	35	24	38	29	31	13	23	-20	32	-16
8	33	11	35	21	28	12	20	-24	33	8
9	34	9	24	3	40	19	21	-23	40	6
10	35	23	44	22	36	22	36	-12	31	1
11	33	9	23	5	37	28	35	20	32	--4
12	36	10	3	- 8	18	10	39	29	40	- 3
13	39	15	4	- 8	1	- 5	46	30	49	25
14	37	18	15	-12	0	-21	45	30	56	33
15	25	18	21	- 3	15	-11	43	23	59	24
16	22	5	11	-18	33	8	38	4	57	22
17	8	3	14	-18	40	28	33	21	56	22
18	- 2	- 7	17	7	40	27	34	13	54	20
19	- 6	-14	35	12	41	12	25	4	56	18
20	- 8	-24	35	20	25	8	34	- 4	55	24
21	6	-27	34	22	39	20	41	20	55	37
22	17	-12	17	8	54	31	44	27	43	26
23	27	8	34	3	41	33	42	31	35	10
24	30	4	42	25	43	27	34	25	37	5
25	34	18	43	34	43	24	17	9		
26	24	8	38	14	25	16	26	-11		
27	33	19	- 6	-15	20	- 5	25	12		
28	29	10	10	-31	17	- 7	24	-18		
29	31	10	10	- 2	-11	-19			54	- 2
30	24	8	11	-14	-20	-25			53	19
31			12	- 4	-11	-41			46	33

BANFF, ALBERTA - 1947 - 1948

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	48	32	27	12	34	16			30	10
2	40	21	27	2	33	14	18	-17	15	2
3	40	22	25	17	33	19	24	1	25	-21
4	34	20	19	6	32	15	8	1	35	- 1
5	25	- 1	29	7	28	12	2	-22	45	6
6	28	6	28	13	42	21	14	-24	46	12
7	38	23	26	16	28	8	20	2	25	10
8	35	26	22	4	32	10	8	- 2	15	- 7
9	34	24	24	7	25	4	0	-14	18	-23
10	33	20	24	6	29	13	14	-29	28	-18
11			28	10	30	18			36	5
12	34	13	30	13	26	- 7			42	15
13	32	20	31	25	30	8			43	21
14	25	18	29	24	35	18			36	25
15	21	11	22	3	19	5			37	16
16	21	- 6	31	4	29	- 3			30	9
17	27	1	35	25	29	14	4	-12	30	- 8
18	27	19	38	31	30	- 2	0	-12	30	20
19	21	9	35	20	39	17	16	-27	32	7
20	18	12			37	16	24	-12	32	- 5
21	18	- 9			47	32	34	8	42	28
22	28	2			40	25	29	19	35	27
23	34	14			38	25	25	0	29	- 1
24	37	24	50	25	25	17	31	3	34	5
25	41	24	54	23	16	- 4	37	26	36	- 8
26	42	27	42	25	18	-21	37	22	34	7
27	35	12	44	34	27	10	34	16	32	- 7
28	30	11	40	34	28	13	25	- 5	48	28
29	36	8	38	17	37	10	27	-19	45	35
30	32	12	19	- 1	29	18			38	12
31			18	1	29	1			40	30

BANFF, ALBERTA - 1948 - 1949

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	40	10	32	23	23	10	16	-2	50	15
2	38	0	33	22	10	-6	15	-16	47	13
3	40	29	18	11	10	-31	14	-6	46	19
4	37	23	20	-9	19	-3	4	-6	48	27
5	36	27	20	-6	40	4	14	-24	50	32
6	33	14	16	-3	43	14	19	-4	44	25
7	30	9	17	1	19	14	2	-6	40	24
8	35	16	3	-15	-2	-17	20	-16	25	10
9	39	15	10	-27	2	-35	22	3	33	-15
10	41	20	19	1	10	-31	23	12	39	-6
11	42	25	24	1	21	-2	1	-11	43	1
12	35	30	8	0	21	3	14	-31	19	15
13	37	29	-6	-17	24	8	16	-11	15	-4
14	43	23	5	-28	28	12	18	2	27	-19
15	36	31	12	-24	27	8	20	-7	19	0
16	34	20	11	-17	21	-5	32	11	32	3
17	35	23	11	-12	25	14	4	-1	40	7
18	30	19	18	-3	11	-7	-11	-18	45	29
19	28	22	27	14	-3	-25	6	-39	46	29
20	31	21	26	18	1	-29	16	-31	41	25
21	32	10	22	6	9	-12	34	2	40	30
22	35	26	8	-12	-6	-22	40	22	40	24
23	35	26	12	-9	-1	-44	43	8	45	20
24	36	26	19	-19	8	-37	40	17	45	18
25	28	14	14	1	10	-12	42	26	41	27
26	23	2	18	0	17	5	46	12	37	23
27	21	2	18	7	14	3	46	14	37	26
28	32	12	18	4	19	-21	50	18	40	17
29	27	18	22	8	22	9			39	20
30	29	17	25	8	24	4			41	25
31			24	18	9	2			49	20

BANFF, ALBERTA - 1949 - 1950

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	58	34	42	28	-21	-33	3	-18	33	2
2	56	27	35	26	-19	-51	10	- 7	39	16
3	57	29	28	9	- 8	-48	13	- 9	43	31
4	58	32	19	8	- 1	-21	23	- 1	38	33
5	60	32	32	10	3	-11	39	19	30	16
6	54	31	33	17	5	- 6	37	16	27	22
7	53	28	22	1	4	- 8	30	2	27	12
8	45	24	20	- 2	2	-26	30	5	17	10
9	41	28	26	14	- 4	-23	25	14	10	- 1
10	41	23	8	- 2	-10	-25	32	12	11	- 8
11	36	29	14	-10	-11	-17	32	9	24	-29
12	37	31	18	7	-18	-21	32	0	23	-20
13	41	25	18	- 1	-20	-28	39	22	29	4
14	42	26	23	10	-13	-30	40	21	34	11
15	43	34	26	16	-13	-36	49	29	35	17
16	39	23	14	5	-18	-50	45	29	21	9
17	54	34	- 1	- 4	- 8	-38	35	4	10	- 1
18	48	37	- 7	-12	- 1	-20	44	25	40	3
19	42	28	1	-17	7	-11	37	26	38	26
20	39	11	14	-11	8	2	33	7	37	19
21	42	22	18	3	30	3	29	18	38	24
22	42	29	23	10	- 3	-12	30	18	38	21
23	42	32	21	- 1	-20	-22	31	15	37	19
24	43	33	17	- 2	-19	-41	37	17	38	14
25	43	33	21	- 6	-12	-60	39	17	37	23
26	41	32	20	8	- 6	-31	39	29	32	21
27	46	33	- 3	-13	4	-43	33	18	38	15
28	40	31	- 2	-13	1	-44	29	- 1	36	22
29	35	30	39	-14	1	-25			34	16
30	35	18	- 8	-17	- 1	-36			34	20
31			- 7	-18	2	-13			38	7

BANFF, ALBERTA - 1950 - 1951

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	32	10	5	- 6	29	5	12	- 5	22	-11
2	32	6	16	-15	16	- 3	27	2	19	- 2
3	51	26	11	4	6	0	32	14	22	-12
4	54	41	6	-20	7	-29	27	3	3	- 6
5	37	31	11	-13	16	-29	9	- 7	-10	-23
6	37	28	22	4	17	1	10	-23	-12	-40
7	32	11	27	6	19	6	22	-16	- 4	-34
8	22	8	29	19	26	12	37	1	- 5	-41
9	25	- 3	29	14	21	7	40	29	- 3	-25
10	32	15	38	25	20	5	20	0	6	-20
11	31	18	37	28	22	12	11	-21	24	-29
12	34	8	35	30	28	5	21	-26	35	11
13	31	10	34	24	27	16	23	- 8	40	24
14	26	11	26	- 3	25	17	30	6	41	23
15	15	1	29	14	27	6	33	10	40	30
16	18	12	35	23	20	9	32	7	30	12
17	4	- 2	33	21	28	15	32	11	30	-15
18	13	-12	24	12	15	-18	35	6	36	- 5
19	21	0	30	7	8	-24	32	11	46	22
20	28	10	40	23	24	- 7	32	12	50	19
21	33	10	44	35	23	11	25	12	43	32
22	1	-10	41	33	28	10	32	-12	37	21
23	22	-28	43	32	29	13	34	- 5	35	25
24	33	14	36	33	17	14	32	14	42	30
25	32	18	35	24	0	- 6	32	18	45	31
26	42	28	23	6	-13	-17	24	11	41	30
27	45	31	26	14	- 4	-41	24	- 1	35	19
28	34	29	32	22	3	-30	26	- 9	42	14
29	23	4	32	12	7	-21			49	25
30	15	5	33	27	4	-38			46	32
31			25	9	5	-32			46	30

BANFF, ALBERTA - 1951 - 1952

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	23	-13	36	30	0	-16	37	25	13	6
2	40	16	30	13	6	- 7	35	22	18	-10
3	30	16	31	16	10	- 4	36	20	22	-12
4	41	25	29	21	17	4	33	25	36	2
5	41	22	24	6	20	3	34	22	35	0
6	39	16	22	6	26	13	36	26	34	7
7	42	22	16	- 6	21	5	28	23	36	2
8	40	28	19	3	21	- 1	34	15	46	22
9	38	28	20	7	24	9	37	26	33	19
10	32	17	31	16	25	10	39	25	19	12
11	40	24	41	22	6	-12	40	19	26	1
12	35	25	35	23	15	-19	35	16	28	-13
13	37	20	18	4	26	6	29	15	34	2
14	26	19	- 4	-16	- 1	-12	28	1	35	6
15	28	14	8	-21	- 9	-20	30	11	40	2
16	20	- 3	14	- 3	20	-29	24	5	38	6
17	25	9	6	- 4	25	16	13	8	39	8
18	33	12	- 6	-12	27	19	13	- 6	36	20
19	35	17	-10	-16	25	- 3	22	-15	32	7
20	28	20	3	-26	3	-12	20	-11	32	6
21	19	7	9	- 2	-15	-23	22	-11	33	3
22	30	14	12	- 2	-12	-32	22	- 8	40	1
23	33	19	13	- 6	- 7	-34	24	-13	44	21
24	30	11	10	- 6	15	-15	30	0	34	27
25	38	16	8	- 6	30	4	28	11	46	20
26	36	28	0	-20	35	0	37	22	48	25
27	38	28	16	-12	38	31	30	1	50	31
28	34	29	24	6	46	32	26	- 2	47	30
29	32	25	10	- 5	39	28	28	4	38	24
30	35	15	-14	-21	36	32			39	26
31			- 2	-39	36	31			35	17

BANFF, ALBERTA - 1952 - 1953

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	38	25	25	12	28	18	35	30	22	0
2	39	15	28	10	23	10	38	28	28	4
3	49	32	32	12	36	21	35	29	35	9
4	47	41	32	23	36	28	35	28	38	28
5	32	17	33	27	14	2	32	18	30	13
6	38	12	32	20	6	-16	32	9	40	8
7	41	24	27	13	17	-17	38	26	44	32
8	38	18	30	12	32	-15	28	2	46	26
9	38	22	28	18	36	- 4	26	- 1	48	26
10	40	29	28	20	29	7	29	18	36	22
11	44	33	24	7	26	2	29	22	32	6
12	38	28	30	11	1	-11	34	12	37	17
13	38	19	39	24	-14	-18	32	26	35	9
14	35	26	38	31	- 5	-25	29	9	33	4
15	28	19	25	21	28	-20	32	23	38	11
16	34	9	26	7	31	22	29	5	41	21
17	36	20	25	12	22	5	31	21	33	25
18	30	17	20	11	25	4	27	- 3	33	6
19	40	23	17	- 3	33	14	24	- 5	36	16
20	34	26	15	- 1	35	28	28	- 4	32	12
21	27	5	24	4	35	7	35	14	35	14
22	30	10	22	8	33	28	32	23	35	6
23	25	9	15	0	30	19	32	0	42	7
24	19	9	20	2	37	27	35	7	54	25
25	14	- 3	16	3	31	21	42	14	44	32
26	19	- 3	15	2	12	4	40	24	42	22
27	22	- 3	20	- 1	21	- 1	30	16	46	20
28	18	7	26	12	34	14	22	14	48	26
29	16	4	30	21	37	28			41	17
30	17	5	35	22	35	15			45	26
31			33	28	39	4			34	24

BANFF, ALBERTA - 1953 - 1954

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	38	32	34	24	22	17	39	33	17	- 2
2	36	26	28	18	28	12	48	30	25	-20
3	39	19	29	18	30	23	49	36	36	3
4	44	20	27	16	30	23	50	36	42	- 2
5	50	29	29	19	33	20	48	30	41	9
6	36	32	29	23	32	19	45	27	29	24
7	40	25	24	2	17	9	48	29	35	8
8	49	34	25	12	17	12	50	33	43	27
9	46	36	35	21	17	- 4	35	24	51	32
10	47	29	29	13	17	- 1	18	12	34	25
11	50	31	29	20	21	8	6	- 3	33	8
12	43	30	32	23	17	- 5	6	- 5	37	2
13	43	26	28	18	18	9	38	--1	39	5
14	48	26	34	24	5	-15	25	- 6	34	22
15	43	33	21	3	-22	-26	31	9	30	- 3
16	36	30	23	0	1	-39	38	27	41	10
17	29	23	28	12	4	-13	45	32	35	19
18	25	6	40	15	6	-19	32	22	41	14
19	26	10	32	28	- 9	-18	30	20	41	22
20	31	13	25	22	-11	-33	36	26	35	19
21	32	16	24	8	-18	-26	37	24	41	12
22	38	24	22	3	-16	-23	40	31	35	9
23	34	26	28	11	-15	-25	43	32	40	10
24	37	26	33	23	-12	-21	35	28	31	19
25	33	26	35	29	- 1	-20	34	27	35	3
26	35	24	32	28	1	-14	38	14	15	10
27	30	13	35	9	17	-24	31	16	9	0
28	35	27	31	27	27	10	31	25	20	-22
29	35	27	31	19	18	- 3			27	9
30	42	28	35	20	38	9			31	- 2
31			32	26	40	32			25	11

APPENDIX 2

DAILY MAXIMUM AND MINIMUM TEMPERATURES FOR WINTER MONTHS, LAKE LOUISE, ALBERTA. 1932 to 1954

LAKE LOUISE, ALBERTA - 1932 - 1933

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	30	4	31	22	20	4	14	-20	23	0
2	35	25	34	26	20	- 1	17	-13	37	- 6
3	30	16	30	20	19	9	28	-10	33	19
4	31	20	30	26	24	13	27	- 1	30	20
5	35	23	17	- 1	27	16	24	12	34	20
6	33	21	- 1	- 3	26	21	7	-31	36	21
7	29	- 6	- 3	-44	29	20	4	-12	31	22
8	31	14	- 6	-36	29	12	- 6	-25	31	- 1
9	30	11	15	-34	30	20	- 3	-47	23	-26
10	24	-12	9	-22	25	11	2	-18	22	-12
11	25	-11	2	-35	24	9	7	-17	31	- 8
12	26	17	3	- 8	29	22	4	-27	37	24
13	5	- 2	3	-24	33	11	4	-31	34	24
14	12	-17	9	-27	30	25	10	-24	33	-15
15	16	2	7	-28	4	2	18	- 3	35	-17
16	28	2	11	-28	4	-27	18	-14	37	- 3
17	34	22	10	-22	1	-23	23	15	34	- 1
18	40	32	11	-22	3	-29	23	-10	36	7
19	38	30	17	4	8	-16	25	8	37	- 3
20	28	10	24	12	14	-13	33	18	39	26
21	26	9	25	11	16	3	31	16	32	18
22	29	19	24	2	18	- 7	30	16	30	6
23	31	12	26	16	24	2	28	14	32	9
24	32	26	20	3	20	- 5	27	7	29	2
25	25	-12	24	7	18	- 4	29	18	34	- 2
26	36	17	24	8	18	- 8	29	26	38	-10
27	40	25	21	10	18	8	22	1	39	2
28	40	31	24	13	18	- 7	18	4	39	26
29	35	30	21	8	16	-18			39	16
30	28	26	19	- 8	16	-18			39	28
31			24	5	18	- 5			35	25

LAKE LOUISE, ALBERTA - 1933 - 1934

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	42	32	32	20	22	-10	32	22	27	18
2	30	16	32	18	22	2	40	12	37	21
3	32	- 3	32	10	32	22	32	-10	39	32
4	42	- 5	22	6	31	20	30	-18	26	- 8
5	41	- 1	30	10	30	6	31	-18	23	- 8
6	30	12	20	0	29	-10	32	- 2	27	6
7	30	2	22	6	19	-18	38	5	28	12
8	60	27	20	6	21	-12	36	27	33	5
9	58	24	24	5	20	-12	36	18	24	-10
10	38	27	19	-13	31	20	36		50	6
11	41	32	10	0	32	8	38	10	48	8
12	42	34	0	- 8	21	-14	38	-20	46	23
13	47	24	7	- 8	26	12	37	-20	47	8
14	48	22	0	- 9	26	12	38	-20	48	18
15	42	20	2	-15	22	-22	37	- 5	43	30
16	37	18	- 3	-24	24	22	35	- 8	53	12
17	40	20	6	0	29	10	38	1	37	14
18	30	14	20	2	21	-16	37	- 9	41	24
19	37	25	14	-10	24	-11	36	- 8	49	29
20	36	28	32	- 5	34	18	27	-18	38	24
21	38	28	28	- 6	32	18	24	-18	32	22
22	37	26	31	-10	28	16	25	-19	35	5
23	38	22	39	-13	27	12	15	-21	40	10
24	40	28	30	- 5	14	-24	9	-21	36	8
25	50	23	- 5	-49	24	-21	8	-40	35	6
26	27	13	- 5	-46	26	20	11	-34	40	4
27	30	5	1	-36	31	24	24	5	32	22
28	30	- 1	19	- 6	41	10	23	8	46	2
29	19	10	32	-14	41	7			40	4
30	32	24	- 8	- 2	30	3			44	21
31			14	- 6	32	22			42	22

LAKE LOUISE, ALBERTA - 1934 - 1935

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	41	32	21	8	30	15	40	9	36	18
2	40	19	21	0	30	-11	40	11	37	20
3	38	28	23	0	22	-17	36	14	33	16
4	35	22	21	1	21	19	41	22	21	- 1
5	40	26	27	6	20	12	40	- 4	20	-15
6	40	21	22	0	20	12	33	- 4	27	-23
7	35	28	28	0	23	-12	22	-19	31	-17
8	38	14	28	0	23	23	32	-15	35	-10
9	35		27	0	22	- 6	32	-11	27	- 7
10	34		25	6	20	3	32	-12	22	-16
11	32		29	14	19	5	30	- 5	34	19
12	39	10	54	20	12	-19	28	- 4	35	29
13	47	12	34	28	11	-20	29	- 5	41	36
14	39	27	34	12	-12	-42	28	- 5	39	31
15	42	30	34	8	1	-30	31	5	38	23
16	38	31	32	6	2	-15	34	12	30	4
17	40	22	34	14	-11	-34	34	24	34	15
18	30	18	34	14	-15	-40	30	4	33	3
19	30	13	31	18	-17	-54	27	0	34	4
20	20	12	32	18	-11	-55	35	12	25	1
21	19	10	27	12	- 5	-18	34	12	26	-12
22	31	13	25	8	15	-20	35	14	30	-10
23	30	14	22	0	19	15	39	14	32	3
24	38	19	25	1	24	22	27	-18	34	21
25	38	20	25	0	35	32	28	-12	25	0
26	21	10	14	-19	35	15	30	-18	26	5
27	20	8	12	-21	36	32	30	-12	26	-13
28	22	- 5	12	-24	38	18	34	10	30	2
29	20	11	8	- 2	35	6			28	- 9
30	28	8	15	- 6	36	8			24	-26
31			16	- 3	41	10			25	-26

LAKE LOUISE, ALBERTA - 1935 - 1936

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	11	-30	32	- 4			14	-37	41	34
2	16	-30	33	- 6			16	-38	44	32
3	29	-15	32	0			17	-35	44	32
4	26	10	28	- 9			18	-36	38	25
5	25	15	21	-10			12	-25	42	14
6	33	19	26	13			0	-26	35	22
7	39	26	30	- 6			- 4	-55	36	23
8	35	17	35	25			-14	-40	36	24
9	15	-13	34	9			-12	-36	29	2
10	17	-19	30	20			- 7	-22	30	- 1
11	22	12	26	9			-12	-22	21	-12
12	27	20	29	16			- 3	-14	32	21
13	24	-13	28	- 4			- 8	-42	31	14
14	22	- 3	22	- 5	32	15	- 8	-52	34	14
15	26	0	18	- 7	29	- 3	- 7	-29	35	16
16	30	10	20	- 5	26	- 3	- 4	-52	34	21
17	30	11	19	- 7	22	- 7	- 2	-50	30	17
18	21	-16	20	-11	13	-32	10	-45	32	27
19	31	20	17	-12	19	-20	18	-32	40	22
20	34	18	21	- 7	23	- 3	14	-10	35	25
21	32	12	26	- 2	27	14	18	-11	48	22
22	21	7	27	-10	35	25	20	- 7	31	- 2
23	30	3	29	10	35	26	10	0	20	9
24	31	10			35	3	10	-25	27	-10
25	30	15			24	-23	40	-41	25	14
26	32	23			20	-23	18	- 2	27	0
27	36	27			13	-10	32	10	17	1
28	34	29			14	-32	35	27	16	-26
29	35	30			16	-31	37	25	9	-10
30	34	0			18	- 5			14	-19
31					18	-31			11	-33

LAKE LOUISE, ALBERTA - 1936 - 1937

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	40	-21	27	10	- 2	-37	4	-10	37	2
2	39	-17	25	10	1	-27	0	-11	39	9
3	29	14	22	- 8	10	-23	14	-30	38	22
4	30	14	15	-10	9	-22	14	-10	43	15
5	20	8	14	-10	12	-20	14	- 8	47	18
6	18	-22	14	-28	6	-47	17	-13	35	26
7	21	-17	18	-10	2	-39	- 8	-17	40	- 3
8	26	8	21	0	1	-26	0	-47	40	- 4
9	32	13	22	- 7	1	-20	-12	-20	43	4
10	31	13	22	- 3	4	-23	19	3	42	24
11	33	22	23	- 3	7	-21	25	16	46	6
12	39	26	26	8	16	-13	20	12	38	18
13	44	30	30	9	7	-21	23	-20	40	- 6
14	42	19	26	21	14	-37	23	- 1	26	- 6
15	42	20	26	-21	7	-34	26	- 3	36	16
16	40	13	21	-23	0	-27	28	14	41	0
17	40	24	25	4	0	-39	24	12	40	- 4
18	43	26	37	20	7	-15	17	1	43	4
19	54	33	38	5	5	-27	17	0	41	10
20	42	16	37	- 8	- 3	-45	14	-26	33	0
21	44	7	38	0	- 5	-47	18	-14	41	-16
22	46	6	37	24	- 3	-29	30	-11	40	0
23	34	7	28	10	5	-20	30	- 1	41	1
24	34	7	22	-10	7	-17	29	15	40	20
25	32	6	22	-17	8	-12	34	- 7	44	12
26	26	3	22	-18	5	-13	31	-17	45	40
27	30	0	17	-30	- 2	-34	33	-14	45	0
28	31	6	6	-28	- 2	-43	33	-26	40	10
29	34	8	0	-35	6	-16			41	14
30	30	6	7	-16	4	-14			43	23
31			- 9	-21	4	-10			44	24

LAKE LOUISE, ALBERTA - 1937 - 1938

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	44	12	16	-13	25	10	5	-13	45	0
2	44	4	22	-10	30	13	12	- 7	43	25
3	46	26	15	4	16	-14	26	- 3	35	22
4	38	11	21	0	22	-15	28	15	44	11
5	39	11	25	16	17	- 9	28	13	35	25
6	35	21	30	10	13	-13	26	- 4	36	4
7	37	19	20	-20	14	-13	15	- 8	35	- 7
8	41	25	13	-33	22	- 9	22	-21	38	0
9	44	25	0	-38	22	2	19	-29	36	7
10	39	24	15	-26	26	17	19	- 7	36	24
11	34	24	30	11	18	-21	15	-20	36	23
12	31	14	20	- 8	18	- 5	16	- 9	46	25
13	20	3	25	- 9	25	11	- 2	-13	45	24
14	7	2	27	9	32	21	- 1	-19	42	25
15	22	8	32	9	31	21	9	-34	35	20
16	17	3	30	20	23	-15	22	-28	35	25
17	16	3	38	16	21	--7	23	-25	32	17
18	18	- 2	36	13	19	-13	24	-10	30	18
19	11	-24	32	- 4	19	2	32	-14	29	16
20	25	8	32	- 2	18	-19	22	- 6	31	- 4
21	16	10	24	12	27	12	34	0	30	-11
22	34	6	13	-10	27	6	36	- 8	29	1
23	35	22	0	-28	23	- 4	37	- 8	36	10
24	33	22	0	-10	19	- 3	39	- 6	38	16
25	32	21	0	-22	25	7	44	0	46	23
26	25	17	6	-18	19	3	47	0	41	16
27	28	0	13	- 5	31	- 7	49	0	36	29
28	28	3	32	0	27	0	53	0	34	26
29	28	4	38	32	3	-40			26	14
30	17	-9	33	32	1	-42			32	14
31			30	22	6	-27			31	-10

LAKE LOUISE, ALBERTA - 1938 - 1939

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	38	17	34	22	33	26	14	-30	26	- 3
2	34	14	29	15	33	23	17	-15	29	8
3	35	27	28	14	30	24	17	-10	20	- 6
4	31	18	26	7	27	10	10	-17	24	-30
5	27	5	35	24	15	- 1	15	- 3	25	-27
6	27	- 3	32	22	18	-17	15	-12	31	- 5
7	33	17	33	26	28	12	5	-24	30	12
8	27	12	33	23	27	9	- 4	-38	31	-17
9	26	2	33	17	26	9	-10	-47	30	-20
10	23	8	21	- 4	27	- 1	- 1	-45	31	-14
11	21	-10	14	-17	23	19	10	-13	31	14
12	24	14	13	-23	23	19	26	9	28	9
13	25	13	18	- 6	31	18	25	10	25	3
14	30	20	19	- 4	27	- 8	29	16	30	-22
15	32	25	13	-17	25	11	28	10	30	5
16	30	25	16	-16	24	- 4	27	- 2	33	- 2
17	29	22	14	-15	25	8	33	23	40	- 7
18	34	23	13	-20	26	12	18	- 6	50	23
19	31	21	12	-21	30	16	26	-24	54	27
20	25	4	9	-25	25	13	25	-26	53	30
21	19	0	11	-18	16	-21	26	-24	52	35
22	17	-20	22	-14	18	- 1	32	-19	57	20
23	16	-21	33	16	25	5	35	6	60	24
24	21	-19	33	17	25	15	34	- 2	50	35
25	32	- 5	29	- 3	37	5	29	16	40	20
26	21	- 7	29	-35	29	7	26	-13	39	5
27	50	- 5	19	-15	26	5	26	- 8	43	- 4
28	26	0	11	-22	26	11	24	-13	49	8
29	27	10	4	-27	26	7			44	8
30	32	19	26	4	21	- 1			40	31
31			27	19	17	-17			44	35

LAKE LOUISE, ALBERTA - 1939 - 1940

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1			36	24	29	14	24	-20		
2			39	32	32	12	16	- 7		
3			39	30	28	0	23	-20		
4			37	28	26	12	31	14		
5			36	22	30	14	34	20		
6			39	28	14	-16	30	25		
7			37	20	12	-17	37	22		
8	NO		39	24	10	-27	34	- 8	NO	
9			36	11	12	-28	38	27		
10			32	26	18	- 5	31	24		
11			34	24	16	-10	28	3		
12	RECORD		30	18	14	-24	25	-16	RECORD	
13			28	2	19	- 5	30	-10		
14			30	24	14	5	34	5		
15			32	20	27	- 8	28	-18		
16	FOR		33	22	30	10	28	- 8	FOR	
17			26	16	15	-16	32	20		
18			21	-10	10	-31	30	2		
19			28	18	10	-35	30	5		
20	NOVEMBER		30	22	8	-36	32	0	MARCH	
21			30	26	13	-29	22	10		
22			24	10	16	-20	32	16		
23			22	-29	12	-37	30	18		
24			20	-10	5	-41	26	8		
25			15	-28	10	-42	22	5		
26			8	-26	16	-22	16	- 8		
27			15	-10	29	8	37	- 7		
28			32	10	37	15	38	16		
29			25	22	41	18	38	19		
30			27	15	30	- 8				
31			18	-18	18	-14				

LAKE LOUISE, ALBERTA - 1940 - 1941

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	36	23	25	8	19	-8	37	23	35	11
2	34	15	31	8	18	-4	38	27	42	7
3	33	19	36	25	14	-17	41	7	41	27
4	27	19	33	6	13	-18	39	4	45	24
5	26	-2	32	25	12	-9	41	-6	42	4
6	27	11	32	19	15	-6	49	-7	42	16
7	22	7	29	23	21	-26	47	-10	47	25
8	18	-8	33	26	30	-7	41	-6	41	24
9	13	-4	29	10	32	15	39	-7	35	-2
10	9	-22	22	-9	37	24	35	14	44	-10
11	8	-29	18	-10	36	22	37	12	50	-10
12	9	-25	15	-28	41	11	33	6	40	-16
13	15	-15	22	-10	36	20	37	7	48	-16
14	23	-3	18	-20	31	5	33	-18	43	4
15	28	12	15	-25	28	8	35	-14	40	0
16	31	-1	20	-22	34	15	41	-14	45	-1
17	31	10	22	-18	22	-1	43	-12	49	22
18	29	6	27	-5	31	20	38	1	45	27
19	32	-3	30	5	28	11	26	15	44	17
20	28	-7	32	22	36	4	31	5	40	9
21	29	-5	32	19	30	-19	17	-2	42	-2
22	22	-19	36	21	20	7	15	-2	43	4
23	21	-3	31	-2	21	0	16	-38	47	16
24	29	12	28	9	16	-18	21	-20	49	11
25	30	17	32	10	26	-8	32	-2	50	16
26	30	11	34	8	33	4	31	12	52	28
27	27	12	36	10	33	12	38	22	53	11
28	29	18	32	5	34	25	44	31	52	9
29	30	20	26	5	36	-1			55	13
30	29	12	25	6	37	2			50	30
31			19	1	37	13			47	33

LAKE LOUISE, ALBERTA - 1941 - 1942

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	33	18	35	22	0	-35	28	9	36	24
2	29	5	39	29	4	-12	34	4	34	21
3	29	19	36	20	7	-31	35	1	31	5
4	39	21	37	11	2	-38	32	18	36	14
5	41	29	34	- 1	0	-40	30	17	32	21
6	40	18	29	21	7	-37	34	3	29	5
7	43	8	30	14	2	-40	33	3	35	7
8	44	17	30	14	10	-27	32	2	40	15
9	47	21	22	12	10	-25	31	-16	36	26
10	43	13	25	- 5	19	3	32	3		
11	37	21	21	- 2	22	3	33	12		
12	39	17	14	-16	30	14	34	- 5		
13	29	8	12	-19	36	14	32	-11		
14	36	29	21	-14	29	- 2	38	- 2		
15	31	16	26	0	24	- 7	29	15		
16	32	1	32	10	27	- 7	20	-30		
17	30	-10	26	5	26	- 4	19	-36		
18	23	-15	28	2	28	8	20	-24		
19	30	- 4	32	22	29	- 3	27	-15		
20	25	- 1	29	0	22	- 8	35	0		
21	21	18	30	21	33	-11	20	-20		
22	19	-17	22	1	32	-11	12	-25		
23	18	-17	25	12	35	- 9	17	-24		
24	28	- 2	17	- 3	37	4	20	- 6		
25	33	24	24	-10	35	11	23	-17		
26	41	28	11	-29	37	13	28	-19		
27	36	19	11	-32	34	22	31	2		
28	39	7	13	-30	35	15	30	- 1		
29	41	27	11	-30	27	-10				
30	41	26	5	-27	29	4				
31			31	-46	27	-12				

LAKE LOUISE, ALBERTA - 1942 - 1943

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	30	11	21	-20	17	-22	18	- 9	33	-18
2	23	- 6	19	- 5	15	-30	26	12	36	-20
3	34	18	17	-14	17	-29	25	3	32	-14
4	24	4	18	-19	10	-31	26	13	26	-15
5	18	0	13	-20	22	-12	27	9	26	-28
6	27	9	18	-19	21	1	33	18	28	-30
7	31	-11	15	-22	23	4	24	- 8	26	- 6
8	28	-10	14	-13	29	17	15	-36	29	4
9	23	-15	18	- 4	26	4	14	-30	28	-21
10	29	16	26	4	21	12	21	-10	27	2
11	35	14	28	14	24	-15	30	15	26	6
12	39	9	34	23	21	- 4	35	7	35	11
13	40	3	36	26	33	17	39	8		
14	46	29	34	21	34	27	40	14		
15	33	28	35	20	31	- 2	45	12		
16	30	17	36	27	22	-32	43	9		
17	19	- 1	35	22	10	-52	46	8		
18	27	-14	27	- 3	2	-48	44	4		
19	24	-10	33	12	- 4	-24	38	22		
20	26	-15	29	10	-14	-36	40	0		
21	25	- 9	30	22	-19	-49	35	21		
22	31	10	28	19	- 4	-38	36	-15		
23	35	31	22	-16	0	-46	31	- 5		
24	33	10	17	-19	4	-45	36	-20		
25	23	9	23	11	9	-38	48	- 3		
26	19	1	12	-28	13	- 7	46	- 5		
27	27	-16	13	-21	20	-12	50	- 6		
28	17	-25	25	5	26	0	59	13		
29	18	-16	16	- 7	28	-20				
30	24	9	27	0	25	-29				
31			21	3	16	-15				

LAKE LOUISE, ALBERTA - 1943 - 1944

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	34	-5	30	19	23	7	30	-8	31	-25
2	33	10	29	18	19	9	34	6	29	2
3	35	24	37	25	18	-5	35	-4	30	-2
4	34	19	28	4	13	-3	27	4	21	-1
5	34	24	27	-14	16	-18	28	8	25	-10
6	35	-1	22	-6	18	-26	30	20	31	-11
7	34	1	25	12	19	9	28	21	39	-16
8	34	14	24	-10	28	5	34	-15	38	23
9	42	5	28	-6	25	-17	22	-15	48	25
10	32	19	21	-9	20	-21	30	-25	36	16
11	43	16	20	-2	13	-23	30	3	29	-7
12	42	3	27	-11	23	2	25	-17	20	8
13	45	11	25	-10	29	17	24	2	24	-27
14	40	17	20	-11	32	13	27	4	38	-11
15	42	6	25	-8	32	18	22	-19	37	2
16	43	4	23	-8	33	20	25	6	35	27
17	34	16	28	-4	35	28	26	-17	37	26
18	36	3	29	-8	32	24	30	-6	39	4
19	38	16	23	-20	45	38	27	-22	38	19
20	35	17	23	-18	43	20	23	-7	35	11
21	39	25	26	-8	35	-9	20	5	31	-10
22	48	20	23	-13	38	2	28	-29	31	21
23	49	7	22	10	31	6	23	-10	29	15
24	45	22	27	17	30	14	35	11	22	-9
25	36	-2	29	18	25	-7	24	-15	22	-10
26	33	-7	31	2	28	-22	30	-9	18	-12
27	36	-1	24	-11	26	-22	32	-14	20	-30
28	23	-3	22	-10	23	-25	25	-4	40	18
29	29	19	14	-15	28	-24	29	-12	48	32
30	33	23	13	-16	34	-22			42	23
31			19	-10	35	-18			43	20

LAKE LOUISE, ALBERTA - 1944 - 1945

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	40	23	31	17	26	- 7	33	-12	33	- 4
2	39	16	35	12	23	- 6	24	10	30	9
3	29	20	28	- 7	25	2	21	5	26	6
4	38	21	28	19	27	9	36	8	18	-39
5	39	29	36	21	30	18	30	16	17	-35
6	38	28	37	27	29	17	32	- 3	27	- 6
7	39	27	29	6	27	7	30	18	29	14
8	40	24	30	8	32	8	39	26	31	3
9	36	28	23	-12	36	25	32	12	39	10
10	36	21	26	-12	30	4	29	8		
11	27	17	28	-10	34	22	29	- 2		
12	35	7	30	-10	32	17	28	14		
13	33	-12	27	- 8	29	5	25	7		
14	33	-10	25	- 3	35	13	19	-18		
15	37	3	29	- 8	25	- 7	13	-10		
16	37	- 3	19	- 8	26	7	17	-43		
17	32	2	18	- 6	25	13	24	-35		
18	27	2	15	- 7	24	10	30	-32		
19	36	0	21	- 2	29	-17	27	-20		
20	28	1	19	-10	18	-30	28	0		
21	30	13	18	-15	28	-11	24	- 9		
22	34	23	14	-28	28	-10	26	- 8		
23	35	26	8	-30	32	- 9	34	-10		
24	33	13	7	-30	33	-16	37	-15		
25	26	- 3	2	-33	30	- 8	46	8		
26	28	13	12	-22	29	-20	43	3		
27	29	13	10	-18	25	-25	34	18		
28	24	-10	24	8	21	-20	28	-10		
29	28	-10	24	0	25	-26				
30	30	11	18	- 5	22	-24				
31			15	- 7	27	-25				

LAKE LOUISE, ALBERTA - 1945 - 1946

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	32	19	29	-10	28	13	20	- 1	33	21
2	27	7	32	-10	29	7	21	- 2	41	20
3	42	23	31	-11	28	16	26	- 7	35	1
4	41	29	31	22	30	12	23	-24	33	- 1
5	31	5	33	12	29	9	22	-30	31	16
6	22	- 6	26	14	30	- 9	21	7	33	14
7	14	- 8	23	10	24	11	22	-20	31	8
8	13	-35	19	-22	27	6	26	6	33	18
9	14	-16	12	-24	24	9	24	10	36	- 8
10	25	- 8	21	- 3	27	10	20	- 5	47	5
11	24	8	23	- 8	24	-14	19	-21	43	23
12	28	7	15	-27	20	- 2	21	- 7		
13	27	1	10	-25	26	16	27	16		
14	26	6	9	-15	31	2	34	20		
15	37	3	12	-12	32	6	34	21		
16	29	- 3	19	-14	26	- 8	37	-15		
17	27	16	12	-20	29	19	31	- 5		
18	28	11	11	-31	31	16	33	10		
19	29	8	10	-18	18	18	39	-17		
20	27	1	16	7	21	-29	33	- 6		
21	28	-20	13	- 3	22	-12	40	6		
22	24	- 4	15	- 8	30	16	35	18		
23	34	2	27	11	25	10	36	20		
24	30	5	31	10	22	14	38	25		
25	32	8	30	14	20	- 7	35	22		
26	28	12	31	11	14	-30	34	- 4		
27	28	10	32	13	19	1	33	17		
28	23	-10	29	11	21	7	31	23		
29	36	4	32	16	21	5				
30	26	10	34	17	18	-26				
31			28	10	19	12				

LAKE LOUISE, ALBERTA - 1946 - 1947

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	29	16	22	-15	- 2	-30	7	-28	25	3
2	28	-12	30	14	13	-30	13	- 6	19	2
3	36	20	32	6	12	-30	11	-12	14	- 6
4	49	9	36	24	14	-12	22	2	20	-38
5	47	7	34	28	18	6	32	18	26	-35
6	40	22	31	21	25	- 8	36	9	28	-31
7	36	13	33	23	22	- 7	22	-30	28	-21
8	30	- 3	29	16	26	- 6	33	-31	33	8
9	28	- 6	20	- 6	28	8	42	-30	32	15
10	30	15	34	14	34	20	35	-28	34	14
11	37	- 5	34	20	35	16	27	17	36	5
12	37	- 3	22	-11	16	6	37	18	33	- 5
13	38	- 3	17	-16	6	- 5	45	21	45	17
14	34	0	15	-13	4	-35	36	22	55	25
15	27	6	19	4	5	-30	39	19	56	15
16	20	4	14	-24	20	2	40	-12	60	16
17	17	5	15	-31	35	13	42	-11	54	9
18	9	- 5	18	- 1	31	25	37	5	51	12
19	0	-14	22	5	27	14	25	8	52	13
20	- 2	-39	29	12	20	13	30	-10	48	17
21	9	-41	27	13	29	14	33	15	44	32
22	14	-29	28	15	34	20	40	21	36	25
23	17	7	25	4	36	25	43	27	37	1
24	27	5	32	13	35	28	35	23	39	4
25	28	9	33	25	28	21	32	11	39	16
26	26	15	29	18	28	14	28	-20	37	5
27	27	11	18	-10	18	-12	27	6	42	5
28	27	7	4	-40	16	4	26	-29	51	18
29	26	3	9	-19	9	-17			52	15
30	30	5	5	-27	-14	-23			50	16
31			8	-19	- 5	-51			46	31

LAKE LOUISE, ALBERTA - 1947 - 1948

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	36	30	30	4	19	11	28	- 2	31	4
2	37	23	29	9	27	9	31	-26	23	0
3	32	18	24	9	22	5	22	-11	31	-31
4	31	6	29	6	23	18	15	4	36	-19
5	31	-14	20	-11	24	- 4	15	-37	38	-13
6	26	0	26	- 5	30	7	20	-34	40	- 6
7	33	17	18	- 9	21	- 9	14	-10	33	13
8	36	19	20	5	25	- 2	12	9	21	- 6
9	32	- 2	20	- 2	27	-13	5	-12	19	-34
10	33	8	21	- 3	24	- 4	30	-36	30	-35
11	35	13	22	3	21	11	25	-24	24	-16
12	29	16	21	4	17	-22	18	-10		
13	32	17	29	17	18	- 3	24	8		
14	25	10	29	10	28	4	26	5		
15	22	9	20	- 8	29	- 2	29	22		
16	26	2	19	-15	25	- 3	24	17		
17	24	-11	35	13	32	3	22	12		
18	30	14	31	12	23	-17	20	- 6		
19	19	-12	27	8	31	13	19	-36		
20	20	11	27	- 4	28	5	23	-27		
21	23	-20	28	7	34	23	28	0		
22	19	-10	25	6	37	20	27	13		
23	25	13	33	21	34	21	28	- 3		
24	27	21	34	22	29	7	32	12		
25	30	9	36	- 2	21	-16	34	14		
26	36	28	38	23	18	-30	32	17		
27	32	- 5	35	28	23	- 9	32	13		
28	33	- 2	30	23	21	0	26	-18		
29	32	- 8	24	11	31	-10	24	-28		
30	25	- 3	19	-11	24	3				
31			20	3	26	- 9				

LAKE LOUISE, ALBERTA - 1948 - 1949

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1			25	12	22	8	15	-15	50	- 9
2			26	10	16	-10	14	-32	46	- 5
3			21	- 4	8	-38	12	-24	41	7
4			14	- 6	13	-19	9	-17	42	22
5			15	- 5	12	-14	14	-38	48	24
6			16	-12	32	9	12	-22	41	14
7			18	2	37	11	6	- 4	36	17
8	VOLUME		15	6	9	-25	16	-18	27	11
9			6	-27	7	-43	20	- 7	35	-24
10			14	- 2	8	-38	23	11	40	-18
11	MISSING		18	- 2	14	-16	19	-10	43	-14
12			12	- 7	17	-18	11	-42	33	13
13			5	-16	20	-14	10	-31	25	- 4
14	FOR		13	-34	24	0	12	-14	26	-33
15			11	-31	25	- 2	16	-18	21	-12
16			12	-29	15	-19	23	5	38	2
17	NOVEMBER		6	-32	22	9	27	7	37	11
18			12	-22	15	-15	-10	-15	41	25
19			12	0	7	-38	8	-43	40	24
20			22	11	- 6	-48	13	-42	44	25
21			17	- 8	6	-31	31	9	42	27
22			10	-19	1	-34	38	21	38	24
23			13	-28	- 6	-49	37	24	47	18
24			20	-26	5	-48	38	3	41	6
25			13	-23	4	-34	45	9	39	15
26			14	-27	13	- 2	48	- 6	36	16
27			14	- 8	16	-10	47	- 8	35	19
28			18	-19	18	-32	46	- 6	36	2
29			15	- 5	18	2			35	5
30			18	- 3	25	-18			42	20
31			19	3	21	-13			44	6

LAKE LOUISE, ALBERTA - 1949 - 1950

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	55	25	33	19	-10	-36				
2	52	19	34	28	-21	-54			33	- 3
3	53	18	24	4	-11	-53			34	19
4	54	20	18	- 6	- 1	-42			35	17
5	57	21	26	0	- 3	-34			29	- 2
6	53	20	27	0	4	-33			31	10
7	51	19	22	3	8	- 5			32	9
8	40	22	18	-20	17	-18	NO		23	7
9	37	24	23	0	- 5	-26			13	- 5
10	38	23	18	-18	- 6	-22			17	-21
11	31	21	14	-22			RECORD		26	-40
12	35	20	16	-13					19	-32
13	37	16	15	-20	-18	-36			25	- 4
14	38	11	17	- 2	-18	-35	FOR		29	3
15	37	21	21	12	-14	-52			31	9
16	38	9	18	0	-18	-54			34	16
17	43	27	16	- 4	- 6	-39	FEBRUARY		19	2
18	40	29	8	-17	- 5	-44			39	- 1
19	39	21	0	-38	4	-26			38	19
20	37	6	6	-31	14	- 1			39	7
21	39	7	11	-14	30	7			33	10
22	40	17	20	4	8	-11			38	8
23	[illegible]	27	18	2	-10	-22			38	14
24	[illegible]	25	18	-4	-21	-55			40	- 5
25	36	28	17	-20	-13	-63			40	17
26	34	24	14	- 6	0	-44			38	18
27	42	28		-11	4	-51			38	7
28	36	26	-11	-13	3	-51			35	16
29	30	22	32	-15	- 1	-42			30	4
30	29	13	31	0	- 1	-46			33	11
31			8	-11	- 4	-38			38	- 8

LAKE LOUISE, ALBERTA - 1950 - 1951

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	33	- 2	12	- 5	23	5	5	-22	26	-24
2	37	-12	13	-18	15	- 8	11	- 2	25	-15
3	35	8	10	7	13	0	26	8	21	-19
4	40	30	8	-28	6	-30	26	12	5	- 4
5	36	26	4	-31	15	-24	22	5	- 5	-20
6	30	16	20	-10	17	-22	14	-28	- 6	-48
7	45	12	26	- 8	18	-13	18	-23	- 2	-45
8	22	- 6	27	3	19	- 4	28	12	- 5	-39
9	22	-17	23	- 4	20	- 9	37	25	- 6	-23
10	29	5	34	21	21	-13	32	14	4	20
11	31	13	31	14	25	- 9	22	-29	25	-33
12	33	- 7	33	23	28	1	24	-28	36	0
13	23	- 6	33	14	22	5	27	-27	35	13
14	20	7	23	0	30	10	32	-20	38	22
15	18	2	24	4	21	2	28	-11	36	32
16	22	12	29	7	25	8	34	-12	28	18
17	33	1	27	12	23	9	28	- 3	28	-18
18	12	-14	25	- 3	18	-17	35	- 8	34	-15
19	22	-15	20	- 8	10	-30	29	1	45	7
20	25	8	30	5	19	- 5	28	3	48	27
21	29	23	35	25	20	- 5	29	2	39	25
22	26	-10	36	27	20	4	30	-25	38	11
23	12	-34	35	26	25	2	31	-24	33	18
24	29	8	34	26	19	4	29	- 4	38	24
25	27	9	33	21	10	-15	31	8	42	22
26	35	23	24	-16	11	-19	31	- 6	37	27
27	38	26	22	- 6	- 3	-49	27	- 1	34	11
28	32	14	28	14	4	-30	25	-15	38	0
29	18	- 5	24	3	4	-43			46	17
30	13	- 2	30	21	7	-45			42	27
31			23	6	6	-43			47	25

LAKE LOUISE, ALBERTA - 1951 - 1952

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	22	-22	32	26	-33	-38	32	19	22	8
2	29	12	29	12	2	-30	32	13	18	- 8
3	26	2	28	8	9	-27	25	9	26	- 5
4	36	16	25	5	15	-15	31	18	32	5
5	36	6	24	- 5	16	-13	29	9	32	8
6	37	3	20	- 4	20	3	34	20	35	-12
7	41	7	14	-22	18	-14	30	18	34	-16
8	34	22	17	-17	10	-16	28	3	38	10
9	33	16	16	-12	21	- 3	34	14	35	8
10	30	4	19	6	19	11	32	8	33	14
11	34	18	30	18	13	-14	40	- 3	33	- 8
12	32	20	34	25	11	-20	31	4	37	5
13	34	18	25	1	16	-17	31	6	30	4
14	27	14	15	-15	- 5	-12	28	-20	36	- 9
15	30	10	7	-24	-10	-20	29	2	38	-16
16	23	-23	9	-22	11	-24	26	-12	36	- 8
17	24	-13	12	-14	18	5	21	5	34	0
18	28	-10	3	- 8	20	13	20	- 9	33	10
19	35	2	- 4	-18	21	3	22	-25	30	0
20	35	16	- 2	-40	13	-13	23	-29	32	- 6
21	24	- 9	7	-15	-14	-22	22	-28	30	-21
22	28	5	9	- 7	-16	-38	22	-24	36	-11
23	28	3	13	-24	2	-35	26	-32	39	24
24	29	- 7	6	-24	11	- 6	29	-20	40	20
25	26	2	7	-32	23	2	32	- 2	42	25
26	29	16	3	-30	29	17	32	6	43	16
27	34	18	12	-22	32	22	27	-15	48	26
28	32	22	11	-13	37	24	26	-14	41	23
29	28	16	10	2	37	21	31	-14	36	10
30	27	3	5	-22	33	22			33	20
31			-15	-48	34	20			30	16

LAKE LOUISE, ALBERTA - 1952 - 1953

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	34		22	0	28	3	36	24	25	-23
2	33		24	- 5	19	- 9	33	17	27	-12
3	38		26	5	32	12	30	20	28	- 5
4	42		29	13	30	15	29	17	34	22
5	40		34	13	22	-10	27	7	34	24
6	39		23	18	13	-30	32	- 7	36	11
7	39		25	5	-15	-17	30	14	42	27
8	39	NO	26	8	29	-15	30	-15	48	15
9	40		23	6	34	4	26	-20	52	14
10	34		25	17	33	8	26	9	42	22
11	43	RECORD	27	0	25	6	42	12	46	12
12	40		25	- 4	33	4	31	8	39	13
13	35		39	15	-14	-16	32	18	35	- 5
14	33	FOR	33	8	- 7	-29	25	- 6	30	-13
15	41		24	9	17	-34	30	18	32	- 9
16	37		22	5	31	14	25	- 4	39	5
17	35	MIN.	26	11	25	10	29	8	37	22
18	28		22	5	22	- 7	30	-20	29	- 9
19	33		24	-22	28	1	27	-25	35	6
20	31		14	-17	32	20	32	-21	35	-10
21	25		21	-18	29	11	37	- 4	39	- 2
22	28		25	3	29	22	32	14	35	0
23	33		19	-12	26	9	34	-15	39	- 8
24	29		18	-14	36	23	32	- 8	53	11
25	22		9	-15	28	11	36	- 4	40	27
26	17		14	-20	22	14	36	28	42	10
27	23		15	-18	19	- 4	33	5	44	6
28	24		20	- 2	26	13	23	3	45	25
29	15		27	5	36	22			37	6
30	21		29	14	32	26			40	18
31			31	12	34	15			32	15

LAKE LOUISE, ALBERTA - 1953 - 1954

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	33	23	31	17	25	4	36	26	19	- 4
2	33	22	28	12	22	3	42	19	24	-36
3	40	7	24	8	26	16	40	20	32	-13
4	42	3	23	4	24	19	42	25	36	-22
5	40	18	23	13	31	6	47	24	34	-15
6	35	25	27	10	31	19	46	13	32	21
7	38	23	21	2	27	17	46	11	35	5
8	42	25	20	5	30	4	45	14	37	18
9	42	29	27	2	18	-25	32	12	46	23
10	65	19	25	5	18	-26	20	6	40	22
11	46	21	22	2	26	- 8	10	- 7	34	-19
12	37	20	28	19	15	-23	9	- 4	35	-14
13	41	20	25	7	16	7	33	2	35	-16
14	36	14	29	18	- 8	-16	33	- 1	28	12
15	35	28	22	-17	-21	-35	27	15	29	-19
16	33	26	22	-18	- 3	-52	35	24	36	- 4
17	29	14	24	- 8	- 2	- 8	39	23	42	19
18	29	- 3	29	1	-8	-31	32	16	40	14
19	22	2	30	19	-15	-32	25	9	39	19
20	30	2	24	16	-12	-47	34	20	37	2
21	26	- 1	22	3	-14	-23	36	15	39	1
22	31	11	18	-14	- 6	-25	34	22	32	- 7
23	30	20	22	- 8	-14	-22	36	24	40	- 4
24	31	20	28	17	-12	-19	33	25	33	7
25	30	4	32	24	- 7	-20	30	19	34	- 8
26	38	10	27	14	15	-12	27	8	25	9
27	27	3	28	- 8	14	-21	26	15	20	- 5
28	30	19	28	23	19	7	29	2	17	-41
29	32	18	26	8	17	-21			26	- 2
30	34	12	26	14	26	-11			27	-18
31			30	12	36	20			28	11

APPENDIX 3

DAILY MAXIMUM AND MINIMUM TEMPERATURES FOR WINTER MONTHS,

CALGARY, ALBERTA. 1954 to 1956

CALGARY, ALBERTA - 1954 - 1955

	November		December		January		February		March	
Day	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	61.4	23.5	32.1	4.5	15.0	6.2	42.7	23.5	0.9	-10.7
2	57.6	32.2	42.1	7.9	19.0	3.7	29.4	16.4	2.3	-18.9
3	53.8	25.9	46.5	32.7	33.1	-5.4	37.4	13.6	-7.6	-15.8
4	59.9	35.3	40.0	29.8	35.1	21.9	38.0	15.0	10.7	-23.9
5	67.1	47.3	45.8	16.0	36.3	10.9	29.8	18.6	25.2	-5.5
6	51.7	36.1	49.5	21.5	33.8	21.5	36.8	6.7	42.9	11.8
7	43.0	19.6	38.0	15.6	45.4	24.5	42.0	24.3	52.1	27.8
8	56.5	25.0	32.0	11.9	27.5	16.7	21.5	15.7	37.4	30.0
9	60.5	25.5	43.2	19.7	19.0	-1.8	14.0	2.5	42.3	23.4
10	53.9	24.7	34.2	17.5	27.6	0.6	26.2	-10.7	41.5	32.0
11	43.2	21.5	43.2	13.7	10.7	-8.9	35.1	-4.4	40.2	21.6
12	47.4	26.2	47.4	15.8	43.1	3.4	38.4	3.7	36.6	17.2
13	34.6	21.6	40.1	24.3	39.2	24.3	46.5	24.3	16.2	-1.6
14	54.6	24.3	39.6	16.5	28.2	2.2	46.1	21.6	15.9	4.6
15	56.2	32.7	39.4	19.0	29.0	6.7	41.1	13.7	29.2	-5.5
16	48.6	29.0	48.2	27.1	23.0	10.7	46.1	19.5	28.4	14.4
17	47.8	31.0	56.7	35.8	15.2	9.7	21.1	13.6	39.5	7.6
18	56.4	26.2	58.3	30.0	15.9	-3.9	21.8	-3.7	27.2	19.8
19	52.5	32.8	62.5	25.4	20.3	4.7	29.6	11.9	12.9	5.8
20	53.4	33.3	57.2	28.3	24.1	0.4	34.0	5.8	16.5	-3.7
21	67.6	37.6	60.8	38.1	30.6	1.8	34.0	17.1	25.2	-0.8
22	58.2	32.0	45.3	31.8	42.0	2.9	5.0	-2.9	3.1	-3.7
23	42.2	20.8	27.7	9.8	37.0	21.2	-2.6	-19.8	-5.8	-12.9
24	57.2	23.7	28.5	15.2	34.6	5.8	1.9	- 9.4	1.8	-22.9
25	58.2	35.1	17.6	11.5	32.8	16.2	-2.0	-10.5	17.2	-11.5
26	46.6	30.0	41.2	9.3	41.2	13.8	-9.8	-16.9	32.5	-6.0
27	33.3	20.6	34.1	10.0	38.5	22.5	10.0	-27.2	52.0	18.2
28	29.3	19.9	41.2	24.3	45.0	16.8	24.0	-19.8	49.1	25.5
29	27.7	20.3	-7.2	-11.0	44.2	21.7			56.5	29.9
30	25.5	17.6	16.2	-14.6	47.0	19.5			37.0	28.0
31			29.5	3.6	40.2	15.4			56.1	31.0

CALGARY, ALBERTA - 1955 - 1956

Day	November Max.	November Min.	December Max.	December Min.	January Max.	January Min.	February Max.	February Min.	March Max.	March Min.
1	19.1	13.6	23.1	9.9	34.9	9.7	29.6	--1.4	39.7	4.7
2	18.4	6.4	10.1	1.3	28.0	4.5	40.5	5.6	29.6	17.0
3	26.0	11.9	23.1	- 7.1	35.0	4.4	38.9	22.8	33.0	20.8
4	20.1	10.7	12.3	-10.3	17.8	7.4	44.2	14.5	14.3	- 1.3
5	34.0	4.2	25.4	- 9.8	3.2	- 4.8	35.2	21.9	2.6	- 1.1
6	38.2	12.2	31.8	8.4	19.6	- 9.8	37.8	23.2	9.4	-12.0
7	57.9	18.6	30.9	8.4	7.3	- 5.4	30.4	14.8	34.7	- 5.8
8	57.0	37.5	35.3	6.6	22.1	- 7.0	43.0	11.3	35.3	5.8
9	50.7	33.1	35.3	10.0	22.2	- 1.8	39.9	28.4	5.2	- 0.8
10	39.6	13.5	30.4	7.6	13.6	- 0.1	36.1	27.2	- 5.0	-15.4
11	- 5.4	-13.5	34.0	14.9	4.2	- 3.1	30.8	11.0	29.3	-18.4
12	- 7.1	-20.7	27.1	5.6	13.2	- 2.9	19.2	9.5	30.1	15.1
13	- 6.2	-25.7	14.8	2.1	0.1	- 4.7	- 8.4	-14.2	28.6	13.0
14	- 4.8	-12.7	14.0	-10.7	- 3.2	-12.7	-19.0	-30.0	35.9	10.9
15	6.2	- 9.1	16.6	- 6.4	- 5.0	-16.3	-13.4	-31.0	44.1	18.6
16	9.7	-15.9	15.6	0.7	- 7.8	-26.3	22.9	-27.8	47.7	25.4
17	4.0	-14.9	2.2	-13.1	6.9	-15.0	22.8	10.5	47.6	27.1
18	22.6	-15.3	-10.6	-33.2	40.1	- 3.6	20.5	- 7.8	57.3	31.2
19	36.8	- 1.6	- 9.8	-16.7	26.3	9.0	23.3	2.9	57.3	31.3
20	37.4	0.1	21.9	-12.4	31.2	3.4	0.2	-10.8	33.9	24.5
21	20.3	1.3	24.0	- 8.0	20.6	9.7	- 0.8	- 5.7	31.2	22.4
22	3.2	- 9.7	32.2	- 2.8	23.4	4.6	0.4	-12.2	49.1	25.2
23	- 5.1	-15.6	-10.6	-22.8	33.8	- 0.5	5.0	- 7.0	54.7	25.5
24	- 1.1	-14.8	-12.6	-28.8	28.2	13.2	2.0	-14.1	45.0	27.5
25	0.4	- 7.7	33.2	-18.8	24.7	13.4	1.1	- 5.1	44.1	21.7
26	3.0	-16.0	33.6	- 2.5	8.8	- 1.3	16.0	-20.1	32.8	27.1
27	12.6	-10.8	- 0.7	- 7.5	- 0.6	- 4.4	29.1	- 5.5	34.3	23.2
28	7.1	-12.3	20.0	-10.3	- 2.8	- 6.8	35.0	- 4.5	33.8	10.3
29	16.1	- 0.4	35.4	- 3.1	- 6.6	-16.4	40.1	19.9	43.0	22.3
30	35.9	3.5	29.6	6.4	5.4	-26.3			44.1	22.7
31			38.4	0.4	17.2	-15.7			25.8	21.4

APPENDIX 4

Mean Monthly Temperatures, Banff, Alberta

Year	November	December	January	February	March
1920-21	27.1	19.1	17.8	22.1	23.1
1921-22	22.2	11.8	8.6	4.1	22.8
1922-23	25.4	7.8	15.4	17.8	26.1
1923-24	31.0	17.8	12.4	25.1	25.0
1924-25	22.1	8.8	15.5	22.6	28.1
1925-26	27.4	27.2	19.8	28.0	33.2
1926-27	26.2	21.2	9.9	16.2	26.1
1927-28	16.0	2.4	19.5	22.6	29.2
1928-29	28.6	17.0	4.3	12.0	30.7
1929-30	26.6	14.3	- 3.9	24.5	25.4
1930-31	28.2	24.0	25.1	25.9	26.7
1931-32	20.2	18.8	10.6	18.4	23.0
1932-33	26.5	13.8	16.4	12.8	25.0
1933-34	34-0	9.2	22.8	22.6	29.3
1934-35	32.4	16.4	9.2	25.8	20.6
1935-36	23.4	23.4	13.5*	- 8.0**	20.4**
1936-37	28.8	14.1	- 4.1	10.7	28.1
1937-38	23.0	15.4	16.8	10.1	28.0
1938-39	23.8	17.0	22.4	12.3	27.8
1939-40	35.8	25.0	10.5	19.0	32.2
1940-41	17.1	22.2	20.0	20.6	30.6
1941-42	30.0	16.8	14.8	16.0	27.2
1942-43	19.7	15.6	2.9	24.6	18.1
1943-44	29.0	19.4	20.0	17.4	23.1
1944-45	27.2	14.9	19.0	17.8	27.0
1945-46	18.1	15.2	20.7	21.5	30.4
1946-47	18.1	16.4	14.9	17.8	21.6
1947-48	22.9	22.9	21.0	7.1	20.6
1948-49	26.2	7.6	4.0	9.4	27.2
1949-50	36.8	9.0	-16.0	22.0	21.6
1950-51	19.7	21.4	6.0	14.0	16.8
1951-52	25.4	6.4	9.0	19.4	22.6
1952-53	24.3	19.4	15.9	23.1	27.4
1953-54	31.6	23.4	3.5	28.8	21.1

* Anthracite, Banff not recorded.
** Lake Louise, Banff not recorded.

APPENDIX 5

Mean Monthly Temperatures, Lake Louise, Alberta

Year	November	December	January	February	March
1932-33	21.1	5.7	10.0	6.2	20.2
1933-34	28.2	5.1	15.3	12.9	25.4
1934-35	25.6	14.7	6.0	16.6	16.2
1935-36	17.1	15.6	11.3	- 8.0	20.4
1936-37	22.1	8.0	-11.1	5.1	24.7
1937-38	20.0	9.8	7.8	7.8	25.0
1938-39	17.8	9.9	16.2	4.6	22.0
1939-40		20.4	4.0	17.1	30.0
1940-41	13.9	15.7	15.1	17.6	27.9
1941-42	22.7	11.5	7.1	11.1	
1942-43	15.3	12.1	- 1.2	17.6	
1943-44	23.8	10.6	13.0	16.6	18.0
1944-45	22.2	8.2	12.6	13.3	
1945-46	15.2	9.9	14.0	15.6	
1946-47	16.5	12.4	9.0	15.5	23.0
1947-48	17.8	15.7	12.8	8.9	
1948-49		1.8	2.4	5.0	23.0
1949-50	30.5	5.6	-19.4		17.5
1950-51	15.7	14.8	2.0	9.6	13.6
1951-52	18.3	1.4	3.7	12.6	19.3
1952-53		12.5	13.4	16.8	15.4
1953-54	25.2	16.0	- 0.4	23.6	15.2

APPENDIX 6

Comparative Records, Calgary, Alberta

Monthly and Annual Averages and Extremes for Total Period

Observations Have Been Taken (1885 - 1955)

Month	Mean Max.	Mean Min.	Monthly Mean	Absolute Min.	Year	Lowest Monthly Mean	Year
Jan.	25.3	4.4	14.8	- 48	1893	-13.6	1950
Feb.	27.0	6.4	16.7	- 49	1893	-12.0	1936
Mar.	36.9	15.4	26.1	- 34	1896	8.8	1899
Apr.	52.3	27.4	39.8	- 22	1954	25.1	1954
May	62.1	36.8	49.4	2	1954	44.2	1907
June	68.2	43.7	55.9	26	1904	49.4	1902
July	75.7	48.2	61.9	32	4 Years	56.3	1912
Aug.	73.1	45.6	59.3	28	1886	54.3	1911
Sept.	63.7	38.0	50.8	8	1926	42.8	1926
Oct.	54.0	29.9	41.9	- 8	1887,1939	32.8	1919
Nov.	38.7	17.9	28.3	- 31	1893	2.4	1896
Dec.	28.6	9.2	18.9	- 45	1924	3.1	1933
No. of years in obs.	53	53	53	69		69	

APPENDIX 7

BANFF, ALBERTA

Annual and 5 - Year Running Mean Temperatures

YEAR	ANNUAL	5 - YEAR	YEAR	ANNUAL	5 - YEAR
1896	34.3		1926	38.1	36.8
1897	34.7		1927	33.2	36.5
1898	36.2		1928	37.7	36.5
1899	34.0		1929	35.2	36.5
1900	37.3	35.3	1930	36.3	36.1
1901	36.5	35.7	1931	38.1	36.1
1902	34.8	35.8	1932	35.6	36.1
1903	35.1	35.5	1933	35.4	36.1
1904	36.4	36.0	1934	39.4	37.0
1905	37.3	36.0	1935	35.5	36.8
1906	37.5	36.2	1936		36.5
1907	34.8	36.2	1937		36.8
1908	37.6	36.7	1938	36.7	37.2
1909	33.4	36.1	1939	37.9	36.7
1910	37.0	36.1	1940	37.4	37.3
1911	33.5	35.3	1941	38.0	37.5
1912	35.9	35.5	1942	35.7	37.1
1913	34.5	34.8	1943	35.0	36.8
1914	37.0	35.6	1944	37.0	36.6
1915	37.9	35.8	1945	34.8	36.1
1916	32.3	35.5	1946	36.2	35.7
1917	34.9	35.3	1947	36.6	35.9
1918	37.0	35.8	1948	34.5	35.8
1919	34.9	35.4	1949	35.2	35.4
1920	35.7	35.0	1950	32.6	35.0
1921	36.0	35.6	1951	31.8	34.1
1922	34.6	35.6	1952	36.4	34.1
1923	37.7	35.8	1953	39.7	35.1
1924	35.5	35.9	1954	37.4	35.6
1925	38.1	36.4	1955	34.9	36.0

APPENDIX 8

Mean Monthly Temperatures for Selected Stations
- WINTER MONTHS -

Year	Month	GOLDEN	ROCKY MOUNTAIN HOUSE	EDSON	EXSHAW
1939	Jan.	23.4	17.8	19.3	26.3
	Feb.	11.4	1.0	11.2	13.6
	Mar.	28.7	23.7	25.0	28.6
1939-40	Nov.	32.8	38.6	34.7	40.7
	Dec.	26.1	27.4	25.0	30.7
	Jan.	13.2	- 3.1	6.0	15.2
	Feb.	26.0		14.2	19.0
	Mar.	40.1		26.8	32.0
1940-41	Nov.	18.6	12.5p	15.2	20.0
	Dec.	26.8	16.0p	16.6	27.0
	Jan.	22.8	8.6p	7.8	21.8
	Feb.	23.9	14.0p	15.5	22.8
	Mar.	37.9	23.8p	29.5	32.0
1941-42	Nov.	29.1	31.6	26.6	34.3
	Dec.	22.2	15.7p	10.6	21.0
	Jan.	11.0	20.7p	23.0	20.9
	Feb.	19.7	13.2p	17.4	19.6
	Mar.	33.2	29.9p	27.8	30.8
1942-43	Nov.	25.9	15.5p	15.6	21.3
	Dec.	17.8	6.5p	5.4	21.0
	Jan.	0.2	- 3.0p	- 1.9	
	Feb.	23.7	16.7	22.5	26.1
	Mar.	24.2	12.6	18.2	18.4
1943-44	Nov.	28.4	32.4	30.6	34.4
	Dec.	17.8	20.0	23.6	25.2
	Jan.	15.6	13.8	18.4	25.9
	Feb.	19.8	13.0	16.8	19.0
	Mar.	27.7	20.9	23.8	22.6
1944-45	Nov.	32.0	24.8	22.6	27.8
	Dec.	13.5	17.1	15.5	19.2
	Jan.	16.5	11.5	14.4	23.0
	Feb.	20.3	9.8	15.5	20.4
	Mar.	31.8	26.5	28.4	30.0
1945-46	Nov.	28.6	9.7	10.8	17.8k
	Dec.	19.8	8.6	10.3	21.0k
	Jan.	21.4	12.1	16.2	24.6k
	Feb.	22.7	11.7	16.8	24.6k
	Mar.	35.5	28.2	31.2	32.2k

p = Penhold
k = Kananaskis

Mean Monthly Temperatures for Selected Stations (cont.)

YEAR	MONTH	GOLDEN	PENHOLD	EDSON	KANANASKIS
1946-47	Nov.	23.4	15.9	17.0	20.4
	Dec.	17.6	9.2	9.2	20.0
	Jan.	15.1	10.4	14.0	19.4
	Feb.	22.0	5.6	8.9	15.6
	Mar.	35.4	18.2	23.1	23.5
1947-48	Nov.	26.8	21.9	24.2	24.4
	Dec.	24.0	17.6	19.3	25.2
	Jan.	16.3	19.1	19.6	25.4
	Feb.	15.2	3.3	7.5	10.6
	Mar.	29.9	13.2	18.7	19.6
1948-49	Nov.				
	Dec.	7.3	3.5	3.0	14.0
	Jan.	0.6	2.4	7.6	11.7
	Feb.	12.4	- 2.4	2.6	9.0
	Mar.	32.1	24.2	26.6	27.5
1949-50	Nov.	34.0	36.4	35.2	
	Dec.	16.4	2.4	1.0	8.0
	Jan.	-12.4	-19.2	-16.4	-19.2
	Feb.	19.8	10.4	11.1	
	Mar.	31.1	17.6	19.4	
1950-51	Nov.	26.4	15.2	9.4	20.8
	Dec.	23.6	12.2	14.6	26.7
	Jan.	10.2	0.0	2.4	10.4
	Feb.	16.0	7.6	10.2	15.1
	Mar.	25.5	8.0	13.2	16.2
1951-52	Nov.	27.0	23.0	23.1	28.7
	Dec.	9.1	4.8	6.8	12.4
	Jan.	10.5	- 2.8	- 1.2	7.9
	Feb.	24.5	12.1	20.2	24.0
	Mar.	31.7	14.2	22.8	23.2
1952-53	Nov.	26.0	28.8	29.8	29.8
	Dec.	23.3	18.3	17.8	25.6
	Jan.	23.8	4.5	1.6	19.5
	Feb.	27.3	19.0	25.6	25.5
	Mar.	34.6	22.9	25.4	28.8

APPENDIX 9

Air Mass Summary - Bow Valley Drainage

Year	Month	Total No. all types frontal passages.	No. cP (cA) cold fronts.	No. days area in cP (cA)air.
1920-21	Nov.	6	2	6
	Dec.	5	3	14
	Jan.	9	3	17
	Feb.	9	2	11
	Mar.	8	3	11
1921-22	Nov.	6	2	14
	Dec.	10	3	13
	Jan.	12	5	14
	Feb.	4	2	22
	Mar.	8	2	5
1922-23	Nov.	9	2	3
	Dec.	7	2	10
	Jan.	10	5	16
	Feb.	10	3	12
	Mar.	16	7	12
1923-24	Nov.	6	0	0
	Dec.	8	2	8
	Jan.	8	3	15
	Feb.	7	2	8
	Mar.	10	5	8
1924-25	Nov.	9	2	10
	Dec.	7	4	20
	Jan.	11	4	16
	Feb.	10	5	15
	Mar.	8	1	16
1925-26	Nov.	9	2	8
	Dec.	11	4	9
	Jan.	7	1	0
	Feb.	6	2	6
	Mar.	5	1	9
1926-27	Nov.	5	1	7
	Dec.	11	5	11
	Jan.	11	3	12
	Feb.	6	4	9
	Mar.	5	0	0

Air Mass Summary - Bow Valley Drainage (cont.)

Year	Month	Total No. all types frontal passages.	No. cP (cA) cold fronts.	No. days area in cP (cA) air.
1927-28	Nov.	7	4	15
	Dec.	4	3	23
	Jan.	10	4	7
	Feb.	7	1	5
	Mar.	4	1	7
1928-29	Nov.	9	1	0
	Dec.	6	3	3
	Jan.	6	3	21
	Feb.	5	2	14
	Mar.	12	3	9
1929-30	Nov.	12	1	4
	Dec.	7	2	17
	Jan.	1	0	30
	Feb.	7	2	5
	Mar.	12	4	14
1930-31	Nov.	7	1	8
	Dec.	9	0	0
	Jan.	9	2	0
	Feb.	10	1	1
	Mar.	8	2	11
1931-32	Nov.	8	4	11
	Dec.	9	3	8
	Jan.	10	4	18
	Feb.	8	3	18
	Mar.	8	4	17
1932-33	Nov.	8	2	5
	Dec.	6	3	8
	Jan.	11	5	19
	Feb.	7	3	14
	Mar.	4	1	7
1933-34-	Nov.	8	3	7
	Dec.	4	2	28
	Jan.	9	2	5
	Feb.	6	2	13
	Mar.	12	6	16

Air Mass Summary - Bow Valley Drainage (cont.)

Year	Month	Total No. all types frontal passages.	No. cP (cA) cold fronts.	No. days area in cP (cA)air.
1934-35	Nov.	12	3	3
	Dec.	3	2	9
	Jan.	9	5	17
	Feb.	7	2	2
	Mar.	8	4	18
1935-36	Nov.	5	1	12
	Dec.	8	3	7
	Jan.	5	2	22
	Feb.	1	0	26
	Mar.	6	3	11
1936-37	Nov.	9	0	7
	Dec.	8	4	18
	Jan.	6	3	22
	Feb.	5	3	13
	Mar.	8	3	6
1937-38	Nov.	8	2	5
	Dec.	8	2	12
	Jan.	12	6	6
	Feb.	4	2	18
	Mar.	6	2	0
1938-39	Nov.	7	3	6
	Dec.	5	1	5
	Jan.	12	4	8
	Feb.	5	2	17
	Mar.	10	3	13
1939-40	to 1944-45 missing.			
1945-46	Nov.	13	4	12
	Dec.	13	5	7
	Jan.	12	5	4
	Feb.	6	2	3
	Mar.	no cA or cP air.		
1946-47	Nov.	10	3	6
	Dec.	8	5	13
	Jan.	8	3	11
	Feb.	8	3	17
	Mar.	6	1	13

Air Mass Summary - Bow Valley Drainage (cont.)

Year	Month	Total No. all types frontal passages	No. cP (cA) cold fronts.	No. days area in cP (cA) air.
1947-48	Missing			
1948-49	Nov.	13	7	10
	Dec.	12	7	16
	Jan.	16	9	15
	Feb.	13	6	16
	Mar.	7	2	11
1949-50	Nov.	4	0	0
	Dec.	9	5	14
	Jan.	3	2	25
	Feb.	3	4	8
	Mar.	4	1	4
1950-51	to 1951-52 missing			
1952-53	Nov.	6	3	4
	Dec.	7	4	5
	Jan.	21	10	15
	Feb.	13	2	4
	Mar.	26	6	10
1953-54	Nov.	23	4	4
	Dec.	21	5	9
	Jan.	20	8	22
	Feb.	17	6	6
	Mar.	18	7	19
1954-55	Nov.	20	3	3
	Dec.	16	3	4
	Jan.	13	4	12
	Feb.	18	6	10
	Mar.	13	3	16

PUBLICATIONS

1. Sequential sampling of the lodgepole needle miner. For. Chron. 28(2):57-60. 1952.

2. Analysis of a population sampling method for the lodgepole needle miner in Canadian Rocky Mountain Parks. Canad. Ent. 84(10):316-321 1952.

3. Distribution and life history of the lodgepole needle miner, *Recurvaria* sp. (Lepidoptera:Gelechiidae) in Canadian Rocky Mountain Parks. Canad. Ent. 86(1):1-13. 1954.

4. Life tables for the lodgepole needle miner, *Recurvaria starki* Free. (Lepidoptera:Gelechiidae) Proc. Tenth Int. Congr. Ent. August, 1956. In Press.

5. (with Henson, W.R. and W.G. Wellington). Effects of the weather of the coldest month on winter mortality of the lodgepole needle miner, *Recurvaria* sp. in Banff National Park. Canad. Ent. 86(1):13-19. 1954.

6. (with K. Graham). Insect population sampling (General considerations). Forest defoliators by R.W. Stark. Proc. Ent. Soc.B.C. 1954.

7. (with J.A. Cook). The effects of defoliation by the lodgepole needle miner (*Recurvaria starki* Free.). In Press. Forest Science.

In addition to the above publications appearing in scientific journals,17 scientific notes have appeared in the Bi-Monthly Progress Report, Division of Forest Biology, Department of Agriculture. Also, yearly Annual Reports (nine) have been prepared which are available for scientific use with the authors' permission.

REFERENCE

Railway, Standard Gauge, Single Track — Station
Road — Route No.
Fire Road, not open to public
Trail
Telephone Line along Road or Trail
Boundary, Provincial
Boundary, National Park — Surveyed / Unsurveyed
Boundary, Township
Glacier
Sand or Gravel
Contours, interval 250 feet — 3000
Post Office — P
Telegraph Office — T
Warden's Cabin with Telephone
Warden's Cabin without Telephone
Camera Station — 426
Park Boundary Monument
Spot Elevation, in feet above mean sea level — 9284

Compiled, drawn and printed at the office of the Surveyor General, July, 1932.
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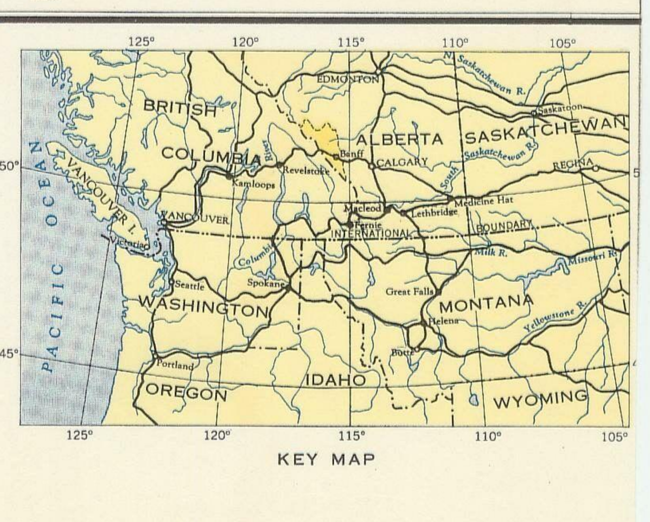
BANFF PARK

ALBERTA

Scale 1:190,080
1 Inch to 3 Miles

Copies may be obtained from the Map Distribution Office, Department of Mines and Technical Surveys, Ottawa, at 25 cents each.



KEY MAP