CLIMATE IN RELATION TO WINTER MORTALITY OF THE LODGEPOLE NEEDLE MINER, RECURVARIA STARKI FREE., IN CANADIAN ROCKY MOUNTAIN PARKS[1]

R. W. STARK[2]

Abstract

Four major air masses, tropical maritime (mT), polar maritime (mP), arctic maritime (mA), and arctic continental (cA) may be used in describing the winter climate of a lodgepole needle miner (*Recurvaria starki* Free.) outbreak area. The main circulation is from the north and west which results in a predominance of mP and cA air. Local topography and its effect on winter climate is described for four areas now sampled on a life-table basis. Variations in winter mortality from year to year and between sampling areas are related to climate. Extensive invasions of cA air, particularly of long duration, cause lethal winter temperatures. Winter mortality usually occurs during the coldest month, January, and may be exceptionally high when extreme minima of −30° F to −40° F persist long enough to depress the monthly mean temperature close to 0° F. However, less extreme temperatures in other months may result in similar high mortalities if these are unseasonably low. The climatic conditions causing high mortality generally occur at the tops of slopes and at valley bottoms, allowing the middle slopes to serve as "refuge areas" for surviving needle miner populations.

Introduction

Larvae of the 2-year cycle needle miner in the Canadian Rocky Mountain Parks are exposed to two successive winters during development. It has become increasingly apparent that mortality during these winters has been a major factor in causing population reductions. The relations between the variations of larval mortality and climate are discussed in this paper while the effect that winter mortality has on the epidemiology of the outbreak is discussed in a subsequent publication.

Atmospheric Circulation and the Climate of the Outbreak Area

The climate of a region is determined largely by the types and circulations of air masses. When an air mass remains stationary for some time it acquires properties of temperature and humidity that are characteristic of that region. Air masses can therefore be classified according to these characteristics. The classification that is most commonly used is that of Bergeron, which recognizes four principal source regions: polar (P), arctic (A), tropical (T), and equatorial (E). Air masses are further identified according to their origin over land (c) or water (m). Climatic effects in this area have been described in previous studies by the use of five air masses (1). On the other hand, Penner (3) has shown that, for practical purposes, four major air masses may be used to describe winter weather in North America as follows: tropical maritime (mT), polar maritime (mP), arctic maritime (mA), and arctic continental (cA).

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[2]Forest Biology Laboratory, Calgary, Alberta.

Penner's system was adopted for the current study and differs from the system used in earlier studies only in that polar continental (cP) is equivalent to arctic continental (cA). The main circulation in the outbreak area is from the north and west, which results in a predominance of mP and cA air. Local topography exerts considerable influence on the behavior of air masses in the outbreak area. The vertical distribution of temperature in the Bow Valley generally is a function of the predominant type of circulation. Thus, in a

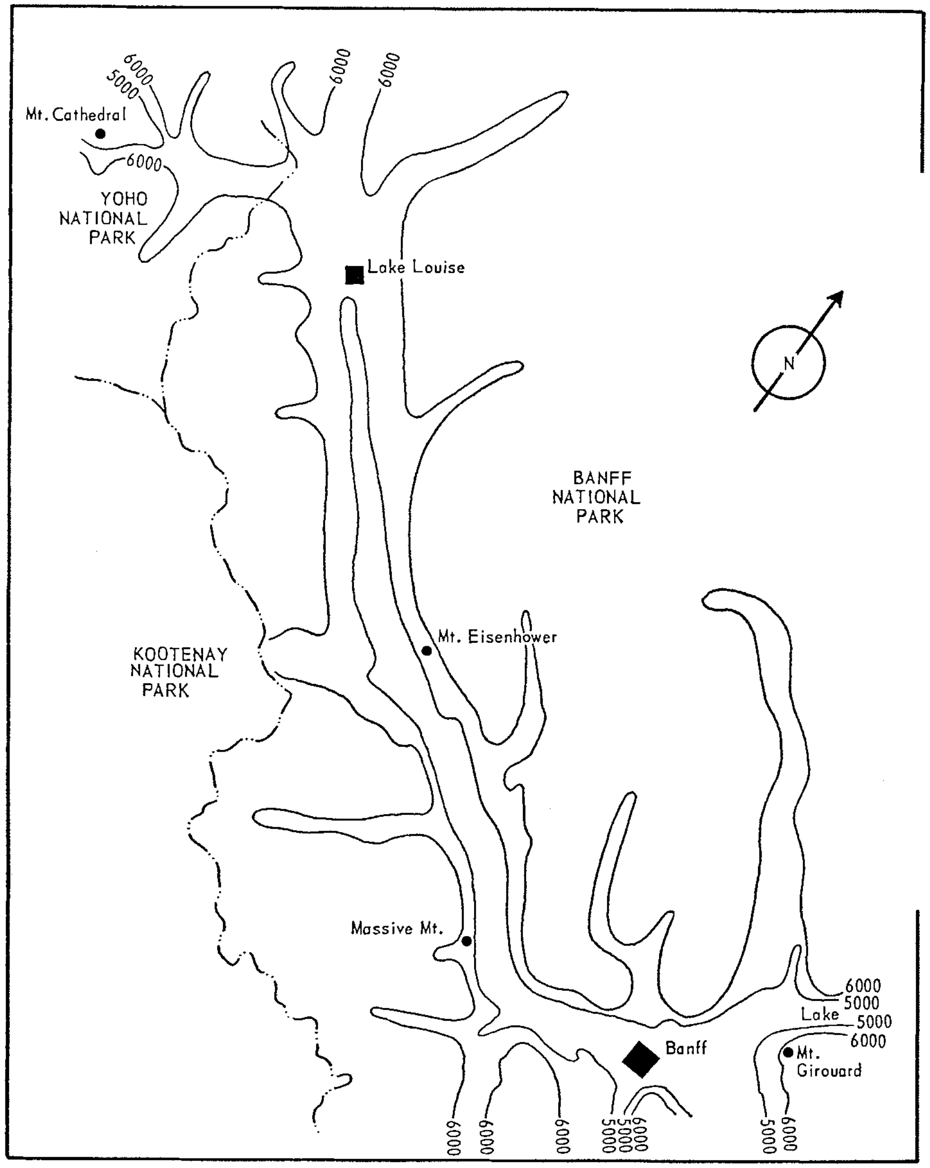

FIG. 1. Schematic illustration of the four sampling areas, the two climatological stations, and the 5000- and 6000-ft contour lines.

month of frequent, rapid invasions of cA air, the upper slopes are usually colder than the valley floor. Extremes of cold at valley bottom are produced when fronts are few and the air stagnates. These conditions are most extreme when the air is of cA origin. The middle of the slopes are consistently warmer than the extreme temperatures whether these occur at valley bottom or the tops of slopes. Considerable variation is found between sampling areas due to local topographic differences such as exposure to trans-divide passes, alpine valleys, and position in the Bow Valley with respect to invading air masses.

The effects of topography on climatic characteristics important to needle miner mortality have been described for four areas (1, 5), three of which are permanent sampling areas. These are redescribed here for the purposes of this study and a description of a fourth permanent sample area, Mount Girouard, added (see Fig. 1).

(1) Massive Mountain.—The slopes of Massive Mountain are protected from the direct influence of trans-divide passes and so are considered representative of most Bow Valley conditions. When cold air invades the valley, the top of Massive Mountain becomes colder than its base while the new air mass is fresh. Approximately equal conditions between the top and base are obtained in a short time but in a winter when cold fronts are plentiful the top of Massive Mountain would be generally colder than its base. On the other hand, if fronts are few, the cold air stagnates and the greatly increased radiational cooling of all surfaces lowers the temperature generally and forms a more and more pronounced inversion in the lower air. Nocturnal temperatures near the valley floor fall much below those at higher elevations and if the air mass persists long enough and is deep, this inversion may persist into the daytime and increase the depth of the cold air pool at valley bottom.

(2) Mount Eisenhower.—This presents a more complicated situation as it is more subject to convective winds and lies directly across the Bow Valley from the mouth of a trans-divide pass, where it is exposed to westerly winds.

(3) Cathedral Mountain.—The climatic conditions are more complex due to the Great Divide, the physiography, and the direction of air flow. Conditions there are obviously not comparable to those in the Bow Valley as the colder cA air is often kept out of the area by the divide or is limited in its western extension. Also, mP air is frequently kept from fully penetrating the Bow Valley.

(4) Mount Girouard.—This area is exposed to air masses coming down the Bow Valley from the northwest and to a limited extent, from the east. It is at the mouth of a large alpine valley which contributes strong down-slope winds and it is also adjacent to a large mountain lake.

Climate and Winter Mortality

Causes of Winter Mortality Variations

Winter mortality is distributed in the same way as zones of extreme cold that occur during the winter. Greatest mortality occurs either at valley bottom or at the tops of slopes, and the middle slopes act as "refuge areas" for needle miner populations. The low temperatures which are believed to cause winter mortality of needle miner larvae may be produced in somewhat different ways. Cold cA air is the basic requirement but lower temperatures are generally produced when such air remains in the area for some time. Repeated invasions of cold cA air generally do not produce as extreme cold weather as stagnating air but may do so when the air is from a very cold, deep, air mass (1,5).

Extremely high mortality of needle miner larvae occurred in the winter of 1949–50 and it has been demonstrated by comparing this winter with that of 1948–49 that the mean monthly temperatures of 1949–50 were higher than those of 1948–49 with one exception, January. Thus it was concluded that the bulk of winter mortality probably occurred in that month (1). Winter sampling in 1953–54 verified that winter mortality occurred mainly during the month of coldest temperatures, again in January. There is some discrepancy between the mortality estimates in the winter months (particularly February) and the final spring estimate (Table I). This is largely because the condition of larvae examined in February was less easily determined than at the other sampling periods. 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 mortality occurred mainly between December 16 and February 5.

TABLE I

Winter mortality of lodgepole needle miner larvae (1953–54)

Location	Elevation (ft)	Dec. 1953	Feb. 1954	Spring 1954
Mount Eisenhower	4800	4.3%	94.6%	98.4%
	5300	2.4	18.1	17.7
	5800	6.2	15.6	6.3
	6300	—	9.1	1.5
Cathedral Mountain	4500	—	18.4	11.2
	5000	—	31.3	7.0
	5500	3.8	8.7	6.8
Lake Louise	5050	5.4	91.7	99.6
	5550	43.5	11.3	15.8
	6050	13.0	20.6	17.4
	6550	—	8.7	6.8

The maximum and minimum temperatures obtained at Banff and Lake Louise for the period January 10 to 29, 1954, demonstrate the sustained low temperatures that coincided with the heavy mortality which occurred that year (Table II). The Banff – Lake Louise area was in cA air for 22 days in 1953–54, only 3 days fewer than in 1949–50. However, in 1949–50, there were only 3 fronts, 2 of which were cA, whereas in 1953–54 there were 8 cA fronts with a total of 20 of all types. This means that there was less stagnation of cA air in 1953–54 and temperatures throughout the valley had less chance of becoming as extreme as in 1949–50. These conditions produced temperature inversions with consequent high mortality in valley bottoms. The air-mass producing the temperature inversion would have to be very deep and intense as the stagnation effect is not usual; generally after an air mass is established there is a gradual warming of the air over the area. The longer the air remains in the area, the more marked the difference and the deeper the pool of cold air becomes. A similar reversal of temperature may be produced by a very intense but shallow air mass which warms comparatively quickly. The steep character of the valleys probably contributes to the stagnation effect.

TABLE II

Daily maximum and minimum temperatures (°F), January 10–29, 1954, Banff and Lake Louise

Date	Banff		Lake Louise	
	Max.	Min.	Max.	Min.
January 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

The temperature inversion was demonstrated in 1956 by operating thermographs at two altitude levels, 4800 ft (valley bottom) and 5400 ft (Mount Eisenhower sampling area), from January 2 to February 14. On January 7, after a day and a half of cold cA air there was an inversion from 0700 to 1100 M.S.T. with a peak difference of 12 F degrees. This was due to a weak invasion of mP air, the warming effect of which was felt first on the upper slopes, 5 hours earlier than in valley bottom. The next inversion occurred on January 13. Arctic continental air had invaded the Bow Valley on January 11 but as the circulation was weak, the air mass could not displace the warm mP air completely. This inversion undoubtedly resulted from the cold cA air displacing the warm mP air at valley bottom before it displaced that on the upper slopes. Another short inversion occurred on January 18 when mP air entered the valley, replacing cA air, and in the same day was replaced by cA air again.

This last air mass remained in the valley from January 24 to February 2 becoming increasingly colder until January 30 when a slight moderating trend began. The conditions approached those postulated by Henson *et al.* (1) for 1949–50. The nightly inversion began on January 28 and was repeated each night until February 1.

The total hourly summations from 0100 to 1100 on the last 3 days of the month showed valley bottom to be 59, 53, and 45 degree-hours colder than the upper slopes (Fig. 2). The temperature during this period was not only more severe at valley bottom but was also much more variable. The diurnal ranges at valley bottom were: 9° F to −25° F, 11° F to −23° F, and 13° F to −18° F and on the upper slopes: 5° F to −19° F, 8° F to −19° F, and 10° F to −13° F. Such conditions are presumed to account for the observed mortality differences and for the confining of high mortality to valley bottom. The typical temperature–altitude relationships are illustrated in Fig. 3 for the same area when mP air had replaced the cA air.

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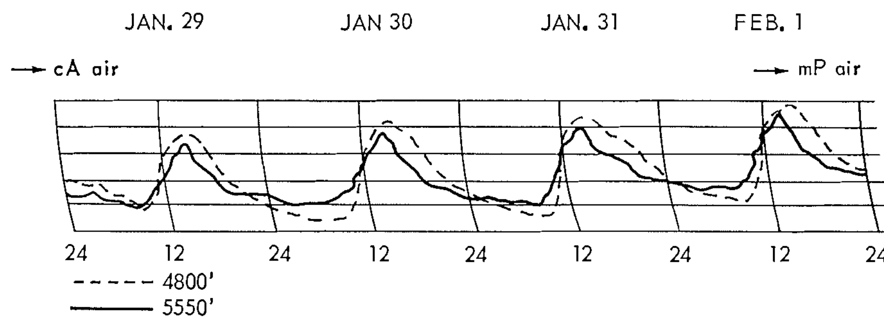

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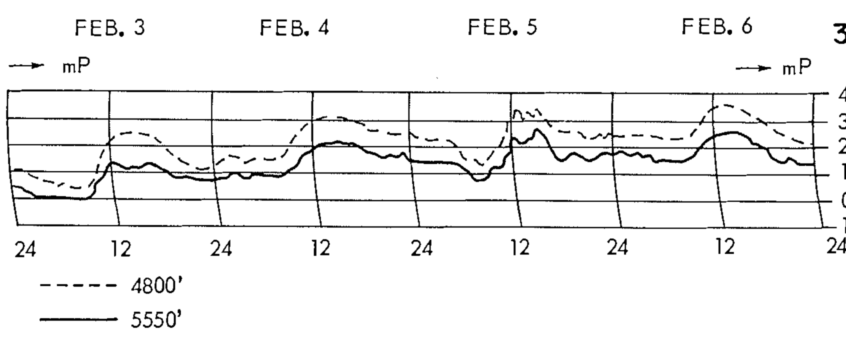

FIGS. 2 and 3. Temperature conditions under arctic continental air (Fig. 2) and under polar maritime air (Fig. 3).

Winter Mortality of Needle Miner Populations

Yearly estimates of winter mortality since 1944 demonstrate the importance of low temperatures as a control factor (Table III). The estimates are based on 86 samplings from 23 areas (5), mainly from the 4 areas described above.

The accuracy of the estimates prior to 1948 is unknown, since that time it is within 10% of the mean. It was concluded from these and other data that five winters since 1943 caused high larval mortality, as follows:

Winter of 1945–46.—Mortality was apparently high, although the degree of mortality is not certain. Daily temperatures for this winter at Banff and Lake Louise show that, in general, it was mild but extremely variable. Thus a minimum of −35° F at Lake Louise and −26° F at Banff was recorded on November 8, whereas on November 3 the minimum was 31° F. Similar, but less extreme cases, occurred throughout the winter. Air-mass analyses show that in November the area was in cA air for 12 days (5). This amount has been exceeded only once (1927–28) and equalled once (1935–36) since 1920.

TABLE III

Winter mortality of lodgepole needle miner larvae (all areas)

Year	Valley bottom (av. 4800 ft)		Elevation above valley bottom: Up to 500 ft		500–1000 ft		Over 1000 ft	
	% mort.	N*	% mort.	N	% mort.	N	% mort.	N
1943–44	—		9.0	1	—		—	
1944–45	—		—		—		—	
1945–46	—	Approx.	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 areas sampled at each altitude.

Winter of 1949–50.—Earlier discussion of the 1949–50 winter climate showed that the weather of the coldest month, January, was the major cause of needle miner mortality for that period (1).

Winter of 1953–54.—The high mortality which occurred in this winter almost certainly was due to the temperatures which obtained during January, 1954 (Table I). November and December were the mildest during the period 1945 to 1956 but the January mean temperature was lower than the winter of low mortality in 1948–49. The mild November and December may have decreased the resistance of the needle miner larvae to the low temperatures of January (4,6). The mean minimum was higher than that of 1948–49 but the mean maximum was lower. The maximum was below zero for 8 days and the minimum for 18 days in 1953–54, whereas in 1948–49 the maximum was below zero for only 4 days and the minimum for 17. Also, in 1953–54 the maximum temperature was below zero for 7 consecutive days and the minimum for 14 consecutive days, whereas in 1948–49 the maximum was below zero for only 2 consecutive days and the minimum for only 8 consecutive days. The air mass analyses show that January, 1954, had 22 days of cold cA air, whereas January, 1949, had only 15 days of cA air. Variations in high mortality are compatible with these data. The conditions of this winter were intermediate between the low mortality year, 1948–49, and the high mortality year, 1949–50. The high mortality in 1953–54 was restricted to valley bottom in contrast to 1949–50 when mortality was high at all altitudes.

Winter of 1954–55.—The observed mortality was similar to, although less severe, than that of 1949–50. Temperature conditions presumed responsible for this are less clear-cut than those in 1949–50. Frontal activity was reduced and there were fewer days in which the area was in cA air. The high mortality probably occurred in March, when cA air persisted in the Bow Valley for 16 days, which has been exceeded only three times and equalled twice since 1920. This was the coldest March since 1945 with the exception of 1951 which was a year of low mortality. There were three periods of below-zero minima separated by above-freezing maxima in 1955, whereas the cold period responsible for lower means in 1951 was restricted to the beginning of the month.

Winter of 1955–56.—Mortality was confined largely to valley bottom and was comparable to that of 1953–54. Monthly mean temperatures were not unusually low but there was an extremely cold period from February 18 to March 5 and again from March 19 to March 26. It is assumed that mortality occurred mainly during these periods.

Discussion

A comparison of the winter temperatures for years of high mortality with those for years of low mortality gives some indication of the low temperature tolerance of the needle miner. It is concluded from the above data and previous studies (1,5) that, in general, the lodgepole needle miner population in the outbreak region of Banff 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 both as to the time of year in which low temperatures occur and to the duration of cold cA air, that is, such extremes of cold would probably not be necessary to cause high mortality in November or March. It is believed that mortality usually occurs during the coldest month, January, but may occur occasionally with equal intensity in any other winter month. The assessment of critical periods requires more than an examination of extreme minima, mean maxima and minima, and mean monthly temperatures because when cold periods develop which overlap into two months their effect is not reflected in means and a careful scrutiny of daily temperatures is necessary.

Fluctuations in needle miner populations in Yoho and Kootenay Parks are subject to speculation only because temperature data and detailed knowledge of air-mass movements are lacking for these areas. The populations in these areas have subsided at equivalent rates to, but for different reasons than those in Banff Park. Climatic factors other than low winter temperatures are probably the cause as neither parasites nor disease have figured prominently in the control complex. Conditions in Yoho Park are more variable, though less extreme, than in Banff Park, and while these conditions have not resulted in excessive mortality except in later years (5) it is possible that they have affected the population in other ways, perhaps through development, fertility, and/or fecundity. The pattern of mortality in Kootenay Park approximated that for Banff. Altitudinal and physiographic differences between the two parks are probably influential in causing any variations noted.

Increased use and refinement of air mass and frontal analysis techniques and knowledge of local variations of climate in the Bow Valley already discussed permit the development of a predictive system for use in population studies. For example, a successful prediction was made that winter mortality of the 1956–58 generation of needle miner for both winters would be low and that of 1957–58 lower than that of 1956–57. It is now reasonably certain that the persistent infestations will be centered on the mid-slopes in the Bow Valley of Banff National Park. Although populations may increase above and below this "refuge" zone for a few years, they will eventually suffer high mortality in years of severe winters (1,5).

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