Not for publication

EMERGENCE OF THE LARCH SAWFLY

Pristiphora erichsonii (Htg.)

IN RELATION TO SOIL TEMPERATURE AND

WEATHER PATTERNS

by

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ABSTRACT

This thesis investigates the factors influencing the duration of the post-diapause stage of the larch sawfly. Laboratory studies showed that the duration of this stage may be altered by varying the temperature immediately after cocoon formation, during cold exposure, and during the post-diapause period. Optimum temperature conditions include at least 14 days at 10° C before cold exposure, about 200 days at 0° to 5° C and incubation at 15° C. Even at these constant temperatures, the length of the post-diapause period varied considerably.

In bog forests near Prince Albert, Saskatchewan, soil temperatures were extremely variable during the period from disappearance of winter snow to the end of the emergence period. Differences in soil temperature were associated with forest cover, water table, microtopographic variation and depth beneath the surface as well as meteorological phenomena. Attempts to predict adult emergence patterns gave variable results and required several assumptions and considerable labour.

The use of large scale meteorological data showed that the number of days from the disappearance of winter snow to the first adult emergence at Prince Albert was increased by anticyclonic activity and decreased by northward-moving cyclones originating in the Colorado - Wyoming region. Light rains favoured emergence by warming the deeper layers of soil but heavy rains raised the bog water levels and retarded sawfly development and increased mortality by submerging the cocoons. Short-term weather forecasts could be used to predict whether development will be hastened or retarded. The results could also be used to

predict the general emergence patterns from long range forecasts of circulation patterns when these become available.

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1. Introduction

The larch sawfly is a major defoliator of trees of the genus *Larix* throughout the Holarctic region. In North America east of the Rocky Mountains it is a serious pest of tamarack, *Larix laricina* (Du Roi) K. Koch., and of European larch, *L. decidua* Mill., in plantations. Heavy defoliation has also occurred in stands of Western larch, *L. occidentalis* Nutt. in central British Columbia and northwestern Montana. In Manitoba and Saskatchewan this insect has been abundant in most tamarack stands since the late 1930's. The generalized life history and average times of occurrence of the various stages are shown in Figure 1.1. In addition to the broad overlap of stages the times of their occurrence have varied considerably from year to year. The main factor controlling the seasonal variations appears to be the length of time required by the larvae in cocoons to complete their post-diapause development in the spring and emerge as adults.

This thesis investigates the factors influencing the duration of the post-diapause period in the larch sawfly. Laboratory rearings under controlled conditions showed that the duration of the post-diapause period was affected by temperature. Two approaches to the study of development in the field were investigated: the distribution of larch sawfly cocoons in the soil and the micro-environmental conditions encountered by them; and the relationships with larger meteorological processes that govern conditions in the micro-environment. An investigation of soil temperatures in bog forests revealed the complex micro-climatic situation that is so common in studies of the micro-environment (Wellington, 1957). Methods of predicting larch

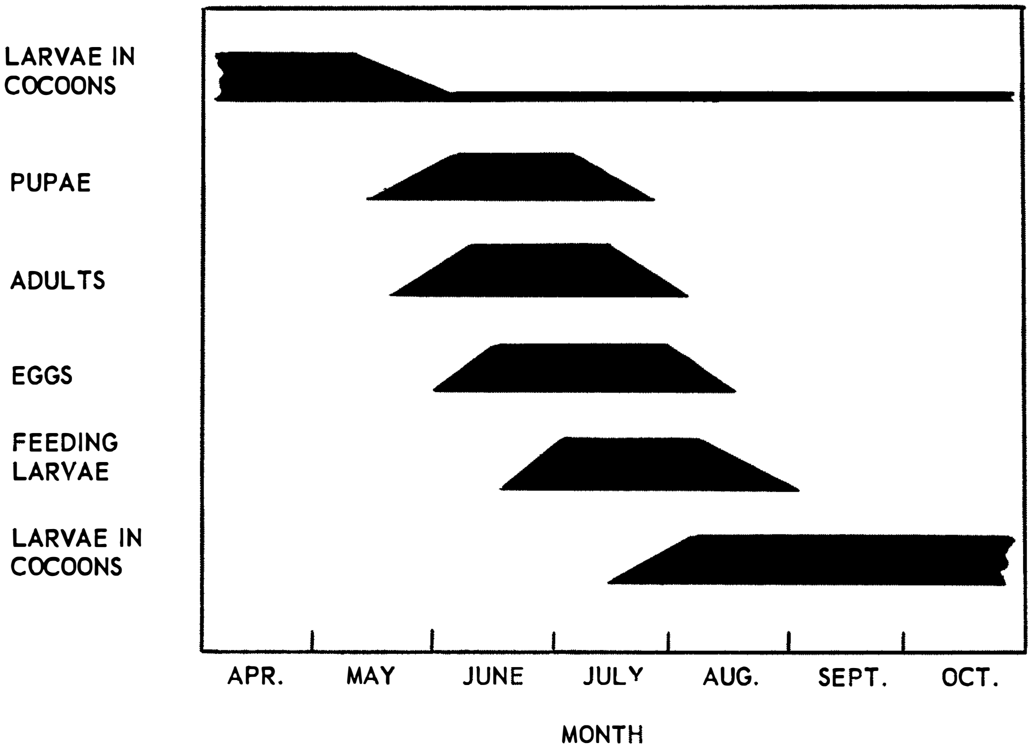

Figure 1.1 – Generalized life cycle of *Pristiphora erichsonii* at Prince Albert. Saskatchewan.

sawfly emergence based on soil temperature involved many assumptions and a great deal of labour. Promising results were obtained by relating the time of adult emergence to the local weather patterns. These local patterns were in turn related to the continental weather picture. This approach, utilizing some of the concepts of dynamic meteorology and their relationship to insect development, shows promise for predictive purposes. Short-term forecasts of emergence patterns are possible but long-term forecasts depend on more accurate weather forecasting. Only three years data on the pattern of adult emergence were available for analysis. Although this may be inadequate to fully substantiate any system of predicting emergence patterns of the larch sawfly, the methods should be useful as a guide in the use of meteorological data for forecasting biological events or for timing control operations. The nature of these events and their effects on control operations are reviewed before proceeding with principal objectives.

The larch sawfly is essentially univoltine. Second generation adults occur rarely, up to two per cent in New Brunswick (Reeks, 1954), and less than 0.05 per cent in Manitoba (Muldrew and Turnock, 1957). Some larvae remain in diapause more than one year. Percentages of living eonymphs still in diapause at the end of the summer, based on the total of emerged adults plus living eonymphs varied as follows:

Prince Albert, Saskatchewan, 1951 -- 57, 38, 41 per cent
Rennie, Manitoba, 1957 -- 0, 9, 12, 16 per cent.

Obligatory parthenogenesis is the characteristic method of reproduction in the larch sawfly. The mechanisms involved are discussed by Smith (1955). Males are rare, and have been found to represent from 0.9 to 1.2 per cent of the adult population in Saskatchewan (Forest Insect Survey Records, Winnipeg Laboratory). The adult female is capable of oviposition almost immediately after eclosion provided a suitable site, the current shoots of tamarack, is available. The eggs are inserted in slits made by the ovipositor on the underside of the shoots. Each slit contains a single egg and individual shoots containing from three to 85 eggs have been recorded. The reproductive capacity of the sawfly based on counts of mature and near-mature oocytes by Reeks (1954) in New Brunswick and Heron (1955) in Saskatchewan show extreme variability with individual counts ranging from 20 to 206 ovules per female.

After about 8 to 10 days in the egg stage the newly hatched larvae feed briefly on the needles of the shoot and then largely confine themselves to the foliage on the older twigs. The larvae feed gregariously, particularly in the first four instars. Some wandering occurs in the fifth instar prior to the cessation of feeding. The feeding period lasts about 20 days (Heron, 1951). The mature larvae drop from the trees, crawl under the surface of the moss or duff ground cover, and form a tough leathery cocoon. The pupal stage begins the following spring and lasts 8 to 14 days. Adult emergence occurs over a period of about two months in Manitoba, Saskatchewan, and in Minnesota (Drooz, 1953).

The time of adult emergence effects the future larval population because it alters the relationships of the adult to the development of suitable oviposition sites and to avian predators. Early emerging females may find the tamarack shoots too small for oviposition as they seem incapable of ovipositing on shoots under 10 mm in length and generally prefer those over 20 mm. For example, in 1951, adult females were observed in the field on May 24, the earliest shoots reached 10 mm length May 31, but no eggs were found until June 12. In 1953, the first adults were recorded on June 7 but no eggs until June 18. Muldrew (1956) has maintained adult females in cages without ovipositing as long as 15 days but survival in the field is probably much shorter due to predation. Early-emerging adults are available to flocks of migrating warblers when other food is scarce, while later emergents are preyed on chiefly by the local nesting birds (Buckner and Turnock, 1957). Late emergence also may be disadvantageous. In stands supporting large larch sawfly populations the progeny of late emerging females may find the hosts stripped of foliage and die of starvation or produce adults with reduced fecundity (Heron, 1955). An increase in bird predation may also occur in late July when the nestlings and early southbound migrants appear.

Investigations on the applicability of chemical control to larch sawfly have been confined to Minnesota. One of the problems emphasized in publications on this work (Butcher and Eaton, 1952; Butcher, 1953; Drooz, 1957) is the difficulty of timing the control operation to coincide with the maximum number of larvae on the trees. The choice of the spraying date was entirely arbitrary in the Minnesota control experiments but ideally would be chosen before any cocoons are spun but after all hatching is finished. Such timing is impossible because cocoons normally appear before adult emergence is completed, but the most suitable compromise could be chosen more readily if the emergence pattern could be predicted before emergence begins. Such a prediction could be more accurately made if the relationships between the emergence pattern and local weather could be used to predict the end of the emergence period. The methods presented in this thesis might be used in planning more effective control operations.

2. Experimental studies on development in the cocoon.

The larch sawfly spins a cocoon in July or August, but development to the adult stage is delayed until the following spring. Before pupation the larva passes through two stages, the 'eonymph' and the 'pronymph', described by Prebble (1941). Normally the winter is spent as an eonymph (in diapause) and the resumption of development is indicated by the change to the pronymphal stage. Under some conditions development may proceed to the pronymphal stage shortly after cocoon formation. The term 'diapause development', which was introduced by Andrewartha (1952) to designate the physiological changes occurring without observable morphogenesis during diapause, will be used throughout this paper.

The experiments reported here represent attempts to describe the effects of varying the temperature during three periods in the cocoon stage: immediately following cocoon formation; during the winter cold exposure period; and the incubation period following cold exposure on the time required to reach the adult stage. Gobeil (1941) and Brown and Daviault (1942) suggested that both temperature and moisture affected development in the cocoon stage. Preliminary experiments showed that reduction of the relative humidity during the cocoon stage increased mortality but did not significantly affect the rate of development. Under natural conditions the cocoon environment is rarely too dry, excessive moisture and submergence of the cocoons is more common, causing delayed development and increased mortality (Butcher, 1951; Lejeune et al, 1955). Therefore, the cocoons used in the following experiments were kept on moist sphagnum moss, and only the temperatures were varied.

The first experiment investigated the effects of varying the temperature and duration of exposure of cocoons during the winter. Cocoons collected at Pierceland, Saskatchewan,on August 11, 1953, were divided into six groups and placed in the University of Minnesota temperature cabinets at constant temperatures of -5°, 0°, 5°, 10°, 15°, and 20° C on August 18. At intervals, samples of cocoons were taken from each temperature and the stage of development of each larva recorded. The prepupal stages were classified as eonymphs (diapause) or pronymphs (post-diapause) The cocoons at 10°, 15° and 20° C were held at these temperatures until adult emergence ceased but at 5° C the experiment had to be terminated when emergence had just begun. At the end of these experiments all unemerged cocoons were opened and the larvae classified as living or dead, diapause or post-diapause stages.

The results of these dissections, summarized in Table 2.1, show considerable variation in the amount of morphogenesis occurring at different temperatures and durations of exposure. At 20° C only 11 per cent of the larvae broke diapause and reached the adult stage; the other remained as eonymphs for 292 days with low mortality. The 11 per cent that successfully reached the adult stage represented either clonal lines with above-average thresholds for diapause development or cocoons that had been formed in 1952 and failed to emerge during the spring of 1953. If the latter is true, these cocoons had already been exposed to low temperatures. At 15° C, no morphogenesis

Table 2.1 Percentage of sawflies in diapause and post-diapause stages at successive periods at different constant temperatures.

							Mortality	
Temp. ° C.	No. days	No. cocoons	Eonymphs	Pronymphs	Pupae	Adults	Eonymphs	Post-diapause*
-5	60	10	90	--	--	--	10	--
	80	10	100	--	--	--	--	--
	100	10	90	--	--	--	10	--
	120	10	90	--	--	--	10	--
0	60	20	40	25	25	--	10	--
	80	20	10	15	50	--	20	5
	100	20	20	20	50	--	10	--
	120	10	10	50	40	--	--	--
	140	10	--	20	40	--	10	30
	160	10	30	20	40	--	10	--
	180	10	10	10	40	--	--	40
	190	18	11	11	33	--	17	28
	200	13	15	38	23	--	--	23
	210	14	14	36	14	--	--	36
5	60	10	100	--	--	--	--	--
	80	10	100	--	--	--	--	--
	100	10	90	10	--	--	--	--
	120	10	100	--	--	--	--	--
	130	10	90	10	--	--	--	--
	292	99	6	--	81**	4	1	8
10	60	10	100	--	--	--	--	--
	80	10	60	40	--	--	--	--
	100	10	60	40	--	--	--	--
	120	10	80	20	--	--	--	--
	140	10	50	50	--	--	--	--
	292	99	4	--	1	83	12	--
15	60	10	100	--	--	--	--	--
	80	10	90	--	--	--	10	--
	355	103	13	1	1	82	3	--

* Post-diapause stages not differentiated

** Emerged within 5 days when brought to room temperature

Table 2.1 continued

Temp. ° C.	No. days	No. cocoons	Eonymphs	Pronymphs	Pupae	Adults	Mortality Eonymphs	Mortality Post-diapause*
20	60	10	100	--	--	--	--	--
	80	10	100	--	--	--	--	--
	292	54	81	--	--	11	7	--
0***	30	10	100	--	--	--	--	--
	60	10	90	--	--	--	--	10
	80	10	90	--	--	--	10	--
	100	10	70	30	--	--	--	--
	120	10	100	--	--	--	--	--

*** Exposed to 20° C for 84 days before 0° C cold treatment.

occurred during the first 80 days, but most of the larvae successfully reached the adult stage. After 355 days only 13 per cent of the larvae remained as eonymphs. Both diapause and post-diapause development occurred at this temperature, mortality was low, and the rate of development was slow. Development at 10° C was similar to that at 15° C but pronymphs occurred within 80 days of exposure and adult emergence was completed about 60 days sooner. The early occurrence of pronymphs indicates that diapause development occurred more rapidly at 10° C than at 15° C.

At 5° C very few pronymphs were recorded in 130 days exposure but 85 per cent of the larvae developed to the pupal stage in 292 days. Four per cent of these emerged as adults at 5° C and the remainder emerged within 5 days at room temperatures. Diapause development seemed slower than at 10° C and post-diapause development was greatly retarded.

Mortality was low to the end of the experiment but might have increased with time among post-diapause stages at 5° C.

At the preceding temperatures no pupae were found during the early part of the exposure. At 0° C, however, morphogenesis began almost immediately and proceeded to the pupal stage in 25 per cent of the collection within 60 days. The percentage in post-diapause stages and the mortality of these stages increased with time. Mortality among eonymphs was light. This rapid development to pronymphal and pupal stages at low temperatures is not usual in the larch sawfly. Under field conditions pronymphs make up a negligible ~~protion~~ proportion of the population until after winter exposure, and pupae do not occur until mid-May or later. The premature development among cocoons at 0° C in this experiment appears to be related to the short period of time between cocoon formation and exposure at 0° C. In a group of cocoons collected at the same time, but kept at 20° C for 84 days before exposure at 0° C, few pronymphs and no pupae formed during 120 days at the low temperature. Other larvae kept at about 10° C until September or October have remained in the eonymphal stage during exposures of up to 200 days at 2° C. Light mortality and no morphogenesis were recorded in exposures of up to 120 days at -5° C.

At the same time (i.e. 60 - 160 days) as cocoons were taken from the various cold temperatures for dissection as described above, larger groups of cocoons, about 100, were removed for rearing. The cocoons were placed on moist sphagnum moss and held at 15° C until emergence appeared complete. Unemerged cocoons were opened and the contents classified as in the dissections. Table 2.2 shows the results of these rearings.

Table 2.2 Percentage and rate of development at 15° C of larch sawfly larvae after exposure to cold temperatures of -5°, 0°, 5° and 10° C for 60, 80, 100 and 120 days.

Cold	No.	Adult emergence	Days incubation		Percentage developed		Percentage eonymphs	
exposure	cocoons	No.	Mean	Range	live	dead	live	dead
			-5° C					
60	100	19	239	176-276	22	2	12	64
80	102	1	159	---	4	0	38	58
100	99	1	148	---	1	0	20	79
120	101	0	---	---	0	0	23	77
			0° C					
60	95	79	209	126-293	87	1	4	8
80	100	77	184	109-273	77	2	17	4
100	100	77	156	60-231	80	1	15	4
120	100	50	144	52-210	59	4	32	5
160	49	12	31	6- 50	24	71	0	4
			5° C					
60	101	81	170	100-243	80	3	11	6
80	100	86	132	72-207	86	1	9	4
100	99	80	101	61-142	83	1	6	10
120	98	86	78	36-118	88	2	4	6
			10° C					
60	104	79	167	90-248	76	3	8	13
80	98	83	124	59-192	87	1	8	4
100	100	87	104	51-145	88	1	7	4
120	99	87	91	45-139	89	2	2	7
			Constant temperature exposure					
10°	100	81	261	188-293	83	0	4	13
15°	102	84	248	152-350	84	0	14	2
20°	54	6	252	242-276	11	0	81	7
5°	99	4	254	241-269	85*	8	6	1

* 80 adults emerged from these cocoons three days after cocoons were raised to 15° - 20° C.

Increasingly higher mortality and a lower percentage of development occurred with increasing length of exposure at -5° C from 60 to 120 days. Adult emergence was low and mortality high. During exposure to -5° C most of the larvae developed a transverse dorsal crease in the central part of the body and shortly after became turgid and died. At the end of the experiment living eonymphs were more common among cocoons exposed to -5° C than among cocoons exposed to other low temperatures.

Development to the adult stage required a longer time among cocoons exposed to 0° C for periods up to 120 days than to 5° or 10° C, despite the early development of many eonymphs to the pupal stage at 0° noted in Table 2.1. This may indicate that diapause in the larch sawfly may be delayed to the pupal stage if newly-formed cocoons are placed at 0° C. Prolonged exposure (e.g. 160 days) at this temperature apparently results in high mortality to such prematurely developed individuals, but the survivors developed to the adult stage more rapidly than any other group in this experiment.

At cold exposures of 5° and 10° C a high percentage of the sawflies developed to the adult stage. Mortality was low in both the eonymphal and post-diapause stages and the percentage remaining in the eonymphal stage declined as the length of exposure was increased.

The foregoing results may have been influenced by placing the cocoons at low temperatures shortly after cocoon formation. The effects of this unnatural treatment were tested in 1954. Larch sawfly cocoons from three regions, Manitoba, Saskatchewan and Minnesota were divided into two groups; one group was placed in a cold room at 2.5° C shortly after cocoon formation and the other held within the normal range of soil temperatures until September 15. The Manitoba cocoons were collected at weekly intervals from moss-filled cans beneath large funnels in the Whiteshell Forest Reserve. Each of four weekly collections from the week ending July 16 to the week ending August 8 was divided into two portions, one of which was placed at 2.5° C after seven days and the other held at about 10° C until September 15. The cocoons from the other two areas were collected from the ground in heavily infested tamarack stands after the bulk of the larvae had formed cocoons. The Saskatchewan cocoons were collected on August 18 at Pierceland. Half of the collection was placed in the cold room on August 21 and the remainder was held at 10° C until September 15. The Minnesota cocoons were collected by Mr. A. T. Drooz at Laporte on August 13. Half the cocoons were placed in the cold room on August 18 and the remainder on September 15.

The cocoons in all treatments were kept in the cold room at 2.5° C for 120 days, then incubated at 15° C until emergence was complete. The results are summarized in Table 2.3. Cocoons that became mouldy during the pre-cold, cold and incubation periods plus the cocoons remaining after the end of emergence were opened and the larvae classified as living or dead, eonymphs or post-diapause stages (pronymphs, pupae, teneral adults). Parasitized larvae were subtracted from the original cocoon totals to give the "Number of cocoons". The column "Percentage developed" is based on the sum of male and female adults emerged plus dead pronymphs, pupae, adults, and any living post-diapause

Table 2.3 Differences in percentage development and rate of development at 15° C of larch sawfly cocoons exposed to 2.5° C for 120 days shortly after cocooning and after 40-60 days exposure to 10° C.

Date collected	Begin cold exposure	No. cocoons	Per cent eonymphs		Per cent developed*	Days to mean emergence	No. adults
			dead	living+			
Whiteshell, Man.							
July 16	July 23	555	73	22	6	63	20
	Sept.15	383	79	3	18	65	60
July 23	July 30	457	44	8	48	38	213
	Sept.15	364	64	1	35	66	111
July 30	Aug. 6	462	48	33	20	46	78
	Sept.15	460	66	1	33	67	144
Aug. 6	Aug. 13	132	39	13	48	47	61
	Sept.15	118	39	0	61	65	69
all dates	7 days after coll.	1606	55	20	25	42	372
	Sept.15	1325	67	2	32	66	384
Laporte, Minn.							
Aug. 7	Aug. 18	542	18	12	70	48	367
	Oct. 7	541	17	2	82	49	428
Pierceland, Sask.							
Aug. 18	Aug. 21	393	20	15	65	48	228
	Sept.15	341	15	1	84	67	261

* Including emerged adults plus dead pronymphs and pupae

\+ Living eonymphs at the end of the incubating period were considered to still be in the diapause state.

stages found inside cocoons at the end of the experiment. Mortality among post-diapause stages never exceeded five per cent of the total number of cocoons.

The results shown in Table 2.3 indicate that exposure of newly formed cocoons to low temperatures affects both the amount and rate of development during incubation. A higher percentage of living larvae remained in the eonymphal stage when the cocoons received the cold treatment shortly after they were formed. The percentage reaching post-diapause stages was higher among material held at 10° C before the cold treatment but an exception occurred in the material collected July 23 at the Whiteshell Forest Reserve. Due to high mortality among the eonymphs in this collection the anomaly may not be important. In the Manitoba and Saskatchewan collections, the time required to complete development at 15° C was about 20 days shorter when the cocoons were placed in the cold room shortly after cocoon formation. The average time from cocoon formation to cold exposure among the Manitoba cocoons was about 10 days. The Saskatchewan cocoons were collected less than 5 days after the bulk of the population cocooned and were thus in the cold room within about 10 days of cocoon formation. On the other hand, the period of cocoon formation at Laporte, Minnesota was from July 4 to July 26. Thus at least 21 days had elapsed from cocoon formation to cold exposure. No difference was noted in the time required for post-diapause development between the two treatments of cocoons from Laporte. The lack of difference in time required to complete development between the two treatments of cocoons collected July 16 at the Whiteshell Forest Reserve cannot be explained.

The effect of increasing the cold exposure time at 2.5° C to 200 days before incubating at 15° C and the effect of incubating at 10° C were tested by R. J. Heron in the Winnipeg Laboratory. In 1955 a collection of cocoons from Pierceland was placed in the cold room at 2.5° C on Sept. 2. The collection was divided in half; one group was held at this temperature for 100 days and the other for 200 days. After the cold exposure both groups were incubated at 15° C. From 48 cocoons held 100 days, 65 per cent emerged, 29 per cent died, and 6 per cent remained in diapause. The time required at 15° C to the mean emergence date was 100 days. The 81 cocoons held at 2.5° C for 200 days gave 75 per cent emergence, 24 per cent mortality, and one per cent remained in diapause. Incubation at 15° C to the mean emergence date was 48 days. Although the length of time at 15° C was decreased by increasing the length of the cold period, the total period from the beginning of cold exposure to emergence increased from 200 to 248 days.

The effect of lowering the incubating temperature to 10° C was shown with cocoons collected in the Whiteshell Forest Reserve and placed in the cold room at 2.5° C on October 1, 1956. After 172 days, 1032 cocoons were incubated at 15° C and 212 at 10° C. At 15° C, 69 per cent emerged, 28 per cent died and 3 per cent remained in diapause. At 10° C, 75 per cent emerged, 19 per cent died and 5 per cent remained in diapause. Development to the adult stage required an average of 53 days at 15° C and 69 days at 10° C. Calculation of the theoretical minimum threshold for post-diapause development from these limited data gave a value of 0° C, which coincides with developmental threshold estimated from the results of earlier experiments.

The minimum threshold for pupal development among cocoons given a normal pre-cold exposure appears to be slightly under 5° C. During the summer of 1957, a student assistant, A. McLellan, made observations on 25 larvae in glass tubes at air temperatures. He found the average length of the pupal period to be 10.5 days at mean temperatures of 12.4 to 18.8° C. From these data a regression formula of rate of development against temperature was calculated and the theoretical minimum threshold for development estimated to be 2.8° C. In 1951, at Prince Albert, three replicates of 200 cocoons each were buried 5 inches beneath the soil surface in a tmarack bog and soil temperature measurements made twice weekly at 0900 and 1600 hrs., M. S.T., at the cocoon depth. To the date of first emergence, July 17, the maximum temperature recorded was 10° C. The mean temperature based on these two biweekly measurements was 6.1° C, supporting the conclusion that pupal development can occur at temperatures well below 10° C.

These experiments and observations lead to the following conclusions on the relationships between temperature and diapause and post-diapause development in the larch sawfly:

1. Exposure to temperatures below 5° C within about 10 days after cocoon formation causes early development to the pronymphal stage of many of the larvae. When such larvae are raised to 15° C they develop more slowly to the adult stage than larvae kept at 10° C for at least two weeks before cold exposure.

2. Diapause development occurs at temperatures from 0° to 15° C. At -5° C some development occurred but was associated with high mortality. The optimum temperature tested was 5° C.

3. Post-diapause development may begin at temperatures slightly above 0° C. The minimum threshold for pupation is about 3° C, and for adult emergence about 5° C. The optimum temperature for development to the adult stage is 15° C; at 10° C the rate is slower and at 20° C high mortality occurs.

These conclusions do not agree with the limited literature on the subject. Gobeil (1941), who studied a few small collections of larch sawfly cocoons from Quebec, concluded that the optimum incubating temperature was 23.9° C and that good emergence was possible at 29.4° C with high humidity. He mentioned that slow development occurred as low as 15.6° C. Unfortunately he presented little data for the larch sawfly and it is difficult to determine if these conclusions were based on adequate data or are merely generalizations based on his results with Diprion polytomum Htg. Brown and Daviault (1942), also using material from Quebec, calculated a theoretical minimum threshold of 9.8° C and a thermal constant of 358 day-degrees Centigrade. They concluded that P. erichsonii, "...perhaps in contrast to some established opinions, exhibited -- high theoretical threshold and lower thermal constants...". This study was limited to observations on a total of 81 females in five temperature treatments without replication. In the field they used air temperature to calculate the thermal constant of 318 day-degrees Centigrade. The sawfly material was kept in cages where "Temperatures...were lower, but approximated air temperatures rather than soil temperature once the snow was gone". The attributed the differences between the two calculations in part to discrepancy between the actual and theoretical threshold and believed some slow development may take place below the theoretical threshold of 9.8° C. Drooz (1956) attempted to use the 9.8° C threshold for the calculation of a thermal constant for emergence in the field in Minnesota but found the results too variable. He found less variability with a lower threshold of 7.2° C (chosen emperically) and reported average thermal constants of 306 and 351 day-degrees Centigrade to 50 per cent adult emergence in a dry and wet tamarack site. He used air temperature data from April 15 and noted considerable variability in the constant between years as well as between sites.

The calculation of thermal constants from the data presented in this section gives variable results. Using a theoretical threshold of 0° C the constants for the period of incubation to the mean emergence date of various collections with pre-cold exposure to about 10° C and cold exposure to 2.5° C were as follows:

Source*	Year	Days cold	Incubation temp. (°C)	Thermal constant (day - °C)
1	1955	100	15	1500
2	1953	119	15	1328
2	1954	120	15	1042
1	1954	120	15	1006
3	1954	120	15	858
5	1954	120	15	729
2	1952	125	16.7	982
1	1954	140	15	796
4	1956	172	15	795
4	1956	172	10	690
4	1955	200	15	837
1	1955	200	15	720

*Cocoons collected from these areas:

1. Pierceland, Sask.
2. Prince Albert, Sask.
3. Sandfly Lake, Sask.
4. Whiteshell, Man.
5. Laporte, Minn.

These thermal constants are considerably larger than those reported by Brown and Daviault and Drooz due to the use of a lower threshold but the variability noted by Drooz remains. This variability may be associated with differences between larvae in the length of time required to complete the diapause stage. In the above table high values for the thermal constant are associated with short periods of cold exposure and suggest that diapause development may not have been completed until some time after the beginning of incubation.

3. Soil temperatures in two tamarack stands near Prince Albert, Saskatchewan.

The soil temperatures encountered by post-diapause stages of the larch sawfly in the field naturally influence their rate of development. Published information on the temperatures in tamarack sites was not found in the review of Zikeev (1951). Duncan (1954) found surface temperatures in tamarack bogs in Minnesota to vary from 10° to 20° C in late May and early June, with extremes up to 28° C, but he did not investigate temperatures beneath the surface. Although work on other projects precluded a complete investigation of soil temperatures, measurements were made during the spring and early summer of 1953 in representative stands. These measurements were confined to the upper four inches of the soil because investigation had shown that about 90 per cent of the cocoons are found within this distance from the surface (see section 4).

3.1 Description of the area.

Two distinctly different types of tamarack stands were located in a depression in the rolling sand hills lying north of the North Saskatchewan River about five miles northeast of Prince Albert in the Red Rock Block of the Nisbet Provincial Forest. This depression was about 40 acres in extent and had no inlet nor outlet streams. Within the area vegetation ranged from a very wet marsh in the centre, through stands of tamarack on progressively drier sites, to a peripheral forest of mixed black spruce - tamarack ~~on a dry~~ er ~~site~~ adjacent to upland jack pine - aspen forests.

A 1/5 acre plot, measuring one by two chains, was laid out in each of two site types. The plots were only 650 feet apart but differed markedly in their vegetational and physical site characteristics. The differences in ground vegetation are summarized in Table 3.1. This list of species and their frequency is based on 10 one-metre quadrats located at the intersections of a 22 x 22 foot grid laid out in each plot. Data on the density of the plant species were not recorded. The ground surface in both plots was extremely irregular and characterized by hummocks and depressions of varying heights and depths. The average ground level referred to in this text was obtained by averaging the distance from the water table to ground surface at 12 locations along a line in each plot. Other characteristics of the plots are discussed below. Throughout the text the plot in the mixed spruce - tamarack stand is called A and the plot in the pure tamarack stand is called B.

Plot A: The trees in this plot had an average height of 23 feet, d.b.h. of 2.4 inches, and density of 2,515 stems per acre (735 tamarack and 1,780 black spruce). The trees, particularly the spruce, were distributed in clumps, with Labrador tea dominating the openings in the stand. Tree seedlings were extremely rare. During the spring run-off, the depressions in the ground surface contained one to six inches of water, but no surface water was present after May 10. After June 1 the water table lay more than four inches below the surface in depressions and about 14 inches beneath the average ground level.

The soil in this plot was composed of fibrous peat, primarily derived from mosses, except in the depressions where the soil was

Table 3.1 Ground vegetation in plots A and B near Prince Albert, Saskatchewan; a list of plant species and their frequency of occurrence in 10 one-metre quadrats.

	Frequency	
Species*	A	B
Larix laricina (Du Roi) K. Koch seedlings		8
Betula glandulosa Michx.		9
Salix sp.	1	5
Ledum groenlandicum Oeder	10	
Arctostaphyos Uva-ursi (L.) Spreng.	10	
Vaccinium Vitis-Idaea L.	2	
Lonicera oblongifolia (Goldie) Hook.		1
Triglochin maritima L.		1
Carex spp.		10
Smilacina trifolia (L.) Desf.		6
Stellaris longipes Goldie		5
Caltha palustris L.		3
Epilobium leptophyllum Raf.		6
Pyrola asarifolia Michx.		6
Menyanthes trifoliata L. var. *minor* Raf.		4
Galium trifidum L.		3
Aster junciformis Rydb.		1
Sonchus arvensis L.		
Polytrichum sp.	3	
Ceratodon sp.	1	1
Aulacomnium palustre (Web & Mohr) Schwaegr.	4	
Camptothecium nitens (Hedw.) Schimp.	8	10
Usnea sp.	4	
Total number of species	9	
Per cent of ground surface covered by vegetation	54.5	83.0

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* Specimens identified by G. Löve, formerly Botany Department, University of Manitoba; stored at Forest Biology Laboratory, Winnipeg. Flowering plants following Fernald (1950) and mosses following Grout (1940).

composed of limnic peat with a surface layer of twigs, fallen needles, and some mosses.

Plot B: The trees in this plot had an average height of 24 feet, d.b.h. of 2.6 inches, and a density of 1,440 stems per acre. They were evenly spaced and tamarack seedlings were common. The microtopography was just as irregular as in plot A but the depressions contained water throughout the season. During the spring run-off some hummocks were almost submerged. On May 6, ice was found about four inches beneath the surface of the hummocks and intermediate locations. In July the water table lay about seven inches beneath the average ground level and about 25 per cent of the surface area was water-covered. The ground in the depressions was saturated throughout the summer. The basic soil constituent in this plot was limnic peat, with a surface layer of mossess in some of the shallower depressions. In the hummocks the fibrous peat was primarily derived from the roots of Carex.

3.2 Equipment

Soil temperature measurements were made with a Rubicon temperature calibrated potentiometer with a range of -10° to 120° C and an error of ± 0.7° C. Thermocouples were constructed from number 24 copper-constantin glass-insulated wire and tested against a standard mercury thermometer at temperatures from 0° to 35° C.

3.3 Methods

The thermocouples were left attached to about two feet of wire. To insert them, the humus was cut vertically to a depth of about six inches. The cut was opened sufficiently to permit the insertion of thermocouple junctions 1-, 2-, and 4-inches beneath the surface. These junctions were pushed horizontally from the cut about two inches into the moss. The cut was then closed, leaving the thermocouple junctions in position with their lead wire extending above the ground surface. To measure temperatures at these junctions, the potentiometer was placed on a small level stand and connected to the lead wire of each thermocouple in turn. The external circuit of the potentiometer was extended by a copper-constantin lead. The copper and constantin wires each terminated on the jaws of a clothes pin so that they could be rapidly transferred from one thermocouple lead wire to another.

3.3.1 Measurement of soil temperatures under winter snow cover.

Soil temperature measurements were taken from April 16 to 24, about a week before the final disappearance of winter snow cover. In each plot three locations were chosen on top of hummocks. At each location the snow was carefully removed in a block, the soil was cut vertically and thermocouples inserted at the 1-, 2-, and 4-inch depths as described above. The lead wires were tagged and then the opening was closed and the snow replaced. The temperature at each junction was recorded at hourly intervals from 0700 to 1900 hrs., Mountain Standard Time. About 20 minutes were required to measure and record the temperatures at the six stations.

3.3.2 Method of measuring soil temperatures during May, June and July.

After the snow disappeared from the plots on April 28, the technique was altered to provide a measure of the variation in soil temperature associated with microtopography as well as with plots and depth beneath the surface. Three sites were selected in each plot and a level stand for the potentiometer built at each site. Within a 4-foot radius of this stand, three points were chosen, one on top of a hummock, one in the bottom of a depression, and one in an intermediate location. At each of these points thermocouples were inserted at the 1-, 2-, and 4-inch depths in the manner described above. Nine temperature reading could be taken without moving the potentiometer. Twenty-seven readings were taken in each plot at hourly intervals from 0800 to 1800 hrs., M.S.T., on 24 days between May 7 and July 20. The time required to read and record the temperature of all 54 junctions was 20 to 25 minutes. Plot A was always measured first, starting on the hour, so the measurements in plot A were taken about 10 minutes earlier than those in plot B.

3.4 Results and Discussion.

The observations indicated that the patterns of soil temperatures in the two types of bog forest were complex and varied in relation to internal factors such as microtopography and the fluctuations of the water table as well as to the environmental factors such as precipitation, air temperature, and insolation.

3.4.1 Soil temperatures under snow in April.

The records taken during April cover the period just prior to and during the final spring thaw, which resulted in the complete disappearance of the winter snow cover in the plots. Table 3.2 summarizes the notes on snow cover and surface water in the two plots during this period. The actual snow depth on the soil surface above each thermocouple was also recorded on each day when measurements were taken (Table 3.3). Snow was still present in depressions and drifts after it left the sample points on top of hummocks. Table 3.4 gives the mean of 13 temperature measurements from 0700 to 1900 daily for each thermocouple. A comparison of tables 3.3 and 3.4 indicates that the effects of snow cover on soil temperature lasted several days following the disappearance of the snow. For example, the ground surface at replicate number 3 in plot B was exposed before April 16 but very little warming occurred until April 21. Similarly, the ground surface at replicate 2 was exposed April 21 but no appreciable effect was noticeable on April 24. The most consistent change in soil temperatures was the rise from the below freezing temperatures of April 16, 17, and 18 to the slightly above freezing temperatures of April 21, 22, and 24. This change is apparently associated with the beginning of the spring thaw. Prior to April 16 the maximum temperatures recorded at the Meteorological Station, two miles away, rose above freezing on nine days, but only three of these were over 4.5° C. The maximum of 6.7° C occurred on April 6. On April 16 and 17 maximum temperatures were below freezing and traces of snow fell during the day. On April 18 a warming trend began and, as shown by the mean and extreme air temperatures given in Table 3.5, thawing occurred throughout the rest of the period. Thus the rise of soil temperatures to slightly above 0° C appears to be associated with air temperature maxima above 10° C and means above 0° C. Insolation did not appear to significantly affect the mean soil temperature, whether the ground was snow covered or not.

Table 3.2 Snow and water cover in plots A and B in the spring of 1953.

Date	Snow cover Av. depth (in.) A	 B	 Area (%) covered A	 B	Surface water Av. depth (in.) A	 B	 Area (%) covered A	 B
Apr. 13	24	18	95	90	--	--	--	--
20	18	10	70	50	--	10	--	40
24	10	2	25	5	5	12	5	50
May 4	--	--	--	--	5	15	1	60

Table 3.3 Depth of snow cover in inches over thermocouples on days when soil temperatures were measured in 1953.

Date	Time (M.S.T.)	Plot A 1	 2	 3	Plot B 1	 2	 3
Apr. 16-18	-	9	11	8	5	5	0
21	0800	5	7	8	2	0	0
	1830	2	4	3	0.5	0	0
24	0700	0	0	0	0	0	0

Table 3.4 Mean daily soil temperatures in ° Centigrade (0700 to 1900 M.S.T.) at one, two, and four inches below the ground surface on top of hummocks before the winter snow cover disappeared in plots A and B in April, 1953.

Depth	1"			2"			4"		
Replicate	1	2	3	1	2	3	1	2	3
Plot A									
Apr. 16	-3.0	-4.1	-4.8	-4.6	-3.5	-4.8	-0.5	-2.8	-3.2
17	-3.1	-4.6	-5.6	-4.2	-4.2	-5.5	-0.9	-3.6	-4.5
18	-2.8	-4.4	-5.2	-3.4	-4.1	-5.2	-1.1	-3.8	-4.7
21	0.1	0.1	0.2	0.1	0.1	0.2	0.0	0.2	0.1
22	0.2	0.2	0.3	0.2	0.2	0.2	0.1	0.2	0.2
24	0.8	0.2	1.2	0.3	0.2	0.3	0.2	0.2	0.3
Plot B									
Apr. 16	0	-1.8	-1.7	0.2	-0.7	-1.1	0.3	-0.6	-0.8
17	-0.3	-2.0	-0.7	-0.2	-1.2	-0.7	0.0	-1.2	-0.7
18	-0.5	-1.5	0.0	-0.7	-1.2	0.0	0.0	-1.2	-0.5
21	0.1	0.0	3.7	0.1	0.0	2.0	0.0	0.0	0.0
22	0.2	0.2	5.0	0.1	0.1	4.1	0.1	0.2	0.2
24	0.2	0.1	4.5	0.1	0.1	3.2	0.1	0.1	0.2

Table 3.5 Daily extreme and mean air temperatures (°C) recorded in Stevenson screens 4.5 ft. above ground level in plots A & B from April 16 to 24 and the number of hours of bright sunshine recorded at the Prince Albert Airport (2 miles away).

	Hours bright sunshine	Plot A Max.	Plot A Min.	Plot A Mean	Plot B Max.	Plot B Min.	Plot B Mean
Apr. 16	8.9	-5.0	-16.7	-9.6	-5.0	-19.5	-9.7
17	10.9	-2.2	-13.9	-7.9	-2.2	-13.9	-7.6
18	13.1	3.3	-13.3	-3.2	5.0	-12.8	-2.1
19	11.4	7.2	-11.7	-0.8	8.3	-11.7	-0.1
20	12.1	13.3	- 5.6	4.0	14.4	- 6.7	5.3
21	8.8	11.1	0.6	5.8	12.2	2.2	7.4
22	13.6	12.2	2.2	6.4	13.3	4.4	7.3
23	10.7	12.8	- 4.4	4.3	13.9	- 3.9	5.2
24	2.1	11.7	- 1.1	5.2	12.2	- 1.1	6.1

This conclusion is supported by the lack of differences between the mean soil temperatures recorded on April 22 and 24, when the number of hours of bright sunshine recorded at the Meteorological Station 2 miles away was 13.6 and 2.1 hours respectively. However, J. E. Church, in the discussion of a paper by Belotelkin (1941), noted that white and black bulb thermometers in snow indicate the sun radiation is effective on dark objects to a depth of 18 inches.

Figure 3.1 shows the mean course of soil temperatures (based on the three replicates) at the 1-, 2-, and 4-inch depths for plots A and B. These graphs illustrate the effects of snow depth and melting on the soil temperatures. In plot A the snow cover was deeper, air temperatures lower, and the melting process slower than in plot B. These differences appear to be associated with the differences in tree cover between the plots. As expected, the leafless tamarack in plot B trapped less snow during the winter and allowed more evaporation and melting

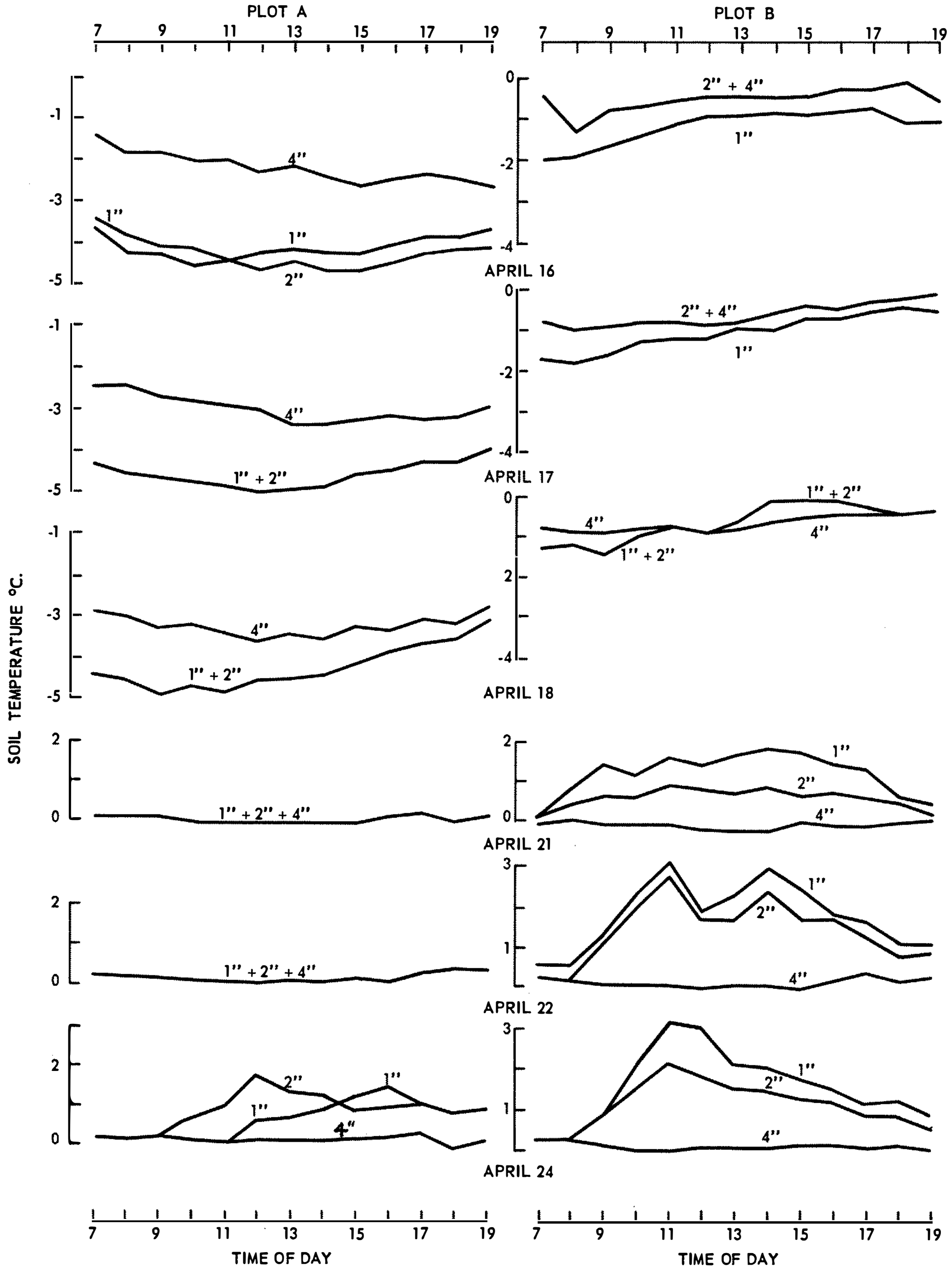


Figure 3.1 – Mean daily soil temperatures at 1, 2, and 4 inches depth under snow cover in Plots A and B for 6 days in April 1953. Temperatures are based on hourly observations between 0800 and 1800 hrs. M.S.T. at three points within each plot.

in April than the clumped black spruce in plot A. The slightly higher air temperatures appear to have started the snow melting earlier in plot B, giving soil temperatures closer to the freezing point during the period April 16 to 18. During the thaw after April 18 when melted snow water began to percolate down into the soil, the soil temperatures in plot A rapidly approached those in plot B.

An analysis of variance was conducted for each plot for each day to compare the temperatures at different depths and different times of day. The "F" values for main factors obtained by these calculations are given in Table 3.6. No significant Depth x Time interaction was found in these analyses. It is notable that the pattern of significant differences between depths in the two plots was the same although the timing differed. In both plots the differences were significant at the beginning of the period, were non-significant as the soil temperatures approached 0° C, and became highly significant again as the temperatures climbed above the freezing point. The change is associated with a reversal of the temperature gradient in the surface layers of the soil. As shown in Fig. 3.1, plot A, the temperature at the 4-inch depth was higher than at the 1- and 2-inch depths until April 21, when there were no significant differences. There were no differences on April 22 but by April 24 the upper layers had become warmer than the 4-inch depth. The reversal was less obvious in plot B and occurred about four days earlier, probably because the snow depth was less in this plot.

Table 3.6 "F" values of analysis of variance for differences in temperature between depths and time of day in plots A & B before the snow cover disappeared. (Total degrees freedom = 57). Throughout this paper * indicates statistical significance to the .05 level and ** indicates significance to the .01 level in tables of "F" values.

	Apr. 16	Apr. 17	Apr. 18	Apr. 21	Apr. 22	Apr. 24
Plot A						
Depth	41.4**	15.7**	6.7**	0.-	0.-	21.8**
Time	0.-	0.-	0.-	6.5**	10.9**	1.6
Plot B						
Depth	7.3**	2.5	0.-	6.9**	4.9**	4.9**
Time	1.0	1.6	1.7	0.-	0.-	0.-

Except for two interesting exceptions, April 21 and 22 in plot A, the differences between soil temperatures at different times of day were not statistically significant. As shown in Fig. 3.1, there was probably less variation in temperature between different times on these days than on any other day. The differences between times on April 21 and 22 in plot A would be unlikely to have biological significance, while the differences recorded on other days in both plots, although not statistically significant, were of sufficient magnitude to affect organisms exposed to them. An explanation for this may be found in comparing the results for April 21 and 22 in plots A and B. As shown in Table 3.4 the variation between the means of the three replicates at each depth in plot A was 0.1° and 0.2° C while in plot B the variation was 3.7° C and 4.9° C. When the same statistical technique was applied to these two sets of data the uniformity of the first emphasizes small differences in temperature between different times of day while the larger differences between different times of day in plot B are obscured by the variability of the data. As biological data are usually variable, a lack of statistical significance may not truly represent the biological relationship. Thus is appears that in plot B the fluctuations noted in Fig. 3.1 on April 21 and 22 were biologically important because the maximum temperatures were sufficiently above the mean to allow some insect development to occur. For example, on April 22, plot B, the one-inch depth mean temperature was 1.9° C and the maximum temperature was 8.9° C, a difference which could be of primary importance in the post diapause development of larch sawfly larvae in the soil.

Analysis of variance for differences in soil temperature between plots gave highly significant "F" values for all six days in April.

3.4.2 Soil temperatures during May, June and July.

The soil temperatures recorded on 24 days during May, June and July are summarized in Tables 3.7 and 3.8. These tables give the mean soil temperature, based on 11 hourly readings at each of three replicates, plus the maximum and minimum soil temperature for each depth and microtopographic location in the two plots. The pattern of soil temperature change during the day varied with weather conditions and seemed to be closely related to the degree of cloudiness. Typical patterns for clear and overcast days were obvious. Partly cloudy days showed intermediate patterns depending on the degree of cloudiness.

Table 3.7 Mean, maximum and minimum soil temperatures (°C) recorded in plot A at one, two, and four inches beneath the surface; on top of hummocks (H), intermediate locations (I) and in depressions (D) of the ground surface from 0800 to 1800 hrs., on days between May 7 and July 20, 1953. (Based on three replicates of each depth and location.)

Plot A		1" depth			2" depth			4" depth		
Date		H	I	D	H	I	D	H	I	D
May 7	Mean	15.7	15.4	9.6	11.8	10.0	5.0	8.2	6.7	1.9
	Max.	22.6	22.4	15.0	21.4	15.6	9.3	14.3	16.0	4.4
	Min.	6.0	4.5	2.9	4.9	2.2	0.9	3.3	-0.5	0
May 11	Mean	0.3	0.1	0.1	0.4	0.1	0.1	0.5	0.1	0.1
	Max.	0.9	0.5	0.6	0.9	0.5	0.5	1.5	0.5	0.6
	Min.	-0.1	-0.4	-0.3	-0.1	-0.4	-0.4	0	-0.2	-0.4
May 14	Mean	6.3	6.7	5.1	4.8	3.7	3.1	3.4	1.8	1.8
	Max.	9.5	10.4	7.1	8.0	5.7	5.2	5.7	4.2	4.2
	Min.	2.0	1.4	1.4	2.0	1.0	1.0	2.0	0	0.4
May 15	Mean	6.2	6.2	4.6	4.1	2.9	2.4	2.4	1.3	1.4
	Max.	11.6	12.6	8.9	9.8	6.7	5.8	5.9	5.1	4.3
	Min.	-0.1	0	0.1	-0.1	0	0	0.8	0	0.2
May 19	Mean	5.3	5.5	4.3	3.5	2.6	2.2	2.2	1.2	1.3
	Max.	14.8	14.6	9.3	10.5	7.9	6.0	5.7	5.6	4.2
	Min.	0.1	0	0.4	0.5	0	0.1	0.1	0	0
May 21	Mean	7.2	7.2	5.7	5.3	3.7	3.4	3.6	1.8	1.5
	Max.	11.3	14.1	11.7	10.0	8.6	7.0	6.7	7.1	3.0
	Min.	2.0	0	0.8	1.5	0.1	0.8	2.0	0	0.7

Table 3.7 continued

Plot A		1" depth			2" depth			4" depth		
Date		H	I	D	H	I	D	H	I	D
May 26	Mean	9.9	9.6	8.3	8.1	5.9	5.7	6.4	3.2	3.3
	Max.	15.1	17.5	14.8	12.4	10.5	8.6	9.5	8.3	5.0
	Min.	3.8	2.3	3.7	3.8	1.4	3.0	4.6	0.3	2.4
May 27	Mean	7.6	6.7	6.2	6.9	4.8	5.1	5.9	3.0	3.3
	Max.	8.9	8.2	7.5	8.2	7.2	6.5	6.4	6.0	4.4
	Min.	6.0	5.0	5.0	6.0	3.0	3.6	4.0	1.0	2.5
June 4	Mean	9.1	7.8	7.7	8.5	6.3	6.6	7.9	4.4	5.0
	Max.	10.2	9.5	8.9	9.1	8.9	7.3	9.3	7.0	6.0
	Min.	8.3	6.4	7.1	8.0	4.9	5.6	7.1	2.2	4.3
June 6	Mean	11.5	11.1	8.8	8.9	7.2	5.4	6.2	3.6	2.7
	Max.	18.6	19.5	15.5	14.1	12.2	9.3	10.1	10.0	4.8
	Min.	4.1	3.2	3.1	4.0	1.3	3.1	3.9	0.5	0.8
June 8	Mean	13.8	12.7	10.4	11.6	8.7	7.0	9.0	4.8	3.2
	Max.	17.4	15.4	14.6	15.5	13.6	10.5	11.1	11.2	4.5
	Min.	9.3	8.4	6.6	8.4	4.9	4.3	7.2	0.9	1.6
June 9	Mean	13.6	12.7	10.4	11.6	9.3	7.6	9.4	5.5	4.3
	Max.	18.9	16.6	14.1	14.9	14.6	10.5	11.5	11.9	5.9
	Min.	9.9	8.2	6.6	8.6	5.1	4.6	7.0	1.4	2.8

Table 3.7 continued

Plot A		1" depth			2" depth			4" depth		
Date		H	I	D	H	I	D	H	I	D
June 11	Mean	16.2	14.7	12.5	13.3	10.8	8.8	10.6	6.5	4.8
	Max.	24.4	23.9	22.7	20.9	19.2	14.8	16.0	15.9	7.5
	Min.	8.6	7.4	6.6	8.3	4.5	6.0	7.9	2.4	3.6
June 16	Mean	12.3	11.2	10.5	11.1	8.9	8.5	9.9	6.2	5.7
	Max.	13.9	14.0	13.1	13.0	12.2	10.0	11.0	10.5	6.5
	Min.	9.8	8.0	8.5	9.2	5.6	7.1	8.6	3.8	4.3
June 18	Mean	11.7	10.8	9.8	11.0	9.3	7.9	10.1	6.8	5.9
	Max.	13.0	12.5	12.0	11.9	11.5	8.4	11.1	9.7	6.9
	Min.	10.0	9.2	8.4	9.9	7.4	7.2	9.3	4.4	4.9
June 23	Mean	14.0	13.7	11.0	11.4	10.5	7.1	8.9	5.8	4.8
	Max.	21.5	21.0	19.5	17.6	17.2	10.5	13.4	13.2	6.6
	Min.	6.3	5.1	4.5	5.9	3.4	4.4	6.1	2.6	3.4
June 25	Mean	14.0	13.4	11.8	12.1	10.7	8.6	10.1	6.8	6.3
	Max.	19.6	17.3	18.5	16.4	14.0	11.7	12.6	11.4	7.9
	Min.	9.2	7.6	7.2	8.5	6.4	6.3	8.2	3.2	5.4
June 27	Mean	11.0	10.7	9.5	9.1	8.1	7.2	7.6	4.8	5.2
	Max.	18.6	19.6	18.6	15.0	13.0	11.8	12.0	10.6	7.1
	Min.	6.2	4.7	5.4	5.9	3.3	5.4	6.0	3.0	4.9

Table 3.7 continued

Plot A		1" depth			2" depth			4" depth		
Date		H	I	D	H	I	D	H	I	D
July 2	Mean	16.3	15.4	14.4	14.4	11.8	10.7	11.9	7.7	7.2
	Max.	21.0	22.6	22.3	18.2	15.8	15.2	15.2	13.7	9.4
	Min.	9.6	7.8	7.6	9.3	6.2	7.4	9.0	4.5	6.0
July 6	Mean	11.7	11.6	10.7	10.1	9.1	8.2	8.6	6.1	5.7
	Max.	16.4	17.5	18.9	14.4	13.3	12.2	11.1	10.7	7.5
	Min.	8.9	8.4	7.6	8.2	6.2	6.6	6.8	4.0	5.1
July 8	Mean	14.5	14.2	12.9	12.2	10.8	9.0	9.7	6.5	5.9
	Max.	22.1	22.2	22.6	18.5	16.9	14.9	14.8	13.0	8.3
	Min.	6.5	5.5	5.1	5.7	3.7	5.0	5.6	3.0	4.0
July 10	Mean	20.7	19.1	17.9	18.1	15.9	13.5	15.2	10.2	8.9
	Max.	25.0	25.6	27.0	23.0	23.0	18.1	18.7	17.5	11.4
	Min.	14.3	12.2	11.6	13.1	9.5	9.5	12.0	6.2	7.0
July 16	Mean	16.2	15.5	15.6	15.3	13.7	13.7	14.3	10.6	11.5
	Max.	18.1	17.6	18.1	17.0	15.8	15.0	15.6	14.2	12.2
	Min.	13.8	12.6	13.4	13.4	11.2	12.3	12.8	8.3	10.1
July 20	Mean	15.5	14.2	13.9	14.2	12.1	11.8	12.6	9.1	9.4
	Max.	18.0	16.5	16.4	16.4	16.6	13.6	14.0	13.4	10.5
	Min.	13.1	12.3	11.7	12.1	8.8	10.1	10.7	7.0	8.7

Table 3.8 Mean, maximum and minimum soil temperatures (°C) recorded in plot B at one, two and four inches beneath the surface; on top of hummocks (H), intermediate locations (I) and in depressions (D) of the ground surface from 0800 to 1800 hrs., on days between May 7 and July 20, 1953. (Based on three replicates of each depth and location)

Plot B		1" depth			2" depth			4" depth		
Date		H	I	D	H	I	D	H	I	D
May 7	Mean	14.8	11.9	11.3	8.3	6.0	10.1	2.0	4.2	5.1
	Max.	23.5	16.4	18.1	15.6	10.5	16.8	4.8	10.7	9.3
	Min.	5.1	4.0	4.3	0.2	0.4	3.4	-0.7	-0.1	1.2
May 11	Mean	0.1	0.1	0.5	0.1	0.1	0.5	0.1	0.1	0.3
	Max.	0.6	0.3	1.3	0.7	0.5	1.0	0.5	0.5	0.6
	Min.	-0.1	-0.1	0	-0.1	-0.1	0.1	-0.1	-0.2	0
May 14	Mean	7.0	6.9	5.2	3.9	4.6	4.9	1.4	3.8	3.7
	Max.	10.3	11.4	7.1	7.4	6.1	7.0	2.5	5.8	6.6
	Min.	1.0	3.1	1.6	0.8	1.7	1.6	0.1	1.2	1.4
May 15	Mean	7.5	6.9	5.5	3.8	4.5	5.2	1.2	3.5	3.9
	Max.	14.2	10.7	10.0	9.0	6.9	9.5	2.9	6.3	7.1
	Min.	0	0.1	1.0	0	0.5	1.1	-0.1	0.5	1.3
May 19	Mean	6.8	6.2	5.3	3.4	3.8	4.7	1.2	3.1	2.8
	Max.	16.2	11.7	12.2	10.2	7.5	11.4	3.1	6.7	6.4
	Min.	0.1	0.6	0.8	0.1	0.5	0.6	0	0.7	0.9
May 21	Mean	8.2	8.3	7.0	4.7	5.3	6.4	1.9	4.5	4.2
	Max.	15.6	12.1	13.0	10.0	7.8	12.3	3.7	7.3	7.3
	Min.	0.2	2.9	2.2	0	2.4	2.0	0	1.6	2.1

Table 3.8 continued

Plot B		1" depth			2" depth			4" depth		
Date		H	I	D	H	I	D	H	I	D
May 26	Mean	12.6	11.5	9.2	7.3	8.3	8.7	3.6	7.5	5.9
	Max.	19.4	14.9	11.4	11.7	10.8	11.2	5.0	10.1	9.8
	Min.	4.4	5.5	4.1	2.0	4.2	4.1	1.6	4.2	3.6
May 27	Mean	7.7	8.0	6.9	5.6	6.7	6.6	3.3	6.3	5.3
	Max.	9.4	9.1	9.0	7.9	7.8	7.8	4.0	7.6	6.8
	Min.	5.2	5.9	5.0	3.0	5.4	5.0	2.8	4.8	3.1
June 4	Mean	9.8	9.8	8.8	8.3	8.8	8.6	6.4	8.5	7.2
	Max.	11.0	10.5	9.5	9.8	9.4	9.5	7.4	9.1	8.7
	Min.	8.5	9.0	7.5	6.5	8.1	7.4	5.8	7.5	4.8
June 6	Mean	13.7	11.1	9.2	9.5	8.6	8.1	5.1	7.7	5.4
	Max.	21.0	15.4	11.6	14.8	11.4	10.2	6.6	10.7	7.4
	Min.	6.4	6.3	4.7	3.6	4.9	4.3	3.3	4.6	3.0
June 8	Mean	14.3	12.5	9.8	10.5	9.8	8.8	6.2	8.9	6.2
	Max.	17.0	14.4	11.2	14.5	12.9	10.4	8.2	11.0	8.2
	Min.	9.8	9.4	6.5	6.0	7.4	5.9	5.1	6.4	3.8
June 9	Mean	14.1	12.9	10.5	10.7	10.3	9.5	7.1	9.6	7.3
	Max.	16.8	15.5	12.6	14.6	13.1	11.7	9.8	12.7	9.7
	Min.	9.5	9.5	7.0	6.6	7.8	6.6	5.6	7.2	4.5

Table 3.8 continued

Plot B		1" depth			2" depth			4" depth		
Date		H	I	D	H	I	D	H	I	D
June 11	Mean	17.0	14.3	12.0	12.8	11.6	10.9	8.3	10.7	8.1
	Max.	25.0	22.3	16.9	19.5	16.0	14.8	11.0	15.0	11.0
	Min.	10.6	9.8	8.8	7.0	7.9	7.8	6.5	7.9	6.9
June 16	Mean	12.2	11.5	10.2	10.4	10.2	9.8	8.7	9.8	9.0
	Max.	16.1	14.0	12.1	13.8	12.1	11.6	10.6	11.9	11.0
	Min.	10.1	10.8	9.7	8.6	10.2	9.5	8.3	9.8	9.0
June 18	Mean	12.8	11.6	10.9	11.2	10.8	10.7	9.7	10.5	9.9
	Max.	14.3	12.9	12.9	12.7	11.4	12.2	11.1	11.4	10.8
	Min.	10.7	10.1	9.5	9.0	9.9	9.5	8.6	9.6	9.4
June 23	Mean	16.9	14.4	12.8	12.8	11.0	11.2	9.1	10.5	9.3
	Max.	24.0	19.1	20.0	17.6	14.0	16.5	11.9	13.7	14.0
	Min.	8.1	7.6	6.8	6.5	6.7	6.7	6.1	6.9	6.5
June 25	Mean	16.0	14.2	12.8	13.1	11.9	12.0	10.4	11.4	10.5
	Max.	21.0	17.4	17.3	15.9	14.2	16.3	12.3	14.1	14.3
	Min.	10.1	10.5	9.1	8.5	9.2	9.2	8.3	8.8	8.2
June 27	Mean	14.6	12.2	10.8	11.8	10.0	10.0	9.3	9.7	8.9
	Max.	23.6	17.5	15.6	17.6	14.1	14.3	11.9	13.3	12.7
	Min.	9.0	9.2	8.4	7.9	8.9	8.2	8.0	8.8	8.2

Table 3.8 continued

Plot B		1" depth			2" depth			4" depth		
Date		H	I	D	H	I	D	H	I	D
July 2	Mean	19.7	17.1	15.1	16.7	13.9	14.0	13.4	13.7	12.4
	Max.	27.6	20.7	19.9	21.6	16.6	16.4	15.6	15.8	14.6
	Min.	12.6	11.8	11.4	10.9	11.4	11.0	10.7	11.0	10.5
July 6	Mean	14.6	12.8	11.7	12.7	11.5	11.1	11.1	10.8	10.3
	Max.	21.6	17.0	15.5	17.0	14.2	14.5	13.5	13.2	13.0
	Min.	12.0	11.6	10.5	10.6	10.8	10.4	10.5	10.5	10.1
July 8	Mean	18.7	15.8	13.4	15.7	13.2	12.6	12.2	11.9	11.2
	Max.	28.6	20.6	17.2	21.6	15.9	15.8	14.0	14.1	13.2
	Min.	10.6	10.0	9.4	9.3	9.5	9.0	9.3	9.6	9.4
July 10	Mean	22.5	19.5	17.0	19.6	17.3	15.9	15.3	15.7	14.3
	Max.	29.4	23.8	23.4	25.0	19.6	19.1	17.5	17.6	16.1
	Min.	15.5	14.1	13.4	13.4	13.2	12.9	13.1	13.3	12.5
July 16	Mean	19.1	18.4	17.2	18.2	17.9	16.8	17.5	17.6	16.3
	Max.	22.1	20.4	19.9	20.5	19.0	18.6	18.5	18.6	17.1
	Min.	16.8	16.5	15.9	16.3	16.7	15.7	16.6	16.7	15.7
July 20	Mean	17.2	16.5	15.6	16.4	16.0	15.2	15.7	15.5	14.6
	Max.	18.7	18.8	18.4	17.9	17.0	17.9	16.6	17.0	15.5
	Min.	15.6	14.8	13.9	14.8	14.8	13.7	15.0	14.6	13.5

A precise measure of the degree of cloud cover was the percentage of total possible bright sunshine during the day. The number of hours bright sunshine for each day at Prince Albert were taken from the 'Monthly Record' published by the Meteorological Service. Each daily figure was converted into a percentage of the total possible bright sunshine for that day and classified as follows:

Cloudy -- 0 to 30 per cent of the total possible bright sunshine
Part cloudy -- 31 to 70 per cent
Clear -- 71 to 100 per cent.

The daily sunshine records for Prince Albert were used throughout this report, but such records are not commonly available for other localities, and the equipment needed to record such data is expensive.

Alternatively, the daily cloud cover may be estimated by observation. During the summers of 1952, 1953, and 1954 five observations of cloud cover were taken daily at 0800, 1000, 1200, 1500, and 1800 hours, M.S.T. The amount of sky obscured by cloud was recorded in tenths, as 0-1 tenth, 2-6, 7-9, and 10 tenths. At the same time the cloud types were described following the U.S. Weather Bureau 'Manual of Cloud Forms' (1949). The most satisfactory method of summarizing the cloud cover for each day was to note the number of observations of each of the four degrees of cloud cover during the day. For example, the summaries for a day with (a) five observations of 0-1 tenth cloud cover, (b) four observations of 10 tenths and one observation of 7-9 tenths, and (c) three observations of 2-6 tenths and two of 7-9 tenths, would be as follows:

	Cloud Cover (tenths)			
	0 - 1	2 - 6	7 - 9	10
(a)	5	0	0	0
(b)	0	0	1	4
(c)	0	3	2	0

All types of cloud do not equally interfere with insolation so a correction for this factor was found to be necessary before the percentage bright sunshine could be estimated from these cloud cover summaries. The most satisfactory results were obtained by classing the degree of cloud cover one group lower than the actual observation when the clouds were entirely of a Cirrus type, e.g. cloud cover 7-9 tenths Cirrus would be summarized as 2-6 tenths.

Data on both bright sunshine and cloud cover were available for 322 days between April 15 and August 10 in 1952, 1953, and 1954. Each day was classed as clear, part cloudy or cloudy on the basis of its percentages of total possible bright sunshine. The relationship between the cloud cover summary and the percentage bright sunshine is shown in Table 3.9.

On the basis of the bright sunshine classification there were 90 cloudy, 110 part cloudy, and 122 clear days while the cloud cover classification gave 90 cloudy, 118 part cloudy, and 114 clear days. The X^2 test indicated that such differences could occur about 6 times in 10 due to chance. From the data presented in Table 3.9, the degree of insolation occurring during a given day may be estimated, within three broad groups, with an accuracy of about 90 per cent.

Table 3.9 Comparison of two methods of describing the amount of interference by cloud of insolation. Daily observations on cloud cover may be used to estimate the percentage of total possible bright sunshine.

Cloud Cover				Percentage total possible bright sunshine			Total days
1.0	0.7 - 0.9	0.2 - 0.6	0 - 0.1	0 - 30	31 - 70	71 - 100	
Cloudy							
5				39			39
4	1			13			13
4		1		4			4
3	2			12			12
3	1	1		11	2		13
2	3			6	3		9
Total Cloudy				85	5		90
Part Cloudy							
1		3	1	1	1		2
3		2			1		1
3		1	1		1		1
2	2	1		1	6		7
2	2		1		1		1
2	1	2			6		6
2	1	1	1		5		5
2		1	2		1		1
1	4			1	3		4
1		4			1		1
1	3	1		1	7	2	10
1	2	2			7	1	8
1	1	3			3		3
1	1		3		1		1
1		3	1		1		1
	5			1	6		7
	4	1			8		8
	4		1		1		1
	3	2			7		7
	2		3		1		1
	3	1	1		9	2	11
	2	3			5	4	9
	1	4			6	1	7
	3		2		1	1	2
1	1	1	2		1		1
2			3		1		1
1	2	1	1		1	1	2
1	1	2	1		3	3	6
	2	1	2		2	1	3
Total Part Cloudy				5	97	16	118

Table 3.9 continued

Cloud Cover 1.0	 0.7 - 0.9	 0.2 - 0.6	 0 - 0.1	Percentage total possible bright sunshine 0 - 30	 31 - 70	 71 - 100	Total days
Clear							
2		2	1			1	1
1		1	3			1	1
	2	2	1		3	4	7
	1	3	1		3	9	12
	1	2	2		1	11	12
	1	1	3			4	4
	1		4			1	1
		5			1	75	76
Total Clear					8	106	114
Grand Total				90	110	122	322

The days on which soil temperatures were measured fell into three cloud cover classes as follows:

	Per cent total possible sunshine	
Cloudy	0 - 30	May 27, June 4, 16, 18, July 20
Part cloudy	31 - 70	May 11, 15, 21, June 8, 9, July 6, 16
Clear	71 - 100	May 7, 14, 19, 26, June 6, 11, June 23, 25, 27, July 2, 8, 10

The soil temperature curves for May 19 and July 8 (Figs. 3.2 and 3.3) show the typical patterns on days when solar radiation was not obstructed by cloud. The differences between these two days represent the difference between early spring and midsummer. Aside from a general increase in temperature of 5 to 10° C, the relative warmth of the microtopographic locations changes, particularly in plot B. In this plot the depressions and intermediate locations were warmer than the hummocks in the early spring (e.g. May 19). Later in the season the warmest temperatures were

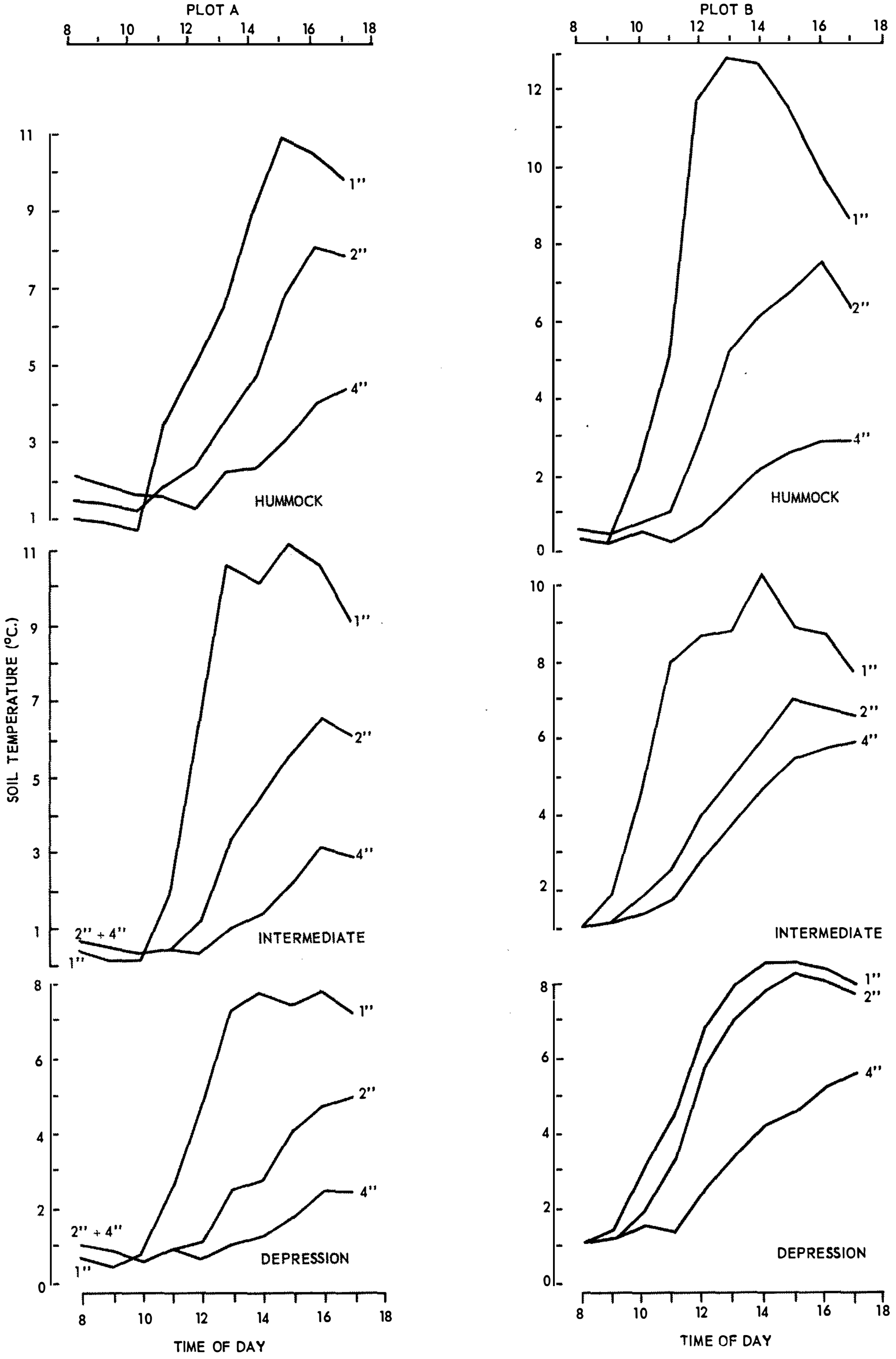


Figure 3.2 – Curves for soil temperatures in hummocks, intermediate locations and depressions in Plots A and B on May 19, 1953, a typical clear day in the spring. 1", 2", and 4" refer to the depth beneath moss surface. Each point on the graphs is the mean of three observations.

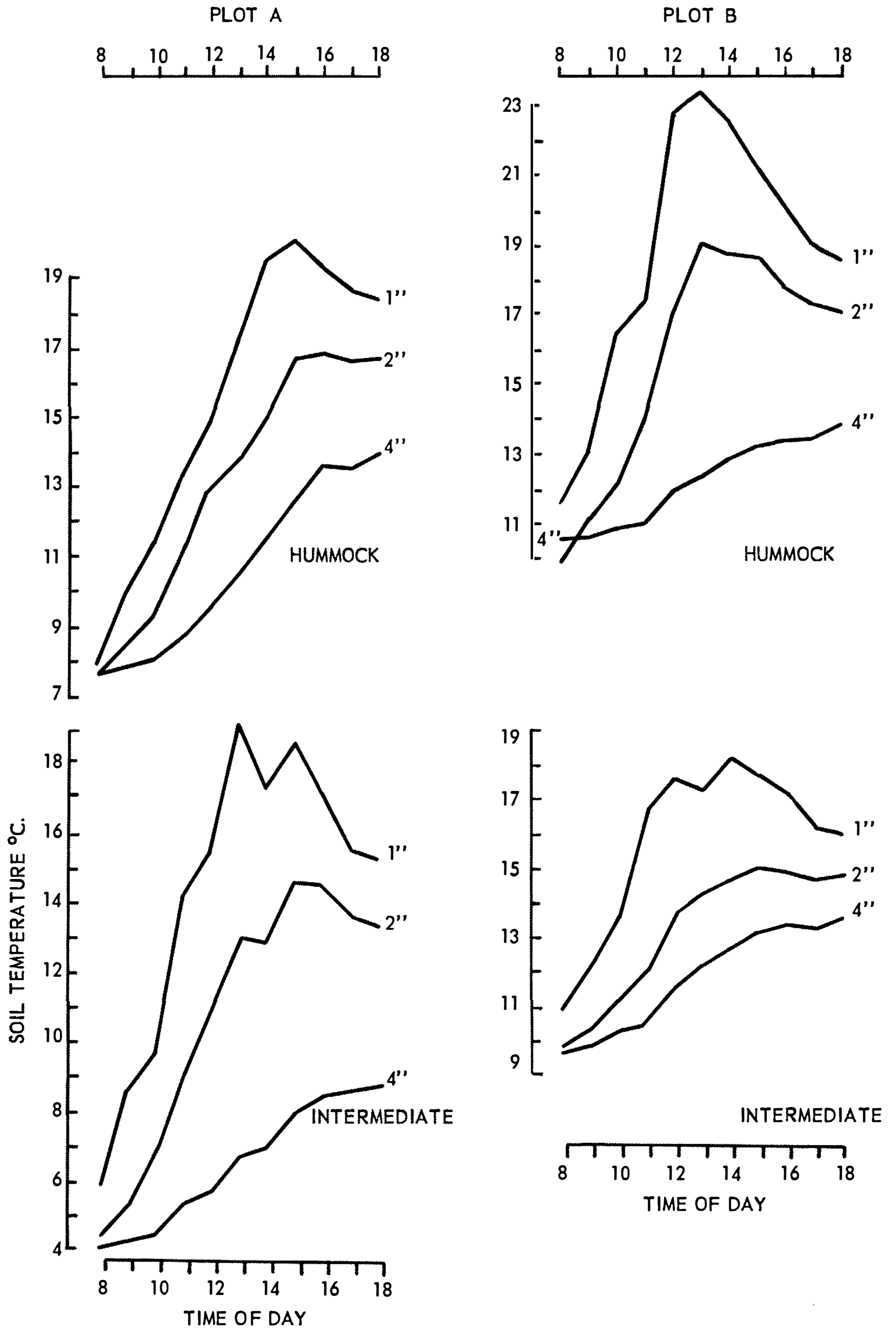


Figure 3.3 – Curves for soil temperatures in hummocks, intermediate locations and depressions in Plots A and B on July 8, 1953, a typical clear day in midsummer. 1", 2" and 4" refer to the depth beneath moss surface. Each point on the graphs is the mean of three observations.

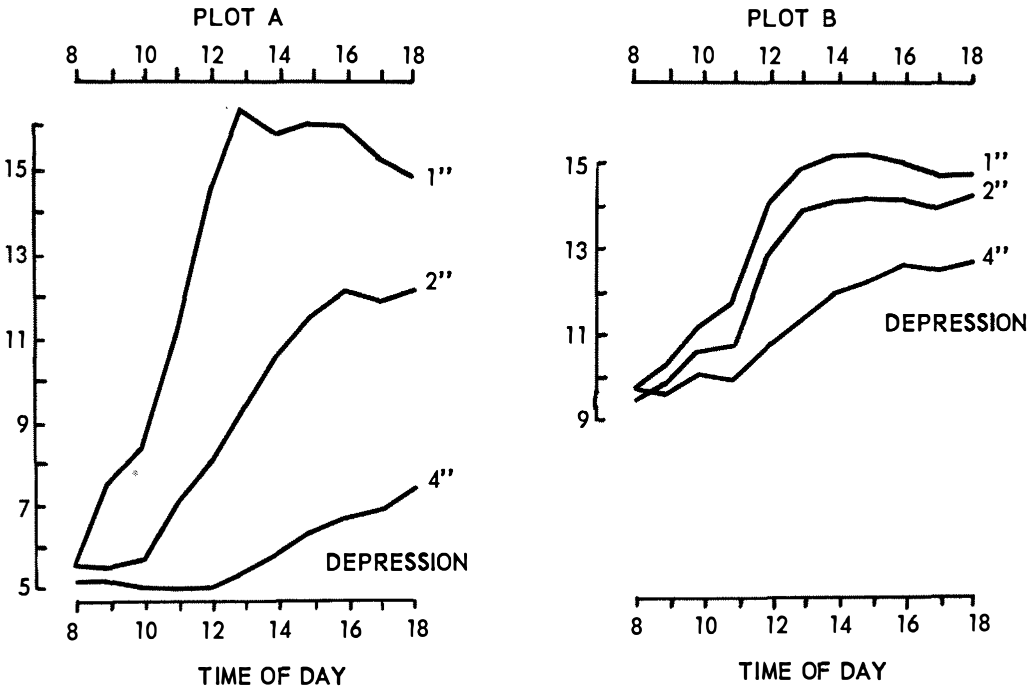


Figure 3.3 – Curves for soil temperatures in hummocks, intermediate locations and depressions in Plots A and B on July 8, 1953, a typical clear day in midsummer. 1", 2" and 4" refer to the depth beneath moss surface. Each point on the graphs is the mean of three observations.

recorded in the hummocks (e.g. July 8). In 1953 the reversal of location of the maximum temperatures occurred in early June. This phenomenon would tend to eliminate the differences in the effect of microtopographic location on the rate of development of the larch sawfly. Thus in the early spring development could be more rapid in the lower locations than in the hummocks while later in the season the reverse would occur.

The soil temperature curves for June 18 (Fig. 3.4) were typical of those recorded on cloudy days. The effects of intermittent cloudiness are discussed below.

3.4.2.1 Differences in soil temperature between plots, microtopographic locations and depths.

A comparison of soil temperatures within and between the two plots shows relationships that are modified by microtopography and depth below surface. In general, temperatures in the wet, pure tamarack stand, plot B, were warmer than the drier spruce - tamarack stand, plot A. This difference was smallest in the early spring and increased throughout the period of observation. Table 3.10 summarizes the differences between mean soil temperatures and indicates both this trend and the variability of its expression with differences in microtopography and depth. This relationship was reversed on May 3, apparently associated with a period of clear, warm weather that lasted from May 4 to May 8. On May 7 the maximum air temperature in the plots reached 30.5° C, the highest temperature recorded during the month of May. Following this warm spell a cold front from the northeast deposited 0.76 inches of precipitation on Prince Albert during the night of

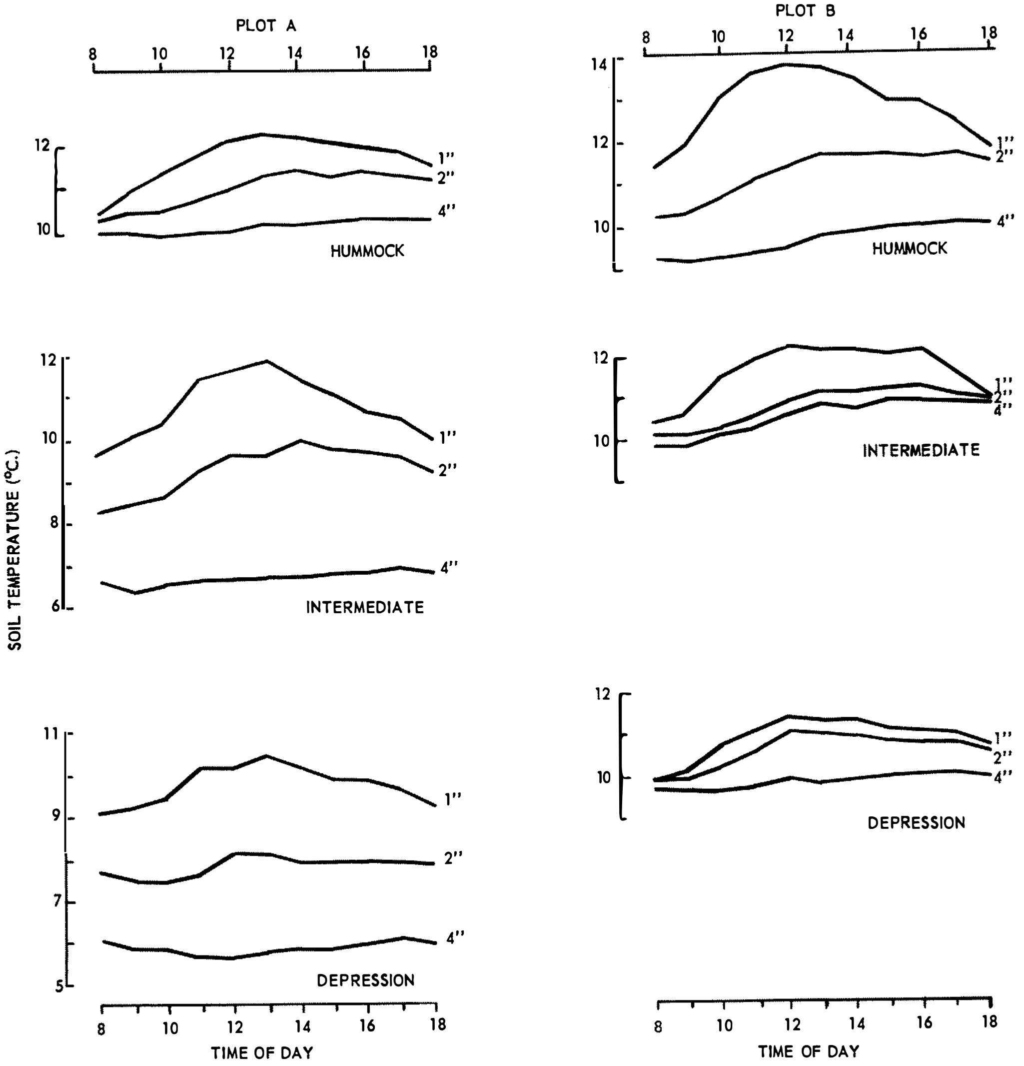


Figure 3.4 – Curves for soil temperatures in hummocks, intermediate locations and depressions in Plots A and B on June 18, 1953, a typical cloudy day. 1", 2" and 4" refer to the depth beneath moss surface. Each point on the graphs is the mean of three observations.

Table 3.10 Differences in ° C between the mean soil temperatures at different depths and microtopographic locations; temperature in plot B minus plot A.

Depth	1" depth			2" depth			4" depth			
Location	H	I	D	H	I	D	H	I	D	Average
May 7	-0.9	-3.5	1.7	-3.5	-4.0	5.1	-6.2	-2.5	3.2	-1.2
May 11	-0.2	0	0.4	-0.3	0	0.4	-0.4	0	0.2	0
May 14	0.7	0.2	0.1	0.9	0.9	1.8	-2.0	2.0	1.9	0.7
May 15	1.3	0.7	0.9	-0.3	1.6	2.8	-1.2	2.2	2.5	1.2
May 19	1.5	0.7	1.0	-0.1	1.2	2.5	-1.0	1.9	1.5	1.0
May 21	1.0	1.1	1.3	-0.6	1.6	3.0	-1.7	2.7	2.7	1.2
May 26	2.7	1.9	0.9	-0.8	2.4	3.0	-2.8	4.3	2.6	1.6
May 27	0.1	1.3	0.7	-1.3	1.9	1.5	-2.6	3.3	2.0	0.8
June 4	2.2	4.0	2.6	-0.2	2.5	2.0	-1.5	4.1	2.2	2.0
June 6	2.2	0	0.4	0.6	1.4	2.7	-1.1	4.1	2.7	1.4
June 8	0.5	-0.2	-0.6	-1.1	1.1	1.8	-2.8	4.1	3.0	0.6
June 9	0.5	0.2	0.1	-0.9	1.0	1.9	-2.3	4.1	3.0	0.8
June 11	0.8	-0.4	-0.5	-0.5	0.8	2.1	-2.3	4.2	3.3	0.8
June 16	-0.1	0.3	-0.3	-0.7	1.3	1.3	-1.2	3.6	3.3	0.8
June 18	1.1	0.8	1.1	0.2	1.5	2.8	-0.4	3.7	4.0	1.6
June 23	2.9	0.7	1.8	1.4	0.5	4.1	0.2	4.7	4.5	2.3
June 25	2.0	0.8	1.0	1.0	1.2	3.4	0.3	4.6	4.2	2.1
June 27	3.6	1.5	1.3	2.7	1.9	2.8	1.7	4.9	3.7	2.7
July 2	3.4	1.7	0.7	2.3	2.1	3.3	1.5	6.0	5.2	2.9
July 6	2.9	1.2	1.0	2.6	2.4	2.9	2.5	4.7	4.6	2.8
July 8	4.2	1.6	0.5	3.5	2.4	3.6	2.5	5.4	5.3	3.2
July 10	1.8	0.4	-0.9	0.7	1.4	2.4	0.1	5.5	5.4	1.9
July 16	2.9	2.9	1.6	2.9	4.2	3.1	3.2	7.0	4.8	3.6
July 20	1.7	2.3	1.7	2.2	3.9	3.4	3.1	6.4	5.3	3.3
Average	1.6	0.8	0.8	0.4	1.5	2.7	-0.6	3.8	3.5	1.6

May 9-10 and left 1.2 inches of snow in the plots. When soil temperatures were measured on May 11 one inch of snow remained and apparently was responsible for the absence of any temperature difference between the plots. The significance of the differences in soil temperature between plots was tested for each day by analysis of variance. These analyses indicated highly significant differences in soil temperature between plots for every day except May 11.

The generally higher temperatures in plot B can probably be attributed to the differences in the forest canopy. Kittredge (1948) notes that the forest canopy may influence soil temperatures through its effect on solar radiation, surface radiation, air temperature, duration of snow cover, and evaporation. It already has been noted that snow persisted later in plot A and Turnock (1955) found differences in air temperature between the two plots. It seems likely that the major influence of the canopy on the soil temperatures is through the interception of solar radiation. Early in the season, until June 15, the tamarack were leafless or only partially foliated (Turnock, 1955). Thus the solar radiation was intercepted only by the bare or partially foliated branches of tamarack in plot B, while in plot A, 80 per cent of the canopy was composed of dense black spruce crowns. Although no measurements of the intensity of radiation at the soil surface were made, the incidence of full sunlight, partial shade, and full shade at the ground surface at each set of thermocouples was recorded each time temperature measurements were made. A total of 1152 observations were taken in each plot. The differences in the interception of direct sunlight by the canopies in the two plots is illustrated by the following percentages:

	Full sunlight	Partial shade	Full shade
Plot A	16.5	39.5	46.0
Plot B	22.7	58.5	18.8

These figures show that the degree of crown cover was about equal in the two plots but the crown in plot A was much denser.

The relationship between soil temperatures and the different microtopographic locations and depths was not the same in the two plots. The negative values for differences between plots at certain locations and depths (Table 3.10) indicate this. Some of these differences can be related to factors associated with the high water table in plot B as opposed to plot A. Soil saturated with water has a higher specific heat and thermal conductivity than dry soil (Keen, 1931). Kittredge (1948: 157) gives the specific heat of dry and saturated organic matter by volume as 0.15 and 0.90 respectively. Geiger (1950: 141) states that peat soils have extreme daily variations and low thermal conductivity despite their high water content. It is difficult to reconcile these statements with the temperatures recorded on the hummocks in plots A and B. Although the water table lay much closer to the tops of the hummocks in plot B the temperature extremes at the 1-inch depth average 1.2° C greater than in plot A. This is apparently related to the higher intensity of solar radiation in plot B. In addition, the 4-inch depth on the hummocks in plot A was warmer than the corresponding depth in plot B until June 23 (Table 3.10). It seems unlikely that this difference was due to a difference in the thermal conductivity of fibrous peat derived from mosses (plot A) versus fibrous peat from Carex (plot B) although no data are available. The difference may be due to the greater amount of heat that would be required to melt ice that formed under the hummocks in plot B during the winter. In plot A the water level was far enough beneath the surface so that it froze only slightly. In plot B the water table froze near the surface and the frozen subsoil under the hummocks was sufficient to offset the effects of greater solar radiation and higher air temperatures.

The differences in soil temperatures between microtopographic locations and depths within plots were also tested by analysis of variance. The 'F' values for differences in soil temperature due to the effects of 'Locations' and 'Depths' were significant to the .01 level for all days in both plots. Significant (.01) differences were also calculated for the 'Time' factor except on June 4 in plot A. The 'F' values for interaction between these factors were more variable (Table 3.11). Non-significance in the 'F' values for 'Depth x Location' and 'Depth x Time' was associated with cloud cover. In plot B a significant value for interaction between 'Location x Time' occurred only on May 11, when the ground was snow-covered and on June 11. In plot A significant values for 'L x T' were more common, and were associated with clear skies. The actual differences in the daily mean temperatures between microtopographic locations are given in Tables 3.12 and 3.13. In both plots there was a general decrease in the average soil temperature from the hummocks down to the depressions but the expression of this tendency varied between the plots and in relation to environmental conditions. In plot A, as shown in Table 3.12, the hummocks were generally warmer than the intermediate locations, particularly at the 2- and 4-inch depths. At the 1-inch depth the difference was much less marked and this relationship was absent or reversed on four occasions during May. These exceptions were associated with low minimum air temperatures the previous night. As the soil at the intermediate locations was moister than on the hummocks, its specific heat would be greater and it would cool more slowly than the drier soil on the hummocks. Later in the season, when the intermediate locations were

Table 3.11 'F' values for interactions between depths (D), locations (L) and time of day (T) in soil temperatures in plots A & B.

	Plot A			Plot B		
Date	D x L	D x T	L x T	D x L	D x T	L x T
May 7	1.29	**2.23	1.43	**19.72	*1.83	0.-
May 11+	**6.85	0.-	1.35	**4.67	0.-	**4.27
May 14	**10.60	**8.32	1.12	**29.23	**2.49	0.-
May 15	**4.23	**13.34	*1.66	**21.77	**4.84	0.-
May 19+	**15.35	**3.19	**1.83	**13.98	**7.22	0.-
May 21+	**5.75	**9.82	**2.01	**22.77	**5.02	0.-
May 26	**7.40	**8.65	*1.82	**49.88	**5.92	0.-
May 27	**9.56	1.51	0.-	**28.39	1.52	0.-
June 4	**11.31	0.-	0.-	**18.30	0.-	0.-
June 6	**3.31	**5.92	*1.81	**40.15	**4.98	1.44
June 8	**6.57	**2.56	0.-	**53.51	1.46	0.-
June 9	**6.63	1.33	0.-	**46.15	**2.76	0.-
June 11	**3.23	**3.43	0.-	**55.01	**4.58	*1.86
June 16	**11.88	1.42	0.-	**28.39	**2.86	0.-
June 18	**15.53	0.-	0.-	**29.98	1.74	0.-
June 23	**7.39	**6.69	**2.93	**17.57	**2.75	0.-
June 25	**8.62	**3.99	1.09	**17.72	*1.72	0.-
June 27+	**6.56	**7.58	**2.29	**18.60	**4.47	1.40
July 2	**7.00	**4.24	0.-	**24.17	**4.63	1.40
July 6+	**8.47	**3.68	0.-	**13.87	**3.88	1.28
July 8	**5.38	**5.18	1.11	**23.04	**4.82	2.15
July 10	**8.61	**2.57	0.-	**25.48	**3.82	1.29
July 16	**15.35	1.28	0.-	*2.92	*1.78	0.-
July 20	**5.66	0.-	0.-	1.65	0.-	0.-

+ Total degrees of freedom = 270, all others had 297 degrees of freedom

Table 3.12 Differences in soil temperatures at the same depth between microtopographic locations in plot A.

	1" depth		2" depth		4" depth		All depths	
	H - I	I - D	H - I	I - D	H - I	I - D	H - I	I - D
May 7	0.3	5.8	1.8	5.0	1.5	4.8	1.2	5.2
May 11	0.2	0	0.3	0	0.4	0	0.3	0
May 14	-0.4	1.6	1.1	0.6	1.6	0	0.8	0.7
May 15	0	1.6	1.2	0.5	1.1	-0.1	0.8	0.7
May 19	-0.2	1.2	0.9	0.4	1.0	-0.1	0.6	0.5
May 21	0	1.5	1.6	0.3	1.8	0.3	1.1	0.7
May 26	0.3	1.3	2.2	0.2	3.2	-0.1	1.9	0.5
May 27	0.9	0.5	2.1	-0.3	2.9	-0.3	2.0	0
June 4	1.3	0.1	2.2	-0.3	3.5	-0.6	2.3	-0.3
June 6	0.4	2.3	1.7	1.8	2.6	0.9	1.6	1.7
June 8	1.1	2.3	2.9	1.7	4.2	1.6	2.7	1.9
June 9	0.9	2.3	2.3	1.7	3.9	1.2	2.4	1.7
June 11	1.5	2.2	2.5	2.0	4.1	1.7	2.7	2.0
June 16	1.1	0.8	2.2	0.4	3.7	0.5	2.3	0.6
June 18	0.9	1.0	1.7	1.4	3.3	0.9	2.0	1.1
June 23	0.3	2.7	0.9	3.4	3.1	1.0	1.4	2.4
June 25	0.6	1.6	1.4	2.1	3.3	0.5	1.8	1.4
June 27	0.3	1.2	1.0	0.9	2.8	-0.4	1.4	0.6
July 2	0.9	1.0	2.6	1.1	4.2	0.5	2.6	0.9
July 6	0.1	0.9	1.0	0.9	2.5	0.4	1.2	0.7
July 8	0.3	1.3	1.4	1.8	3.2	0.6	1.6	1.2
July 10	1.6	1.2	2.2	2.4	5.0	1.3	2.9	1.6
July 16	0.7	-0.1	1.6	0	3.7	-0.9	2.0	-0.3
July 20	1.3	0.3	2.1	0.3	3.5	-0.3	2.3	0.1
Average	0.6	1.4	1.7	1.2	2.9	0.6	1.7	1.1

Table 3.13 Differences in mean soil temperatures at the same depth between microtopographic locations in plot B.

	1" depth		2" depth		4" depth		All depths	
	H - I	I - D	H - I	I - D	H - I	I - D	H - I	I - D
May 7	2.9	0.6	2.3	-4.1	-2.2	-0.9	1.0	-1.5
May 11	0	-0.4	0	-0.4	0	-0.2	0	-0.3
May 14	0.1	1.7	-0.7	-0.3	-2.4	0.1	-1.0	0.5
May 15	0.6	1.4	-0.7	-0.7	-2.3	-0.4	-0.8	0.1
May 19	0.6	0.9	-0.4	-0.9	-1.9	0.3	-0.6	0.1
May 21	-0.1	1.3	-0.6	-1.1	-2.6	0.3	-1.1	0.2
May 26	1.1	2.3	-1.0	-0.4	-3.9	1.6	-1.3	1.2
May 27	-0.3	1.1	-1.1	0.1	-3.0	1.0	-1.5	0.7
June 4	0	1.0	-0.5	0.2	-2.1	1.3	-0.9	0.8
June 6	2.6	1.9	0.9	0.5	-2.6	2.3	0.3	1.6
June 8	1.8	2.7	0.7	1.0	-2.7	2.7	-0.1	2.1
June 9	1.2	2.4	0.4	0.8	-2.5	2.3	-0.3	1.8
June 11	2.7	2.3	1.2	0.5	-2.4	2.6	0.5	1.8
June 16	0.7	1.3	0.2	0.4	-1.1	0.8	-0.1	0.8
June 18	1.2	0.7	0.4	0.1	-0.8	0.6	0.3	0.5
June 23	2.5	1.6	1.8	-0.2	-1.4	1.2	1.0	0.9
June 25	1.8	1.4	1.2	-0.1	-1.0	0.9	0.7	0.7
June 27	2.2	1.4	0.8	0	-0.4	0.8	0.9	0.7
July 2	2.6	2.0	2.8	-0.1	-0.3	1.3	1.7	1.1
July 6	1.8	1.1	1.2	0.4	0.3	0.5	1.1	0.7
July 8	2.9	2.4	2.5	0.6	0.3	0.7	1.9	1.2
July 10	3.0	2.5	2.3	1.4	-0.4	1.4	1.6	1.8
July 16	0.7	1.2	0.3	1.1	-0.1	1.3	0.3	1.2
July 20	0.7	0.9	0.4	0.8	0.2	0.9	0.4	0.9
Average	1.4	1.5	0.6	0	-1.5	1.0	0.2	0.8

drier, the low minimum air temperatures recorded on June 23, June 27, July 6 and July 8, merely reduced the difference between the two locations. The relationship between intermediate locations and depressions was less consistent, particularly at the 4-inch depth. As the depressions received less direct sunlight than the higher locations they would tend to be colder. But this tendency may be partially overcome at the 4-inch depth by the more rapid penetration of heat through moist peat than through dry peat. The occasions when the depressions were warmer than the intermediate locations were associated with rainfall within the previous 24 hours, except on May 15 for which there is no obvious explanation.

In plot B, as shown in Table 3.13, the relationship between soil temperature and microtopography was more complex. At the 1-inch depth the temperatures were generally highest on the hummocks and lowest in the depressions. The exceptions can be related to low minimum air temperatures and rainfall as in plot A. At the 2-inch depth, on the average, there was no difference between the intermediate locations and the depressions while the hummocks were only slightly warmer. at the 4-inch depth, on the average, the highest temperatures were found at the intermediate locations and the lowest on the hummocks. This situation appears to be related to the high water table. The relationship of ice under the hummocks to low temperatures at the 4-inch depth has already been discussed. The differences in temperatures at the 4-inch depth between intermediate locations and depressions may be related to a different thermal conductivity between the saturated fibrous peat at the intermediate locations and saturated limnic peat in the depressions.

When the data were grouped regardless of location, the highest temperatures in both plots were at the 1-inch depths and the lowest at the 4-inch depths. In plot A the average reduction in temperature from both the 1 to 2 and from the 2 to 4 inch depths was 2.4° C. The greatest difference between depths, 3.0° C, was recorded at the intermediate locations and the least, 1.8° C, on hummocks. In plot B the average reduction was 1.9° and 1.7° C, with differences of 2.9° and 2.8° on hummocks, 2.2° and 0.7° at intermediate locations and 0.7° and 1.7° C in depressions. The small differences between the 2- and 4-inch depths at intermediate locations and the 1- and 2-inch depths in depressions probably reflected the high conductivity of the wet moss just above the water table.

3.4.2.2 Effect of environmental factors on soil temperatures.

The soil temperatures recorded in this study showed the effects of snow cover, precipitation, cloudiness, and the intensity of solar radiation. The storm on the night of May 9-10, left snow which remained until May 13. The soil temperatures recorded on May 11, when one inch of snow covered the ground, averaged 0.2° C in both plots and showed less variability than temperatures under the winter snow. This may have been due to the damping effect of the heavy rain preceeding the snowfall. On May 11 the maximum air temperature was 6.1° C in plot A and 7.2° C in plot B. The mean air temperatures during the 11 hour period when soil temperatures were recorded were 3.6° and 3.8° C, respectively. Therefore, on the basis of a single day's observation, it appears that soil temperatures in both types of bog forest reamin slightly above 0° C, regardless of air temperature, when the soil surface is covered by spring snow.

The amount of cloud cover in the sky affects soil temperatures by reducing heating by solar radiation and loss of heat through surface radiation. In California, Smith (1929) noted that sudden changes in cloudiness and wind direction and velocity were reflected in soil temperature to a depth of at least three inches when these conditions endured for as short a period as 10 minutes. This conclusion applied to soil temperatures under a surface kept free of all vegetation. In the bog forests the effects of changes in wind direction and velocity could not be discerned in the data and the effects of brief changes in cloudiness were obscured by the vegetative cover, particularly the forest canopy. In general, periods of cloudiness under 30 minutes had no noticeable effect on the air or soil temperatures. The soil temperature curves at the 1-inch depth in plot B for June 23 show a slight effect of 31 minutes of cloudiness. The differences in forest canopy between the two plots had a discernable effect on this relationship. The air and soil temperatures in plot B were affected on many occasions when the denser black spruce canopy in plot A obscured the effects of cloudiness. On July 16, as shown in Fig. 3.5, bright sunshine between 1100 and 1200 hrs. followed by 60 minutes of shade caused a rise in both air and soil temperatures followed by a general fall. In plot B this rise and fall occurred at the 4-inch depth at the same time as at the 1- and 2-inch depths. In plot A, although the response at the 1-inch depth was greater than in plot B, at the 4-inch depth the increase in temperature was barely noticeable and the fall was deferred until 1400 hrs. On June 25, cloudy periods were less prolonged and a period of cloud from 1520 to 1610 affected only the air temperature and the

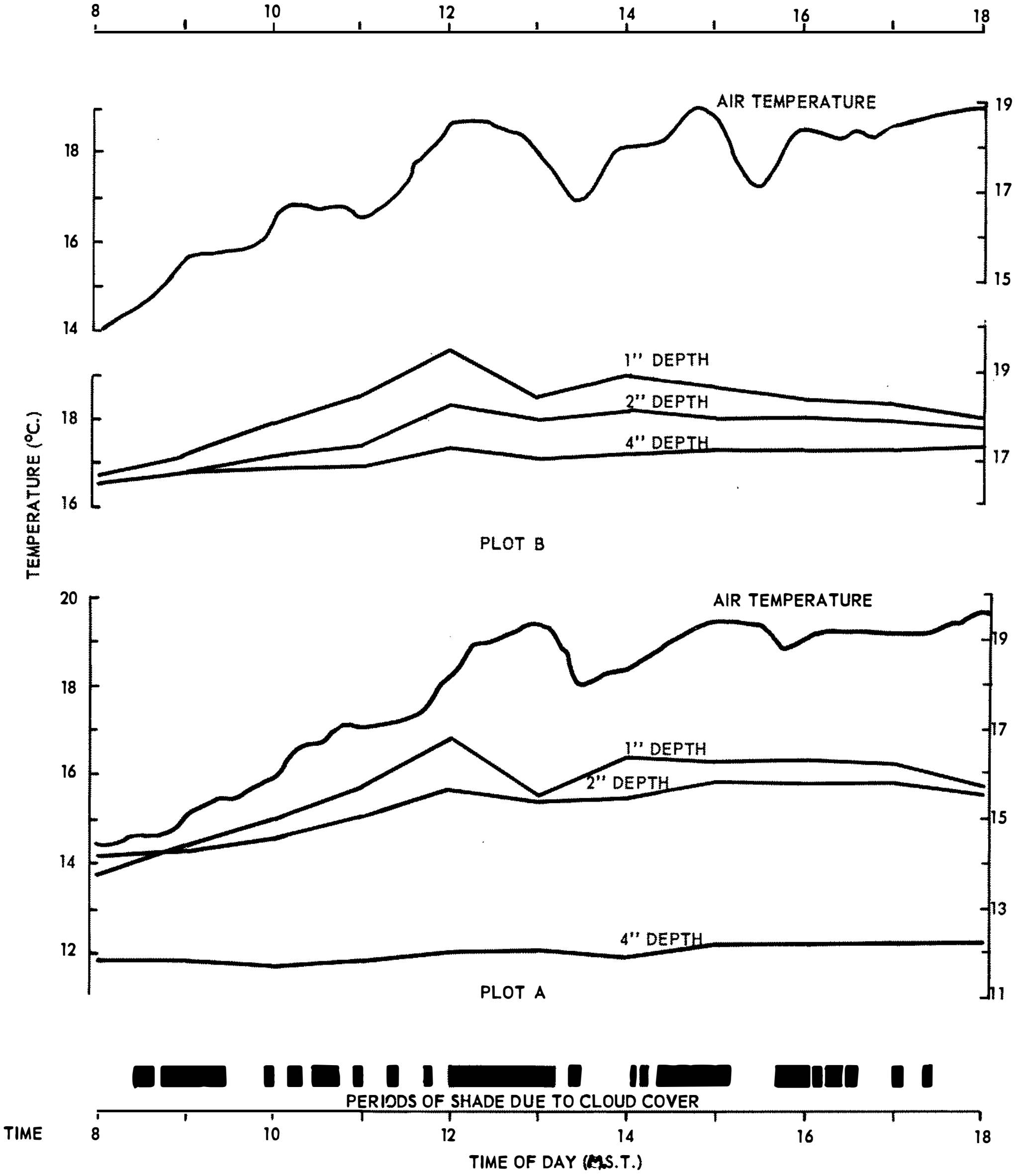


Figure 3.5 – Effect of intermittent cloud cover on air and soil temperatures in Plots A and B. July 16, 1953.

soil temperature at the 1-inch depth in plot B. In plot A the effect on the air temperature was slight and no effects on the soil temperatures were noted.

A comparison of air and soil temperatures at the 1-inch depth in plot B on May 19 and May 21 illustrates the effects of heavy cloud after 1300 on the temperature curves. On May 19 solar radiation was not obstructed by cloud while on May 21 the sky was clear till 1000 hrs., then cumulus and stratocumulus clouds increased in amount until 1254, after which the sun was obscured except for 5 minutes at 1500 hrs. Fig. 3.6 shows that on May 19 the air temperature rose steadily from 2.5° at 0800 hrs. to 10.5° C at 1600 hrs., and the 1-inch soil temperature from 0.8° C to 10.5° C at 1400 hrs. On May 21 the air temperature was 8.5° C at 0800 and rose to 16.1° C and the 1-inch soil temperature rose from 1.3° C to 10.2° C by 1300 hrs. After 1300 both air and soil temperatures fell steadily. The heavy cloud cover caused both air and soil temperatures at the 1-inch depth to reach their maxima earlier than on the similar day without clouds. On May 14 cumulus clouds between 1200 and 1415 depressed air and soil temperatures at the 1-inch depth and subsequent clearing was correlated with slight rises in both air and soil temperatures.

In addition to lowering soil temperatures, increased cloud cover decreased the mean difference in soil temperatures between plots, depths, and microtopographic locations. The days on which soil temperatures were measured were divided into three classes on the basis of the percentage of the total possible bright sunshine recorded during

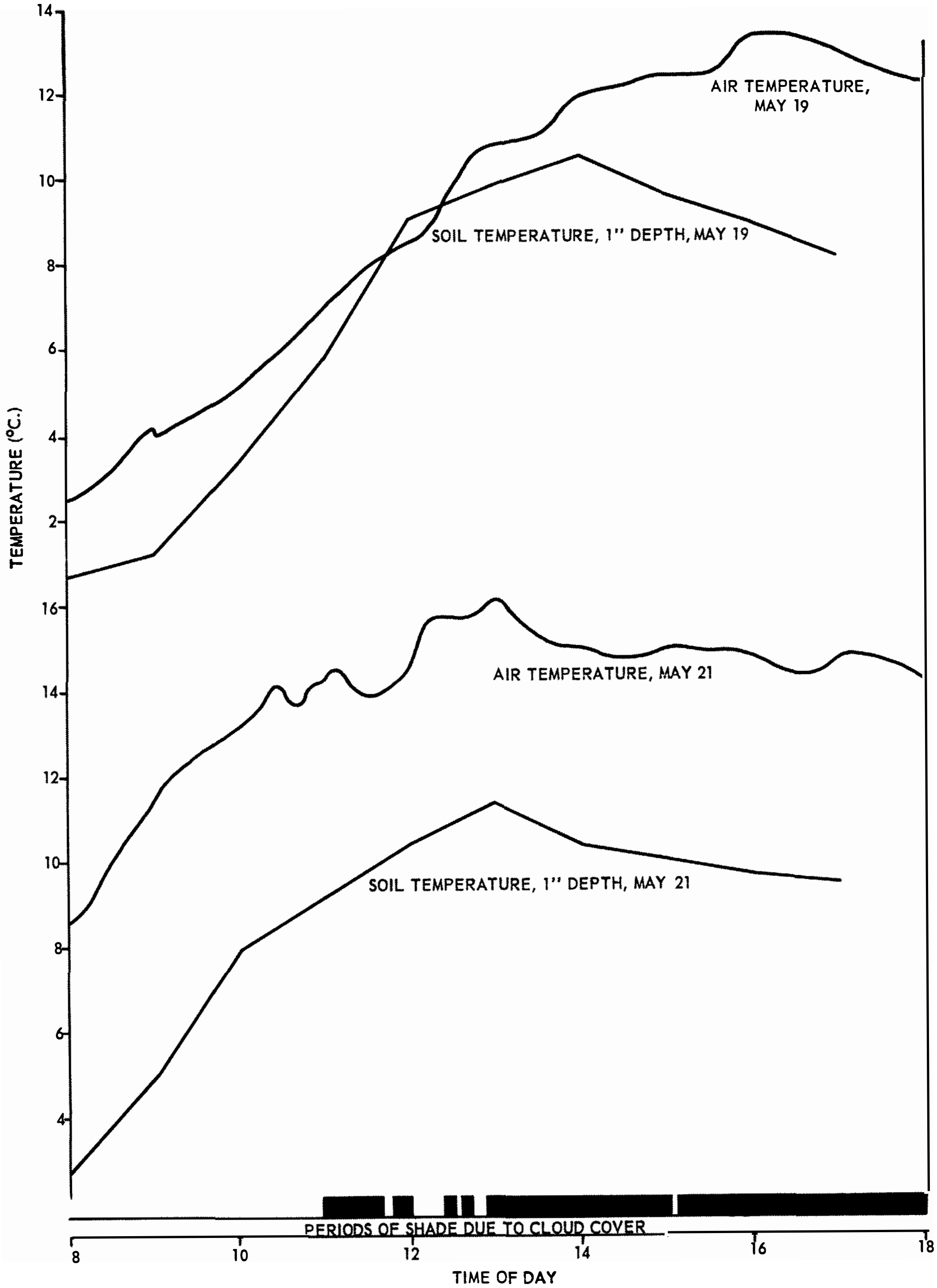


Figure 3.6 – A comparison of air and 1-inch depth soil temperatures in Plot B on May 19, a clear day, and on May 21, 1953, a day with afternoon cloudiness.

each day by the Meteorological Station at Prince Albert Airport. The three classes and the number of days falling in each class were:

0 - 30 per cent, 5 days
31 - 70 per cent, 6 days
71 - 100 per cent, 11 days

The records taken on May 7 and May 11 were not included in these calculations because the soil temperatures on these two days were aberrant due to the early heat wave on May 7 and the snow cover on May 11. The mean difference (plot B minus plot A) between plots at different depths and microtopographic locations in relation to the percentage bright sunshine was:

	Depth (all locations)			Microtopographic Location (all depths)		
Per cent sunshine	1"	2"	4"	Hummock	Intermediate	Depressi
0 - 30	1.5	1.7	2.3	0.2	2.7	2.2
31 - 70	1.1	1.7	2.4	0.5	2.4	2.4
71 - 100	1.2	1.8	2.6	1.1	2.2	2.2

The most significant variation appears in the differences between the temperatures on hummocks. The effect of cloud cover is less pronounced at the other locations, possibly due to the higher specific heat of moist soil, and is obscured by this factor when the data are grouped by depth below the surface.

Within plots increased cloudiness had a more pronounced effect. The decrease in the mean difference in temperatures between the 1- and 2-inch depths and between the 2- and 4-inch depths was:

	Plot A		Plot B	
Percentage sunshine	1" - 2"	2" - 4"	1" - 2"	2" - 4"
0 - 30	1.4	1.9	1.0	1.0
31 - 70	2.4	2.3	1.9	1.6
71 - 100	2.9	2.9	2.3	2.0

The difference between depths increases directly with solar radiation in both plots.

Cloud accompanied by rain had a pronounced effect on both air and soil temperatures. On July 2, .02 inches of rain fell between 1425 and 1515 hrs., during a period of strong cumulus and cumulonimbus activity on an otherwise clear day. Fig. 3.7 shows the relationship between the cloudy period with rain and the average soil temperature curves for the three depths and the air temperature in both plots on this day. In addition to the immediate effect of rain on soil temperatures; there is a continuing effect due to an increase in soil moisture. Wollny (1876) indicated that a high moisture content lowered the maximum and mean soil temperature and slightly raised the minimum. Li (1926) stressed the importance of this relationship in explaining soil temperatur phenomena. This effect of rainfall through raising the soil moisture content was less important in the bog forest than in drier sites. Rainfall had no noticeable effect on the differences in soil temperature between the plots but reduced the differences between depths within the plots. As shown below the mean difference between depths on days with rain was smaller than on days without rain. Days without rain which had rainfall the previous day had intermediate mean differences.

		Mean difference between depths			
		Plot A		Plot B	
Rainfall	No. of days	1" - 2"	2" - 4"	1" - 2"	2" - 4"
same day	5	1.7	2.1	1.1	1.1
day before	6	2.4	2.4	1.9	1.5
nil	11	2.8	2.6	2.2	2.0

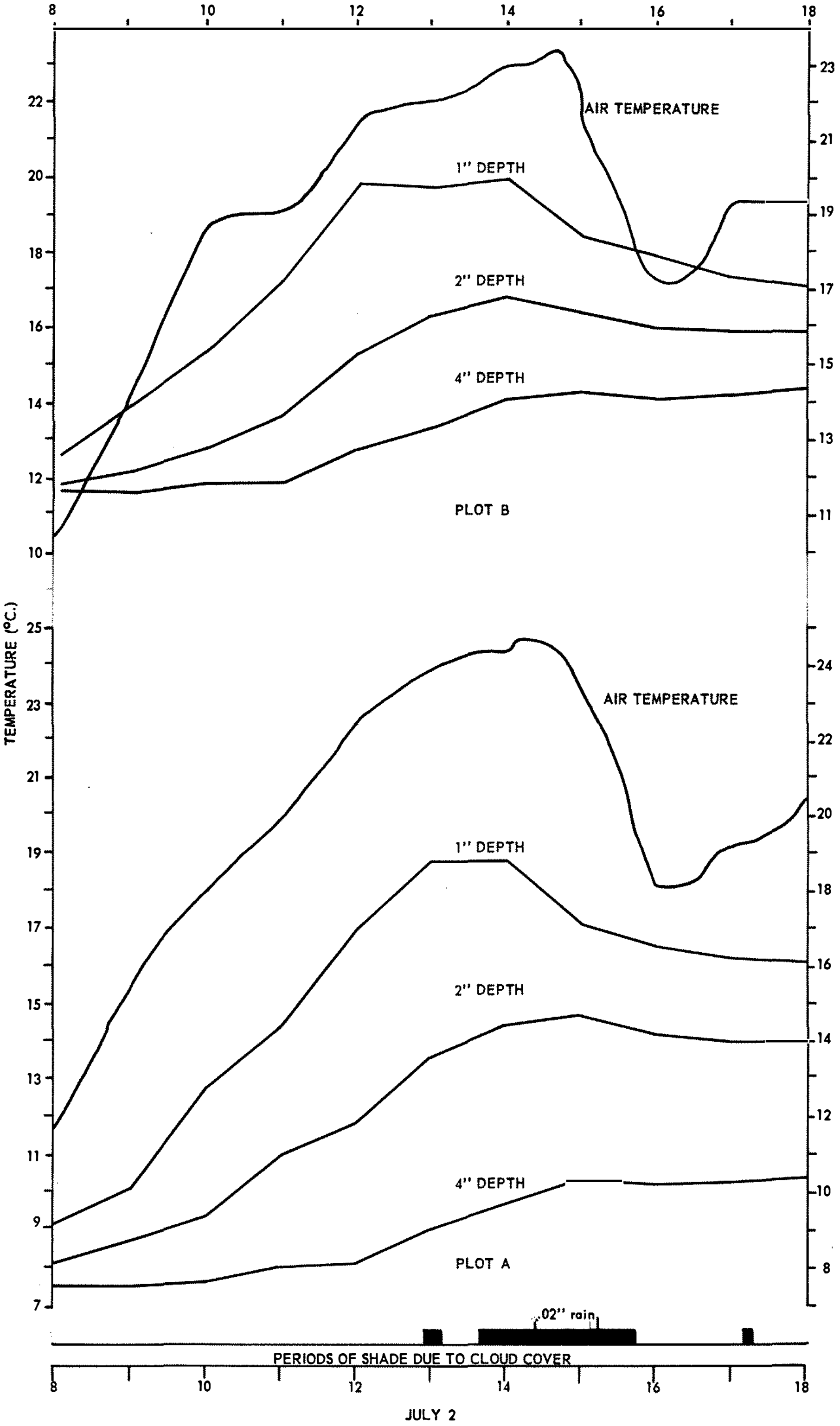


Figure 3.7 – Effect of a brief period of cloudiness and rain on air and soil temperatures in Plots A and B July 2, 1953.

4. Relationship between emergence patterns of larch sawfly and soil temperatures.

The previous section gave some information on the soil temperatures encountered by larch sawfly cocoons at different locations in two different site types. In addition, data were collected on the seasonal pattern of larch sawfly emergence from hummocks, intermediate locations and depressions in the two plots. These records, together with information on the distribution of larch sawfly cocoons beneath the soil surface, were used in an attempt to determine if any relationship existed between larch sawfly emergence and the accumulation of thermal units of soil temperature.

The distribution of cocoons beneath the surface of hummocks, intermediate locations and depressions was investigated by examining soil samples. These samples were 1/2-square-foot in surface area and 9 inches deep (except where the water table or limnic peat occurred at less than 9 inches). The samples were sectioned horizontally at the 1-, 3-, 5-, 7-, and 9-inch depths. Each section was examined and the number of cocoons recorded. Each microtopographic location was represented by three samples from plot A. In plot B four samples were taken from both the hummocks and intermediate locations but the depressions were submerged and were not sampled. In plot A limnic peat occurred 1 to 3 inches beneath the surface of the depressions. On June 10, when the samples were taken, the water table in plot A was 3 inches beneath the surface of the depressions, and 7 to 10 inches beneath the intermediate locations. In plot B the water table was 7 to 9 inches beneath the hummocks, and 3 to 5 inches beneath the intermediate locations. Table 4.1 gives the percentage distribution of cocoons at different depths for each microtopographic location. The cocoons found in these samples were the accumulation of several years. The annual distribution would vary with fluctuations in water table, soil moisture and soil temperature.

Table 4.1 Distribution of larch sawfly cocoons beneath the ground surface at different microtopographic locations in plots A and B. Percentage of the location total is given for each depth, based on three samples per depth in plot A and four samples per depth in plot B.

	Depth beneath soil surface (inches)					Total
	0 - 1	1 - 3	3 - 5	5 - 7	7 - 9	cocoons
Plot A						
Hummocks	24	41	22	12	0*	300
Intermediate	17	72	10	2	-	194
Depressions	33	67	--	--	-	168
Plot B						
Hummocks	44	39	9	4	4+	23
Intermediate	3	63	34+	-	-	38

* Based on 1 sample.
\+ Based on three samples.

4.1 Larch sawfly emergence in 1953 and 1954.

Data on the adult emergence patterns were collected from pyramidal, open-bottomed screen cages (Fig. 4.1) placed on the ground in tamarack stands where larch sawfly cocoons were present. Each cage covered 2 sq. ft. of ground surface. The cages were examined every second day and all adult sawflies on the screen or ground vegetation inside the cages were counted and removed. An improved model of this cage was described by Turnock (1957). Ten cages were used in each plot in 1953 and 20 in 1954.

The effectiveness of these cages was tested during the summer of 1954 at Prince Albert, and at the Whiteshell Field Station, Manitoba, in co-operation with J. A. Muldrew. Cages were placed on typical bog forest ground surfaces where larch sawfly cocoons were not present. A known number of freshly emerged larch sawfly adults were introduced into each cage and at daily or twice daily intervals following these introductions the cages were examined. All adults visible on the screen and ground vegetation inside the cages were counted but the cages were not lifted to search the ground surface. Table 4.2 shows the results of these observations. After two days from 77 to 82 per cent of the adults still could be seen. As the sampling cages were lifted and the ground vegetation examined closely, a higher degree of recovery can be assumed in them than in the experimental cages. Higher counts were made in the experimental cages in the afternoons than in the mornings, indicating that the adults may move down into the moss at night and upward as the temperature rises. The adults disappeared more quickly

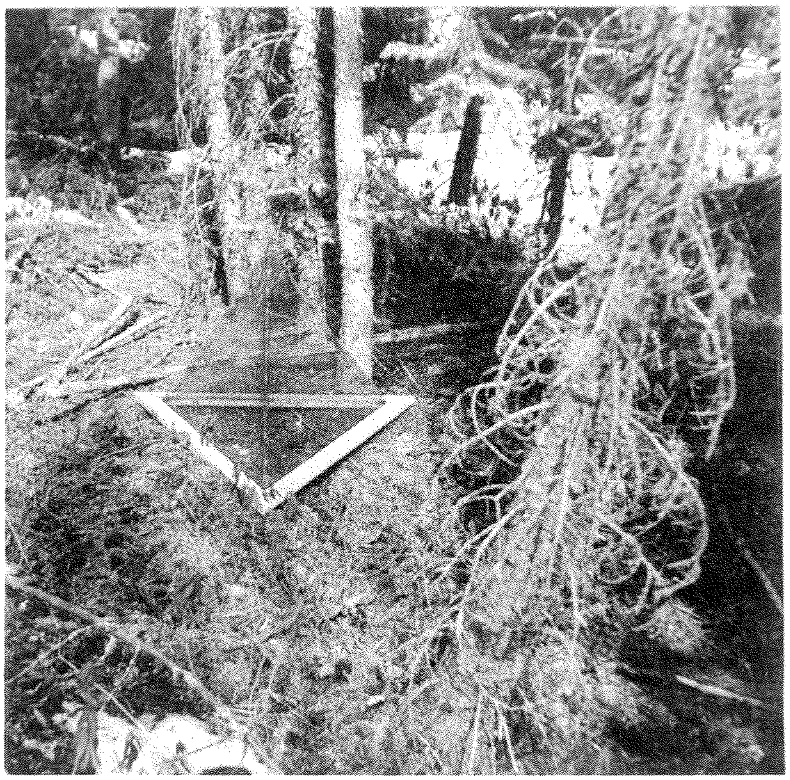


Figure 4.1 – Screen emergence cage used to collect larch sawfly adults emerging from the ground. Collecting area is two square feet.

Table 4.2 Number of adults observed in emergence cages up to four days after being released in the cages. Adults were placed in cages over sphagnum moss (A) at 1500 hrs. on day 0, in cages over a needle surface (B) at 1100 hrs. on day 0.

Day	0		1		2		3	4
Hour	1500	1900	0730	1300	1000	1300	1300	1230
Cage A 1	5	4	2	3	5	5	3	3
A 2	6	6	3	3	3	4	2	2
A 3	6	4	3	6	4	5	4	2
A 4	6	6	6	6	5	4	3	2
A 5	10	10	-	8	-	7	7	4
A 6	10	10	-	8	-	8	6	6
Recovery (%)	—	93	61	79	74	77	58	44
Hour	1100		1015		0730		1330	1130
Cage B 1	5		5		4		0	0
B 2	6		6		5		2	0
Recovery (%)	-		100		82		18	0

from cages over sparse vegetation than from areas with thick moss and other low vegetation. This difference may have been associated with increased mortality in the cages over bare ground. Ants, Camponotus herculianus (L.), and a spider, Xysticus sp., were observed preying on adults in the cages and their efficiency may have been higher where cover was sparse.

The emergence patterns for adults from hummocks, intermediate locations, and depressions were available for both plots A and B for 1953 and 1954. The average number of adults per cage varied both between plots and between microtopographic locations within the plots as shown below. The number of cages is shown in brackets.

	Hummocks	Intermediate	Depressions
Plot A			
1953	12.5 (4)	13.0 (3)	2.0 (3)
1954	9.5 (8)	17.0 (9)	3.7 (3)
Plot B			
1953	3.0 (3)	0.5 (4)	0.0 (3)
1954	2.3 (7)	0.2 (13)	----

These figures may be compared to those given in Table 4.1 for an indication of the relative suitability of the different locations for the formation of cocoons and emergence of adults. In both plots the cocoon formation and adult emergence were successful in the hummocks and intermediate locations. In plot A nearly as many cocoons were found in samples from depressions as from intermediate locations but relatively few adults emerged. In late July and August, when the cocoons are formed, the water table was low enough in plot A to present suitable conditions to larvae seeking a site to cocoon, but the following spring high water tables submerged these cocoons and killed the sawflies before emergence. In plot B the depressions were normally under water and few cocoons were formed. Differences in the water table between years may cause changes in the location of cocoons and subsequent mortality. For example, despite the rise in the average number of adults per cage in plot A from 9.5 in 1953 to 12.0 in 1954, the average number per cage on hummocks dropped. This situation was associated with low water tables from cocoon formation in 1953 to adult emergence the following year. With low water tables the intermediate locations were more favourable for cocoon formation than the hummocks and continued low water levels allowed successful adult emergence in 1954.

The differences between microtopographic locations made it necessary to compare adult emergence and soil temperature for each depth and location separately. For these calculations enough adults were required to allow calculation of valid statistics. Unfortunately, only the hummocks and intermediate locations in plot A gave sufficient data. Table 4.3 gives the emergence patterns for these locations for 1953 and 1954. The records on which this table was based were collected every second day, but the data were grouped to give the number of adults emerging in a 4-day period ending on the afternoon of the given date. Calculations were based on the original records.

The soil temperature records indicated sufficient differences between depths in these locations (Table 3.7) to affect the rate of development of cocoons. The records of adult emergence did not show the depth from which the adults had emerged. An estimate of the number of adults emerging from each depth was made by applying the percentage distribution of cocoons in the hummocks and intermediate locations in plot A (Table 4.1) to the appropriate adult emergence figures given in Table 4.3. Emergence curves for each depth were then prepared, on the assumption that the earliest emerging adults came from the surface layers of the soil and emergence at each depth was completed before emergence began in the next layer. The emergence curves for each depth

Table 4.3 Emergence patterns of adult larch sawfly from hummocks and intermediate locations in plot A in 1953 and 1954. The number of adults emerging in a 4-day period ending on the afternoon of the date given.

	Hummocks		Intermediate	
Date	1953	1954	1953	1954
June 9	4	0	0	0
13	3	0	3	1
17	3	1	2	10
21	1	2	2	12
25	5	4	10	6
29	12	7	4	14
July 3	4	6	8	16
7	7	18	4	26
11	8	16	2	23
15	0	1	1	16
19	2	15	1	24
23	1	3	2	2
27	0	2	0	3
31	0	1	0	0
Total	50	76	39	153

were used to estimate the dates of first, mean, median, and last emergence for the hummocks and intermediate locations in plot A. The estimated number of adults and emergence dates for each depth and location are given in Table 4.4. The foregoing assumption can be criticized on the grounds that emergence of adults from cocoons at different depths would overlap due to the variability in the length of the post-diapause period found in experimental rearings (Sec. 2). The following calculations must therefore be treated only as an example of one method of calculating thermal constants from scanty and variable biological data.

Table 4.4 Estimated number of adults emerging from different depths in hummocks and intermediate locations in plot A and the dates of first, mean, median, and last emergence.

	Hummocks			Intermediate		
	1"	2"	4"	1"	2"	4"
No. adults						
1953	14	19	11	10	25	4
1954	23	27	17	42	93	15
	Date of Emergence					
First						
1953	June 6	June 24	July 4	June 10	June 23	July 12
1954	June 14	July 4	July 10	June 13	June 29	July 16
Mean						
1953	June 15	June 29	July 7	June 18	July 1	--
1954	June 28	July 8	July 15	June 22	July 9	July 19
Median						
1953	June 13	June 29	July 7	June 16	July 2	--
1954	June 27	July 6	July 16	June 21	July 8	July 18
Last						
1953	June 25	July 4	July 9	June 23	July 9	July 23
1954	July 5	July 11	July 18	June 29	July 17	July 21

4.2 Estimation of soil temperatures during post-diapause development and calculation of thermal constants.

To determine a field thermal constant for larch sawfly development, data on the length of the post-diapause stage and the temperatures of the soil are necessary. The length of the post-diapause stage at certain depths and locations was estimated in section 4.1, using the date of snow disappearance as the zero day. The other requirement for the calculation of a thermal constant is a knowledge of the temperatures encountered during development. Section 3.4.2 gives information on the soil temperatures at one, two, and four inches beneath the surface on 24 days during the larch sawfly developmental period in 1953. Measurements such as these could not be taken daily due to the labour involved. However, because both soil and air temperatures are governed by the same major weather factors and heat exchange between them occurs continually except when the ground is snow-covered, a high degree of correlation between the soil and air temperatures in each plot was expected. To test this, correlation coefficients were calculated for the relationship between daily mean soil and air temperatures. The mean soil temperature for each depth and location was taken from Tables 3.7 and 3.8. Air temperature records were available for each plot from a thermograph kept in a Stevenson screen 4.5 feet above the ground surface. Four different daily air temperature means were calculated, based on the sums of the temperatures at 2-hour intervals during: the same 12-hour period (0800 - 1800 hrs.) as the soil temperatures; the same day as the soil temperatures (24 hours from 0001 - 2400 hrs.); a 24-hour period extending from 1801 hrs. the day before to 1800 hrs. the day soil temperatures were measured; and a 48-hour period including the day on which soil temperatures were measured plus the previous day. Each of the correlation coefficients given in Table 4.5 is based on 23 pairs of mean air and soil temperatures. The data for May 11, 1953, were not included because of the snow cover on the ground.

Table 4.5 Correlation coefficients for the relationship between mean soil temperatures at different depths and microtopographic locations and mean air temperature based on different periods of time.

Location of soil temp.		Period of air temperature observations			
		10 hours 0800-1800	24 hours 0000-2400	24 hours 1800-1800	48 hours day + day previous
Plot A					
Hummocks	1"	0.926	0.975	0.959	0.943
	2"	0.862	0.954	0.969	0.969
	4"	0.773	0.905	0.950	0.971
Intermediate	1"	0.932	0.961	0.935	0.924
	2"	0.850	0.932	0.941	0.949
	4"	0.729	0.861	0.904	0.945
Depressions	1"	0.862	0.960	0.940	0.952
	2"	0.744	0.875	0.920	0.967
	4"	0.568	0.730	0.799	0.887
Plot B					
Hummocks	1"	0.874	0.923	0.892	0.879
	2"	0.796	0.861	0.907	0.900
	4"	0.668	0.822	0.851	0.860
Intermediate	1"	0.843	0.930	0.924	0.921
	2"	0.752	0.895	0.919	0.926
	4"	0.711	0.869	0.899	0.923
Depressions	1"	0.782	0.896	0.901	0.905
	2"	0.735	0.871	0.890	0.901
	4"	0.629	0.795	0.833	0.847

In general, the highest correlation coefficients were noted when the mean air temperature was based on the 48-hour period, so this relationship was used to calculate regression lines for the estimation of soil temperatures from air temperatures. Calculation of regression formulae was confined to the three depths of hummocks and intermediate locations in plot A. The data were available for the other location and plot but low emergence of adults from these points (see section 4.1) made further treatment impossible. The regression formulae, with appropriate variances, are given below:

Plot A	Depth	Regression formula	S_b	S_a
Hummocks	1"	$Y = 0.938\ X + 1.372$	0.0740	0.889
	2"	$Y = 0.923\ X + 0.229$	0.0528	0.634
	4"	$Y = 0.867\ X - 1.398$	0.0477	0.574
Intermediate	1"	$Y = 0.835\ X + 1.910$	0.0771	0.926
	2"	$Y = 0.848\ X - 1.141$	0.0632	0.758
	4"	$Y = 0.640\ X - 1.920$	0.0493	0.592

These formulae were used to calculate mean soil temperatures for each day in 1953 and 1954 from the disappearance of winter snow to the end of July. As the soil temperatures on which the formulae were based covered only 11 hours of the day, the soil temperature means are only indices. The daily indices for each depth and location were then summed, from the date of spring thaw to the various dates given in Table 4.4 to provide an estimate of the thermal accumulation (day-degrees C) to various points in the larch sawfly emergence pattern (Table 4.6). Days when the ground was snow-covered due to late storms (May 10-13, 1953 and May 30 - June 2, 1954) were not included in the summation (see page 61).

Table 4.6 Number of day-degree C indices accumulted from the spring thaw to various points in the larch sawfly emergence pattern at different depths and locations in plot A.

Emergence dates	Year	Hummocks 1"	2"	4"	Intermediate 1"	2"	4"
First	1953	386	562	552	429	432	415
	1954	303	517	504	276	362	372
Mean	1953	524	624	579	536	516	---
	1954	498	588	564	389	487	390
Median	1953	490	624	579	512	529	---
	1954	483	552	576	375	470	400
Last	1953	644	696	601	586	600	523
	1954	594	641	603	483	587	423

The variability between depths and locations in the amount of heat accumulation to the same point in the emergence pattern is considerable. This variability may be due to the irregularities of soil temperature, the small number of cocoons at certain depths, and inaccuracies in the method of calculation. However, the figures show that no sawfly emergence occurs before the accumulation of 300 day-degrees C or after 700 day-degrees C. The average accumulation to the mean date of emergence was 516 day-degrees C. A comparison of these figures with the theoretical thermal constants given on page 20 shows that the variability is similar but the theoretical constants were 200 to 500 day - degrees C higher. This may be due to the differences in treatment or to the use of the soil temperature index. The average of 516 day-degrees C is about 200 higher than the field thermal constant of Brown and

Daviault (1942) but falls within the range of values calculated from air temperatures for a dry tamarack site by Drooz (see page 20).

5. Larch sawfly emergence in several bogs in the Prince Albert area.

The previous sections have indicated that attempts to predict larch sawfly emergence on the basis of soil temperature and theoretical thermal constants for the post-diapause stages are laborious and the results variable. In the following sections the possibility of relating larch sawfly emergence over a larger area to general weather conditions is presented.

The adult emergence data were collected in the manner described in section 4.1 from four plots; two in the Airport Bog (plots A and B described in section 3.1) and one in each of the Railroad and Crutwell Bogs. Each plot was 1/5 acre in extent.

The Railroad Bog is within the Prince Albert city limits on the first terrace above the north bank of the North Saskatchewan River. The forest stand varied from scattered tamarack on the sedge mat around spring fed pools to pure stands of black spruce on higher ground. At the north edge of the bog rolling sand hills supporting jack pine rose abruptly from a narrow transition zone of black poplar, white spruce and aspen. The study plot resembled plot A in the Airport Bog but was wetter. The trees had a density of 1010 tamarack and 615 black spruce per acre with an average d.b.h. of 3.5 and 2.8 inches, respectively. Ground vegetation was similar in species and distribution to plot A.

The Crutwell Bog is in the Home Block of the Nisbet Provincial Forest, 12 miles west of Prince Albert. The bog forest surrounds the bed of Bennet's Lake, a dry slough containing water only during the spring run-off. The depression containing this bog was apparently occupied at one time by a lake, connected, at least during high water, to the North Saskatchewan River. A fine clay loam of alluvial origin, imbedded with snail shells, is found at depths of 30 to 40 inches. The soil is composed of fibrous peat with a generally alkaline reaction. The upper 6 to 12 inches have a neutral reaction except in the vicinity of clumps of living moss. The soil structure, the presence of an almost pure stand of tamarack, and the recollections of local residents, indicated that this bog was formerly wet, perhaps like plot B, but a change of drainage occurring between 1925 and 1930 due to road construction and general land clearing lowered the water table. At present it lies more than 36 inches beneath the surface. The study plot supported a pure tamarack stand with a density of 1960 stems per acre and an average d.b.h. of 2.5 inches. Ground vegetation was scarce, as shown in Table 5.1, and even mosses were rare. The vegetation quadrats were laid out and plants listed as described in section 3.1.

The number of emergence cages was increased from 1952 to 1954, as the technique was developed. Only 12 cages were used in 1952, 40 in 1953, and 70 in 1954. The emergence data for all four plots were grouped for each year, partly because the data for any one plot for 1952 were insufficient, but primarily because the grouped emergence for the four plots gave a better indication of the effect of climate on larch sawfly emergence in the Prince Albert area. Table 5.2 gives the number of adults taken in each plot in 1954 and Figure 5.1 shows the shape of the emergence curves when the percentage of total emergence for each plot is plotted against the date.

Table 5.1 Ground vegetation in the Crutwell plot; a list of plant species and their occurrence in 10 one-metre quadrats.

Species	Number
Betula glandulosa Michx.	2
Salix sp.	1
Carex spp.	6
Smilacina trifolia (L.) Desf.	5
Epilobium angustifolium (L.) Scop.	2
Urtica sp.	1
Aulacommium palustre (Web & Mohr) Schwaegr.	10

Total number of species — 7
Percentage of surface covered by vegetation — 30

Table 5.2 Seasonal emergence of larch sawfly adult females in four plots in 1954. The number of adults recorded during two day periods ending on the afternoon of the date given.

Date	Crutwell	Railroad	Airport A	Airport B
June 13			1	
15	3		10	
17	2	3	1	
19	5	3	7	
21	9	1	7	1
23	4	5	3	
25	3	2	7	
27	13	3	11	2
29	13	4	10	
July 1	8	5	13	
3	8		9	
5	14	7	18	4
7	15	6	28	1
9	20	4	20	2
11	23	9	20	4
13	12	18	18	
15	17	5	3	
17	17	11	27	3
19	15	8	15	
21	16	9	6	1
23	4	4		
25	4	10	2	
27	3	4	3	
29	1			
31		3	1	
Aug. 2		1		
4		2		
6				
8	1			
Total	230	127	240	18
Mean date	July 9	July 13	July 7	July 9
Standard deviation	0.66	1.00	0.64	1.82

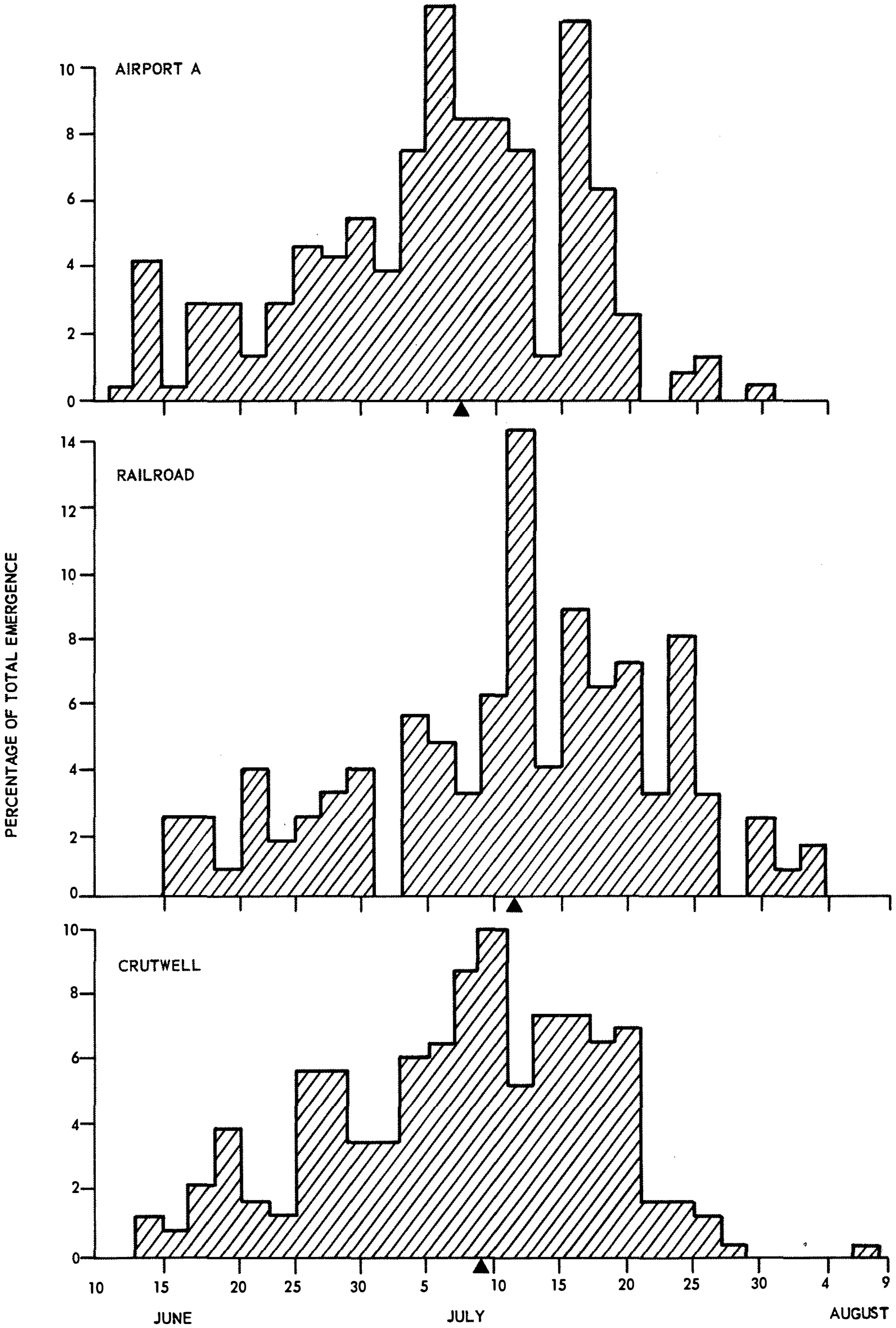


Figure 5.1 – Emergence patterns of larch sawfly adult females in three tamarack stands during 1954. ▲ denotes mean emergence date.

The mean emergence dates for plots within years are very close despite the differences in the sites. The significance of the differences between these means was tested by the method described by Kramer (1956), which extends the multiple range test of Duncan (1955) to group means with unequal frequencies. Table 5.3 gives the 'Appropriate Significant Range Factors' for the one per cent and five per cent Duncan Multiple Range Test and the differences between pairs of means for the four plots, corrected for unequal frequencies by the Kramer Method. Only the plot in the Railroad Bog differed significantly from any of the other three plots in the mean emergence date. This supports statistically the grouping of the emergence data for all four plots for each year. The above test was also applied to the grouped data for 1952, 1953 and 1954 and each mean differed significantly from the others.

Table 5.3 Test of the significance of the differences between the mean emergence dates of larch sawfly adults in four bogs in 1954.

Means compared	Appropriate Significant Range Factor 5%	Appropriate Significant Range Factor 1%	Difference between pairs of means, corrected for unequal frequency
Railroad vs Airport A	30.86	39.86	69.60**
" vs Airport B	29.84	38.84	22.46
" vs Crutwell	28.30	37.20	46.06**
Crutwell vs Airport A	29.84	38.84	27.58
" vs Airport B	28.30	37.20	2.32
Airport B vs Airport A	28.30	37.20	8.10

Table 5.4 shows the number of adult female larch sawfly taken from the emergence cages in 1952, 1953 and 1954. The percentage of the total emergence for each year for each observation date was graphed in the form of histograms (Fig. 5.2) to show the variations in the form of the emergence curve. Despite the differences in the date of first emergence, last emergence, mean emergence date and form of the emergence histogram between the three years, the total length of the period from first to last emergence remained remarkably constant. In 1952 it was 52 days, in 1953 - 57 days, and 1954 - 56 days. Apart from this similarity the emergence patterns were different in the three years. The relationships between these differences and the weather for each year will be discussed in later sections.

Table 5.4 Emergence of larch sawfly adults in 1952, 1953 and 1954. Number of adults recorded on the afternoons of the given dates.

	1952		1953	1954
May 27	1	June 7	3	
May 30	1	9	4	
June 4	3	11	8	
7	6	13	8	1
10	5	15	7	13
13	2	17	6	6
16	4	19	5	15
18	4	21	8	18
21	6	23	19	12
23	1	25	29	12
25	6	27	16	29
28	11	29	28	27
30	14	July 1	18	26
July 2	10	3	30	17
4	8	5	29	43
7	7	7	23	50
9	10	9	70	46
12	2	11	44	56
14	4	13	27	48
18	2	15	16	25
		17	13	58
		19	7	38
		21	4	32
		23	7	8
		25	5	16
		27	3	10
		29	3	1
		31	2	4
		Aug. 2		1
		4		2
		8		1
Total	107		442	615
Mean	June 25		July 3	July 7

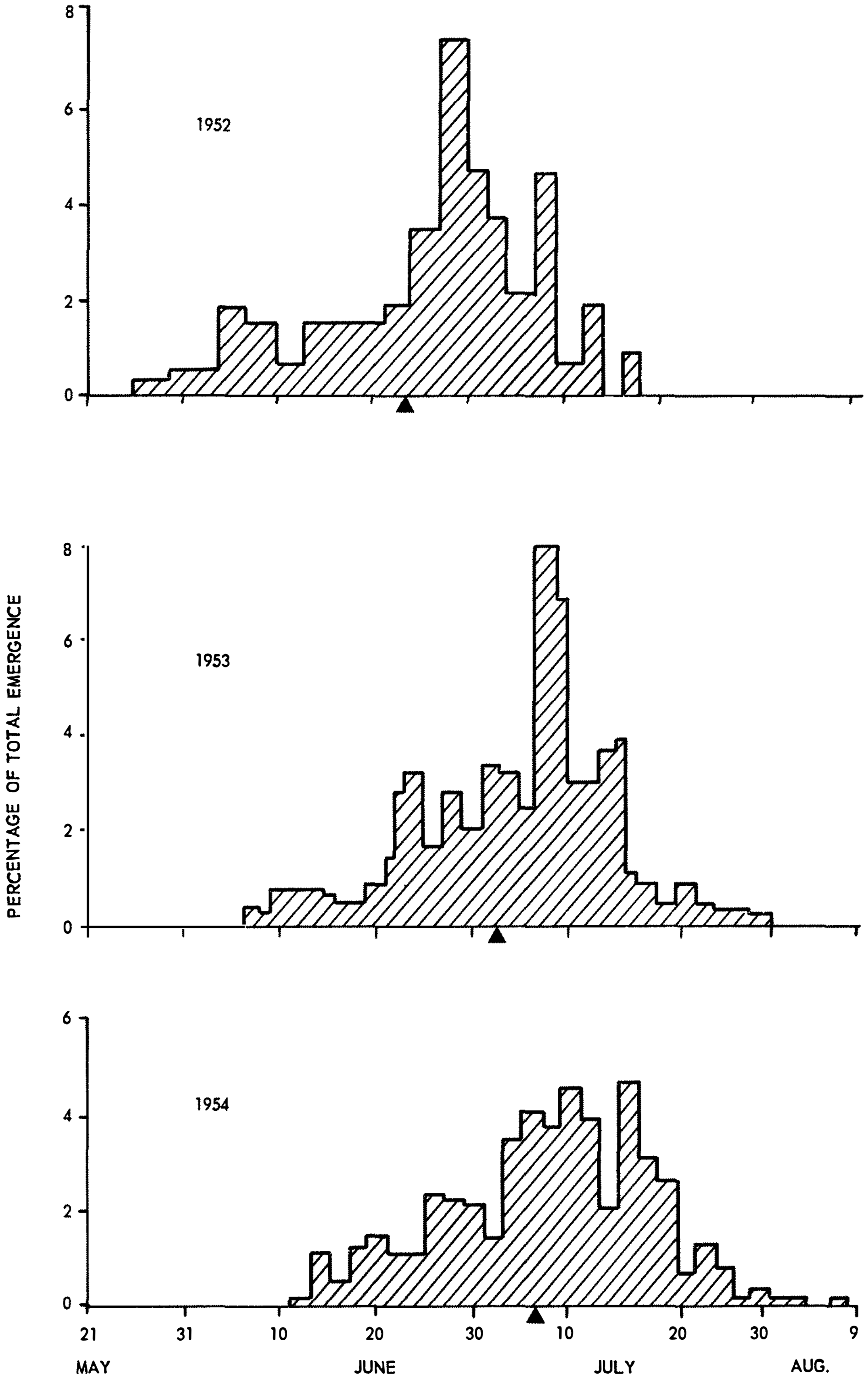


Figure 5.2 – Emergence patterns of larch sawfly adult females in 1952, 1953 and 1954. Each histogram is based on emergence records in four plots. ▲ denotes the mean emergence date.

6. Weather associated with larch sawfly emergence in 1952, 1953, and 1954.

The larch sawfly emergence curves given in Section 5 showed considerable variation in the dates of various occurrences as well as in the form of the curve. The type of weather during the pre-emergence and emergence periods also varied widely. In order to discover correlations between the weather types and emergence pattern, the spring of each year was divided into three periods based on the phenology of the larch sawfly. These were from the date of disappearance of winter snow to the date of the first larch sawfly emergence, from the date of the first to the mean sawfly emergence date, and from the mean to the last emergence date. The weather for the three years was examined to determine if differences in the length of the three phenological periods in different years could be attributed to the weather, and if predictive patterns could be described.

In this weather analysis extensive use was made of the 'Monthly Record' and the 'Daily Weather Map' published by the Meteorological Division, Dept. of Transport, Canada, and the 'Monthly Weather Review' and 'Daily Weather Map' published by the Weather Bureau, U.S. Dept. of Commerce. The principal tracks and mean frequencies of cyclones and anticyclones (Klein 1957) were used for comparison with the tracks for each year. A general description of the area with climatological summaries for Prince Albert is given by Kendrew and Currie (1955).

Prince Albert lies on the northern edge of the aspen parkland at lat. 53° 10' N, long. 105° 45' W, at 1432 feet above sea level.

Thus situated on the northern edge of the central North American plain, it has a continental climate with cold winters and short warm summers. The months of April to July, when the larch sawfly goes through its post-diapause stages, encompass the rapid change from winter to midsummer weather conditions. Following the disappearance of the winter snow cover, the establishment of summer weather patterns is rapid, and vegetation develops quickly under the influence of long hours of daylight, warm temperatures, and ample rainfall. During July the highest temperatures of the year are recorded and most trees complete their summer growth. However, this rapid spring development is by no means orderly. Prince Albert lies on or near the path of most of the major weather systems crossing the northern part of the continent. The frequency of both cyclones and anticyclones and the paths they follow across the continent determine the daily weather. The variability of the weather is reflected by differences in the time of occurrence of the phenomena listed in Table 6.1.

The date when the snow cover disappeared from the bogs varied greatly, indicating differences in the change from winter to spring weather. The dates of plant phenological events recorded in this table indicate the differences between the seasons even more than the larch sawfly emergence data. For example, the number of days between the plant phenological events in 1952 and 1954 was almost twice the number of days between the date of first larch sawfly emergence in these two years. None of the events listed here coincided with specific periods in the larch sawfly emergence pattern but the appearance of jack pine pollen might be used to predict the date of first emergence. The pollen fell 11, 10 and 8 days before the first emergence in these three years.

Table 6.1 Dates of occurrence of natural events during the spring of 1952, 1953, and 1954 at Prince Albert, Saskatchewan. Plant specimens preserved at Forest Biology Laboratory, Winnipeg, Manitoba.

	1952	1953	1954
Snow absent from tamarack bogs	April 12	April 28	May 15+
Ice out, N. Saskatchewan River	April 12	April 20	May 3
Populus tremuloides Michx. catkins out	April 15	April 13	April 25-30
Larix laricina (Du Roi) K. Koch. buds split	April 23	May 8	May 20
P. tremuloides - buds split	April 25	May 8	May 21
Thermopsis rhombifolia Rich. first bloom	May 3	May 26	June 6
Pinus Banksiana Lamb. pollen falling	May 15	June 7	June 18
Caltha palustris L. first bloom	May 15	May 26	June 4
Ledum groenlandicum Oeder first bloom	---	June 15	June 27
Pyrola asarifolia Michx. first bloom	---	July 2	July 13

+ A storm on the night of May 29-30, 1954, deposited 10 inches of snow which persisted until June 2.

A classification of the major weather systems affecting Prince Albert aided in the analysis and description of the weather. This classification was prepared after examining the daily weather maps and noting the dominant weather systems and their effects on the temperature, cloud cover, precipitation, and direction of air flow over Prince Albert. The daily weather maps published by the Meteorological Services of the United States and Canada gave a total of three pictures per day of the isobars, wind direction and positions of major weather systems. From these maps the direction of air flow over Prince Albert for each day was described on the basis of the constancy of direction and cause of shifts in the trajectory. Days when the trajectory did not shift more than 90° were classified on the basis of the direction (primary compass point) of the air flow. Where the trajectory shifted more than 90° during the day the classification depended upon whether the shift was associated with anticyclonic or cyclonic circulation. The six classes of air flow were:

Trajectory constant within 90°

N - flow from north
E - flow from east
S - flow from south
W - flow from west.

Trajectory shifting more than 90°

A - in anticyclonic circulation
C - in cyclonic circulation.

Both the source and trajectory of cyclonic and anticyclonic systems affected the weather at Prince Albert, and each major weather system was sub-classified on the basis of its trajectory and the position of its centre. The following outline of the major weather systems will be followed in describing the weather associated with larch sawfly emergence patterns. General terms are used in describing the minimum and maximum temperatures because the absolute values varied.

Anticyclonic systems.

I. Polar air, originating in the Arctic Ocean or northern North America, and including those air masses originating in the northern Pacific Ocean and moving through Alaska to northern Canada.

I a. Polar anticyclones centred in Canada north of 60° N lat. These anticyclones either travelled across the Northwest Territories or surged southward into southern Canada. While north of 60° N lat. they gave an easterly flow of cool air with a variable moisture content.

I b. Polar outbreaks southward into the prairie provinces west of 100° W long. These brough clear, dry air to the prairies, with low minima, warm maxima, and very little cloud or precipitation. This type of surge often followed a cyclonic centre moving from west to east through the prairies north of 50° N.

I c. Polar anticyclones moving southward east of 100° W long.; the 'Hudson Bay High' of Schroeder (1950). These anticyclones differed little from the previous type in the initial stages but the strong southerly flow along their western flank raised maximum temperatures at Prince Albert. The low minima and clear skies were similar to the previous type. This type of centre sometimes moved into the central U.S., as described under III.

II. Pacific air, moving across the Cordillera north of 40° N lat.; originally relatively warm and moist, the air was dried by passage over the mountains.

II a. Anticyclonic centre over the Cordillera with its frontal surface penetrating the prairie region. The flow over Prince Albert was northerly or westerly and moderate minimum and maximum temperatures were recorded. Cloud was variable and precipitation low under these conditions.

II b. Anticyclonic centre crossing the Rockies and moving in a northeasterly direction into Alberta and Saskatchewan. The air flow over Prince Albert was generally westerly with moderately high maxima and low minima, clear skies, and no precipitation.

II c. Anticyclonic centres moving southeasterly across the north-central U.S. The flow over Prince Albert was westerly, with low minima, high maxima, clear skies and no precipitation. If a centre of this type of anticyclone reached the central U.S. it gave conditions described in III.

III. Anticyclonic centre in central or west central U.S., derived either from I c or II c. Prince Albert received a strong southerly flow with high maxima, moderately high minima, clear skies and no precipitation.

Cyclonic systems.

IV. Originating north of 60° N lat.

IV a. Travelling eastward through the NWT; associated with a westerly or southerly flow at Prince Albert with high maxima and minima, clear skies and no precipitation.

IV b. Travelling south or southeast into the prairie provinces; associated with heavy precipitation, thick cloud and very low temperatures at Prince Albert.

V. Originating in the prairie provinces north of 50° N lat. (Alberta lows). This common weather type brought a great deal of cloud and precipitation to Prince Albert. The centres normally moved eastward and their effect varied according to their position east or west of the city.

V a. Cyclonic centres in Alberta and western Saskatchewan, were associated with heavy cloud, rain, and moderate temperatures at Prince Albert.

V b. Cyclonic centres in eastern Saskatchewan and Manitoba gave much less cloud and precipitation at Prince Albert. They often were followed by a strong northerly flow of cold air. Maximum and minimum temperatures were lower.

VI. Cyclones originating in west-central U.S. and moving east or northeast across the north-central U.S. These 'Colorado-Wyoming' cyclones often occluded strongly into the Canadian Prairies and brought heavy cloud and rain to Prince Albert. Polar surges of cold air often moved southward following the passage of the cyclonic system.

VI a. Cyclonic centres west of the Rockies. The southerly flow along the eastern flanks of cyclones in this area gave high maxima, moderate minima, and clear skies to Prince Albert especially when associated with an anticyclonic centre in the central U.S. (Type III).

VI b. Cyclonic centres moving across the north-central U.S. These centres, usually occluded, brought heavy cloud and rain with moderate temperatures to the Prince Albert area.

The frequency of occurrence of these weather systems varied greatly from year to year. The specific weather associated with them and their effects on larch sawfly emergence will be discussed in the following three sections. The general relationships between the weather systems and conditions at Prince Albert may be summarized as follows:

When the Prince Albert weather was dominated by anticyclones, precipitation was generally absent, skies were clear to partly cloudy, minimum temperatures generally low to moderate and maximum temperatures moderate to high. Precipitation was generally derived from cyclonic activity, particularly the 'Alberta' and 'Wyoming-Colorado' lows. These systems brought heavy cloud, low maxima and relatively high minima to the area but were often followed by cold air from the north. High cyclonic activity north of 60° N lat. indicated a general northward movement of the circulation pattern and was associated with warm air and low precipitation over Prince Albert.

6.1 Weather during the pre-emergence period.

The number of days required by the larch sawfly to complete the period from the disappearance of snow cover to the first emergence varied widely, as follows:

1952 -- 44 days, April 13 to May 26
1953 -- 37 days, April 29 to June 4
1954 -- 27 days, May 16 to June 11.

The weather during this period for each year is summarized in Table 6.2. The temperature and precipitation figures were taken from the 'Monthly Record' and cloud cover data were recorded as described on page 44.

Table 6.2 Summary of weather conditions during the pre-emergence period (snow disappearance to first larch sawfly emergence) in 1952, 1953, and 1954 at Prince Albert.

	1952	1953	1954
No. days to first emergence	44	37	27
Air temperature (°C)			
Mean	11.5	9.0	10.2
Mean Maximum	19.9	16.3	15.9
Mean Minimum	3.1	1.8	4.5
Precipitation			
Total (inches)	2.87	1.53	3.86
No. days $\geq$ .01 inches	10	12	11
No. days with snow on ground*	0	4	4
Cloud Cover ** (No. days)			
Clear	24	14	4
Part cloudy	14	10	8
Cloudy	6	13	15

* due to storms after melting of winter snow.
** see page 44.

Unexpectedly, there appeared to be no correlation between the highest temperatures and shortest pre-emergence period, i.e. the longest period was associated with the highest mean maximum and mean daily air temperatures. The only temperature statistic in which the highest value was associated with the shortest pre-emergence period was the mean minimum. The maximum and minimum air temperatures and cloud cover for each day in the pre-emergence periods of 1952, 1953 and 1954 were recorded as shown in Table 6.3. Cloud cover was included because with the same minimum air temperature, the amount of heat lost from the soil is greater under clear skies than under cloudy skies. These figures

Table 6.3 Distribution of daily air temperature extremes and cloud cover during the pre-emergence periods of 1952, 1953 and 1954.

Minimum temperature (°C)	Cloud cover*	Maximum temperature (°C)				Total no. days
		10	11 - 15	16 - 20	21	
1952						
<0	clear		1	5	3	9
	cloudy					0
1 - 5	clear		3	5	11	19
	cloudy	1	3			4
6 - 10	clear		1	1	6	8
	cloudy	1			1	2
11 - 15	clear			1	1	2
	cloudy					0
1953						
<0	clear	1	4	5	3	13
	cloudy	2				2
1 - 5	clear		1	1	3	5
	cloudy	2	4	1		7
6 - 10	clear		1	1	3	5
	cloudy		3	1	1	5
1954						
<0	clear		1	1		2
	cloudy	2	1			3
1 - 5	clear		1	4	1	6
	cloudy	2	4	1		7
6 - 10	clear			1	2	3
	cloudy	2			1	3
11 - 15	clear				1	1
	cloudy			1	1	2

* see page 44. In this table 'Clear' includes days with more than 30 per cent of the total possible bright sunshine.

indicate that 1952 was characterized by a high frequency of nights with low minima and clear skies, and clear, warm days. In 1953, cloud was more frequent but clear, cold nights were common and no maxima over 10° C were recorded. The major change during 1954 was the low frequency of minimum temperatures below 0° C.

These figures lead to the conclusion that although clear skies and warm air during the day should result in rapid warming of the soil, they are much less effective when combined with low temperatures and clear skies during the night. Some indication of this effect can be seen by comparing the soil temperatures recorded at 0800 hrs. on days with different minimum air temperatures and cloud cover. Table 6.4 compares soil temperatures at one, two and four inches beneath the surface of the soil in plot A following nights with different minimum temperatures and cloud cover. Only a few examples are available but these illustrate the lower soil temperatures associated with clear skies and low minimum temperatures. It appears that much of the heat absorbed during clear warm days was lost during the night and the warming of the deeper soil layers was retarded. The effect of this type of weather on the duration of the pre-emergence period can be seen in Table 6.3, where the differences between the three years occurred almost entirely in the group with low minima.

Two other factors may have influenced the rate of development in the three years through their effects on soil temperature. Firstly, the angle of the sun's rays, and consequently the effectiveness of radiant heating of the soil during the pre-emergence period, differed

Table 6.4 Mean soil temperatures at one, two and four inches beneath the surface at 0800 hours under different conditions of cloud cover following high and low minimum temperatures in 1953.

Date	Cloud Cover (Tenths)	Min. Air Temp. (°C)	Mean soil temperatures (°C) 1"	2"	4"
May 7	0	5	4.5	2.7	0.9
19	0	-1.7	0.2	0.2	0
May 26	0	0.6	3.3	2.7	2.4
27	10	7.0	5.3	4.2	2.5
June 6	0 - 1	-0.6	3.5	2.8	1.7
4	10	7.0	7.3	6.2	4.5
June 25	2 - 6	8.9	8.0	7.1	5.6
16	10	9.4	8.8	7.3	5.6

between the years, so that the soil temperature on a day near the beginning of the pre-emergence period in 1952 (mid April) would be lower than on a day at the beginning of the period in 1954 (mid May), assuming all other meteorological factors to be identical. Secondly, although precipitation generally was associated with lower soil temperatures (page 67), moist fibrous peat warms more evenly to greater depths than dry peat. Therefore the shorter pre-emergence period in 1954 may have been partially related to the heavier rainfall.

The distribution of air temperature extremes and cloud cover (Table 6.3) suggested a classification based on their combined effect on soil temperatures. Cloud cover was used in modifying the grouping of the daily minima because soil temperatures drop lower under clear skies than under heavy cloud. Thus the effect of minimum air temperatures between 0° and 5° C on a cloudy night was arbitrarily considered the equivalent of a minima from 5° to 10° C on nights with clear or partly clouded skies. This system was not used in classifying the maximum air temperatures because they did not seem to be related to differences in the length of the pre-emergence period. The temperature classes are designated by letters as follows:

Types	Minimum Temperatures
K	<5° C, clear or part cloudy <0° C, cloudy
C	1 - 5° C, cloudy 6 - 10° C, clear or part cloudy
W	>6° C, cloudy >11° C, clear or part cloudy
	Maximum Temperatures
k	<10° C
c	11 - 15° C
w	16 - 20° C
h	>21° C

The preceding analyses indicated the types of weather which appeared favourable for rapid post-diapause development of the larch sawfly. Each day during the pre-emergence period of the three years was classified as dominated by one or more of the major weather systems described on pages 96 & 97. Where two or more systems occurred, a dominant system was chosen on the basis of the circulation pattern and weather at Prince Albert. Intermediate types were listed under the two or more systems involved. Table 6.5 summarizes the air temperatures, cloud, air flow, and precipitation occurring on days dominated by various major weather systems and combinations of systems. Each day was also classified on the basis of its temperature extremes and cloud cover as described on page 100 and the number of days of each weather type and temperature class recorded for each year (Table 6.6). This table suggests that the shorter developmental period in 1954 was due to the absence of prolonged periods when the weather was dominated by weather systems giving low minima at Prince Albert (type K in Table 6.6).

Table 6.5 Weather at Prince Albert during the pre-emergence period associated with different major weather systems.

Weather system	No. days	Mean air temp. (°C)		Cloud cover*	Air flow**	Precipitation	
		Maximum	Minimum			Total	No. days
I a	4	14.0	-0.1	3,1,0	E		
b	10	16.4	-1.7	6,3,1	S, A	T	1
c	10	17.6	1.8	5,3,2	S, A	.13	3
II a	5	18.4	7.2	0,5,0	W, N	.12	2
b	5	19.8	2.1	4,1,0	W		
c	2	27.0	-1.7	2,0,0	W		
III	8	26.0	4.2	2,6,0	S	T	1
IV a	6	25.6	6.4	4,2,0	var.	T	1
b	1	6.7	-1.7	0,0,1	C	.24	1
V a	7	19.8	6.8	0,1,6	var.		
b	7	14.2	3.6	4,0,3	N, C	.36	2
VI a	1	27.8	0.0	1,0,0	C		
b	26	15.6	4.2	4,6,15	E, C	4.91	12

* see page 45.
** see page 95.

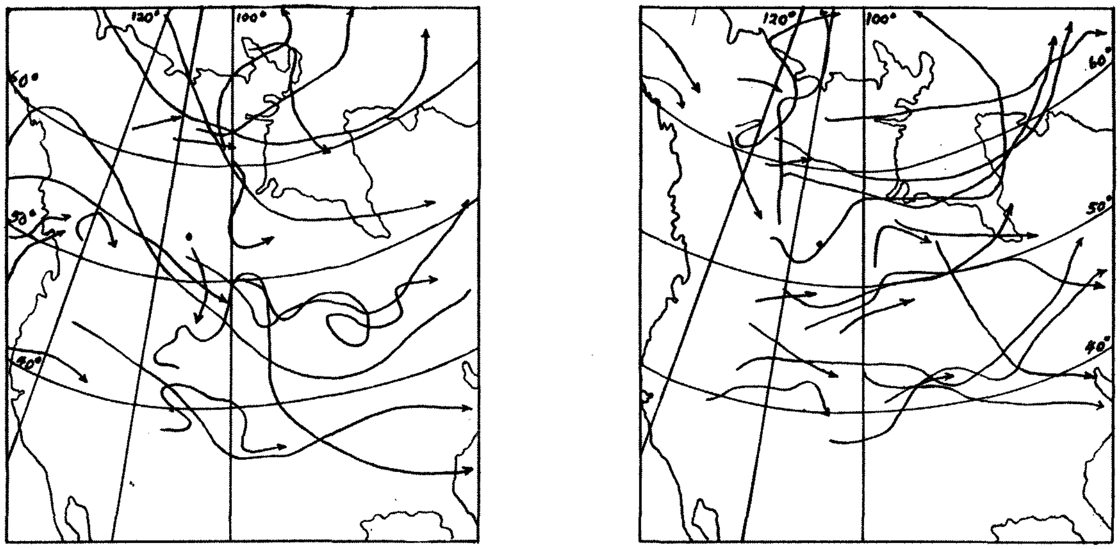
Table 6.6 Types of weather occurring at Prince Albert during the pre-emergence period, the weather systems associated with them, and the number of days of each type in 1952, 1953, and 1954. Underlined systems produced precipitation at Prince Albert.

Weather type		Associated weather systems	No. days dominated by type		
			1952	1953	1954
K	k	IVb, (VIb, Ia) (VIb, Ic)		6	3
	c	Ia	1	1	2
	w	Ib, Ic, IIb, (Ib, Vb)	13	9	4
	h	IIc, III, VIa (III, IIb) (Ic, IVa)	9	4	1
C	c	Vb	2	1	3
	w	IIa, (Ia, III, VIa), VIb	14	10	9
	h	IVa, (IIb, IIc, III), (VIa, IVa, III)	3	3	2
W	w	Va	2	3	2
	h	(VIb, Ic, III)			1

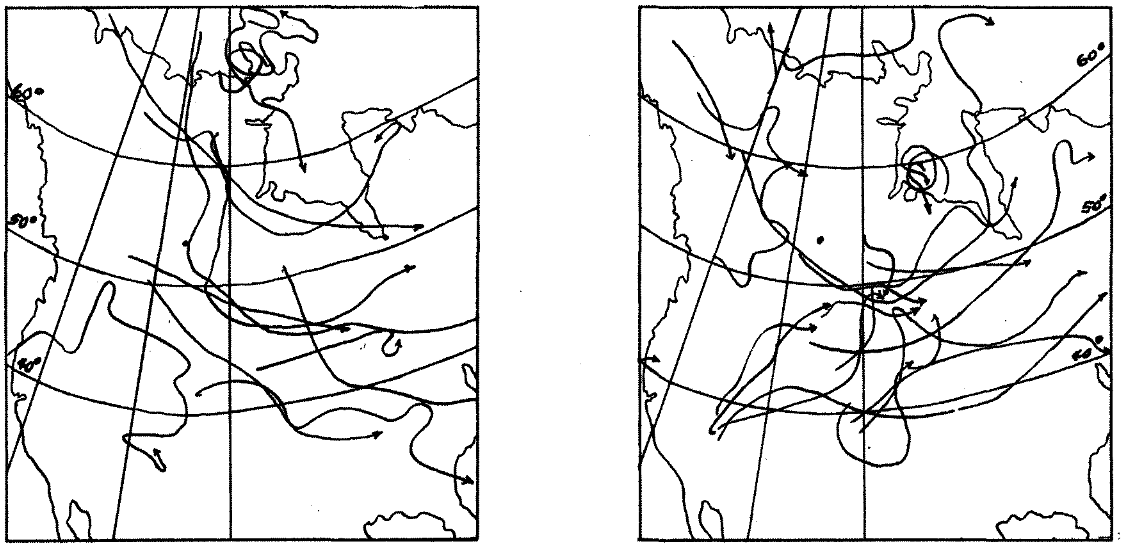
In order to relate these weather phenomena to the general circulation pattern, the tracks of anticyclonic and cyclonic centres entering the North American continent north of 40° N lat. and west of 90° W long. were plotted for the pre-emergence period of each of the three years as shown in Figure 6.1.

Wellington (1954) discussed changes in the number, source, and trajectory of centres, their relationships to the general circulation pattern and their effects on local weather. The differences in the tracks of both cyclones and anticyclones in these three years was striking. In 1952 no well-developed cyclonic track occurred. Most of the cyclones were weak, short-lived and travelled almost due east from their points of origin. Cyclonic activity was dispersed from north to

ANTICYCLONES CYCLONES



APRIL 13 - MAY 26, 1952



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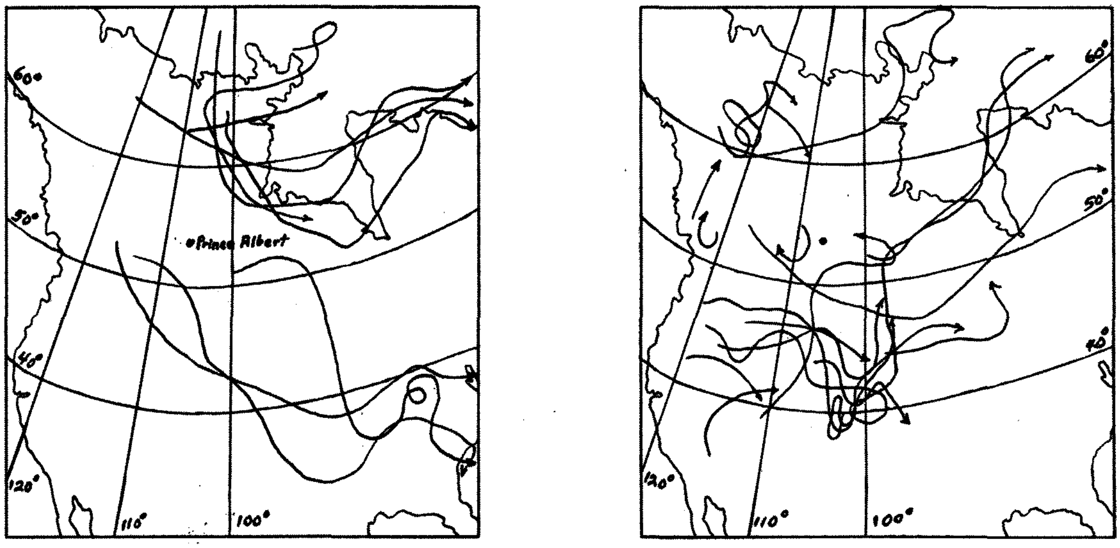

MAY 16 - JUNE 11, 1954

Figure 6.1. Tracks of anticyclonic and cyclonic centres entering North America north of 40°N lat. and west of 90°W long. during the pre-emergence period. Taken from 'Monthly Weather Review' , U.S. Dept. of Commerce.

south and cyclogenesis east of 110° W long. was prominent. In 1953 cyclonic activity was very much reduced, particularly north of 55° N lat. In addition, the major cyclonic systems originated in the southwestern U.S. and travelled in northeasterly direction, rarely entering the Prairie Provinces sufficiently to give rain to Prince Albert. During 1954 cyclones also originated primarily in the southwestern U.S. but had a more pronounced northerly track with resultant heavy rains in the Prairie Provinces.

The frequency and trajectory of anticyclones was similarily variable. The year 1952 was dominated by strong Pacific highs entering North America between 45° and 55° N lat.; while in 1953 anticyclonic activity was dominated by a few strong highs of Arctic origin, which travelled through the Prairie Provinces and deep into the United States. The dominant anticyclones in 1954 were Arctic highs moving southward in the region of Hudson Bay, the 'Hudson Bay Highs' of Schroeder (1950). Polar air penetration west of 100° W long. was rare and Pacific air did not enter the continent.

The changes in the circulation pattern are shown in Table 6.7 by the number of centres of each type described on pages 96 & 97. This summary indicates the areas of cyclonic and anticyclonic activity but does not show how many of these affected the weather at Prince Albert. For example, in 1952 thirteen cyclonic centres were active north of 60° N but the weather was affected by these on only two days. The lack of effect of these cyclonic passages was due to the dominance of Pacific anticyclones over the prairies.

Table 6.7 Variations in the circulation pattern during the pre-emergence periods of 1952, 1953 and 1954. Numbers of centres of the types described on pages 96 & 97.

Type	1952	1953	1954
Arctic anticyclones			
I a	7	2	1
b	4	4	2
c	8	3	4
Pacific anticyclones			
II a	2		
b	8		
c	5	1	
Anticyclones in central U.S.			
III	7	4	1
Arctic cyclones			
IV a	13	5	2
b	1	1	
Alberta cyclones			
V a	3	1	1
b	3	3	1
Colorado-Wyoming cyclones			
VI a			2
b	8	11	7

The duration of the period from snow disappearance to the first larch sawfly adult emergence at Prince Albert was lengthened by the following major circulation types:

1. Pacific anticyclones entering the prairie region.
2. Arctic anticyclones entering the prairies west of 100° W long.
3. Strong cyclonic activity from west to east along 50° N lat. when Arctic anticyclones are present. This commonly results in a surge of cold air as in 2.

4. Cyclonic centres moving from the Northwest Territories south in the prairies.

The major weather types favouring reduction of the duration of the pre-emergence period are:

1. Well developed cyclonic systems moving in a northerly direction from the southwestern U.S.
2. Cyclonic activity in the NWT in the absence of Pacific air on the prairies. This indicates a general northward movement of the whole circulation pattern.
3. Active 'Hudson Bay Highs' with cyclonic activity from the southwest. Well developed anticyclones of this type give a strong southerly flow with high maximum temperatures. The cloud associated with cyclonic activity in the north-central U.S. keeps minimum temperatures above 5° C.

6.2 Weather during the early emergence period.

The dates when the first adult sawfly emergent was recorded approximately coincided with the end of the type of weather characterized by clear cold nights. In 1954 no minimum air temperatures below 1° C were recorded; in 1953 only two days; and in 1952 only three days. These five days almost account for the small differences in the length of the period from the date of first to mean emergence in the three years. The number of days from the first to the mean emergence date varied as follows:

1952 — 30 days, May 27 to June 25
1953 — 29 days, June 5 to July 3
1954 — 26 days, June 12 to July 7.

The weather during this part of the emergence period is summarized in Table 6.8. Unlike the pre-emergence period an obvious correlation between higher air temperatures and the shorter duration of this period in 1954 can be seen. This correlation seems to be due to the generally higher minimum temperatures recorded after the date of first emergence. Table 6.9 shows the distribution of daily air temperature extremes and cloud cover in the three years. The major differences in the distribution of temperatures between the three years are the higher incidence of clear days with minima under 6° C in 1952, and of days with intermediate minima in 1953. Due to the

Table 6.8 Summary of weather conditions during the early emergence period (first larch sawfly emergence to the mean emergence date) in 1952, 1953, and 1954 at Prince Albert.

	1952	1953	1954
No. days	30	29	26
Air temperature (°C)			
Mean	13.1	14.0	14.3
Mean Maximum	19.5	20.7	21.3
Mean Minimum	6.8	7.2	7.4
Precipitation			
Total (inches)	2.76	2.14	1.56
No. days ≥ .01 inches	15	11	12
Cloud Cover* (No. days)			
Clear	11	9	10
Part cloudy	10	11	8
Cloudy	9	9	8

* see page 44.

Table 6.9 Distribution of daily air temperature extremes and cloud cover during the period from the date of first emergence to mean emergence in 1952, 1953, and 1954.

Minimum temperature (°C)	Cloud cover*	Maximum temperature (°C)				Total no. days
		15	16 - 20	21 - 25	26	
1952						
5	clear	1	7	3	1	12
	cloudy		1			1
6 - 10	clear		1	3	1	5
	cloudy	2	2	1		5
11 - 15	clear		1	2	1	4
	cloudy	1	2			3
1953						
5	clear		5	1		6
	cloudy	1	1			2
6 - 10	clear		1	5	3	9
	cloudy	2	4			6
11 - 15	clear		1	1	3	5
	cloudy		1			1
1954						
5	clear		2	5	1	8
	cloudy					0
6 - 10	clear		2	5		7
	cloudy	1	3	1		5
11 - 15	clear				3	3
	cloudy		2	1		3

* see page 44. In this table 'Clear' includes days with more than 30 per cent of the total possible bright sunshine.

general absence of unfavourable minima, a fair degree of agreement was found in the results of summing mean air temperatures above a base of 0° C. The totals were 394 day-degrees C for 1952, 407 for 1953, and 383 for 1954. As days with minima below 0° C occurred during this period in both 1952 and 1953, the theoretical air temperature constant is probably about 380 day-degrees C.

As in section 6.1, each day during the early emergence period of the three years was classified on the basis of the major circulation system or systems affecting the weather. Table 6.10 summarizes the air temperatures, cloud, air flow, and precipitation associated with the different systems.

Table 6.10 Weather at Prince Albert during the early emergence period associated with different major circulation systems.

Weather system		No. days	Mean air temp. (°C) Maximum	Minimum	Cloud cover*	Air flow**	Precipitation Total	No. days
I	a	0						
	b	7	18.5	1.1	4,3,0	A	.62	3
	c	4	21.2	5.4	3,1,0	S	0	0
II	a	8	23.1	7.9	7,1,0	W, A	.47	3
	b	6	26.7	9.5	4,2,0	W, A	0	0
	c	8	21.5	3.6	6,2,0	W, A	T	1
III		1	21.1	3.3	1,0,0	A	0	0
IV	a	2	23.9	8.3	2,0,0	W	0	0
	b	0						
V	a	10	20.4	10.0	1,2,7	C	2.00	7
	b	11	16.2	7.9	0,5,6	N	1.10	10
VI	a	3	19.1	3.5	1,0,2	S	.46	1
	b	12	18.2	8.2	1,4,7	N, E	.65	10

* see page 44.
** see page 95.

Classification of the major systems on the basis of their minimum and maximum air temperatures followed the method described in section 6.1. The number of days of each class found in 1952, 1953, and 1954 are given in Table 6.11. The difference between the years was much less striking than during the pre-emergence period but the increased length of the early emergence periods of 1952 and 1953 again appears to be associated with anticyclonic circulation, clear cold nights, and warm days. Figure 6.2 shows the tracks of anticyclonic and cyclonic centres entering the North American continent north of 40° N lat. and west of 90° W lat.

Table 6.11 Types of weather occurring at Prince Albert during the early emergence period, the weather systems associated with them, and the number of days of each type in 1952, 1953, and 1954.

Weather type Min.	Max.	Associated weather systems	1952	1953	1954
K	h	IIc, III, Ib, (IIb Va)	7	6	4
C	c	(Ia VIb)		1	
	w	VIa (Ib III)	1	2	1
	h	Ic, IIa, IVa, (IIa IVa) (IIb IVa) (III VIb) (IIa Vb)	7	6	12
W	w	Vb, VIb, (Ic VIb)	9	11	7
	h	Va, (Ic Va)	6	3	2

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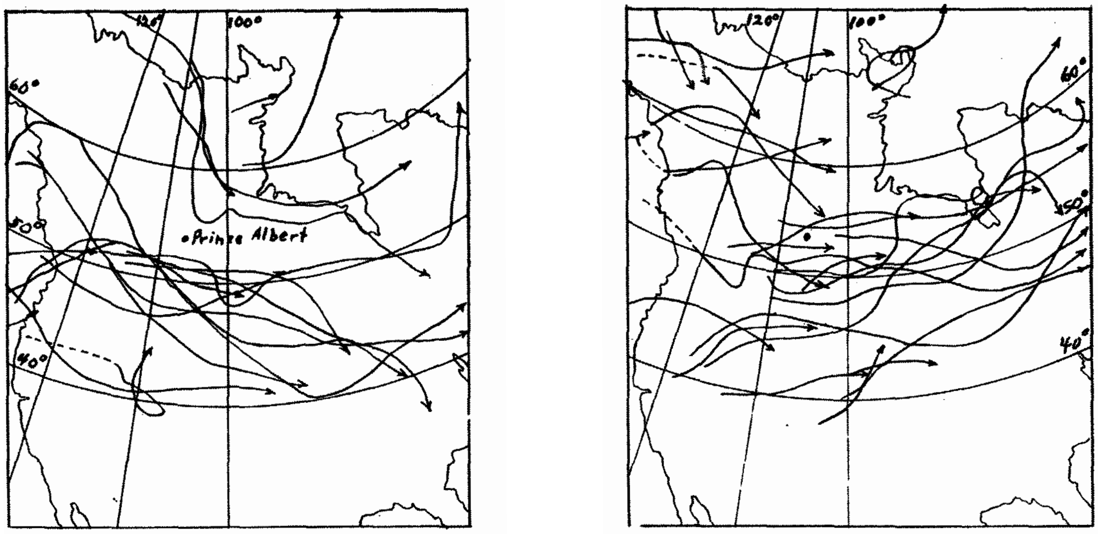
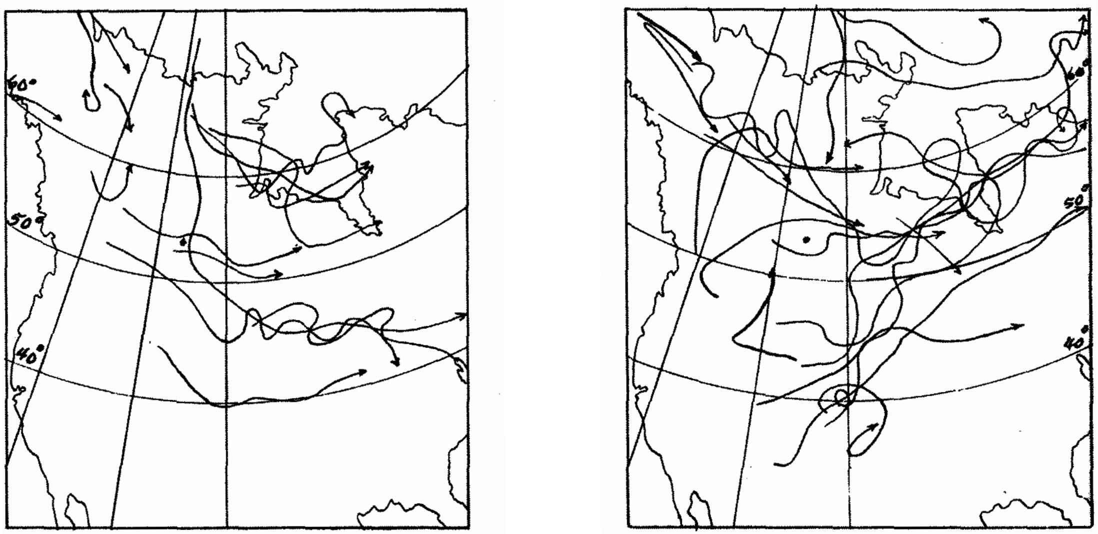
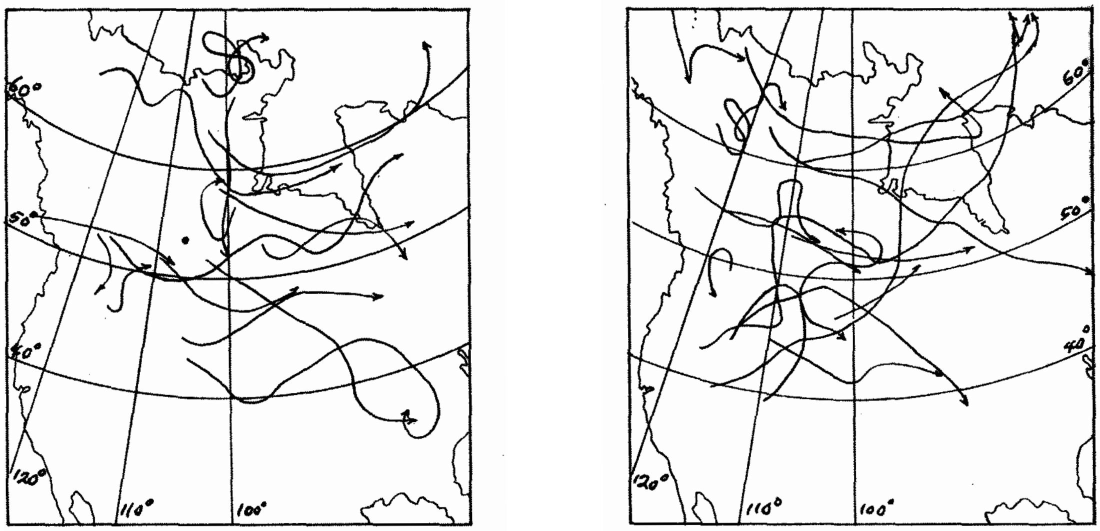


MAY 27 – JUNE 25, 1952



JUNE 5 – JULY 3, 1953



JUNE 12 – JULY 7, 1954

Figure 6.2. Tracks of anticyclonic and cyclonic centres entering North America north of 40°N lat. and west of 90°W long. during the period from the date of the first to the mean larch sawfly emergence. From the 'Monthly Weather Review', U.S. Dept. of Commerce.

In 1952 the 10 days following the date of first emergence were dominated by anticyclones originating in the Pacific Ocean. Cyclonic centres were weak and generally originated east of 110° W lat. This pattern was modified during the next 10 days by a general increase in cyclogenesis in Colorado, Alberta, and the Yukon. The 10 days before the date of mean emergence were dominated by Colorado cyclones, with increased cloud and precipitation at Prince Albert.

In 1953 Pacific anticyclones did not enter North America south of 60° N lat. but Arctic anticyclones frequently penetrated the Prairie Provinces and the north-central U.S. Several Alberta cyclones were active and heavy rain was associated with one of these. In general, however, cyclogenesis occurred east of 110° W long. and only light rains fell at Prince Albert.

The circulation pattern that produced the rather uniform weather of 1954, with moderately high temperatures and rather low rainfall, featured anticyclones originating on the prairies and moving eastward. Cyclonic centres had a similar easterly track, although a northward movement of Colorado lows was evident, particularly in the early part of the period. The persistantly high temperatures recorded during this period seem to have been due to the absence of outbreaks of either Pacific or Arctic air into the prairies. Any invasions from the north were associated with slow moving centres that had been modified by passage over the Northwest Territories. These air masses carried more moisture, cloud cover was more frequent and low minimum temperatures were rarer than in the fast-moving air masses. The higher incidence of Colorado cyclones with a strong northerly trend indicates the introduction to western Canada of warm, moist tropical maritime air, modified by passage over the central U.S.

In general, the weather types that tended to lengthen the pre-emergence period had the same effect after emergence had begun. Similarly, northward movement of Colorado lows and cyclonic activity in the Northwest Territories brought warm weather to Prince Albert and tended to shorten the period from the first to the mean date of emergence.

6.3 Weather during the latter part of the emergence period.

The length of the period from the mean date to the last emergence date, and its relationship to weather is of interest primarily as a further test of the applicability of the methods used in the previous sections. The length of this period in the three years studied varied more widely than for the early part of the total emergence period. The length of the two periods in these years shows an inverse relationship, as indicated below:

	first to mean	mean to last	Total
1952	30	22	52
1953	29	28	57
1954	26	31	57

Under constant temperature conditions the mean date of emergence falls mid-way between the first and last emergence dates (see Table 2.2). Deviations from this pattern should indicate differences in the favourability of the environment before and after the mean emergence date. The previous section indicated association of more favourable temperatures with the shorter period from first to mean emergence in 1954. Table 6.12 summarizes the weather from the mean to the last emergence date for each year. As in the pre-emergence period, the highest temperatures were not associated with the shortest period. Table 6.13 shows the distribution of daily maximum and minimum temperatures and cloud cover during the latter part of the emergence period of the three years. In 1952 and 1953 the frequency of days with minima in the warmest two classes are about equal, but 1953 has more days in the '6 - 10° C' minimum temperature class. This relationship agrees with the results of the previous section and explains the difference between 1952 and 1953 but it does not explain the length of this period in 1954.

Table 6.12 Summary of weather during the period from the mean to the last date of adult emergence in 1952, 1953, and 1954.

	1952	1953	1954
No. days	22	29	31
Air temperature (°C)			
Mean	16.9	17.1	17.2
Mean Maximum	23.7	24.2	23.1
Mean Minimum	9.9	10.0	11.4
Precipitation			
Total (inches)	1.34	1.95	4.90
No. days $\geq$ .01 inches	8	14	15
Cloud cover*			
Clear	10	15	9
Part cloudy	8	11	15
Cloudy	4	3	7

* see page 44.

Table 6.13 Distribution of daily air temperature extremes and cloud cover during the period from the date of mean emergence to last emergence in 1952, 1953, and 1954.

Minimum temperature (°C)	Cloud cover*	Maximum temperature (°C)				Total no. days
		16 - 20	21 - 25	25 - 26	31	
1952						
0 - 5	clear		3	1		4
6 - 10	clear	1	2	2	1	6
11 - 15	clear		4	4		8
	cloudy	1	3			4
1953						
0 - 5	clear	1	2			3
6 - 10	clear	2	8	3		13
	cloudy	1				1
11 - 15	clear		3	3	2	8
	cloudy	2				2
16 - 20	clear				2	2
1954						
6 - 10	clear	1	7			8
11 - 15	clear		11	4	1	16
	cloudy	5				5
16 - 20	cloudy		1	1		2

* see page 44. In this table 'Clear' includes days with more than 30 per cent of the total possible bright sunshine.

The duration of the period from the mean to the last emergence date in 1954 was longer than in the other two years but the maximum and minimum temperatures were consistantly warmer (Table 6.2). This anomaly can be explained by the heavy rains that occurred after the date of mean emergence in 1954. During this 31-day period nearly five inches of rain fell, 15 days had ≥ .01 inches of rain, and three other days recorded a trace of rain. The amount of this excess in relation to normal rainfall expressed in both inches and as a percentage of normal, is indicated below:

	Deviation from normal (inches)	Precipitation (per cent)
July 8	+2.13	+38
July 19	+2.86	+44
July 29	+4.18	+58
August 7	+4.78	+61

These heavy rains caused a general rise in the level of ground water in the bogs and probably submerged many of the unemerged cocoons. Submergence of diapause and post-diapause larvae of the larch sawfly increases mortality and retards development (Lejeune et al, 1955), and Butcher (1951:82-84) noted late emergence of larch sawfly adults in a bog where a dam raised the water levels as compared to emergence in a bog with natural drainage.

In the previous sections rapid development of the post-diapause stages of the larch sawfly has been associated with cyclonic activity, with northward-moving 'Alberta' and 'Colorado-Wyoming' lows the most favourable types. Table 6.10 shows that during the early emergence period these cyclonic systems are also associated with most of the precipitation. During the latter part of the emergence period, July and early August, thunderstorms are much more abundant than in June (Kendrew and Currie, 1955:146) and more rain occurs in all types of weather (Table 6.14). Although thunderstorms may occur under the influence of various anticyclonic systems, the moisture must be drawn from the south. According to Kendrew and Currie (1955) "The heaviest precipitation results from extensions of the Arctic Anticyclones over the NWT with simultanious moderately high pressures over the Great Basin. At such times depressions are forced south through the Prairie Provinces, moist air, occasionally even maritime tropical air from the Gulf of Mexico and the Atlantic, is drawn into their orbit (usually in the upper atmosphere)". Such conditions prevailed during much of the latter part of the emergence period in 1954, but in 1952 and 1953 the northward movement of damp air was commonly blocked by anticyclones moving eastward across the continent between 45° and 55° N lat. (Fig. 6.3).

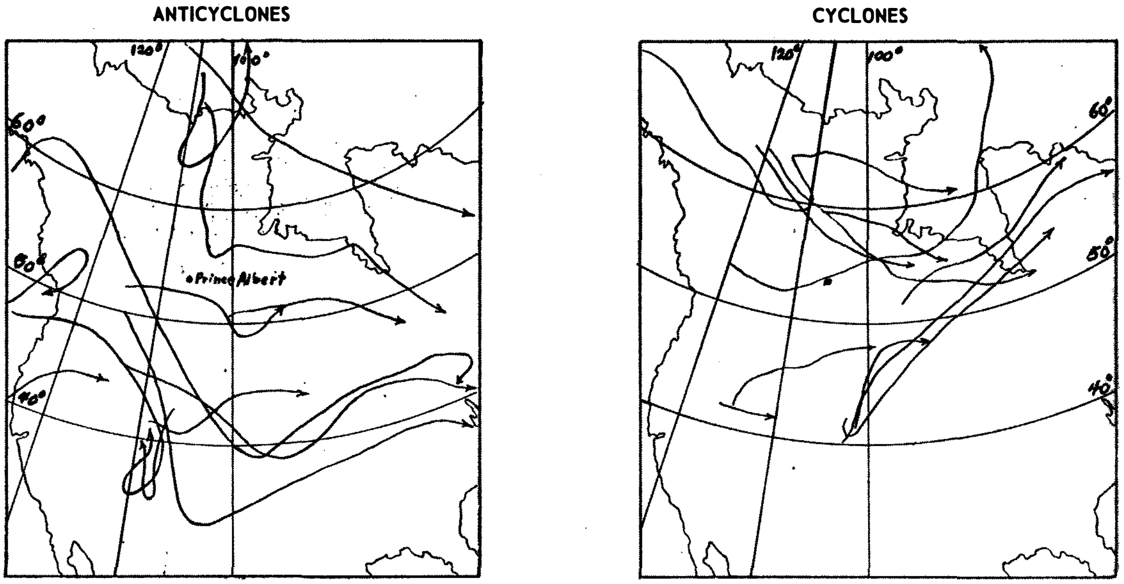
The relationships between weather patterns and the duration of the period from the mean date to the date of last emergence confirm the conclusions reached in the previous two sections but add a complicating factor. The favourable effects of northward moving cyclonic centres may be reversed if they deposit heavy precipitation. The amount of precipitation is partially governed by the amount of moisture in the air drawn from the south which is in turn governed by its path over the United States. Southern air reaching the Prairie Provinces by direct route up the Mississippi valley will contain much more moisture than air which has moved across the western plains of the U.S.

Table 6.14 Weather associated with different weather systems at Prince Albert during the latter part of the emergence period.

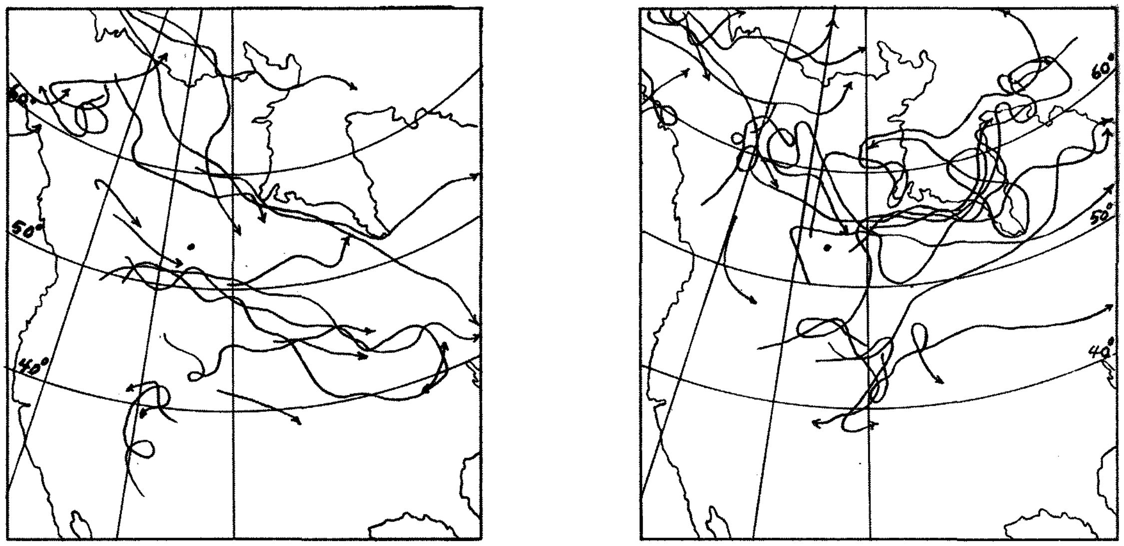
Weather system		No. days	Mean air temp. (°C) Maximum	Minimum	Cloud cover*	Air flow**	Precipitation Total	No. days
I	a	3	21.9	11.1	0,3,0	E	T	1
	b	8	24.7	8.9	6,2,0	A, S	.42	1
	c	9	25.6	13.3	3,2,4	S	1.96	4
II	a	2	21.4	10.3	1,1,0	A, N	.01	1
	b	6	23.5	7.0	4,2,0	A	.12	3
	c	11	23.7	7.8	6,5,0	W	.46	4
III		4	27.3	10.9	3,1,0	S	.50	1
IV	a	5	24.3	12.1	1,3,1	W, C	.08	1
	b	7	23.2	12.6	2,4,2	N	.24	4
V	a	5	24.2	13.1	0,3,2	C	1.11	5
	b	8	22.3	12.8	3,3,2	C, N	.64	6
VI	a	1	23.3	10.6	0,1,0	C	T	1
	b	4	19.3	11.1	0,1,3	E	.56	2

* see page 44.
** see page 95.

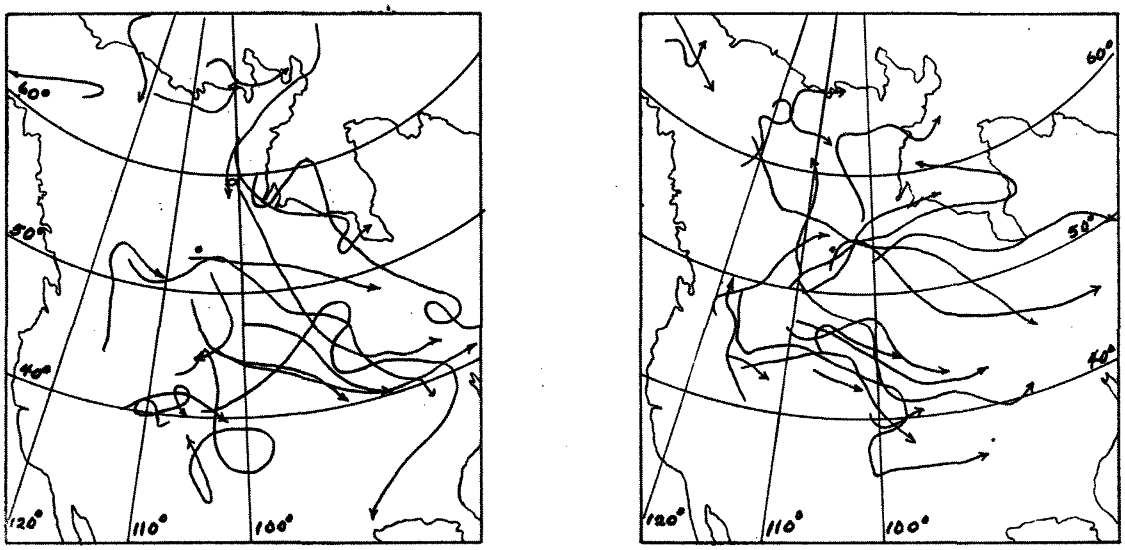
In the three years studied here no comparison of the differential effects of the path of southern air can be made. Figure 6.3 indicates no movement of such air to the Prairie Provinces in 1952 and 1953 while in 1954 the path seems to have been well west of the most direct route.



JUNE 26 – JULY 17, 1952



JULY 4 – AUGUST 1, 1953



JULY 15 – AUGUST 7, 1954

Figure 6.3. Tracks of anticyclonic and cyclonic centres entering North America north of 40°N lat. and west of 90°W long. during the latter part of the emergence period; from the date of mean emergence to the last emergence date. Taken from 'Monthly Weather Review', U.S. Dept. of Commerce.

7. Summary and conclusions.

The larch sawfly was capable of completing its post-diapause development at temperatures between 5° and 20° C. Under laboratory conditions the optimum temperature for rapid development and low mortality was 15° C. The duration of the post-diapause stages was also affected by the temperatures experienced by the larvae following cocoon formation and by the length and temperature of the cold exposure period. The minimum temperature threshold for development during the eonymphal and pronymphal stages is approximately 0° C, for pupation about 3° C, and for adult emergence about 5° C. In laboratory experiments the 'theoretical thermal constant' was found to be very variable. Some of the variability was related to the length of the cold exposure period. After short cold exposure periods a much longer time is required to complete emergence.

The soil temperatures encountered by the larch sawfly in bog forests near Prince Albert, Sask., were fairly constant under snow cover in April, 1953. Before percolation of melted snow began, temperatures in the upper four inches of soil varied from -2° to -6° C. As the snow melted the temperatures rose to approximately 0° C. Following the disappearance of winter snow cover soil temperatures rose rapidly in the surface layers to as high as 15° C. At four inches beneath the surface, soil temperatures remained below 5° C throughout May but gradually rose to 15° C in June and July. A snow fall in May rapidly reduced soil temperature to slightly above 0° C. The daily soil temperature was found to be affected by air temperature, cloud cover, precipitation, vegetation, microtopographic variation and the level of ground water.

Soil temperatures were correlated with air temperatures and the daily soil temperature estimated for the larch sawfly post-diapause period of two years. From these estimates the 'theoretical thermal constant' for sawfly developing at different depths beneath the surface was estimated. The average estimate was 516 day-degrees C, about 200 day-degrees C lower than the estimate made from experimental rearings.

The relationship between adult emergence and the larger weather processes showed more promise as a method of predicting the time and duration of the emergence period. The effects of various weather systems on the duration of the post-diapause period of the larch sawfly were quite constant, and could be used to predict the length of time from the disappearance of snow to the date of first emergence and mean emergence. The major weather systems that favoured rapid completion of the pre-emergence period were:

1. Frequent cyclonic activity north of 60° N lat. and northward moving centres that originated in the Colorado-Wyoming area.
2. Anticyclones in the south-central and Lake States associated with cyclones in the prairies.

The duration of the period was lengthened by:

1. Dominance of the Prairie Provinces by anticyclones of either Arctic or Pacific origin.
2. Cyclones that originated in southern Alberta or the Colorado-Wyoming area and travelled eastward in association with well developed Arctic anticyclones.

3. Cyclones that originated north of 60° N lat. and moved southward over the Prairie Provinces.

After adult emergence began, the same associations occurred but differences were less striking due to the general warming of the continent. The association of rapid development with the favourable circulation types listed above continued to be valid but an excess of northward moving 'Colorado-Wyoming' cyclones, associated with Arctic anticyclones and moderately high pressures in the Great Basin may have the reverse effect. Under these conditions rainfall was heavy and the water table in the bog forests rose. This submerged unemerged cocoons and retarded development and increased mortality.

The prediction of emergence from these conclusions depends upon reliable weather forecasts. Short-term forecast of circulation patterns and local weather have greatly improved in recent years and could be used to predict whether development will be retarded or hastened. This type of prediction would be useful in planning research or control activities by personnel at the location. For long-term planning, accurate predictions of circulation patterns would be necessary. However, satisfactory long-range forecasts have not yet been developed.

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