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ABSTRACT

Spring phenology of balsam fir in Maine was investigated during 1978. Multiple regression models based on climatic and geographic factors were developed for predicting fir phenology and accounted for a maximum of 52.6% of the observed phenological variation. Generalized maps depicting observed and expected phenology patterns are also presented.

Balsam Fir (*Abies balsamea* (L.) Mill.) Phenology in Maine

T. M. Mingo and J. B. Dimond[1]

The most abundant conifer in Maine, balsam fir (*Abies balsamea* (L.) Mill.), occurs commonly in all areas of the state except the southern-most extremes. It is used extensively in the pulp and paper industry and is of major economic importance. It is also the principal host of the spruce budworm (*Choristoneura fumiferana* (Clem.)).

Budworm populations have been at outbreak levels throughout much of the state since 1971, and in restricted portions of the state prior to 1971. Attempts to reduce budworm populations and to prevent tree mortality have required aerial application of insecticides over millions of acres of forest land on an annual basis. Critical to these programs has been the proper timing of sampling periods and spray application.

The present study was conducted during 1978 to examine phenological trends in the spring development of balsam fir in Maine. Additional objectives included the development of multiple regression models for predicting fir phenology throughout the state, the construction of general phenology maps depicting observed and expected phenology, and the association of phenological events of balsam fir with those of the spruce budworm.

METHODS AND MATERIALS

Phenological procedures used during this study are described in detail by Morris, Webb, and Bennett (1956). The method has two major advantages when compared to traditional phenology techniques

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which require an observer to evaluate subjectively phenological events such as full-bloom or end-of-bloom of selected flowers. The method used in this study is quantitative and enables different observers to produce comparable data. The method also allows a small number of observers to cover large geographic areas. Details of the procedure are given below.

Reference stations were located near Augusta, Orono, and Waite, Maine. These served as control sites and were used to determine current shoot growth curves for trees within these areas of the state. The Augusta and Waite stations consisted of a plot of 15 trees, approximately 10-12 feet in height, that were located in exposed areas. The reference station located at Orono contained two plots. One plot was located under a dense canopy of white pine (*Pinus strobus* L.) and the second was located in an exposed open area. Both plots contained 20 trees.

To determine growth rates, a single branch near the top of each tree was selected and marked with a numbered tag. The terminal shoot of each tagged branch was then periodically measured. Measurements were initiated prior to any bud development and were continued until cessation of all growth. Measurements, from the base of the dormant bud to its apex, were taken to the nearest millimeter using a plastic ruler. Following initiation of growth, the bud scales drop leaving a well-defined scar at the base of the developing shoot. This scar forms an excellent reference point and was used during later measurements. Measurements were taken at weekly intervals at the Augusta and Waite reference stations and at biweekly intervals at the Orono reference station.

After the completion of all growth, the length of the dormant bud was subtracted from the total length of its respective shoot. The resulting measurements represented the actual shoot lengths for each date of measurement. These were then converted to percent of final growth and plotted against time to produce growth curves for each reference station. The growth curves were subsequently used to determine phenological variation at numerous survey stations distributed throughout the state.

A total of 87 survey stations was established throughout the range of balsam fir in Maine. Survey stations were located at approximately 20 mile intervals and included all areas of the state except the southwest corner. Each survey station contained 15-20 trees which were located in exposed areas. A single branch on each tree was selected and marked with a numbered tag for subsequent measurements. Shoot measurements at each survey station were taken only twice during this study. The first measurements were taken during early spring when shoots were approximately 20-35% elongated. (Timing for this measurement can be estimated from internode lengths of growth from previous years.) The final shoot measurements were taken in late summer following the completion of all growth and were necessary to calculate the precise percent growth of each shoot when the initial measurements were made.

Phenological variation occurring at each survey station was determined by comparing the survey station data to the growth curves derived from the reference stations. To illustrate this procedure, a particular survey station was first measured on June 5th and again during late summer. It was found that at the time the initial measurements were taken (June 5th) the shoots were 30% elongated. Examination of the growth curve indicated that trees at the Orono reference station had reached the same level of growth (30% elongation) four days earlier on June 1st. Therefore, the survey station was phenologically four days behind the Orono reference station. Phenology values for each survey station were determined using this procedure.

The phenology values from the survey stations were plotted on state maps, and isophenes (lines separating zones of equal phenology) were drawn by hand. To facilitate map construction, phenology values were grouped into increments of from 1-6 days before plotting.

Multiple regression analysis was used to develop models for predicting balsam fir phenology throughout the state. Factors which were considered included: longitude, latitude, altitude, cumulative annual rainfall, degree days, temperature, and monthly rainfall. Values for longitude, altitude, and latitude were obtained from topographic maps. Weather data for 53 weather stations used for comparison with the phenological data obtained during this study were taken from monthly National Oceanic and Atmosphere Administration weather summaries.

In order to develop multiple regression models, phenology data from the survey stations were compared with the geographic and climatic parameters listed above. Each survey station was compared with data obtained from the nearest weather station. Comparisons were made for May and June weather data only.

The actual regression analysis involved two methods of calculation: backward elimination and stepwise regression. Both methods are described in detail by Draper and Smith (1966) and were used to determine the regression model containing the smallest number of significant variables. All calculations were made on the University of Maine IBM computer using Statistical Procedures for the Social Sciences programs.

RESULTS AND DISCUSSION

Both methods of regression calculation produced identical models which are summarized in Table I. The regression model containing all variables was found to be statistically significant and accounted for a maximum of 53.7% of the observed phenological variation. However, only three factors (altitude, latitude, and May degree days) were found to have a major effect on phenology. The regression model containing these three factors accounted for 52.6% of the observed variation, a reduction of only 1.1% following the removal of the non-significant variables from the model.

Degree day data made a significant contribution to phenology, as measured from fir shoots, only during May. During all other periods, altitude and latitude were the only factors that significantly affected phenology. The regression model based on these two variables accounted for 50.3% of the total variation. The remaining unexplained variation is probably the result of site and stand factors such as soil quality, stand vigor, genetic variation, snow cover, and frost depth.

Reference station growth curves (Figure 1) displayed typically sigmoid patterns of growth and clearly reflected the progression of phenology across the state. Reference stations were phenologically separated from each other by approximately 5-7 days. During late May and early June drought conditions developed throughout the state and resulted in decreased rates of growth. This reduction of growth was reflected in the growth curves by a change in slope and was most evident at the Augusta reference station and to a lesser extent at the Orono and Waite reference stations.

Growth curves for the control plots located at Orono (Figure 2) displayed essentially identical rates of growth during the early spring periods. During late May and early June, trees growing in the open became heavily infested with the balsam twig aphid, *Mindarus abietinus* Koch. The infestation resulted in arrested growth, retardation of the growth curve and in some cases shoot mortality. Sheltered trees, by contrast, were free from aphid populations.

The clearest representation of phenology from the survey stations during spring 1978 (Figure 3) was produced using a 3-day interval. (The 3-day interval included all values from 1.5 to 4.5 days.) The map presented in Figure 3 should be considered to be an approximate representation of phenology in Maine. The placement of hand-drawn isophenes depends upon the subjective evaluation of the observer and becomes particularly difficult for areas having few data points or rapid topographic changes (Hopp and Blair 1973). However, within these restrictions, general trends of phenology can be depicted.

Table 1. Regression models for predicting balsam fir phenology in Maine.[1]

Regression Models				R square	Standard error
Phenology = 8.659[2]	−0.004 (altitude)	−0.014 (latitude)	−0.016 (May degree days)	52.64%	2.76
Phenology = 4.412[2]	−0.005 (altitude)	−0.019 (latitude)		50.33%	2.81

[1] Latitude values coded as follows: 43°00′ = 0, 44°00′ = 60, 45°00′ = 120 . . .; degree day values are the sums of the negative departures of average daily temperatures from 65°F; R square equals the amount of phenological variation accounted for by the regression model and the standard error equals the square root of the residual mean square.

[2] Value indicates Y intercept when X equals zero.

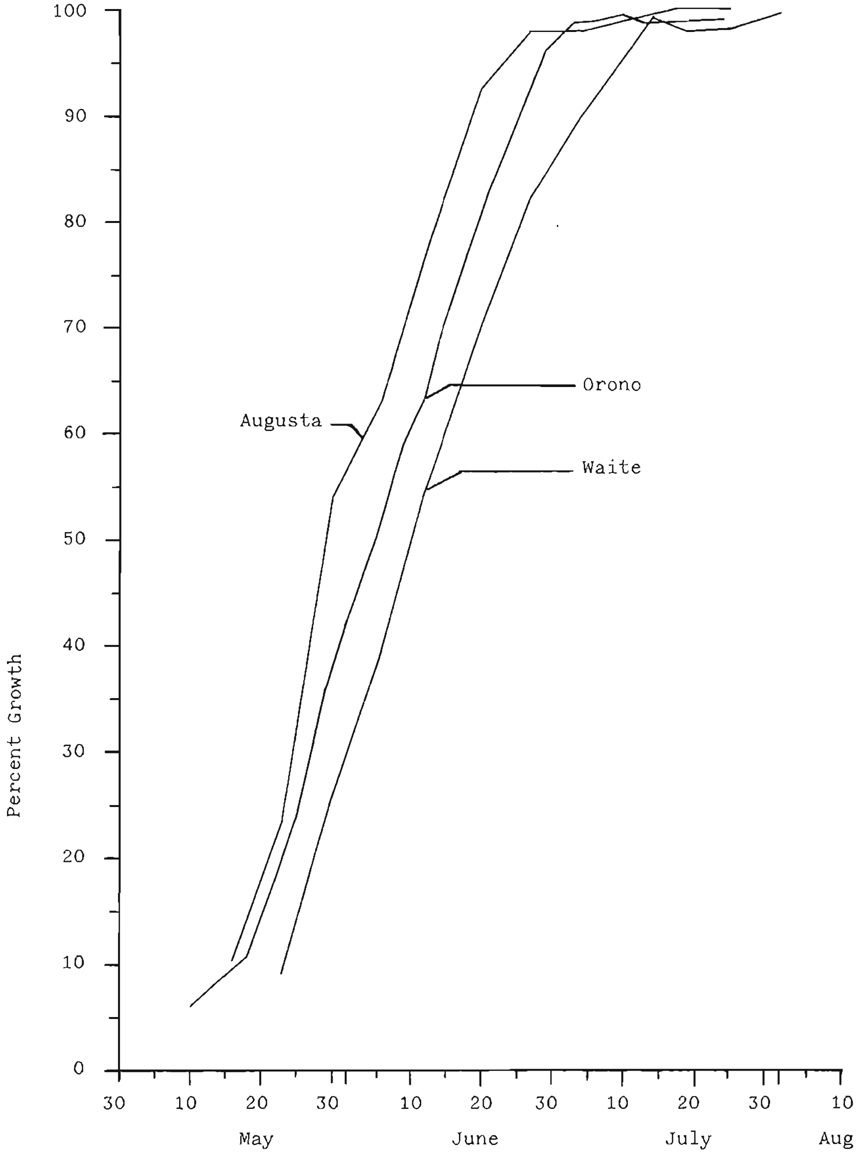

Figure 1. Growth curves for reference stations located at Augusta, Waite, and Orono, Maine.

An oceanic influence is particularly evident along the southeastern coastal areas of the state and is expressed as a delay of phenology in those areas. This effect is probably the result of consistently cooler coastal temperatures during the spring and summer periods.

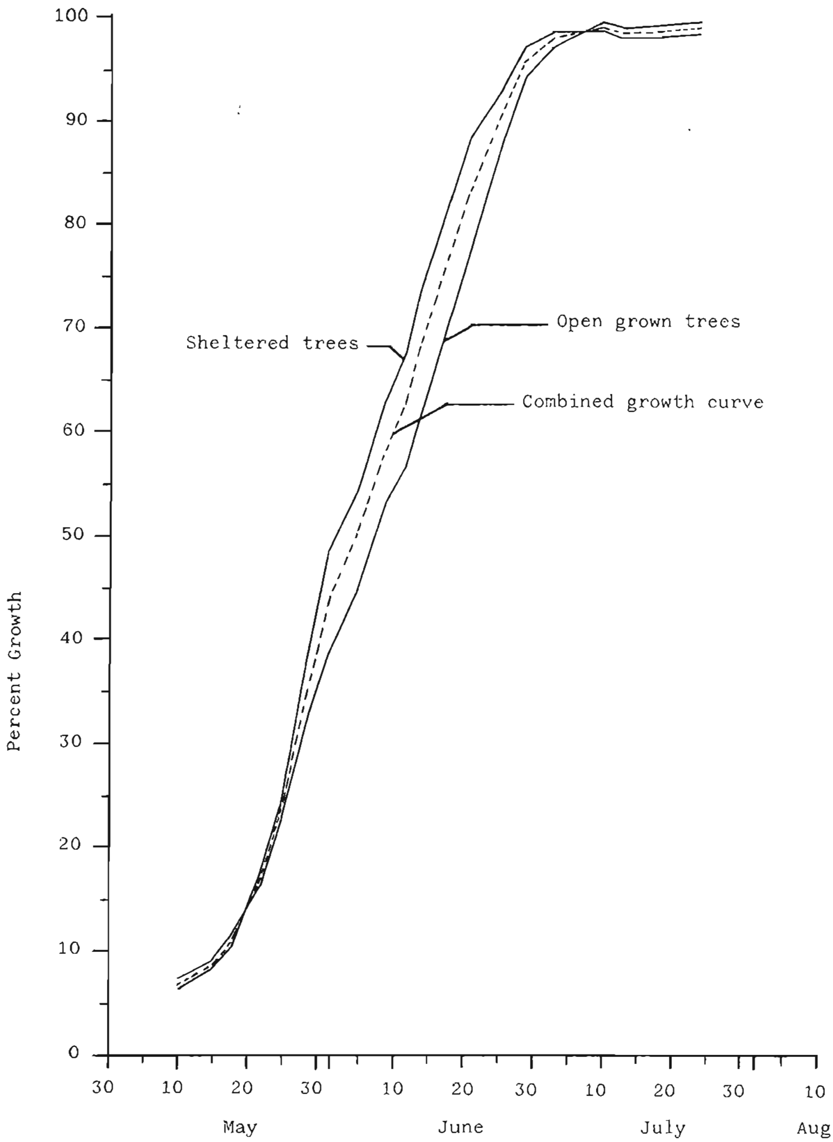

Figure 2. Growth curves for control groups located at the Orono reference station.

The area of latest phenology occupies the general region of the state north of Greenville and west of Ashland. The delay of phenology in this area is probably the result of higher latitudes, higher average altitudes, and possibly from differing forest types (coniferous forests as opposed to hardwood or mixed forest types).

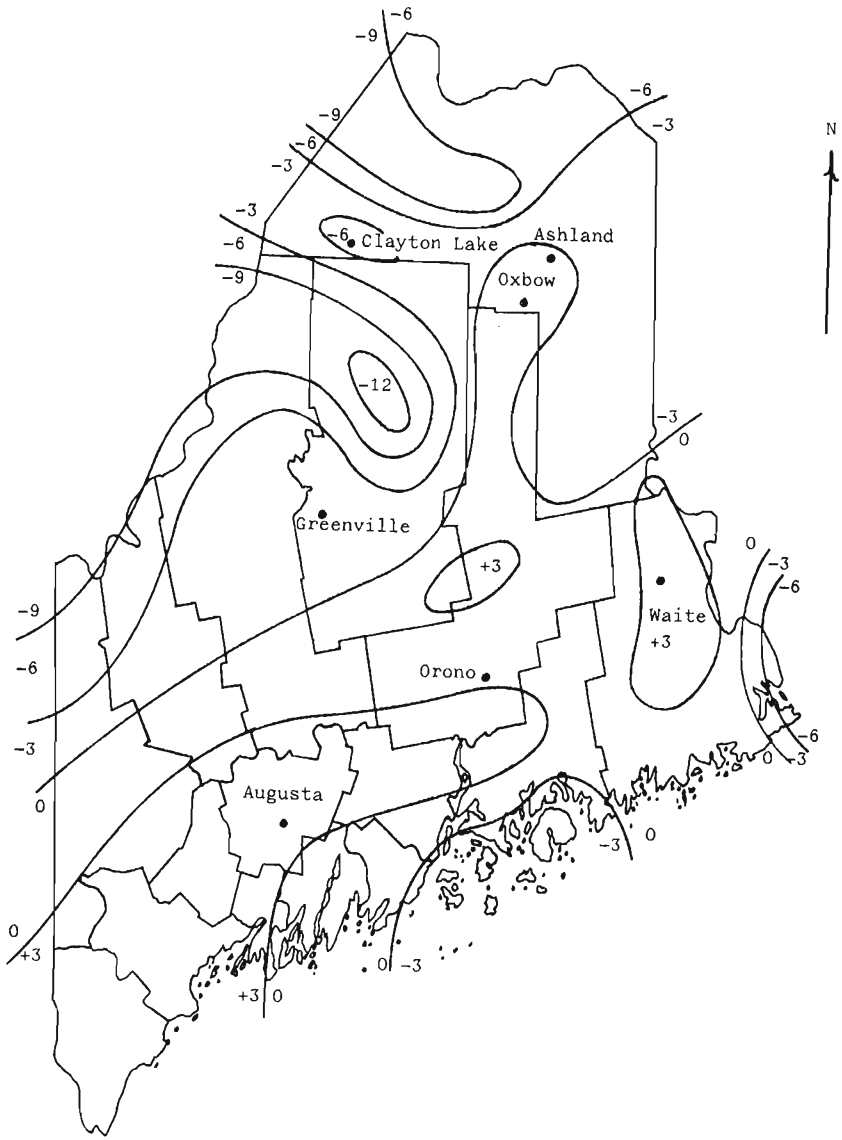

Figure 3. Observed phenology of balsam fir in Maine during Spring 1978. Isophenes separate zones of equal phenology using a three-day interval based on the Orono reference station.

The effect of agricultural activities may also be reflected in the phenology map. The zero and -3 day phenology zones display a marked northward extension into an area of the state that is used extensively for the commercial production of potatoes. Since this area contains many cleared fields, the northern extension of these two intervals may reflect higher rates of warming due to increased exposure of the land surface.

Both field workers and spruce budworm researchers (H. Trial, Jr. personal communication) generally believe that 1978 was an atypical year in Maine. Very rapid warming occurred in the northern and eastern areas of the state. As a result the Oxbow and Waite areas, which are normally expected to be behind the Orono area in spring phenology, were either in the same or in an earlier phenology zone. Consequently the map depicting observed phenology (Figure 3) may not represent the typical phenological patterns that would be expected to occur in Maine.

In order to refine the phenology map presented in Figure 3, the regression model presented in Table I was used to calculate expected phenology. Values for altitude, latitude, and May degree days in 1978 were inserted into the regression formula and the expected phenology value for each survey station was calculated. These values were plotted on a map using a 3-day interval and isophenes were then drawn by hand. The map of expected phenology is presented in Figure 4.

The amount of snow cover and the depth of frost penetration influences soil warming and is of considerable importance in the initiation of spring growth. Hickin and Vittum (1976) have in fact shown that soil temperature as well as air temperature, above a certain threshold, are significant factors in predicting spring phenology. As a result it is probable that snow cover and frost penetration are among the more important unmeasured variables, leading to an r^2 value of only 52% in the regression equation.

The importance of snow cover and frost depth may be reflected in differences between Figures 3 and 4. Greater amounts of snow cover as well as greater depths of frost in the northwestern areas of Maine probably led to greater phenological delays in those areas (Figure 3) than were predicted using the regression model based on altitude, latitude, and May degree days (Figure 4). In addition to snow and frost, the unexplained variation is probably the result of unmeasured site and stand variables such as stand vigor, soil quality, and genetic variation.

The most accurate map depicting typical phenology in Maine would probably contain elements of both Figures 3 and 4. However, this can only be verified by continuing the present type of study for

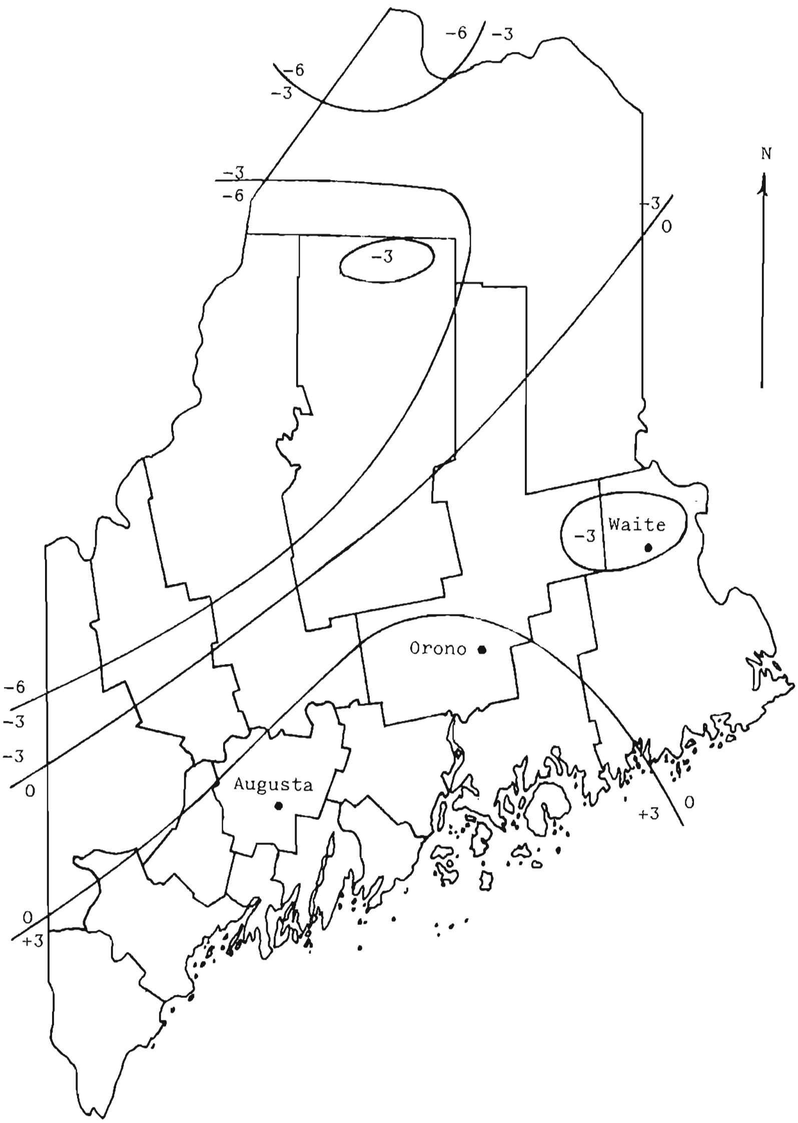

Figure 4. Balsam fir phenology in Maine during Spring 1978 predicted by the regression model based on altitude, latitude, and May degree day variables. Isophenes separate zones of equal phenology using a three-day interval.

several years. The establishment of four or five reference stations widely distributed across the state would probably be adequate for the purpose and would probably require little expense.

Morris, Webb, and Bennett (1956) have shown that balsam fir growth curves can vary from year to year depending upon the onset of spring conditions and the rate of warming. The arrival of spring can be predicted in part by examination of degree day data, however, the rate of warming cannot, and may change rapidly with latitudinal shifts of the storm track (Greenbank 1956). Morris, Webb, and Bennett (1956) also observed that differences in phenology between two New Brunswick sites varied from 10-18 days during six different years. Variation was usually in the range of 10-13 days and did not change by more than one day from one year to the next with the exception of a single unusually cold year.

The annual phenological variation occurring in Maine has yet to be reported but can be estimated by using past weather data (NOAA weather summaries) and the regression model presented in Table I. By inserting the appropriate values for altitude, latitude, and May degree days into the regression formula, the phenology value for any survey station during any year can be calculated. A comparison of widely separated survey stations will reveal the amount of variation occurring across the state during any particular year. Similarly, the comparison of data of individual survey stations will reveal the amount of change from any one year to the next at that particular location.

Phenology values for selected sites throughout the state were calculated for the period from 1971 through 1978. The resulting values were compared to the Orono reference station to determine the magnitude of phenological difference across the state and the extent of variation from one year to the next. To illustrate this procedure, the comparison between the Clayton Lake survey station and the Orono reference station is summarized in Table II. Phenological differences between these two sites ranged from 6.2 to 8.4 days. The greatest change in phenology from any one year to the next between these two sites occurred during 1972-1973 and was 1.3 days. However, the average change in phenology from one year to the next was only 0.8 days. The greatest difference in phenology during the entire eight year period was only 2.2 days. The greatest annual change in phenology between the Orono reference station and any other survey station did not exceed 2.2 days while the largest total variation during the same period did not exceed 2.7 days. As a result phenological variation in Maine can be expected to remain relatively constant, based on May degree days, except during abnormal years. However, it should be noted that differences in unmeasured variables such as snow cover and frost depth between areas may act to increase the variation in excess of that explained by the regression model alone.

Table II. Comparison between the Clayton Lake survey station and the Orono reference station.

	Clayton Lake		Orono			
Year	Degree Days[1]	Phenology[2] (days)	Degree Days	Phenology (days)	Phenological Difference (days)	Annual Change (days)
1971	448	–5.547	306	1.707	7.254	
						1.200
1972	497	–6.331	280	2.123	8.454	
						1.328
1973	546	–7.115	412	0.011	7.126	
						0.960
1974	652	–8.811	458	–0.725	8.086	
						0.768
1975	370	–4.299	224	3.019	7.318	
						0.550
1976	446	–5.509	334	1.259	6.768	
						0.214
1977	412	–4.971	287	2.011	6.982	
						0.720
1978	364	–4.203	284	2.059	6.262	

[1] Degree day values equal the sums of the negative departures of average daily temperature from 65°F.

[2] Phenology values are based on the regression model containing latitude, altitude, and May degree day values.

Due to the economic importance of both the spruce budworm and balsam fir, attempts were made to associate phenological events of these two species. Dates of peak occurrence of budworm larvae (third and fourth instars) in the Oxbow area of northern Maine (data from H. Trial, Jr.) were compared with degree day data for the period from 1971 through 1978. The date of peak occurrence of third instar larvae was found to be highly correlated ($r = 0.85$, $P < 0.02$) with May degree day values. The specific correlation formula was:

$$\text{date of peak occurrence} = 390.8 + 18.0 \text{ (May degree days)}$$

where May 23rd, the earliest date of occurrence, was coded to equal day number one. The correlation between peak occurrence of fourth instar larvae and May degree day values was not significant ($r = 0.52$, $P < 0.20 > 0.10$). The average dates of peak occurrence of third and fourth instar larvae in the Oxbow area were May 28th and June 2nd respectively.

Phenological values for the Oxbow area (1971-1978) were calculated using weather data and the regression model as previously described and compared to the Orono reference station to determine the amount of phenological difference between these two areas. The Orono reference station was found to be 6.3 ± 0.8 days phenologically ahead of the Oxbow area. The occurrence of budworm larvae would also be expected to be 6.3 ± 0.8 days earlier at the Orono reference station than in the Oxbow area. The corresponding dates of peak occurrence of third and fourth instar larvae in the Orono area would therefore be approximately May 22nd and May 27th respectively. Since such differences are known or can be determined, the phenology maps can be calibrated to reflect dates of peak occurrence of budworm larvae rather than zones of equal phenology.

By using the regression models and phenology maps presented in this study, the proper timing of sampling periods as well as the initiation of spray programs should be facilitated. Similarly, the data presented here should enable an observer to predict the occurrence of phenological events throughout the state.

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