A METHOD OF PHENOLOGICAL SURVEY FOR USE IN FOREST INSECT STUDIES

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Abstract

To ensure correct sequence in the timing of insect sampling or control operations over a large forest area it is desirable to know what phenological differences may be expected. Measurements of shoot elongation provide a simple and objective method for comparing a large number of phenological stations in one season. By this method one or more reference stations have to be visited weekly to permit the plotting of growth curves, but the great majority of the stations have to be visited only twice a year. At any one station the major source of variance in cumulative shoot growth on a given date is between trees and the optimum allocation of sampling resources will usually be based on the selection of one shoot per tree and 10 or more trees of balsam fir per station. The variance is greater for cherry and larger samples are necessary.

Introduction

This is the sixth in a series of papers dealing with techniques for studying natural populations of the spruce budworm, Choristoneura fumiferana (Clem.). In an earlier paper in the series it was shown that the intensive population sampling on which life tables are based must be very carefully timed in relation to the phenology of the insect (4). It was suggested that phenological indices based on more easily recorded phenomena than insect development may be useful if the study area is large enough to include sampling plots that are phenologically different. It is the object in the present paper to describe a simple, and apparently new, technique that has been useful in the measurement of phenological differences in northern New Brunswick.

Phenological studies are commonly based on easily observed events, such as the first flowering dates of various species of plants. Leopold and Jones (3) and Williams (6) have pointed out the weaknesses to which most studies of this type have been subject. Discrepancy arises through differences in the perspicacity of observers, the intensity of observation, and the populations of the plants on which the records are made. When a plant is abundant on one plot and scarce on another, chance and genetic variability favor the recording of an earlier flowering date on the plot where it is abundant. Studies of this type also suffer from the fact that they are generally subjective and qualitative.

For purposes of extensive phenological survey, the common techniques have shortcomings that are even more serious, for they require that each plot be examined carefully at least once a day. The time and travel that this involves limit one observer to the study of a very few plots. This means that we must accept the possible disparities between different observers if

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widely separated areas are to be compared. The method that is described below circumvents both of these difficulties. The measurements of shoot growth are quantitative and objective, so different workers can combine their results. Extensive areas can be covered because each station has to be visited only twice a year.

If more extensive application reveals no serious weaknesses the method should also be useful for other purposes. Personnel of the Forest Insect Survey in Canada generally have to prepare their spring and summer itineraries well in advance. More adequate data on average phenological differences between different parts of their districts would facilitate this type of planning and ensure optimum sequence in insect collecting and sampling. The importance of timing in aerial forest spraying has also been demonstrated (5). Here again, a better knowledge of phenological differences would be of considerable value in planning the logistics of extensive operations, and in determining the sequence in which the different parts of the area should be treated.

Materials and Methods

Seasonal shoot elongation can be readily measured on most species of trees or shrubs. The present work is based largely on balsam fir, Abies balsamea (L.) Mill., because it is the principal host of the spruce budworm and is likely to be common in any areas where this insect is being studied. When budworm infestations become severe, however, the shoot growth of balsam fir may be affected by the feeding of the larvae, or the shoots may be completely destroyed. To meet this situation we have made similar measurements on pin cherry, Prunus pensylvanica L.f. No doubt another species would have served equally well, and cherry was selected only because it is common on roadsides and cutover lands throughout New Brunswick.

As the main object was to assess differences in phenology associated with latitude, longitude, and elevation, only well-exposed trees growing along roadsides or in cutover areas were selected for measurement. If appropriate species of trees or shrubs are selected, however, there is no reason why the same technique could not be used under a crown canopy to measure the effect of stand density on phenology. At each phenological station five or more trees were used and shoots were marked on different sides of each tree by the use of numbered tags. The vigorous terminal shoots of primary branches were generally selected. The number of trees and shoots that should be marked to ensure reliable averages will be discussed under a separate heading.

Shoot length was measured to the nearest millimeter with a ruler. The measurements were started in the early spring before the growing season and the base of the bud was used as the zero point. This serves as a good reference point throughout the season as it becomes marked by a well defined scar after the bud scales have dropped. The first measurement, then, is simply the length of the dormant bud. As the bud bursts and the new shoot elongates, the measurements are made from the same reference point to the tip of the
new shoot. In the broad-leaved species, like cherry, two leaves commonly appear before the shoot itself elongates appreciably; if they are parted carefully the tip of the shoot can usually be seen.

In compiling the data, the initial length of the bud is first subtracted from each measurement. The remainder then represents the cumulative shoot growth that has occurred during the season up to the date of measurement. It is convenient to express this as a percentage of the total shoot growth that occurred during the whole growing season, for this permits the summarizing and comparing of the records regardless of the absolute growth of the individual shoots. In short, the data are expressed as cumulative growth in per cent for any date on which the shoot is measured.

At laboratories or field stations where personnel are stationed throughout the season, it is a simple matter to measure the marked shoots at intervals of about one week and to plot the results as curves of cumulative growth (Fig. 1). Phenological stations where this is done will be called reference stations. The great majority of stations, where only two measurements are made during the year, will be called survey stations. At survey stations the first measurement is made early in the season, when cumulative growth is approximately 25%. The second measurement is made at the end of the growing season, at any time after it is certain that growth has been completed.

The Comparison of Reference Stations

Personnel of the Green River Laboratory spend the winter at the Forest Biology Laboratory in Fredericton. One of our first objects was to find the mean phenological difference between the two laboratory sites so that events
observed at Fredericton in the early spring could be interpreted in terms of their probable time of occurrence at Green River. This is of use in predicting when field work should be started, particularly in unusually early or late seasons. Reference stations were established near both laboratories and the shoot growth curves for all years in which Fredericton data are available for comparison are shown in Fig. 1.

These curves are typically sigmoid but may vary considerably in slope, particularly in the early part of the growing season. For example, 1947 had a relatively late season but warm weather came suddenly and initial shoot growth was rapid. In 1954, by comparison, growth was initiated much earlier but proceeded slowly under the influence of cooler weather. In seasons like 1954 the date of growth initiation is difficult to establish reliably because of the flatness of the lower portion of the curves. For this reason it is better to make comparisons between some other point on the curves, such as the 25% point. On this basis the differences between Fredericton and Green River are as follows: 1946—10 days, 1947—18 days, 1950—13 days, 1953—12 days, 1954 fir—11 days, 1954 cherry—10 days. Constant differences are not to be expected between these two stations because northern and southern New Brunswick may be affected differently by latitudinal shifts in the storm track (1). It is helpful to know, however, that a mean difference of about 12 days may be expected except in unusual seasons like 1947.

Although the growth curves for the two stations show a surprising degree of parallelism, the choice of other points gives somewhat different results. The choice of the 25% level for general comparisons is based on several considerations: (1) This is about the lowest point at which the slopes are always steep enough to permit reliable comparisons. (2) Experience at Green River has shown that the 25% point provides a good index to the general phenology of early June, which is an important period in budworm sampling. Many other events have been recorded qualitatively on the same plot over the past 10 years and will be described in a later paper dealing with other phenological indices. (3) There is no assurance that curves for different areas will be as parallel as those in Fig. 1; use of the 25% point provides an index of spring differences whereas subsequent convergence or divergence of the curves may be influenced by other factors.

The Comparison of Survey Stations

The present method is based largely on data from survey stations, but it is always necessary that at least one reference station be established. At Green River, for instance, one reference station is maintained at the laboratory while a number of survey stations are distributed over the other parts of the Watershed.

It has been mentioned that the first measurement at the survey stations is made when cumulative growth is about 25%. This point cannot be recognized in advance, of course, but the examination of average total shoot length in an area will give a close enough approximation of the length to be
expected at the 25% point. In the Green River area, vigorous fir shoots of
the type used for phenological measurements commonly have a length of
4 to 6 in., so the first measurement is made when the new shoots are 1 to 1 ½ in.
long. The second measurement is made any time after growth is completed.
The initial bud length is not recorded for each shoot, as it is at the reference
station, for it is sufficiently accurate to deduct a constant mean bud length
from all the survey measurements. Once this is done, the cumulative growth
in per cent on the date of the first measurement is calculated for each survey
station. The date on which the same percentage was recorded at the reference
station is then read from the growth curve. The comparison of the two dates
(date of first measurement at a survey station and date corresponding to the
same cumulative growth at the reference station) gives the number of days
by which each survey station is earlier or later than the reference station in
its spring phenology.

An example may help to clarify this procedure. At Survey Station 26 in
1953, the first measurements were made on 10 shoots on June 9. The same
shoots were measured after the growing season and the percentage growth put
on by June 9 was calculated separately for each shoot. This varied between
10% and 24% for different trees and averaged 16%. From the growth curve
prepared for the laboratory in the same year, it was found that 16% of the
total growth had been put on by June 3, and it was therefore concluded that
Station 26 was about six days later than the reference station in its spring
phenology. As a matter of interest, Station 26 was followed for two more
years and was found to be seven and one-half days later than the reference
station in 1954 and seven days later in 1955. Annual variations of this
magnitude or greater could easily result from sampling error, as will be shown
in the next section, unless a larger sample of shoots is measured. Over a
limited area like the Green River Watershed differences between stations do
not appear to vary greatly from year to year, so if an adequate sample of
shoots is measured at each station for one or two years this will generally be
sufficient to establish the sequence in which the various stations should be
visited for insect sampling in early June.

The method is useful in establishing sequences, and where the survey
stations are sufficiently numerous and well distributed it is also possible to
plot isophenes. For an insect like the spruce budworm, however, the method
does not necessarily indicate when sampling should be initiated in a given year.
The development rate of this insect is affected not only by climate but also by
the presence or absence of such favorable sources of food as staminate flowers.
Thus the point of 25% shoot growth may occur in one year when budworm
larvae are in the early part of the third instar, and in another year when they
are in the latter part of the fourth instar (1). It is always necessary to follow
larval development on at least one station (preferably an early station) in
order to find its relation to shoot development each year. The results of
phenological surveys made in the preceding years will then be very useful in
indicating the rotation in which the various stations should be visited for
insect sampling.
Optimum Sample Size

In the early work at Green River five trees were selected at each station and on each tree shoots were measured on the north, east, south, and west sides. Variance analyses revealed that intertree variance was highly significant but directional variance within trees was not significant. As all tagged shoots were about five feet from the ground, possible differences associated with height in the crown were not involved. As the trees were young, well exposed, and not severely attacked by the spruce budworm, the effects of flower production, exposure, and defoliation were also excluded from the study. In order that an estimate of intertree variance based on larger samples might be obtained, groups of 10 to 25 trees of each species were marked at the Green River and Fredericton reference stations in 1954 and two shoots per tree were measured at weekly intervals throughout the growing season. The inter- and intra-tree variances in cumulative growth in per cent were plotted over cumulative growth in per cent so that mean values could be read for any desired point. The variance ($s^2$) at the 25% point was found to average:

\[
\begin{array}{c|c|c}
\text{Fir} & \text{Cherry} \\
\hline
\text{Between trees} & 70 & 115 \\
\text{Between shoots within trees} & 15 & 40 \\
\end{array}
\]

Variance was clearly related to the percentage of cumulative growth, the maximum for fir (intertree, 125; intratree, 55) occurring at approximately the 60% point. For present purposes, however, we are interested only in the 25% point and no attempt has been made to find what kind of statistical transformation will stabilize variance.

By using components of variance we may find the number of shoots and trees that must be used to provide any desired degree of precision. This type of analysis is illustrated in an earlier paper of the series (4). If $s^2$ is the component for shoots (15 for fir), $s^2$ the component for trees ($70 - 15$)/2 for fir), $N_t$ the required number of shoots per tree, $N_s$ the required number of trees per station, and $s_2$ the desired standard error of the mean, then

\[
s_2 = \sqrt{s^2 + N_s s^2}/N_t N_s
\]

The slope of the growth curves at the 25% point (Fig. 1) is such that a change of 1% in cumulative growth corresponds to a change of 0.75 days. If the purposes of the survey permit us to accept a standard error of 1.5 days we may double these figures and set $s_2$ at 2%. This seems like a reasonably acceptable error, especially if replication is achieved by continuing the survey for a second or third year. Then, by solving for $N_t$ and substituting:

\[
N_t = (15 + 27.5 N_s)/4 N_s \text{ for balsam fir,}
\]

\[
N_t = (40 + 37.5 N_s)/4 N_s \text{ for pin cherry.}
\]

By inserting arbitrary values for $N_s$, it is found that:

\[
\begin{array}{c|c|c}
\text{Fir} & \text{Cherry} \\
\hline
\text{When } N_s = 1, N_t = & 10 & 19 \\
\text{When } N_s = 2, N_t = & 9 & 14 \\
\text{When } N_s = 4, N_t = & 8 & 12 \\
\end{array}
\]
As the total number of shoots that must be measured at each station is \( N, N_s \), it is better to measure only one shoot per tree unless the number of trees available at each station is very limited. It is also better to select fir in preference to cherry unless there is a real danger of budworm injury to the shoots.

It is considered that possible convergence or divergence of growth curves will not be an important source of error in limited areas like the Green River Watershed, particularly if care is taken to make the first measurement as near the 25% point as possible. For more extensive areas, however, a number of reference stations should be established to provide more adequate data on this factor. As the reference stations play a very important role in the comparisons, it is suggested that a lower error be accepted and that sample size be correspondingly greater than that at the survey stations.

**Application**

An adequate phenological survey has not been completed for either the Green River Watershed or other parts of New Brunswick. As a matter of interest, however, stations for which preliminary data based on the present method are available are plotted in Fig. 2. The stations in northwestern New Brunswick were measured from the Green River Laboratory, while those in the north-central part were measured from field stations on the Tobique and Upsilonquitch Rivers in connection with studies on aerial spraying. The
measurements were made in 1953 and 1954. At some stations only five trees were included, so the standard errors are too high to permit reliable conclusions.

If Hopkins's Bioclimatic Law (2) is shown to be applicable in a given area, it can be used to extend the results of a limited phenological survey. The isophenes (Fig. 2) are based entirely on this Law and in some parts of New Brunswick appear to agree fairly well with the preliminary results from the survey stations; in other parts, Hopkins's Law would lead us to expect greater phenological differences than were actually recorded. However, the survey stations show considerable variation, even over limited areas (Fig. 2), and this may be attributed both to sampling error and to local topography and aspect. Before more definite conclusions can be drawn for New Brunswick as a whole the survey must be greatly expanded, with a minimum of 10 trees per station and with careful notes on the location of each station with reference to local topography.

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References