Lecture 16: Phenology Models

Tools to Improve the Efficiency of Insect Sampling (and Control)

References:

- Consult the University of California's web site titled Degree-Days and Phenology Models.
- Consult the University of Illinois web site titled Degree-Day Calculator.

Know:

- Insect growth and development are temperature-dependent.
- The **developmental** threshold for a phenology model represents the temperature below which insect development is negligible.
- Insect development models calculate developmental units -- "**degree-days**" -- that can be used to measure and predict insect development.
- Know how to calculate the number of degree-days that accumulate in a day if given the maximum and minimum temperatures and a specific insect's developmental threshold.
- A **biofix** is an observable event (often the capture of insects in a pheromone trap) that signals when to start counting degree days.
- **Phenology models** are designed to predict or understand insect development to time sampling or control efforts as efficiently as possible.

Sampling and controlling insects takes time and costs money ... think of the work involved to take multiple samples around a field, orchard, or nursery if you need to know the number of insects per foot of row, per stem, per leaf, or per sweep. (Think of counting corn borer egg masses in fields that are shedding pollen on a 95-degree day in early August, or think of cutting square-foot samples of turf grass on the same kinds of days to check for annual white grub larvae.) Understanding insect development and using temperature-based phenology models to time sampling and control actions saves time, effort, and money.

Phenology from a naive starting point:

Damaging stages of insects show up, then are gone, then show up again. It sure would be nice to predict when they'll occur. Then we would know when to spray, or (much better) when to sample. To some extent, we do some predicting anyway by calendar ...

- Annual white grubs damage turf in August and September
- elm bark beetle adults emerge in the spring
- eastern tent caterpillars hatch from eggs in May

- first generation corn borer infests corn in June
- control of apple maggot is most important in July and early-mid August

Seasons differ, however, and calendars don't reflect that. So sometimes we predict insect timing by host development ...

- the first flight of codling moths begins around bloom to petal fall
- The book **Coincide** (D.A. Ort, 1989, White Oak's Group [publ.], Flossmoor, IL) provides a summary for many pests in relation to bud development and other seasonal changes in specific perennial plants.

Although these approaches are useful, insects and their hosts don't always seem to be on exactly the same schedule; and for annual crops, early or late planting changes the relationship between pest and host development.

The obvious seasonality in growth and activity of insects is related to poikilothermy ... cold-blooded animals' developmental rates are temperature-dependant. So if we want to predict the timing of insect occurrence, it makes sense to base predictions on “physiological time” -- developmental time indicated somehow by heat accumulations, not calendar days.

Accounting for different developmental rates at different temperatures allows us to more accurately describe insect **phenology** ... the study of the relationship between the occurrence of a biological event and another event or process. Think of phenology as another way to understand timing and the manner in which related occurrences coincide.

Major cues for insect development:

- Photoperiod / day length (especially for hormones important to pupation or diapause)
- Temperature (higher temps mean faster development, at least to a point)
- Other factors such as moisture, food source, etc.

If we can somehow establish how much development occurs in relation to heat accumulation from a given starting point, we can use climatological data to predict the timing of insect occurrence. How is this done?

First, to determine the influence of temperature on an insect's rate of development, insects are reared under one of a range of constant temperatures, say 30 individuals each at 10, 13, 16, 19, 22, 25, 28, 31, and 34 degrees C. The dates of egg hatch and subsequent molts are recorded for individual insects. Then on a stage-specific basis (meaning egg, individual larval instar, preoviposition adult), the mean number of days required to complete development (y) is plotted against rearing temperature (x).

Although this is the first logical step, a more useful presentation of the data is provided by graphing the **rate** of development (y) against rearing temperature (x). The result:

A graph of developmental rate yields several important pieces of information:

- A portion of the development rate curve is pretty much a straight line. Extending it through the x-axis estimates the lower developmental threshold for this stage of this species. At temperatures below the lower developmental threshold, Th_L, no development occurs (at least in a practical sense, though this is not entirely accurate).

- Examining the upper portion of the curve allows estimation of the optimum temperature for development of this insect (essentially the developmental maximum or upper developmental threshold, Th_U): this is the maximum temperature before the development rate plateaus or declines. Above the upper threshold, rate of development levels off and then drops rapidly.
- We can determine the number of degree days (DD) above the threshold required for development through the stage(s) studied.
  - Total DD = d (T - Th_L)

  where d = days to develop at rearing temperature T; and Th_L = lower developmental threshold.

  Example:

What is a degree day?

1 degree > lower threshold for 24 hours

2 degrees > lower threshold for 12 hours

3 degrees > lower threshold for 8 hours, etc.

So we might then look at insect development under field conditions:

Development occurs during the time that the insect's environment is warmer than the lower developmental threshold. Calculating actual degree days using weather data is the next step... Common methods are 1. rectangular; 2. triangular; and 3. sine wave. All use daily maximum and minimum temperatures to try to estimate DD totals. Triangular and sine-wave methods use curve fitting at half-day intervals, are more accurate, and are done using a computer program. The rectangular method employs simple averaging, is slightly less accurate, but usually provides adequate results; it can be done by hand, using data provided by max-min thermometers ...

A. Daily maximum and minimum temps exceed the lower threshold, but not the upper: DD accumulation = [(Max + Min) / 2] - Lower Threshold

B. Daily maximum temperature exceeds lower threshold, daily minimum is less than lower threshold: DD accumulation = [(Max + Lower Threshold) / 2] - Lower Threshold

C. Daily maximum temperature exceeds upper threshold, daily minimum exceeds lower threshold: DD accumulation = [(Upper Threshold + Minimum) / 2] - Lower Threshold

D. Daily maximum temperature is less than lower threshold... no degree day accumulations.

When to start counting degree-days for use in predictive models

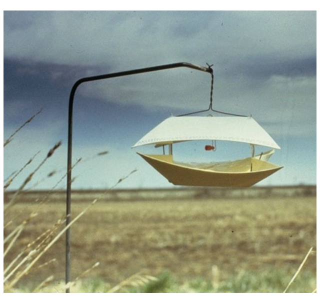
We have some ways to count DD; we have an insect ready to develop as spring temperatures rise or eggs are laid. When do we start counting?

Initiation of development of overwintered insects may be dependent upon a factor that breaks diapause, and that factor may be more than temperature alone; photoperiod, moisture, etc. may be the key. In most of the U.S. photoperiod, in addition to temperature, is a trigger in breaking dormancy associated with diapause. So …

Suppose you know that no development occurs before midwinter; do you count degree days that accumulate during a one-week "January thaw" even though subsequent temps drop to well below freezing? (Does the insect develop any during the thaw?) The answer to this question remains unknown (or at least not known with great certainty) for many insects. To answer it, sometimes researchers use an established threshold with several starting points with several season's data on weather and pest occurrence data, then they attempt to identify which starting date provides most consistent prediction of actual occurrence. (Counting backwards using historical data on insect occurrence and degree-days also can bracket the right starting period.)

In knowing when to start counting degree-days, the best option often is to use a **biofix** (if possible): an observable biological event. Forexample:

- Significant captures of black cutworm male moths in pheromone traps indicates arrival of the species from the south in the spring on weather fronts. Phenology models that predict and measure degree-days start on this date (the biofix) and help to time scouting for "cutting" of corn seedlings beginning about 320 F degree-days (base 50 F) later.



Left to fight: Black cutworm pheromone trap, adult moth, and larva by cut seedling.

- Significant and sustained captures of codling moth males in pheromones indicates presence of adults and the beginning of egg-laying by the overwintered generation. Phenology models that predict and measure degree-days start on this date (the biofix); sprays that protect fruit from larval entry have to be on the fruit by 240 F degree-days (base 50 F) after the biofix.

Left to right: Codling moth pheromone trap, adult moths, and larva in fruit.

How are degree-day data used? See handouts on codling moth and field crop insects.

Useful web sites:

University of California's web site titled Degree-Days and Phenology Models.

University of California's phenology model data base

University of Illinois' Degree-Day Calculator