ISSN 0317-6908

bi-monthly research notes

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Vol. 34, No. 2, MARCH-APRIL 1978

Fisheries and Environment Canada
Pêches et Environnement Canada

Forestry Service
Service des forêts

Do Weather Factors Influence the Dynamics of Spruce Budworm Populations? — Since the initial proposal of a climatic release (or the relaxation of climatic control) theory for spruce budworm, *Choristoneura fumiferana* (Clem.), outbreaks by Wellington et al. (Can. J. Res. [D] 28:308-331, 1950), some supporting arguments have followed (Greenbank, Can. J. Zool. 34:453-476, 1956; Mem. Entomol Soc. Can 31:19-23 and 174-180, 1963; Morris, Mem. Entomol Soc. Can. 31:116-129, 1963). This note points out that the arguments supporting the theory should be reviewed with caution, not so much for the lack of factual evidence as for inappropriate methods used in the analysis of data on which their conclusions are based.

The climatic release theory was formulated largely from the finding that spruce budworm outbreaks that occurred in eight different areas in eastern Canada between 1909 and 1940 invariably coincided with periods of on-the-average dry weather (in terms of a lower annual average number of cyclonic centers passing through these areas, as expressed in a series of 3-year moving averages). The theory contends that unless the host plants (mainly *Abies* and *Picea* spp.) are in a poor condition, it is mainly weather that controls budwarm population: dry warm weather favors budworm development and allows populations to increase repidly, provided that the forest condition is "ready" to support high larval densities.

Greenbank (1963) supported this idea by showing that summer (June-July) weather conditions experienced in the Green River area were changing from an on-the-average dry warm period between 1945 and 1949, through an intermediate condition between 1950 and 1955 to an on-the-average wet cool period between 1956 and 1958. He took 5-year moving averages of June and July precipitation (in terms of deviations from normal) to demonstrate such a dry (warm)-to-wet (cool) trend in weather over the period studied. The spruce budworm populations in the area increased rapidly from 1945 to 1949, reached a plateau during 1950 to 1954, and began to fall steeply after 1955. In other words, the weather conditions and the yearly rate of change in budworm populations exhibited the same downward trend between 1945 and 1958. More precisely, it was the survival of large larvae (fourth- to sixth-instar larvae) that showed a downward trend coincident with the dry (warm)-to-wet (cool) weather trend. Thus, Greenbank concluded that weather controlled the epidemic budworm population through its effect on the survival of large larvae. This is tempting reasoning, particularly in view of the fact that the speed of larval development is directly controlled by temperature.

This, however, is a questionable conclusion. It is probable that the coincidence in trends between weather and larval survival was spurious. Yule (J. R. Stat. Soc. 89:1-64, 1926) showed that the chance of getting a nonsense correlation between time series is far greater than it might appear to one who applied the classical concept of correlations uncritically.

A high correlation between time series may arise from two different situations: (1) when trends in the series to be compared coincide, and (2) when deviations from a trend in one series fluctuate concurrently with those in another series, while their trends are not necessarily the same.

From the point of view outlined elsewhere (Royama, Ecol. Monogr. 47:1-35, 1977), it is a correlation arising from the second situation that should be taken seriously if one wishes to evaluate the effect of any density-independent factor, such as weather, by correlation methods. Yule showed that chances of getting a fortuitously high correlation between unrelated time series are very high because of the first situation. Comparison of a series of moving averages (or, alternatively, sectional averages) in precipitation with the annual fluctuation in survival of large larvae, as in Greenbank's analysis, effectively ruins chances of getting the second type of correlation, while at the same time in enhances the possibility of obtaining the first.

Morris (1963) seemed to have been aware of the nature of correlations and developed what is known as "key factor analysis," in which he employed a linear first-order autoregression in larval density, expressed in logarithms. This is a simple Markov chain model in which the density of one generation is dependent only on density of the immediately preceding generation. He then compared the residuals, calculated after fitting the model, with the mean daily maximum temperature for the average large larval period (i.e. June 1 to July 13), which yielded a reasonably high correlation, apparently supporting the idea that larval survival is dependent on temperature.

Although the basic idea was good, it was unfortunate that Morris employed a linear first-order autoregression in his analysis. As I have shown (Royama, 1977), the systematic part of the linear first-order model will not generate such a gradual decline in (log) survival as the one exhibited by the Green River data. This implies that, on fitting the model, the downward trend in the data was bound to appear in the residual (or the random) term of the model. Under these circumstances, a substantial part of correlation between the calculated residuals and the mean daily maximum temperature must have been due to a correlation between the downward trend in both series. This result defeats Morris's intention.

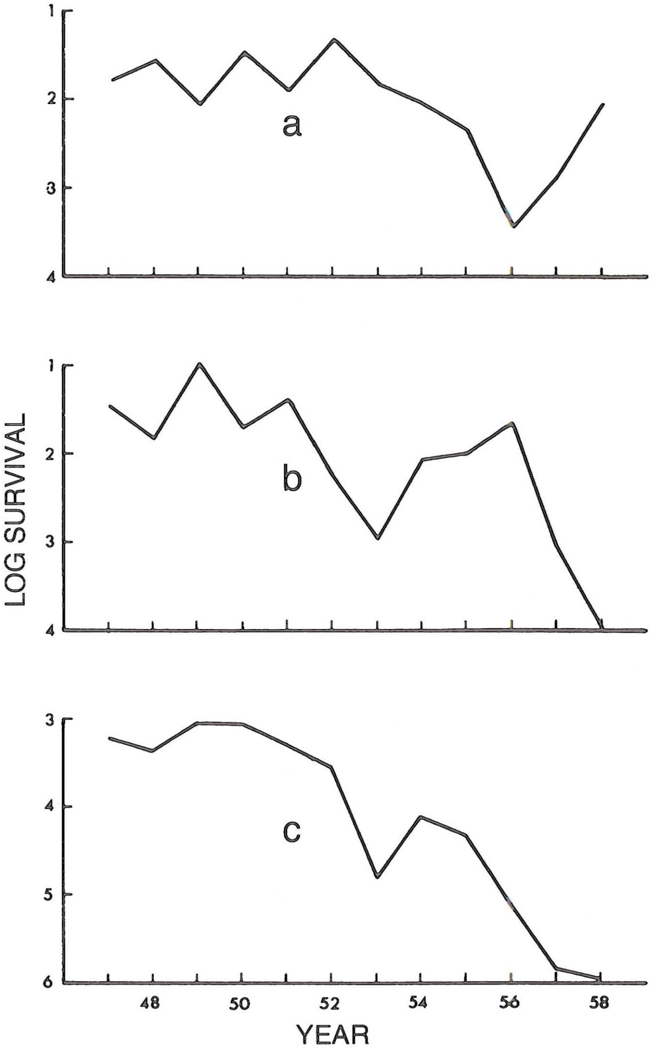

Figure 1. The survival (expressed in natural logarithms) of small larvae (graph a) and large larvae (graph b), and the total survival over the whole larval period (graph c), as observed at Plot G4 in the Green River Project between 1947 and 1958.

A visual inspection of the pattern of fluctuations in survival rates, rather than the employment of any model, seems to be the simplest, yet most practical, method to test the climatic control theory. Fig. 1 shows the annual fluctuations in survival observed at Plot G4 of the Green River Project (same data used by Morris [1963]); note that graph c = graph a + graph b because the survivals are expressed in logarithms. Graph b may be compared with the annual fluctuation in the mean daily maximum temperature (June 1 to July 13) as shown in the bottom graph of figure 18.2 in Morris's paper (1963). There is no clear correspondence in fluctuations between the two series, except that both show a downward trend, as already mentioned. If weather does, in fact, exert a strong influence, why were the two series not fluctuating concurrently about the trend?

Inspection of Fig. 1 reveals that the fluctuation about the trend in graph b tends to compensate for that in graph a. The result is a much smoother downward trend in graph c, except in 1953. In other words, the fluctuation in survival of large larvae about its trend is explained largely by its compensation for the small larval survival through, perhaps, come sort of density-dependent relationship within each generation. Thus, contrary to what has been postulated by some authors, the survival of large larvae seems to be comparatively insensitive to weather conditions to which the larvae were exposed; larval development is directly influenced by weather but survival is not. The example shown is typical, but the situation is much the same in data taken from other plots.

I do not mean to imply that larval survival is totally uninfluenced by weather. A high mortality, such as in 1953, might have resulted from an occasional, violent, adverse weather condition to which larvae could have been susceptible only at certain critical points of time, such as pupation of molting between instars. Nor does my argument eliminate the possibility of "climatic release." It disagrees with some interpretations of detailed mechanisms; in particular, the idea of "climatic control" is doubtful. Although a direct comparison with data is impractical as the observation time was too short, spruce budworm dynamics may best be explained by adopting a second-order double-equilibrium theory, which I elaborated in my monograph (Royama, 1977). According to it, an outbreak is supposed to be triggered by perturbation of an endemic equilibrium state, possibly by moth migration from outside, a phenomenon that might well be governed by weather conditions as summarized by Greenbank (Can. J. Zool. 35:385-403, 1957). — T. Royama, Maritimes Forest Research Centre, Fredericton, N.B.

FOREST PRODUCTS

Detection of Blisters and Blows in Waferboard by Ultrasonic Testing. — Ultrasonics has been used for detecting defects in poles (Breeze and Nilberg, Forest Prod. J. 21(5):39-43, 1970), for locating glueline separations in plywood (Collins, Instrum. Soc. Am. Trans. 6(4):303-306, 1967), and for determining strength of wood (Lee, J. Inst. Wood Sci. 1:43-57, 1958). High-frequency technology has also demonstrated its usefulness in detecting natural defects in lumber (McDonald et al., USDA Forest Serv. Res. Pap. FPL 120, 1967). Preliminary investigations carried out at the Eastern Forest Products Laboratory have indicated that commercially available ultrasonic pulse equipment can also be used in detecting delaminations in waferboards.

The velocity (v) of ultrasonic pulses travelling in a solid medium depends on the mass density (d) and elastic properties (E) of the medium. From the theory of plane wave motion in solids, the relationship between these three quantities is given by the following equation:

$$v = \sqrt{\frac{E\,(1-\mu)}{d\,(1-\mu)\,(1-2\mu)}} \qquad (1)$$

where μ = Poisson's ratio.

The pulse velocity can be calculated from the measured values of path length (L) and the transit time (t):

$$v = \frac{L}{t} \qquad (2)$$

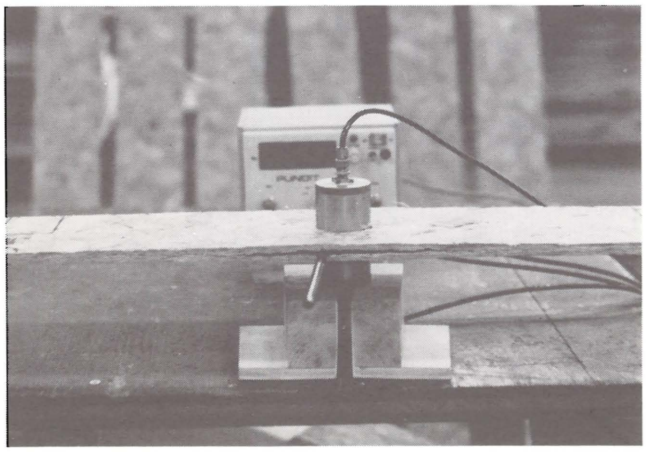

Figure 1. Ultrasonic pulse equipment used to determine internal defects in waferboard.

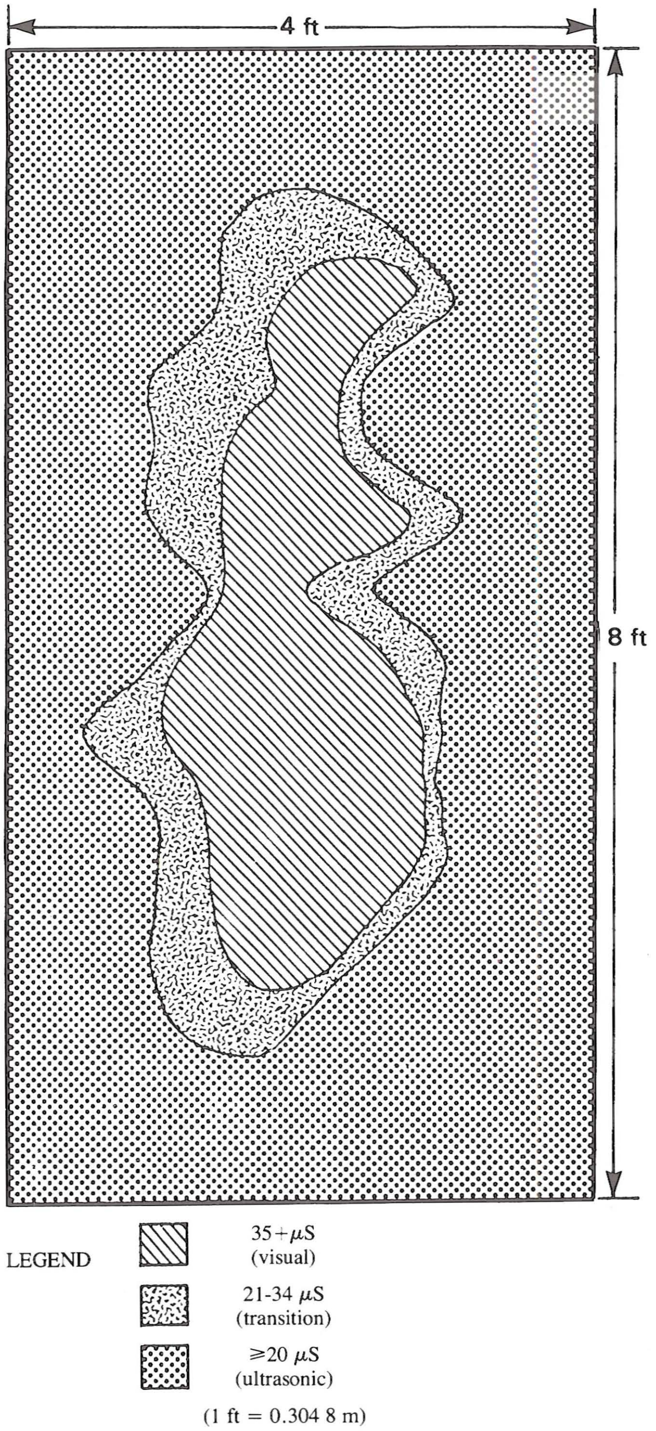

Figure 2. Location of delaminated area within a panel by ultrasonic testing and visual inspection over a 6 x 6-in. grid.

The detection of internal cracks or delaminations by ultrasonics is simple, since the transit time can be related directly to the presence of defects (air gaps in solids). The interface between solid material and air lengthens the path of the pulses between the transmitter and the receiver and thereby increases the transit time. This phenomenon also occurs when there are changes in the density of the material.

An ultrasonic tester known as Pundit "B" and made by M & L Testing Equipment Co. Ltd., Montreal (Fig. 1), with a glycerine-based