Forest Sci., Vol. 25, No. 2, 1979, pp. 217–222

Made in the United States of America
Reprinted from FOREST SCIENCE
Vol. 25, No. 1, June 1979
pp. 217-222

#85

Predictors of Southern Pine Beetle Flight Activity

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ABSTRACT. An equation based on weather data explained differences in capture counts of pine bark beetles trapped twice weekly for an entire year at a single infestation and contributed to the understanding of some aspects of beetle dynamics. The proportion of the beetles that reached the traps increased with maximum temperature and decreased with heavy rain. Production of adults tended to be low in midsummer. FOREST SCI. 25:217–222.

ADDITIONAL KEY WORDS. *Dendroctonus frontalis*, potential evapotranspiration, weather, seasonal pattern, Scolytidae.

CURRENT METHODS OF EVALUATING DAMAGE by the southern pine beetle (*Dendroctonus frontalis* Zimm.) rely on the use of aerial detection (Ciesla and others 1967). This survey method reliably records past damage over large areas, but methods for quantifying beetle population changes over short periods and small areas are needed. Earlier Thatcher and Pickard (1964) used a ratio of increase formula based on brood emergence and number of attacks to successfully predict the short-term pattern of beetle activity. Later Thatcher (1974) documented that highest brood survival occurred in trees which became infested during the fall through early spring, that the severity of outbreaks was greatest in the spring, and that survival and activity were lowest in the summer.

In this study, we recorded for the first time flying populations of the southern pine beetle over an entire year, showing the short-term and seasonal fluctuations. The objective was to explore the relationships between weather data and average daily capture counts.

METHODS AND DATA

The study was conducted in a natural stand in the Kisatchie National Forest, Catahoula Ranger District. In the 29-year-old stand, loblolly pine (*Pinus taeda* L.) predominated. The average basal area was 32.8 m^2/ha for pine and 3.4 m^2/ha for hardwoods. The pines averaged 28 cm in diameter at breast height; the dominants were about 21 m high. A mesic understory contained blackgum, *Nyssa sylvatica* Marsh.; flowering dogwood, *Cornus florida* L.; "huckleberry," *Vaccinium elliotti* Chapm.; sweetgum, *Liquidambar styraciflua* L.; and water oak, *Quercus nigra* L.

The procedure of Moser and Browne (1978) details the beetle trapping methodology used here. Bucket traps baited with a potent attractant (Kinzer and others 1969) were placed along the "front" of an infestation from November 1,

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1974, through October 30, 1975, and moved forward as the "front" advanced. Beetles were collected from the traps twice weekly, necessitating alternate 3- and 4-day trapping periods. Maximum temperatures were read from a shaded maximum-minimum thermometer at a height of 1 m inside the infestation. Rainfall data were taken from the Esler Regional Airport, National Weather Service Station, located about 7.25 km southeast of the infestation. In future studies we would recommend placing thermometers at standard height and collecting rain data on the site.

With the exception of one 4-day period in early December of 1974 and another early in January 1975, some beetles were caught during each trapping period throughout the 12 months of the study. Of 1,512 beetles examined for sex determination, the majority (98.7 percent) were males (Moser and Browne 1978). The high percentage suggests that the bucket trap may simulate a newly initiated female gallery, which like the trap, attracts only males when the point source of the attractant is at a high concentration. Renwick and Vité (1969, 1970) and Hughes (1976) showed that females are attracted to, but skirt high concentrations of Frontalure. Thus, it would seem that the numbers of males trapped in this study would reflect the relative beetle population.

Statistical Analysis and Interpretation

The average number of male beetles captured per day for each of the 104 trapping periods was computed. Regression equations utilizing predictor variables based upon weather data were developed to explain the differences in the capture values. Both the maximum temperature (MT) and the average daily rainfall (AR) during the collection period proved to be useful predictors. However, there remained a definite seasonal pattern in the residuals when only these two short-term variables were used. Predictions were too low for warm days that occurred in the cooler part of the year and generally too high for the warm months.

Work by Lorio and Hodges (1971) and by Kalkstein (1976) prompted us to consider a variable involving the potential evapotranspiration (PE) (Thornthwaite and Mather 1955) as the needed seasonal factor. PE estimates the water loss by a vegetation-covered surface through evaporation and transpiration when thermal energy is the only controlling factor and moisture availability is not limiting. The PE values were computed as functions of the weather data during the period of the study. Monthly PE values were established through the use of a computer routine (Muller 1972, Muller and Larrimore 1975). Straight line interpolation was used to estimate PE values between the midpoints of the months, and the result defined a smooth trend in the PE values that was not responsive to short term weather influences.

In formulating a model to predict beetle capture values, we reasoned that there was a potential value for the trapping area denoted by e^{B_0} where e is the base of the natural logarithms. A certain proportion, P_1, of this potential would be realized depending upon the season as expressed by the PE, and two additional proportional adjustments, P_2 and P_3, were included for the maximum temperature and average rainfall, during the collection period. Thus:

Estimated number of males trapped per day $= e^{B_0}P_1P_2P_3$ or

$$N = e^{B_0}e^{g(\mathrm{PE})}e^{h(\mathrm{MT})}e^{f(\mathrm{AR})}$$
$$= e^{B_0+g(\mathrm{PE})+h(\mathrm{MT})+f(\mathrm{AR})}$$

Thus,

$$\ln(N) = B_0 + g(\mathrm{PE}) + h(\mathrm{MT}) + f(\mathrm{AR})$$

where ln denotes the natural logarithm.

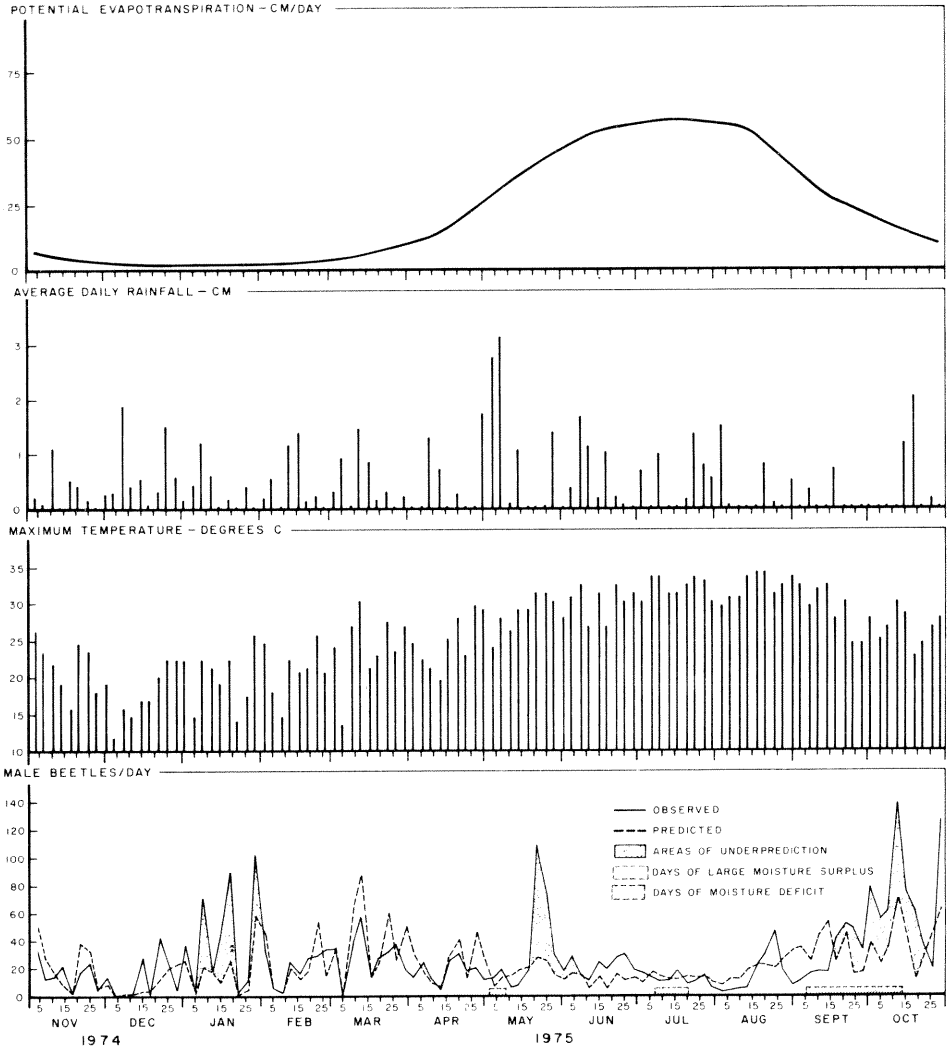

FIGURE 1. The observed and predicted beetle counts (male beetles/day) correspond by day with the values for the three predictor values (potential evapotranspiration, average daily rainfall—cm/day, maximum temperature—degrees C).

We defined $g(\mathrm{PE}) = B_1(\mathrm{PE})$, $h(\mathrm{MT}) = B_2(\mathrm{MT})^{-2}$ and $f(\mathrm{AR}) = B_3(\mathrm{AR})$ and since no beetles were captured in two of the trapping periods, the average number per day plus 0.1 was used as the response to avoid consideration of ln (zero).

When the coefficients were estimated from linear regression techniques, the equation explained 60 percent of the variation and the F value was 51.1 with 3 and 100 degrees of freedom. The final prediction equation can be written as follows with PE and AR given in cm per day and MT in degrees centigrade:

$$N = -0.1 + \exp[8.7799 - 4.5654\mathrm{PE} - 28{,}100(1.8\mathrm{MT} + 32)^{-2} - 0.18343\mathrm{AR}].$$

The notation of the form exp[Z] indicates the operation of raising e to the power z. The temperature term may be simplified by utilizing the Fahrenheit scale.

Two Short-Term Factors.—By comparing the observed and predicted counts for corresponding trapping periods along with the values of the three predictor variables for corresponding days (Fig. 1), it becomes clear that maximum temperature during the colder periods of the year is the most obvious influence. Consider for example a day in midwinter and assume no rain and a typical PE value of 0.022 cm/day. The equation predicts daily catches for the selected maximum temperatures as follows:

MT	*N*	*MT*	*N*
10	0.0	20	13.4
12	.2	22	24.4
14	1.0	24	40.8
16	2.8	26	63.6
18	6.6		

These results agree with the conclusion by Franklin (1970) that brood development occurs throughout the winter, but beetles are able to fly only when the temperature is above 14.4°C (58°F). Also, there is no sign of a reduced influence on beetle flight at the highest temperature encountered in this study.

The influence of temperature on what we interpret to be the proportion of beetles accomplishing a flight should not be confused with the more long-term influence of temperature on brood activities. In fact there is evidence[1] that brood activities, including development, production, and survival, decline with very high temperatures. The component of the model involving PE is related to this long-term aspect of temperature, but the component involving MT is not.

Rain during the collection period causes a reduction in the number of beetles caught. According to the equation, the proportional adjustment due to rain is $\exp[-0.18343AR]$. For example, with an average daily rainfall of 2.5 cm (1 inch) during a collection period, the catch would be 63 percent of what it would have been with no rain. With AR at 0.25 cm, the catch would be 95 percent of that expected for a dry period. This implies that an extended rainstorm could reduce the effectiveness of the synthetic "bait" and cause a lack of orientation in the beetle's flight. Franklin (1970) also reached this conclusion.

The Seasonal Component.—The other component of the model is related to the seasonal pattern and involves PE values. Both model and data indicate that in midsummer when the PE values are high, the catch of male beetles is at a consistently low level. In the winter and fall when PE values are low, the catch is potentially high; and if there is a brief period of warm weather, large numbers of beetles will find their way to the sources of pheromone.

The model as presented implies that the changes in PE values directly influence the differences in catches associated with the seasonal trend. But it is also possible that some other factor having a seasonal pattern correlated with PE is the causal factor, and that we are being occupied with either a secondary mimic or an accidentally correlated variable. This realization prompted us to try other variables in place of current PE. The level of soil moisture storage was estimated utilizing a computer routine[2] and daily weather data. A variable expressing the

[1] Bremer, J. E. 1967. Laboratory studies on the biology and ecology of the Southern pine beetle, *Dendroctonus frontalis* Zimm. Unpublished MS Thesis, Texas A&M University.

[2] This FORTRAN program was obtained from M. A. Marsden, Intermountain Forest and Range Experiment Station, U.S. Forest Service, and is based on concepts presented by Zahner and Stage (1966).

level of soil moisture during each trapping period and one giving the average level of soil moisture for the 21-day period previous to the close of each trapping period were considered. Other variables concerned with actual evapotranspiration and average PE for the 21-day period previous to the end of each trapping period were also substituted. None of the variables proved to be as effective as PE. In a further attempt to refine the predictions we also computed the mean PE for each collection period using daily estimates obtained from the soil moisture storage program. These PE values expressed short-term fluctuations. The equation based on them did not predict quite as well as the original one using the monthly values.

We conclude that brood potential is low when PE is high. Since PE is to a large extent a function of thermal energy, the trend supports the conclusion of various writers including Bremer,[1] Hodges and Thatcher (1976), and Kalkstein (1976), that high temperatures inhibit brood potential.

Periods of Departure from the Model.—Figure 1 reveals three periods during the year for which the model consistently predicted counts lower than the observed ones. When a warm period followed a cold one, our model predicted lower catches than were observed. Obviously some beetles emerge but do not fly during cold periods. With the next warming trend, these "holdovers" join the emerging beetles, and as a result, the capture count is unexpectedly high. Our model ignores this holdover effect and thus predicts low for warm periods in winter that immediately follow a cold period.

A second period of obvious deviation was in the last half of May 1975, when for two consecutive trapping periods the observed catch was five times what was predicted. We assume here that the departures were related to the extremely heavy rains that occurred early in May (Fig. 1). The soil was very wet at the end of April, and approximately 25 cm of rain fell during the first half of May. Computations with a soil moisture model indicated that this period involved by far the most extreme water surplus conditions of the year. This rainy period in some way set the stage for a short-term expansion of beetle production which soon thereafter caused the high catches that were not anticipated by the model.

The idea that conditions associated with a moisture surplus may be correlated with intensified beetle activity is supported by Kalkstein (1976), Lorio and Hodges (1968). However, the short duration of the soil moisture surplus observed here would not be expected to stress the trees.

The third period in which observed catches persisted above the predicted values was during October 1975. We believe this was caused by increased susceptibility of the trees due to stress caused by a soil moisture deficiency. Estimates of soil moisture from a water balance model indicated that a soil moisture deficiency developed in the study area early in September and persisted until mid-October. Evidence relating increased bark beetle activity to soil moisture deficiencies was considered by Kalkstein (1976) and Lorio and Hodges (1977). Note in Figure 1, there was a long period of departure from the predictions associated with the long period of moisture deficit. For the short period of moisture surplus there was a corresponding short period of departure from the predicted catches.

Discussion

When a brood emerges, the proportion of the beetles that reach their destination will tend to increase with the maximum temperature and decrease with heavy rain during their period of flight. The general level of brood activity and production tends to be low during the midsummer when the rate of potential evapotranspiration is high. Population expansion appears to depend upon the simultaneous occurrence of consistently mild temperature, a rather low rate of PE, and either a surplus or a deficiency of soil moisture.

It is essential in interpreting the results of this study to recall that we are modeling only the counts of male beetles trapped during short periods. We did not measure directly the population levels nor do we have an index of the expectation that a beetle would become established after its flight. It would be desirable in future work to predict the number of beetles becoming established by extending the model with a term P_4 which could estimate the proportion of the beetles becoming established after having arrived at a suitable site. It is reasonable to assume that the proportion becoming established is itself a function of the variables already covered.

The fact that extreme fluctuations in capture counts can be explained reasonably well by variables based on conventional weather station data is encouraging. This formulation aids our understanding of some aspects of the beetle population dynamics and is a step toward prediction of population trends. Since trends in long-term, wide-area damage and short-term capture counts (as adjusted for flight weather) tend to agree, it may be possible to make rapid small-scale evaluations of treatment activities.

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