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USING HISTORICAL TEMPERATURE RECORDS TO ADJUST THE FEDERAL QUARANTINE OF THE PINE SHOOT BEETLE

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1. INTRODUCTION

The pine shoot beetle (*Tomicus piniperda* (L.); Coleoptera: Scolytidae) is a native of Eurasia and attacks primarily pine trees (*Pinus*). *Tomicus* was discovered in Ohio in 1992 and as of August 1998 it has spread to 243 counties in nine US states (Illinois=IL, Indiana=IN, Michigan=MI, Ohio=OH, Pennsylvania=PA, New York=NY, Maryland=MD, West Virginia = WV, and Wisconsin = WI; Fig. 1).

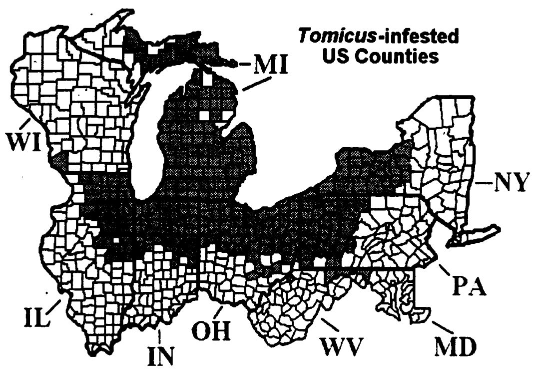

Fig. 1. US range of *Tomicus piniperda* as of August 1998; infested counties are shaded.

In 1992, a federal quarantine was imposed by the United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) on the movement of pine from infested counties to uninfested counties within the US (Haack 1997; Haack et al. 1997). The *Tomicus* quarantine allows for the movement of pine logs, pine Christmas trees, and pine nursery stock during specific times of the year based on the beetle's biology. For timing specific requirements of the quarantine, APHIS often uses single dates for the entire infested area. APHIS recognizes that considerable climatic variation takes place within the infested region, and that even more variation will occur in the future as *Tomicus* continues to spread. Therefore, we became interested in developing "phenological maps" that would help APHIS predict various *Tomicus* life history events.

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Specifically, this study addresses two temperature-dependent aspects of *Tomicus*' life history that are relevant to the quarantine: (1) the timing of initial adult flight in spring and (2) the timing of initial shoot departure in fall.

2. METHODS AND MATERIALS

To develop the isopleth maps, we used 1950-1993 daily maximum and minimum temperature records from 824 reporting stations in a 23-state region of the northeastern US. In Europe, initial spring flight of *Tomicus* usually begins when daily maximum temperatures reach 10-12°C (Bakke 1968). In the Great Lakes region of the US, initial spring flight of *Tomicus* has usually required temperatures of at least 12°C (Haack and Lawrence 1995, 1997). However, it has been our experience that the first strong burst of spring flight activity requires at least two consecutive days with maximum temperatures of 13°C or greater. For the present study, therefore, we developed a map with isopleths for when average daily maximum temperature in spring first reached 13°C or greater on two consecutive days, and then similarly 15°C or greater. We feel that initial *Tomicus* spring flight will almost always occur before the dates derived when using the 15°C threshold temperature.

In the fall, *Tomicus* adults move from inside the shoots of pine trees where they feed, to the lower trunks of pine trees where they spend the winter. *Tomicus* adults typically overwinter inside the thick outer bark of the trunk near groundline, and they can be found both below and above the soil line. Initiation of shoot departure in fall often coincides with the first few hard freezes (Haack and Lawrence 1997; Langstrom 1983). To estimate the average date for initiation of fall shoot departure, we developed isopleth maps for the second occurrence of when the average daily minimum temperature first reached 0°C or lower, as well as -2°C or lower. These two days did not have to be consecutive.

For each of the 44 years (1950-1993) at each of the 824 recording stations, we assigned the appropriate calendar day to the particular weather event of interest (15°C, 13°C, 0°C, and –2°C). Then, using the numerical calendar days, we determined the average date for each temperature event at each station. Isopleth maps were then developed from these individual average station dates, using the kriging interpolation procedures within ARCINFO. The isopleth lines were drawn at approximately 2-week intervals to represent the beginning of a month and mid-month. This time frame was selected so that any resulting changes to the federal quarantine would be relatively easy to implement by both the regulatory agencies and the affected pine industries.

Given that the present study used air temperature data to predict various *Tomicus* life-history events, it was important to compare air temperatures with both inside-bark and inside-shoot temperatures in live pine trees. To determine the degree of similarity, comparisons were conducted at three localities in Indiana and Michigan in fall 1997 and spring 1998. At each site, two air temperature recordings were made, one on the north side of a single pine tree and one on the south side. The recordings were made with Campbell Scientific temperature probes enclosed in radiation shields and mounted approximately 1.3 m above ground. In addition, four internal tree temperature recordings were made at each site. In spring, inside-bark temperatures were recorded 15 cm above-ground and 10 cm below-ground on both the north side and south side of each test tree. In fall, upper-canopy and lower-canopy inside-shoot temperatures were measured on the north side and south side of each test tree. Inside-bark and inside-shoot temperatures were measured with Omega Engineering hypodermic thermocouple probes. Hourly temperatures, and daily maximum, minimum, and average temperatures for all six probes at each site were recorded using Campbell Scientific dataloggers and support software.

3. RESULTS AND DISCUSSION

3.1 *Estimating Initial Spring Flight*

Isopleth maps for the average date in spring when daily maximum temperatures first reached or exceeded 13°C or 15°C on two consecutive days are shown in Figs. 2 and 3, respectively. For most of the study region, there is only a single 15-day isopleth difference between the timing of initial spring flight at 13°C (Fig. 2) compared with 15°C (Fig.3). Considering the current range of *Tomicus* (Fig. 1) and the 13°C threshold map (Fig. 2), then initial *Tomicus* spring flight would likely begin as early as 1 February at the southern portion of the current range (MD and WV), and as late as 1 April at the northern part of the range (northern MI). Similarly, using the 15°C threshold map (Fig. 3), then initial *Tomicus* spring flight would likely begin as early as 15 February and as late as 15 April. In both cases, these dates represent a two month difference in initiation of spring flight within the current range of *Tomicus*.

Unusual weather events do occur, of course, with some years being warmer earlier than average and others being cooler for longer than average. Therefore, caution must be used when using Figs. 2-5. For example, at one of our field sites near Battle Creek in southern Michigan, actual initial *Tomicus* spring flight has varied from as early as 28 February 1998 to as late as 3 April 1996 during 1993-1998 (Haack and Lawrence 1997; Poland et al. unpublished). For this same location, Figs. 2-3 would indicate initial flight dates between March 1 and 15. Similar year to year variation in timing of initial flight was reported in Europe by Bakke (1968) and Langstrom (1983).

3.2 *Estimating Initial Shoot Departure*

Isopleth maps for the average date in fall when daily minimum temperatures fell to 0°C or colder, or to -2°C or colder, for the second time are given in Figs. 4 and 5, respectively. For most of the area, there is only a single 15-day isopleth difference between the timing of initial shoot departure at 0°C (Fig. 4) compared with -2°C (Fig. 5). Considering the 0°C threshold (Fig. 4), *Tomicus* fall shoot departure would likely begin as early as 15 September in the northern part of the current range (northern MI), and as late as 1 November in parts of the southern range (central IL). Similarly, using the -2°C threshold map (Fig. 5), fall shoot departure would usually begin between 15 October to the north and 1 November to the south. These values represent a 6-wk difference in initiation of fall shoot departure across the current range of *Tomicus* at 0°C (Fig. 4), but only a 2-wk difference at -2°C (Fig. 5). During 1992 to 1997, *Tomicus* initiated shoot departure in mid- to late October at all field sites in northern Indiana and southern Michigan (Haack and Lawrence 1997; Poland et al. unpublished). For these Indiana and Michigan sites, Figs. 4 and 5 estimate that initial shoot departure in fall would occur between 15 October and 1 November.

3.3 *Actual Air and Tree Temperatures*

Relative differences between air temperatures and inside-tree temperatures followed similar patterns at all field sites. Therefore, data from

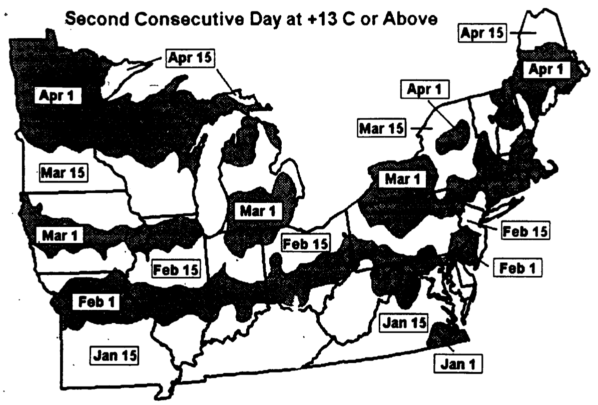

Fig. 2. Isopleths at ca. 15-day intervals for the average date at which the daily maximum temperature first reached 13°C or warmer on two consecutive days during the period 1950 to 1993.

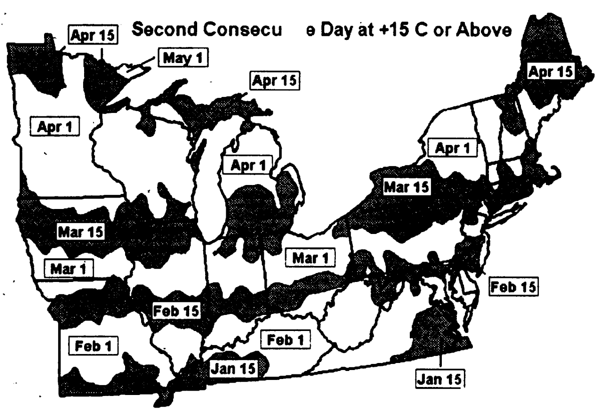

Fig. 3. Isopleths at ca. 15-day intervals for the average date at which the daily maximum temperature first reached 15°C or warmer on two consecutive days during the period 1950 to 1993.

only one field site is presented here, i.e., Shepherd, MI at 43°35' N Latitude. Below-ground bark temperatures were more uniform throughout the day than were either air temperatures or above-ground bark temperatures (Fig. 6). Air and bark temperatures tended to be slightly warmer on the south side of the test trees than on the north side (data not shown). Prior to initial spring flight, below-ground bark temperatures were warmer at night and cooler during the day than above-ground air or bark temperatures (Fig. 6b). As daytime and nighttime temperatures increased, below-ground diurnal temperatures continued to be stable but they were always cooler than the air and above-ground bark temperatures. On 27 March 1998, which was the day when *Tomicus* initiated spring flight at Shepherd, MI, air and above-ground bark temperatures tracked closely, and often exceeded the below-ground bark temperature by more than 10°C (Fig. 6a).

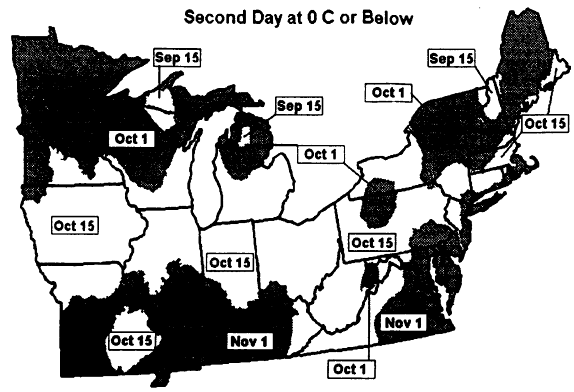

Fig. 4. Isopleths at ca. 15-day intervals for the average date in fall when the daily minimum temperature reached for the second time 0°C or colder during the period 1950 to 1993.

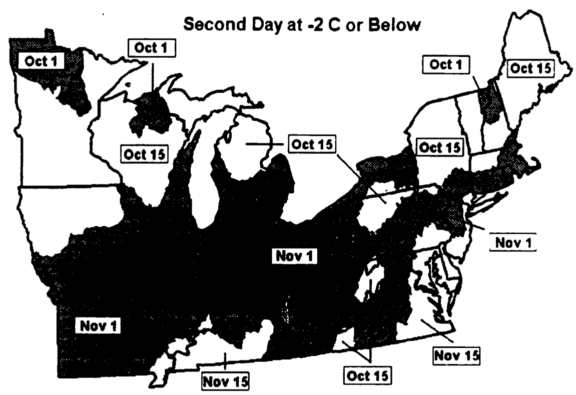

Fig. 5. Isopleths at ca. 15-day intervals for the average date in fall when the daily minimum temperature reached for the second time -2°C or colder during the period 1950 to 1993.

Beetles overwintering above-ground at the base of the tree would most likely be the first to fly in spring because they experience much warmer temperatures than those overwintering below ground. Overwintering below ground, however, may afford greater protection to beetles from extreme cold temperatures. Bakke (1968) estimated that temperatures below -18.4°C were lethal to overwintering *Tomicus piniperda* adults. Overall, given the close tracking of air temperatures and above-ground inside-bark temperatures, phenological maps that use air temperature should accurately predict initial *Tomicus* flight, especially for those beetles that overwinter above ground.

Inside-shoot temperatures were very similar to air temperatures at all test sites. Temperatures on the north side of the tree tended to be somewhat cooler than those on the south side. Overall, of the

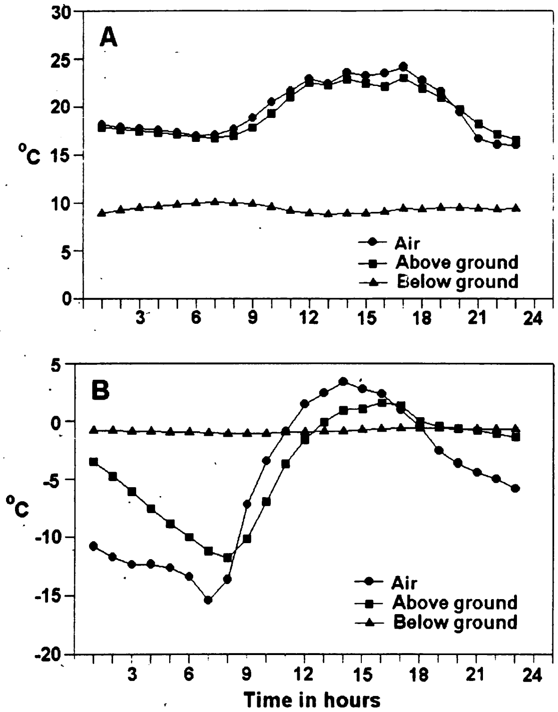

Fig. 6. Hourly (A) or average hourly (B) south-side air temperatures and inside-bark temperatures taken both above-ground (15 cm) and below-ground (10 cm) on a Scotch pine tree in Shepherd, Michigan: (A) 27 March 1998, and (B) 15-17 March 1998.

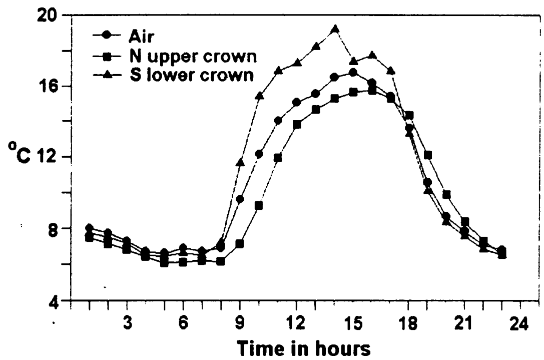

Fig. 7. Hourly north-side air temperatures, south-side lower-crown inside-shoot temperatures, and north-side upper-crown inside-shoot temperatures measured on a Scotch pine tree in Shepherd, MI, on 15 October 1997.

four shoot temperatures recorded from each test tree, the warmest and coolest average temperatures were consistently recorded from the lower-crown shoot on the south side of the tree and the upper-crown shoot on the north side of the test tree, respectively (see Fig. 7). Overall, given that the air and inside-shoot temperatures were similar, phenological maps based on air temperatures alone should accurately reflect inside-shoot conditions where the beetles feed during summer and fall.

In summary, historical air temperature data can be used to adjust the timing of specific management requirements that are listed in the *Tomicus* federal quarantine. Such modifications will allow the quarantine to maintain its biological accuracy as *Tomicus* continues to spread.

4. ACKNOWLEDGMENTS

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5. REFERENCES

Bakke, A., 1968: Ecological studies on bark beetles (Coleoptera: Scolytidae) associated with Scots pine (*Pinus sylvestris* L.) in Norway with particular reference to the influence of temperature. *Meddelelser fra Det Norske Skogforsoksvesen,* **21** (No. 83), 447-593.

Haack, R. A., 1997: Early history and spread of *Tomicus piniperda* in North America. *1997 Japanese beetle and the pine shoot beetle regulatory review: Proceedings,* USDA APHIS, Riverdale, Maryland, 142-149.

Haack, R. A., and R. K. Lawrence, 1995: Spring flight of *Tomicus piniperda* in relation to native Michigan pine bark beetles and their associated predators. *Behavior, population dynamics and control of forest insects*, F. P. Hain, S. M. Salom, F. W. Ravlin, T. L. Payne, and K. F. Raffa, Eds., Ohio State University, Wooster, Ohio, 524-535.

-----, and -----, 1997: Highlights of Forest Service research on *Tomicus piniperda*: 1992-1996. *1997 Japanese beetle and the pine shoot beetle regulatory review: Proceedings,* USDA APHIS, Riverdale, Maryland, 115-122.

Haack, R. A., R. K. Lawrence., D. G. McCullough, and C. S. Sadof, 1997: *Tomicus piniperda* in North America: an integrated response to a new exotic scolytid. *Proceedings: Integrating cultural tactics into the management of bark beetle and reforestation pests,* J. C. Gregoire, A. M. Liebhold, F. M. Stephen, K. R. Day, and S. M. Salom, Eds., USDA Forest Service, General Tech. Report NE-GTR-236, 62-72.

Langstrom, B., 1983: Life cycles and shoot-feeding of the pine shoot beetles. *Studia Forestalia Suecica,* **163:** 1-29.