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DIFFERENTIAL SHOOT FEEDING BY ADULT *TOMICUS PINIPERDA* (COLEOPTERA: SCOLYTIDAE) IN MIXED STANDS OF NATIVE AND INTRODUCED PINES IN INDIANA.

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ABSTRACT

The larger pine shoot beetle *Tomicus piniperda*, a native bark beetle of Europe and Asia, was found in North American Christmas tree plantations in 1992 in Ohio. Subsequent surveys found it in six U.S. states and in one Canadian province. The first natural area where *Tomicus* was found to be established was at the Indiana Dunes State Park, in northwestern Indiana near the Lake Michigan shoreline. Pine stands were surveyed for fallen shoots to determine the extent and range of shoot feeding in the park. Within the study area adult *Tomicus* fed on the shoots of all native pines (*Pinus banksiana*, *P. resinosa*, and *P. strobus*.), as well as the European species (*P. sylvestris*). More fallen shoots were collected from both *P. resinosa* and *P. sylvestris* than expected from their basal areas in the sampled stands. This contrasted with *P. banksiana* and *P. strobus* whose shoots were underrepresented relative to their basal areas. The relatively high numbers of fallen shoots found for *P. resinosa* suggests that red pines in the Great Lakes region will easily support populations of *T. piniperda*.

The larger pine shoot beetle, *Tomicus piniperda* (L.) (Coleoptera: Scolytidae), is an important pest of pines, *Pinus* spp., throughout Europe and Asia (Bakke 1968). This beetle was probably introduced to the Great Lakes Region of the United States through one or more recent introductions from cargo ships (Anonymous 1993; USDA, APHIS, PPQ 1992). Since being first reported in Lorrain County, Ohio, on 1 July 1992, it has been found, as of 20 July 1994, in 107 counties in Illinois, Indiana, Michigan, Ohio, Pennsylvania, New York, and in 7 counties in the province of Ontario, Canada (source: USDA-APHIS-PPQ). We believe that the broad and relatively contiguous distribution of this beetle suggests that it has been in the United States for several years. In Indiana, the known infestation is restricted to 29 counties in the northern one-third of the state (Fig. 1). Delaware County, located approximately 100 miles south of Lake Michigan is currently the southern border of the known infestation in Indiana. Concern about the potential impact of this pest on North American pines has resulted in a federal quarantine designed to slow the spread of this beetle to non-infested areas (USDA, APHIS, PPQ 1992).

Tomicus piniperda has been reported to feed on many species of pine in Europe and Asia (Bakke 1968, Langstrom 1983, Hui 1991). In Europe, adult beetles spend the winter in shallow galleries in the outer bark at the base of their

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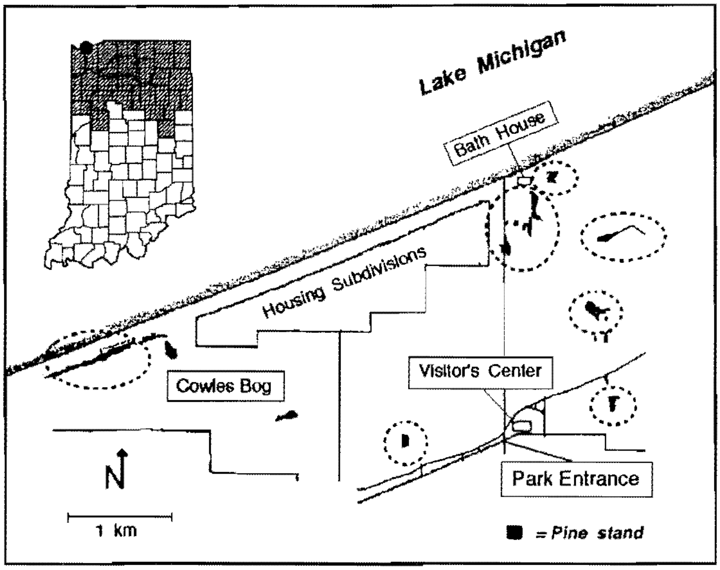

Figure 1. Map of pine stands at Indiana Dunes State Park and distribution of Indiana counties infested with *Tomicus piniperda*. Circled pine stands were sampled. Location of park in indicated by a solid black dot on Indiana map inset. Infested counties are shaded.

host trees. In early spring, when temperatures exceed 12°C, adults fly to stumps or trunks of recently cut or killed pines where they mate and lay their eggs in galleries under the bark. After approximately 6–10 weeks, depending on temperature, a new generation of adults begins to emerge and flies to the tops of pine trees where they feed inside shoots until autumn. This feeding is needed to mature their reproductive systems. Typically, adults enter shoots by boring à circular hole in a lateral twig and excavate it while tunneling toward the shoot tip. Shoot feeding continues until the first hard frost, when adults crawl out of the shoots and move to the base of trees where they construct their over wintering galleries. From autumn, through the winter, excavated shoots break and fall to the ground.

Not all shoot feeding is caused by the new generation of *T. piniperda* that have emerged from brood logs in the spring. Some shoot feeding is caused by the beetles in the parent generation of adults. These individuals may leave brood logs and feed in shoots after they have constructed their first egg gallery prior to finding new sites for depositing the remainder of their eggs (Langstrom 1983, Sauvard 1993, Haack and Lawrence 1994). A substantial portion of parental adults that have mated and depleted their supply of eggs and sperm will also return to feed on shoots to regenerate their reproductive capacity. In cooler regions of northern Europe these beetles can mate and reproduce during the following year (Schroeder and Risberg 1989). In warmer regions, such as in Kunming China, many of these adults can mate and enter new pine to produce new egg galleries after only two months (Hui 1991).

Damage to forest trees occurs primarily when beetles feed in shoots and kill new growth. Heavy defoliation in northern Europe resulted in up to 70% reduction in the volume of tree growth (Langstrom and Hellqvist 1991). Economic injury is most common in forests containing large quantities of freshly killed or dying pine trees that can serve as breeding material for the larger pine shoot beetle (Langstrom 1984, Langstrom and Hellqvist 1991). Although this beetle is seldom a significant mortality factor of pines in northern Europe, it can kill drought stressed pines in southern Europe and Asia (Hui 1991, Langstrom and Hellqvist 1993) .

The establishment of *T. piniperda* in North America can potentially threaten the productivity of native and introduced pines throughout the continent. To assess this threat on a local level, we have initiated a long-term study on patterns of adult shoot feeding in undisturbed stands of native and introduced pines in northwestern Indiana. In this paper we report on the results of our initial census of pines and shoot feeding by *T. piniperda.*

MATERIALS AND METHODS

Study site selection. Our study site, the Indiana Dunes State Park (Porter County), is located on the southern shore of Lake Michigan and is bordered on the west by the Port of Indiana in Burns Harbor. Some pine stands in the park are natural, representing post-glacial remnants, while others were planted during the early 1900's through the mid-1960's. Four species of pine are present in the park. These include: jack pine (*P. banksiana*), red pine (*P. resinosa*), Scotch pine (*P. sylvestris*), and eastern white pine, (*P. strobus*). Nineteen pine stands were located throughout the park on maps of existing vegetation (Fig. 1). Twelve of the 19 pine stands were surveyed on 5 and 7 April 1993. At that time, little new growth had occurred on the forest floor, making the fallen pine shoots clearly visible.

Survey methods. At each pine of the 12 pine stands, at least one 25m × 1m transect was sampled to characterize stand composition. When stands were large (> 0.4 ha, or > 100 m long), more than one transect was sampled, yielding a total of 28 transects (= 700 m^2) for the 12 stands in this study. Along each transect, all trees whose trunks were within 0.5 m of the transect line were identified to species and their diameters at breast height (DBH; 1.4 meters above the ground), were recorded. The total number of live trees was tallied. To estimate the trees cross sectional area at 1.4 m, the basal area for each live tree was calculated as π *(DBH/2)^2. Percent of basal area contributed by each species was determined.

Differential Shoot Feeding. During the April surveys, we counted the number of detached pine shoots on the forest floor within each transect described above. Shoots that had a frass-free tunnel bored from the base toward the tip were counted as positive feeding sites for *T. piniperda.* Each fallen pine shoot within the transect area was identified to species. This method assumes a proportional relationship between adult beetles feeding in shoots and the number of shoots that fall to the ground (Langstrom and Hellqvist 1991). Moreover, in the present study this method assumes that shoots hollowed out by these scolytids break off equally among all pine species.

Differential shoot feeding among the four pine species was examined by comparing the frequency of fallen shoots with the relative basal area contributed by each pine species using a G-test (Sokal and Rohlf 1981). Basal area of pines surveyed was used to approximate the relative numbers of shoots available to adult larger pine shoot beetles. This measure of cross-sectional area has been correlated with canopy size for several pine species (Stephens 1969, Whitehead 1978).

Table 1. Summary data for the 28 transects that were surveyed at Indiana Dunes State Park in April 1993

Species of pine	No. of trees: No.	No. of trees: % of total	Average DBH*: $\bar{x}$ + SEM	Total basal area (BA): BA in m^2	Total basal area (BA): % of total	Fallen Shoots: No. shoots	Fallen Shoots: % of total
P. sylvestris	64	21.9	16.94±0.54	1.442	19.4	41	31.5
P. resinosa	60	20.5	20.06±0.43	1.896	25.5	57	43.8
P. banksiana	117	40.0	15.08±0.99	2.090	28.1	30	23.1
P. strobus	51	17.5	22.33±1.69	1.997	26.9	2	1.5

*Diameter of tree at breast height, in cm.

RESULTS

The overall composition of pine stands sampled in the Indiana Dunes State Park study site is summarized in Table 1. Jack pine was the most common pine (40%) and contributed the most (28%) to the total basal area of pines surveyed. Based on DBH, white pines were the largest of all tree four species sampled.

The overall density of fallen shoots per transect was 0.185 ± 0.051(SE) /m^2. Densities of shoots in transects ranged from 0 to 1.24/m^2. A total of 130 shoots was found in the 28 transects (Table 1). The species distribution of fallen shoots did not correspond with the proportional species distribution of cross sectional areas ($G=87.2$, $df=3$, $p<0.0001$). Overall, more red pine and Scotch pine shoots were found on the forest floor than their percent contribution to the total basal area of sampled pines. In contrast, feeding on both jack pine and white pine was less frequent than expected from their respective basal areas. For example, *Tomicus*-fed white pine shoots constituted less than 2% of the total shoots found even though white pines represented 27% of the total basal area.

DISCUSSION

Tomicus piniperda shoot-feeds on both native and European pines at the Indiana Dunes State Park. Most of the pine shoots found in this survey (44%) came from red pine, a native species. This suggests that in undisturbed stands native pines can be at least as susceptible to maturation feeding as Scotch pine, the preferred host of this beetle in Europe (Gibbs and Inman 1991). In contrast, many fewer jack pine and especially eastern white pine shoots were found than expected from their relative contribution to the basal area of pines surveyed. This suggests that white pine stands may not be highly susceptible to shoot feeding by *T. piniperda*. Our findings are consistent with those of Lawrence and Haack (1994) who observed that caged adult beetles in southern Michigan excavated longer tunnels in Scotch pines and red pines than either jack pines or eastern white pines.

Interpretation of the number of fallen shoots that we collected assumes that attacked shoots detach from these 4 species of pines at the same rate. Studies of shoot diameters reveal that red pine shoots are much thicker (6mm) than eastern white pine, jack pine, or Scotch pine (4 mm) at the point of attack by adult beetles (Lawrence and Haack 1994). Thus, our counts of fallen pine shoots may underestimate shoot feeding on red pines because their thicker stems could delay shoot detachment. This bias strengthens our ability to infer that *T. piniperda* feeds more readily on red pine shoots than on those of jack or white pine.

The under-representation of *Tomicus* -fed white pine shoots may be related to the quantity and quality of oleoresins that these trees produce in response to shoot feeding. Caged field experiments show 30-40% of adult *T. piniperda* attempting to enter eastern white pine shoots were trapped in resin flows compared to only 5-10% in Scotch pine (Lawrence and Haack 1994). The abundance of non-crystallizing resins in eastern white pines has been shown to confer resistance to *Pissodes strobi* (Peck), a weevil that enters actively growing shoots as an adult (van Buijtenen and Santamour 1972).

Differences in monoterpene composition of the four pine species in the park may also contribute to the distribution of *Tomicus*-fed shoots among species. "East Anglia" Scotch pine, a strain commonly planted in northern Indiana, is reported to have a monoterpene profile that is lower in both alpha-pinene and limonene when compared to eastern white pine (Hanover 1975, Tobolski and Hanover 1971). Limonene has been associated with resistance of *P. ponderosa* to another scolytid, *Dendroctinous brevicomis* LeConte (Smith 1965). However, both the more and lesser preferred species in our study, red pine and jack pine respectively, are reported to have a relatively low content of limonene (Mirov 1961, McCullough and Kulman 1991a, b). Clearly, there is a need for direct studies to examine the relation of shoot feeding and monoterpene composition.

Compared with European conditions, the intensity of shoot feeding was relatively light at our study area. In Sweden, when densities of fallen shoots are below 1 shoot/m^2 of forest floor, stands are considered to be well managed and are not likely to experience growth loss from *T. piniperda* (Langstrom and Hellqvist 1991). Densities of fallen shoots exceeded this level in only 1 of the 28 transects. This density of 1.24 shoot/m^2 of forest floor occurred in a mixed pine transect of 50% red pine and 50% Scotch pine. Using data from Sweden (Langstrom and Hellqvist 1991) to estimate a possible linear relationship between density of fallen shoots (x) and tree volume growth loss (y), ($y = 5.641 + 0.711x$, $R^2 = 0.97$), this density is not likely to affect tree growth. It is almost 5 times less than the density of 6.12 shoots needed to reduce tree volume by 10% in Sweden.

In conclusion, we found that *T. piniperda* shoot-feeds on both native and introduce pines at the Indiana Dunes State Park. The relatively high frequency of *Tomicus* -fed red pine shoots collected in this survey suggests that red pine stands in the Great Lakes region will easily support *Tomicus piniperda* populations. In contrast, jack pine and especially white pine stands may be less at risk.

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