BIOLOGY AND SAMPLING OF RED OAK BORER POPULATIONS IN THE OZARK MOUNTAINS OF ARKANSAS

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ABSTRACT—A complex interaction of multiple factors has resulted in >75 percent mortality/decline of more than 1 million acres of red oak (*Quercus*, subgenus *Erythrobalanus*) on the Ozark-St. Francis National Forests. The most striking feature of this oak decline event is an unprecedented outbreak of red oak borer. A visual stand assessment method was devised for categorizing red oak borer infestation based on crown condition and number of adult emergence holes in the tree bark. An intensive sampling method was also developed to study borer populations at the within-tree level. Complete tree dissections revealed that red oak borer colonizes the entire tree bole. Emergence holes are the highest ever reported in the literature averaging 19.97/m^2 of bark despite high mortality during early larval stages.

INTRODUCTION

The red oak borer *Enaphalodes rufulus* (Haldeman) (Coleoptera: Cerambycidae), a normally endemic insect species of only minor importance, is currently undergoing a remarkable outbreak of unprecedented magnitude within the forests of the Ozark Mountains in Arkansas and Missouri (USA) (Stephen and others, in press).

Forests of the Ozark Mountains have been recently subject to stress from a widespread disease complex known as "oak decline" (Oak and others 1996). This complex is believed to result from a series of predisposing, inciting and contributing factors (Manion 1991). In the Ozark Mountains predisposing factors are tree age, prolonged drought, poor soils and low site quality. Inciting factors are thought to be short periods of severe drought stress (Starkey and others 2000). Data from the National Oceanic and Atmospheric Administration suggest there has been a drought of moderate consequence from 1998 until 2000, and two more serious droughts in the past 50 years (fig. 1). Whether these periods of drought have been sufficient to serve as an inciting factor for an oak decline event is speculation. Contributing factors have been postulated as being defoliating insects (walking sticks, *Diapheromera femorata* Say), root diseases (e.g., *Armillaria mellea* (Vahl: Fr.) Kumm., stem cankers (*Hypoxylon* species) along with secondary borers such as the two-lined chestnut borer, *Agrilis bilineatus* (Weber) and the red oak borer.

The red oak borer has an interesting two-year life cycle in the central US, with adults emerging synchronously, only in odd numbered years, around mid June (Hay 1972, Donley and Acciavatti 1983). Females oviposit eggs within bark crevices or under lichens (Donley 1978) which hatch within 14 days (Solomon 1995). Resulting larvae then chew into the bark and excavate a gallery in phloem tissue. After a winter-long quiescent period, larvae move from the phloem into the sapwood where in their second year they again overwinter before pupating around May. During the later feeding stages frass is ejected from entrance holes and can be seen at the base of infested trees. Preliminary estimates of red oak borer densities, made by our lab during 2001, were striking. The number of early larval attack holes averaged 244/m^2. Density of mature (2nd year) larvae averaged 21.4/m^2 while emerging adult density averaged 18.5/m^2. The magnitude of the outbreak becomes clear when compared to Hay's (1974) study that examined 480 trees but reported only 2.5 to 3.7 average attacks per tree (the highest being 71). Hay (1974) also trapped emerging adults and reported that the highest number of emerging adults on a tree was 15.

We present here a summary of our sampling methods. We also present an update on red oak borer biology and mortality, along with preliminary data on population levels at the within-tree level. The importance of red oak borer as the main contributing factor to current oak mortality will also be discussed.

METHODS

A plot was selected within the "Fly Gap/Morgan Mountain" area of the Ozark-St. Francis National Forest so that it incorporated an appropriate representation of variation in site and stand conditions as well as red oak borer infestation density. All trees sampled within the plot were geo-spatially referenced using a GPS navigator unit (Garmin III+). Stand conditions were assessed in a 100 m x 30 m (3000 m^2 area) plot. Species and diameter at breast height (d.b.h., 1.3 m) was determined for all trees >10 cm. Crown condition and emergence hole density (from 0-2 m ht) were recorded as in table 1. Crown class, epicormic branching (shoots arising from latent buds of the tree bole), current year red oak borer attack and *Hypoxylon* presence were also recorded, as summarized in table 2.

Three trees were selected for felling using the rating system summarized in table 1. The three trees sampled were rated as emergence hole density classes of 1 low tree and 2 medium trees on the dates shown in table 3. Trees with a crown condition of 4 or 5 were not sampled as they were dead. Felled trees were cut into 0.5m sections; each log having the north-facing side marked with a line cut into the bark. Samples were then labeled, before being taken back to the laboratory for intensive sampling. Samples were

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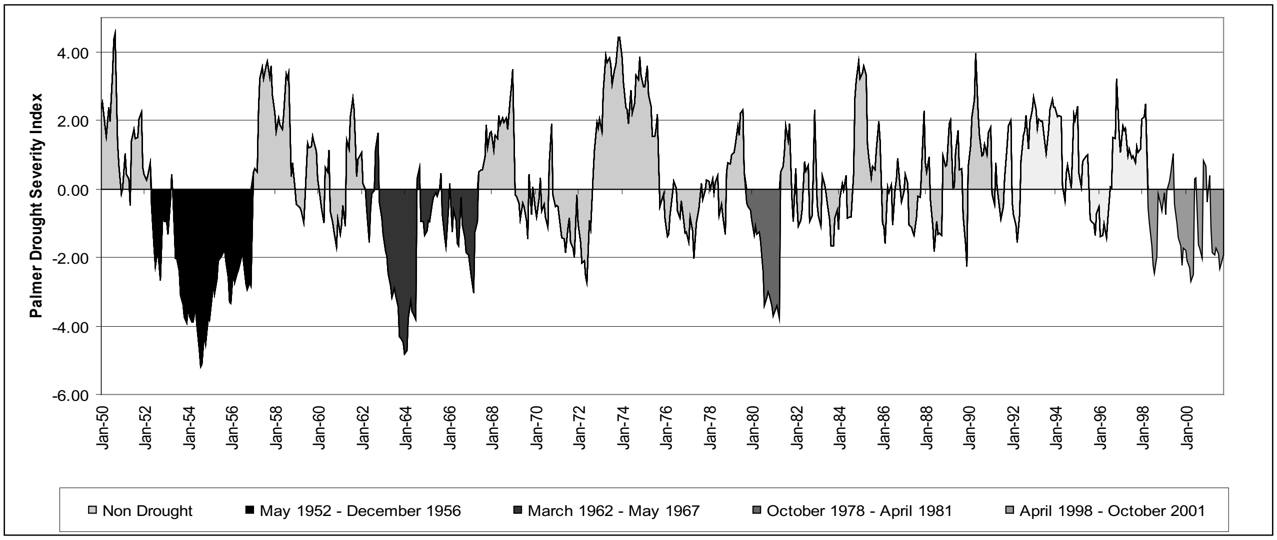
Drought Number	Drought Period	Duration (months)	Peak monthly PDSI	Mean monthly PDSI	s.e. for mean PDSI
1	May 1952 – Dec 1956	56	-5.19	-2.93 (a)	0.16
2	Mar 1962 – May 1967	63	-4.81	-1.55 (b/c)	0.19
3	Oct 1978 – Apr 1981	19	-3.79	-2.21 (a/b)	0.29
4	Apr 1998 – Oct 2001	41	-2.69	-1.22 (c)	0.16



The Palmer Drought Severity Index (PDSI): An Index based on the principles of balance between moisture supply and demand, uses temperature and rainfall information to indicate the severity of a wet or dry spell. The above monthly values are averages of time-bias-corrected divisional temperature-precipitation-drought index data from Arkansas division 1, 2, 4 and 5 for the past 50 years obtained from National Oceanic and Atmospheric Administration

(http://wf.ncdc.noaa.gov/oa/climate/onlineprod/drought/xmgr.html)

The four droughts indicated above displayed extended periods of moderate to extreme drought.

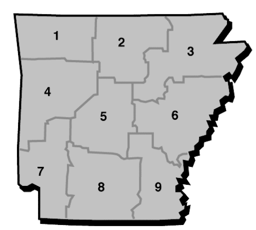


Figure 1—Evidence for droughts in the Ozark Mountain region, from 1950 through 2000.

Table 1—Tree sampling categorization A

Crown condition	Emergence hole density classess
0 = No dieback	
1 = 1 – 33% dieback	0 = None
2 = 33 – 66% dieback	1 – 5 = Light
4 = Died this year (brown leaves in August)	5 – 20 = Medium
5 = Dead 2 – 4 years (no fine twigs)	>20 = Heavy
6 = Dead >4years	

kept in a refrigerated room at 2 °C to prevent larval development or migration within the tree. Chilling appeared to have no effect on larval mortality. Lichens and moss were cleaned off the bark surface with a 14 cm diameter wire wheel brush (drill-powered) after which attack and emergence holes were mapped (ht versus circumference from north-facing line). The logs then had the surface layer of bark scraped off with a ten-inch ‘Ox-Head’ draw knife so that early larval galleries and larvae (dead and alive) could be counted and mapped. Older, deeper galleries were then traced down into the sapwood, using chisels, before being mapped.

RESULTS

Stand Description

Total live tree (>10 cm d.b.h.) density was 450 trees/ha and total basal area occupied by large trees was 24.3 m^2/ha. Tree species richness (gamma diversity, Whittaker 1975) was 12 with red oaks being dominant (123 trees/ha and 11.3 m^2/ha basal area). White oaks were the next dominant tree species (113 trees/ha and 7.0 m^2/ha basal area). Other tree species totaled 214 trees/ha with a basal area of 6.32 m^2/ha. Standing dead tree density was 107 trees/ha, 38 percent of which comprised of red oaks (50 percent of these red oaks died this year).

Table 2—Tree sampling categorization B

Crown class	Epicormic branching	Hypoxylon	Current year attack
1 = suppressed	Yes	Present	Brown ooze on bole
2 = intermediate	No	Absent	Frass at tree base
3 = codominant		Is it associated	
4 = dominant		with ROB (Y/N)	Attack holes

ROB = red oak borer.

Table 3—Dates of tree felling 2002

Tree	Rating	Date
Tree 1	High	1-16-02
Tree 2	Low	3-12-02
Tree 3	Medium	4-4-02
Tree 4	Medium	4-5-02
Tree 5	Medium	6-28-02

Crown condition of the red oaks was generally poor with severe epicormic branching being apparent on trees with greater dieback. Twenty-two percent of live red oaks appeared to suffer no apparent dieback, 35 percent experienced 1-33 percent dieback, 27 percent had 34-66 percent dieback, and 16 percent had >67 percent crown dieback.

Emergence hole categories appear to be related to crown condition (fig 2). Of 21 trees sampled with 0-33 percent dieback, 20 had less than 5 emergence holes. All but one standing dead red oak tree with intact bark (n=9) had >5 emergence holes, indicating that they had undergone a longer 'history' of attack by previous generations of red oak borer.

Crown class of live red oaks showed that in this particular plot, trees were mainly dominant and co-dominant with respect to other tree species. Of the 37 live red oaks examined all showed signs that they had been attacked by the latest generation of larvae (July/August 2001). Dead trees and trees with very severe crown dieback tended not to show signs of recent attack. *Hypoxylon* was only observed on dead and dying trees.

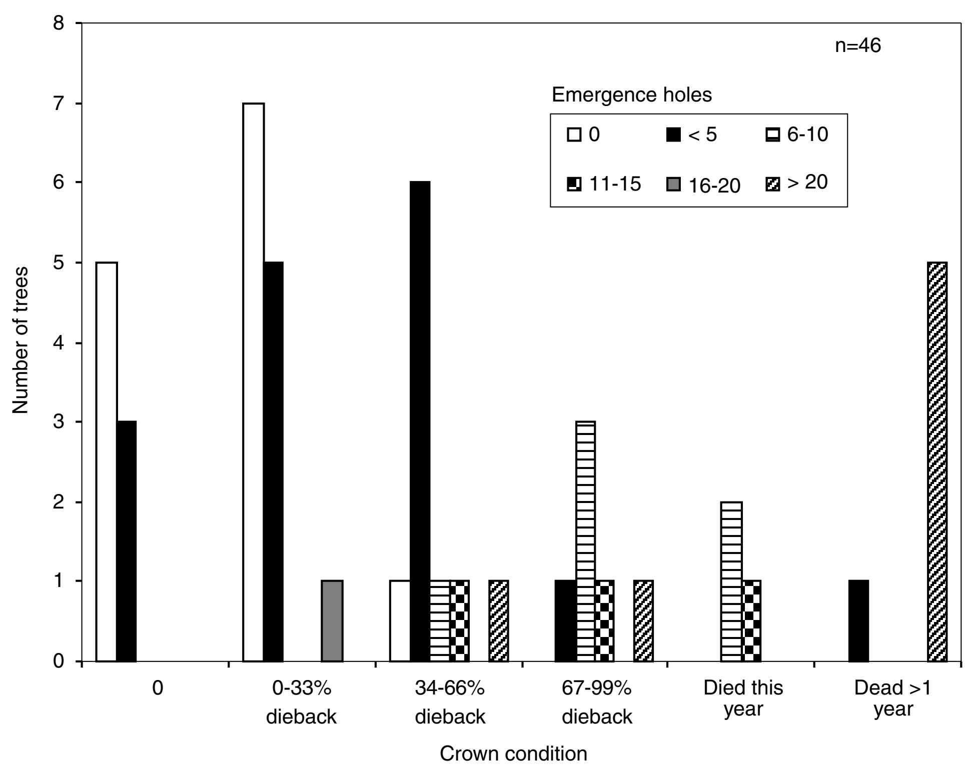


Figure 2—Red oak borer emergence hole category in relation to tree crown condition for the Fly Gap/Morgan mountain area of the Ozark National Forest.

TREE DISSECTIONS

Examination of infested log sections revealed some interesting facts from which several assumptions could be made about borer/tree interactions. First, after newly hatched larvae burrow into phloem tissue they form small, irregular, circle-shaped galleries of approximately 4 cm^2. When, around November, temperatures drop it appears larvae enter a quiescent period until the following May. Dissections revealed that cell tissue around these galleries became necrotic and blackened. It is uncertain when this necrotic tissue formed around the larvae but it appeared to occur once larval feeding stopped during winter.

During June 2002, dissections revealed that the surviving larvae had not yet moved out of the necrotic galleries. For all three trees sampled the mean number of attack holes/m^2 of bark was 179 (±16.4SE). The mean number of emergence holes/m^2 of bark for all three trees was 19.97 (±2.51SE).

Dissections revealed that borers attacked every section of the tree's main bole. Bark attack site density increased in number from the base of the tree to the middle, after which density decreased (fig. 3). Numbers appeared to dip slightly just before halfway up the infested bole. Late larval galleries and emergence site density also followed this general trend (figs. 4 and 5). Early larval galleries, however, appeared to gradually decrease in density from base to top of the tree (fig. 6).

Mortality was calculated for three time periods from July 2001 – Aug 2001

1. mortality from attacks of newly hatched larvae: from July 2001 until formation of early first year gallery by larvae (Aug-Nov 2001 approx) (n=82)

$$1-\left(\frac{total\ \#1^{st}\ year\ galleries}{total\ \#\ bark\ attack\ sites}\right)=0.337\pm0.07\,(SE)$$

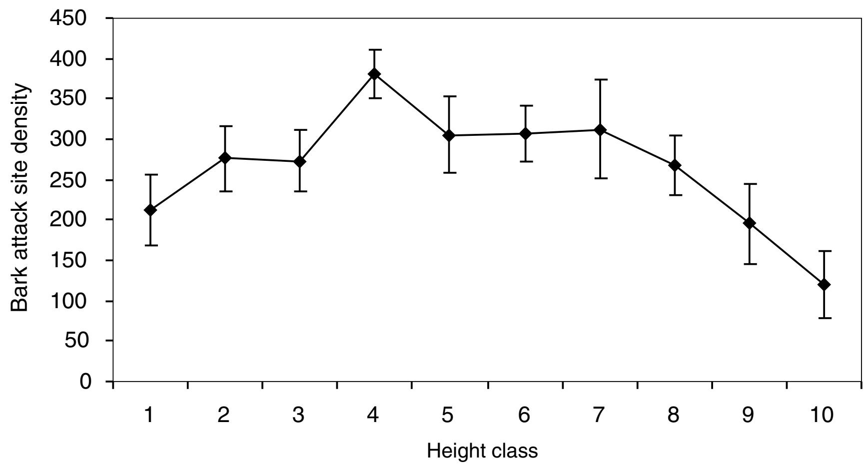


Figure 3—Distribution of bark attack densities (per 1 m^2) of red oak borer larvae from the base (1) to the tip of the tree (10). n=3.

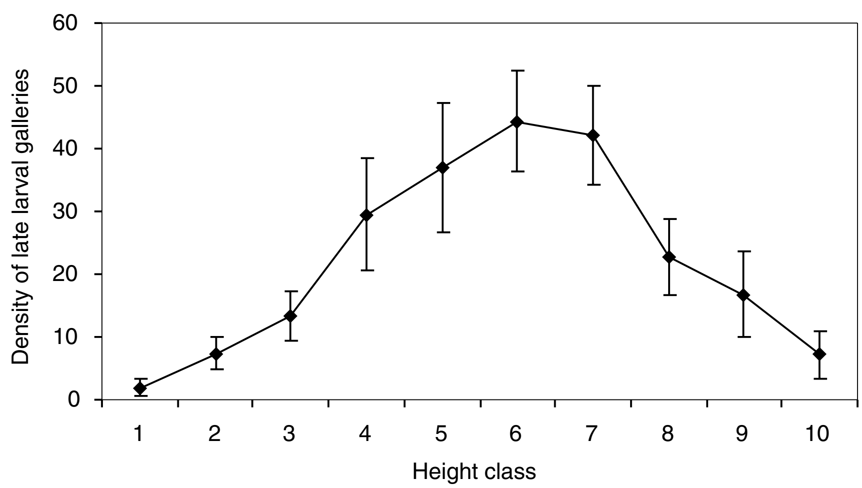


Figure 4—Distribution of late larval galleries (per 1 m^2) from the base (1) to the tip of the tree (10). n=3.

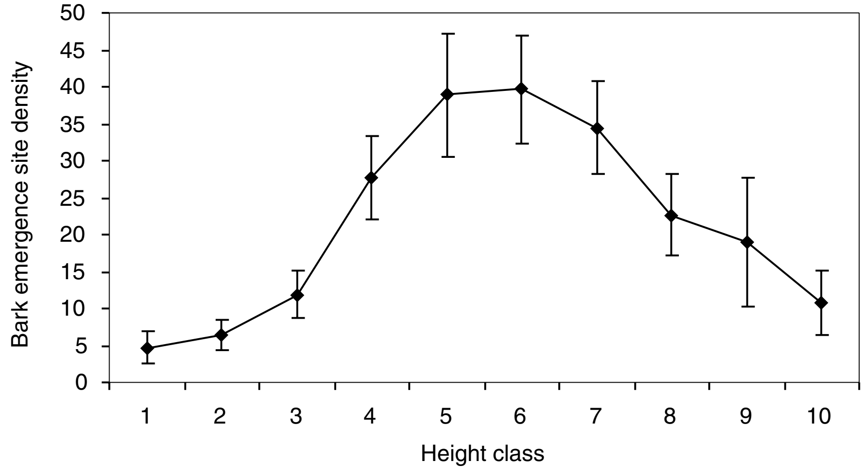


Figure 5—Distribution of bark emergence sites (per 1 m^2) from the base (1) to the tip of the tree (10). n=3.

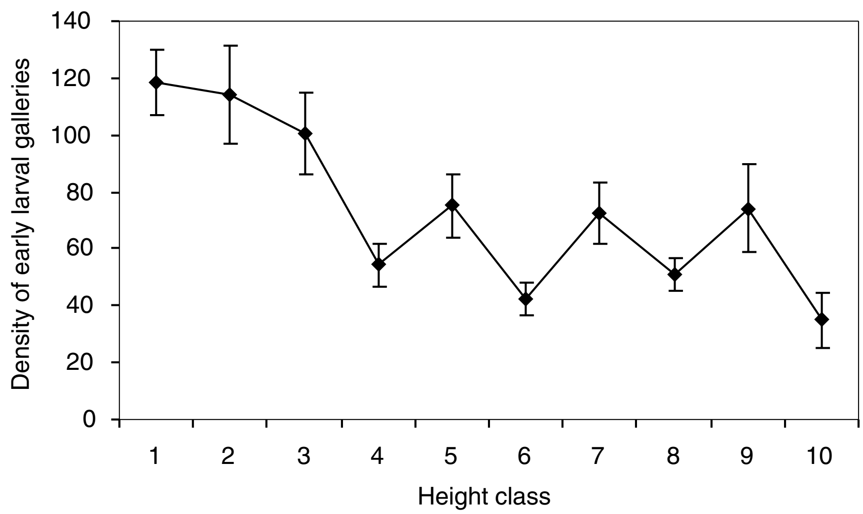


Figure 6—Distribution of live early larvae (per 1 m^2) from the base (1) to the tip of the tree (10). n=3.

2. mortality from live early larvae: larvae in galleries formed from Aug-Nov 2001 until live larvae were sampled in trees during Jan-May (n=82)

$$1-\left(\frac{total\,\#\,live\ early\ larvae}{total\,\#\,1^{st}\ year\ galleries}\right)=0.442\pm0.03(SE)$$

3. total mortality from attack of new larvae: from July 2001 until live larvae in necrotic gallery (sampled Jan-May 2002) (n=82)

$$1-\left(\frac{total\,\#\,live\ early\ larvae}{total\,\#\,bark\ attack\ sites}\right)=0.657\pm0.04(SE)$$

It is important to note that these mortality estimates are not calculated from number of eggs oviposited on the bark surface, but from newly hatched larvae that are able to first bore into the bark surface. Mortality is expected to be low when later stage larvae have burrowed into the sapwood of the tree (mainly due to protection offered by living in gallery so deep inside the bole).

DISCUSSION

It is clear from our preliminary results that red oak borer population densities are remarkably high and that trees within the Ozark National forest are undergoing severe levels of attack. Despite heavy larval mortality during the past year surviving larvae boring into the sapwood were still at incredibly high densities, especially when compared to Hay's results from 1974. The only other reported survey of red oak borer attack was done by Donley and Rast (1984) who reported that red oak borer adult emergence (from 421 red oaks) averaged 2.0 per tree in Pennsylvania and 3.6 in Indiana.

At present we cannot explain the apparent trend for population densities to dip near the center of the infested boles. This may simply be an artifact. Further tree dissections will clarify whether the borer population has a uni- or bi-modal distribution within trees.

Although predisposing factors such as old tree age, shallow soils, periods of drought, low species diversity and fungal pathogens may be indicted as possible contributors to the current 'oak decline' event, it is clear that red oak borer populations are much higher than ever seen in recorded history and that they are the main factor responsible for tree death. If oak decline has reduced tree vigor in such a manner as to permit higher survival of red oak borers over several generations, it is perplexing to note that such high levels of red oak borer populations have never been reported with other oak decline events, despite the fact that this endemic insect species has been present in those forests. The consequences of the current outbreak in terms of changes to forest composition and structure are as yet unclear. It is predicted that changes to some groups, such as the complex of neotropical migrant birds, may be significant (Smith and Stephen, in press).

Mortality studies are continuing and it is hoped that by July/August 2003 partial life tables will be completed for an entire generation. Current sampling methods at the within-tree level are being refined to optimize number of tree sections needed to accurately estimate within tree population densities. This will enable more trees to be sampled from different areas and allow populations to be compared between stands of different conditions.

Our initial stand assessments show that crown condition and emergence hole density (from 0-2 m) give a quick and simple method of assessing red oak borer infestation. This method is presently being used by USDA Forest Service survey teams to assess red oak borer populations in stands over the entire Ozark-St. Francis National Forests. These surveys should be able to more precisely estimate the severity of the current epidemic.

ACKNOWLEDGMENTS

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