Monitoring and predicting populations of red oak borer in the Ozark Mountains

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Red oak borer, *Enaphalodes rufulus* (Haldeman) (Coleoptera; Cerambycidae), is a native insect that develops in living oak trees in the eastern U.S. Extraordinarily high populations have recently contributed to the death of tens of thousands of red oaks in a widespread oak decline event in the Ozark Mountains of Arkansas, Fig. 1. Populations have historically been documented at low endemic levels and these wood-boring beetles have never been reported as significant mortality agents, despite there being other oak decline events within their range. Developing sampling methods for this insect is complicated by the two-year life cycle of this cryptic species and synchronous adult emergence only in odd-numbered years. Despite this, we have developed methods for sampling within-tree populations of red oak borer over the past four years. We have also investigated multiple factors affecting red oak borer populations and their interactions with tree mortality.

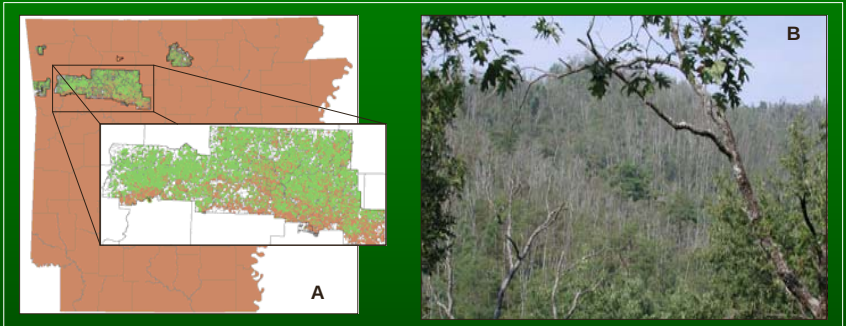


Fig. 1. The Ozark National Forest in Northwest Arkansas (A) is experiencing an oak decline event characterized by the death of thousands of northern red oaks, *Quercus rubra* L. (B). Green areas on the map represent white oak/red oak/hickory forest types as designated by the USDA Forest Service. Many affected stands are even-aged as a result of extensive logging in the early 1900s and are on low quality sites. Symptoms include dead and dying crowns, epicormic branching and tree mortality.

A Rapid Estimation Procedure was developed after making extensive field observations and intensively sampling whole trees in the lab. This survey method takes less than 5 minutes using 2 tree variables: basal emergence holes and tree crown condition based on dieback and transparency, Fig 2. Quantification of these data allow classification of trees into three general infestation histories; high, moderate and low. Analysis of sampling data show significant differences between classes and data yield acceptable estimates of within-tree populations (Fierke et al. 2005a).

Fig 2. The rapid estimation procedure is based on crown condition and basal emergence holes. Class 1 trees are characterized by healthy crowns and <5 basal emergence holes and have a low red oak borer infestation history. Class II trees generally have 33-66% dieback and 5-20 emergence holes. Class III trees usually have >66% dieback and >5 emergence holes and a high infestation history.

Intensive or whole-tree dissection (Fig. 3) yields accurate red oak borer within-tree population data. It was the first step in method development but is time-consuming, ~130 hours/tree, and required large amounts of storage space (Fierke et al. 2005b).

Extensive dissection uses nine sub-samples taken systematically up the tree bole and data are extrapolated to the whole-tree. Statistical analysis revealed that extensive estimates are acceptably accurate and further analysis indicated that seven sub-samples was the optimal number of samples to dissect considering both accuracy and efficiency, Table 1.

Fig. 3. Tree dissection involves felling trees, cutting them into 0.5 m sub-samples, transporting samples to the lab, and storing in a cooler until processing. Samples are wire-brushed to remove lichens and moss prior to mapping attack and emergence holes. Outer bark is scraped off to expose 1st year phloem feeding galleries. Scar tissue is chiseled away to expose previous generation galleries and the final step is to split each sample to locate all red oak borer.

Table 1. Seven is the optimal number of sub-samples to dissect as estimates based on these data are not statistically different than taking nine sub-samples and they are acceptably accurate when compared to actual data. Data are in density per m^2. Estimates in white are closest to the actual mean.

	Attack holes			Current Gen. Galleries			Emergence holes			Live Larvae		
	Actual	9	7	Actual	9	7	Actual	9	7	Actual	9	7
Class 1	106.1	116.2	109.1	45.1	48.1	46.4	3.1	3.5	4.2	5.8	6.5	5.7
Class 2	265.4	289.1	283.8	66.8	68.1	68.6	13.2	13.9	14.9	17.1	17.3	17.7
Class 3							22.5	25.2	25.2	7.2	7.7	7.4

Within-tree and stand-level population estimates based sampling immediately prior to adult emergence in 2003 and again in 2005 allowed evaluation of emerging adult populations and confirmed extremely high populations as well as documenting a population crash in the 2005 cohort (Table 2 & 3).

Table 2. Late-stage live red oak borer found in trees sampled on ridge topographic positions from three areas of the Ozark National Forest. Number of trees sampled are given below each area, ± standard error is after the mean and ranges are below. There were significant differences between years for all areas with different letters within columns indicating significant differences between areas using Tukey HSD at α = 0.05.

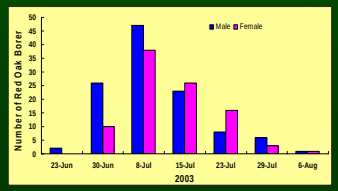
	2003	2005
Fly Gap n = 21	42.6 ± 6.7 AB 0 – 93	3.1 ± 1.8 A 0 - 13
Oark n = 3	10.2 ± 7 B 0 – 24	3 ± 1.3 A 0 -10
White Rock n = 3	71.7 ± 10.3 A 51 – 83	1.8 ± 0.8 A 0 - 6

Table 3. Population estimates for the number of red oak borers emerging per acre in stands located on ridge topographic positions from three areas of the Ozark National Forest. Estimates are based on late-stage live larvae (Table 2) found in trees categorized into the three red oak borer infestation classes combined with data on the number of northern red oaks in each class within 30 x 100 m fixed vegetation plots.

	Emerging red oak borer	
	2003	2005
Fly Gap	4,517 ± 940	192 ± 112
Oark	2,654 ± 579	120 ± 52
White Rock	5,866 ± 1,269	135 ± 60

Sampling has added to our knowledge of red oak borer biology, including flight period, male/female ratios and mortality agents, e.g. intra/interguild predation (Ware and Stephen 2006), pathogens, parasitoids. Adult flight has been investigated with results indicating that optimum trap placement for monitoring is near the canopy. Investigations of host selection, e.g. preferential landing, tree volatiles and beetle pheromones have not been conclusive, but baseline data are available and will be used for further research. Other potential mortality influences/agents include stand and tree data associated with differentially infested trees, *Armillaria* root rot, two-lined chestnut borer presence and abundance and tree defenses.

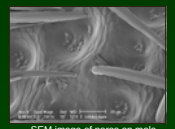
More beetles caught near the canopy.



Peak emergence in early July with 1:1 sex ratios and male flight occurring earlier.

Ants are egg/neonate predators based on field observations and molecular studies.

Elaterids and carpenter worms are voracious predators of red oak borer larvae. Red oak borer mortality also occurs when nitidulid larva are introduced, but not through direct predation.



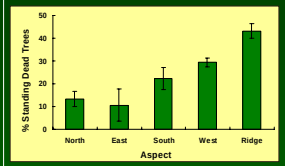
SEM image of pores on male red oak borer.

Host selection.

Oak volatile collection.

Red oak borer larvae can be cannabalistic and weigh more if they are.

Beauveria bassiana is associated with larvae mortality and is a potential control agent.

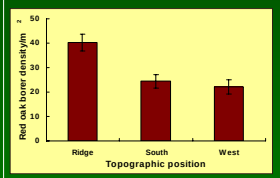


There are more dead trees on ridge plots.

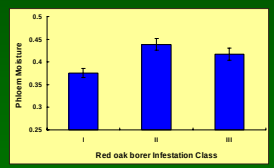
Wounds made on Class I trees heal over faster than those on Class II and III trees .

Two-lined chestnut borer are present at low levels, but do not appear to be associated with tree mortality

Three species of *Armillaria* are present in the Arkansas Ozarks, though it does not appear to be associated with tree mortality on ridges.



Trees on ridges have more previous generation galleries.



Class I trees had less phloem moisture than Class II and III trees. This trend also held for total phenolics, protein-binding capacity, and concentrations of individual phenolic compounds.

Future research includes investigating environmental contributors to tree mortality and interactions of silvicultural treatments on tree health and red oak borer populations, e.g. controlled burns, removal of "brood trees". Research toward elucidating biological and mortality factors associated with changes in red oak borer populations continue as does development of an interactive prediction model of stand hazard and efforts continue toward making it available to the public.

References

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