



A rapid estimation procedure for within-tree populations of red oak borer (Coleoptera: Cerambycidae)

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Abstract

Epidemic populations of red oak borer, *Enaphalodes rufulus* (Haldeman), a native wood-boring cerambycid beetle, appear to be a primary factor contributing to oak mortality across the Ozark Mountains of Arkansas, Oklahoma and Missouri. We developed a rapid estimation procedure (REP) to quickly, non-destructively and economically assess current density and infestation history of red oak borer in northern red oaks, *Quercus rubra* L., under outbreak conditions in the Ozark National Forest, Arkansas. The REP is a survey method for classifying individual trees that takes less than 2 min per tree and uses two variables: crown condition and number of emergence holes on the basal 2 m of a tree. Data obtained through intensive and extensive population sampling validate classification of trees into three REP infestation classes, which exhibited significantly different densities of measured red oak borer population variables. Numbers of emergence holes and previous generation galleries increased significantly across infestation classes from I (low) to III (high). Class I trees had significantly fewer attack holes than did Class II or III trees. Numbers of current generation galleries and live larvae were significantly lower in Class I than Class II trees, but Class III trees could not be distinguished from the other classes. The REP is an efficient sampling procedure as it facilitates greatly increased sample sizes, thus, allowing estimation of red oak borer populations at the stand, area and landscape level. Information provided by this kind of survey method may be vital to understand causes and extent of the current outbreak as well as predict future outbreaks and design silvicultural treatments for enhancing forest health.

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1. Introduction

Red oak borer, *Enaphalodes rufulus* (Haldeman) (Coleoptera: Cerambycidae), is a native wood-boring

beetle normally occurring at low population levels (Hay, 1974; Donley and Rast, 1984). Intensive and extensive sampling of northern red oaks, *Quercus rubra* L., from 2001 to 2003 revealed exceptionally high red oak borer population levels with trees containing on average, across all life stages, 577 live larvae per tree and up to 130 per tree just prior to adult emergence (Fierke et al., 2005). This unprecedented

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outbreak is linked to an oak decline event in the Ozark National Forest of Arkansas (Starkey et al., 2000; Stephen et al., 2001).

Manion (1991) described forest decline in terms of predisposing, inciting and contributing factors. Predisposing factors include tree genotype, tree age, prolonged drought and low site quality. Acute short-term drought, late frost and defoliation cause tree stress and are considered inciting factors. Contributing factors include boring from secondary insects, root diseases and cankers. In northern Arkansas, up to 67% of the forested area is oak-hickory (USDA Forest Service, 1999) with red oaks, sub-genus *Erythrobalanus*, being common tree species and preferred hosts for red oak borer (Hay, 1974; Donley, 1978).

Intensive sampling of whole trees provides accurate data on within-tree red oak borer population variables (Fierke et al., 2005). These destructive techniques, however, require immense time and monetary investment, thus restricting sampling to small numbers of trees, stands and geographic areas. Extensive sampling methods, using sub-samples, permit increased sampling in more habitats over a larger geographic area while maintaining reliable population estimates, but are still time-consuming and also require destructive sampling (Southwood and Henderson, 2000; Fierke et al., 2005).

The primary objective of this research was to develop a survey method, a rapid estimation procedure (REP), for estimating red oak borer population variables and classifying infestation history in northern red oaks under outbreak conditions. Our goal was to allow quick estimation of red oak borer population densities in the field without destructive sampling. Intensive and extensive within-tree sampling data (Fierke et al., 2005) were used to validate REP classifications as predictors of red oak borer within-tree population levels.

2. Methods

2.1. Study areas

The study was carried out in three areas of the Ozark National Forest, Arkansas (UTM Zone 15–S NAD83: Fly Gap—0431660, 3954978, White Rock—412668, 3949429 and Oark—0450792, 3952369).

2.2. Tree sampling

Red oak borers have a rather unique 2-year life cycle with synchronous emergence of adults occurring only in summers of odd-numbered years (Hay, 1969; Fierke et al., 2005). Sixty-nine northern red oaks were harvested from January 2002 to June 2003. This sampling period included life stages from the first winter quiescence through emergence of the 2003 generation. Twenty-four trees were sampled according to intensive sampling methods and 45 were sampled according to extensive sampling methods developed by Fierke et al. (2005). Trees ranged from 50 to 105 years old, diameter at breast height from 18 to 49 cm and height from 14.5 to 30 m. Trees, representing a continuum of tree health based on crown condition, were chosen for sampling using two criteria: evidence of current red oak borer infestation and opportunity to safely fell the tree.

2.3. Rapid estimation procedure

The REP used two variables that can be evaluated in less than 2 min per tree: crown condition and number of red oak borer emergence holes from tree base to a height of 2 m. Evaluation of crown condition was based on techniques described by Starkey et al. (2000) and estimated percent crown dieback, combining foliage transparency and crown measurement outlines (USDA, 2001) to yield crown condition classes (CCC) of 0 (healthy, normal), 1 (<33% dieback), 2 (34–66% dieback), 3 (66–100% dieback) and 4 (recently dead). Basal emergence holes were counted and grouped into basal emergence hole classes (BEC) of 0, 1 (1–5 holes), 2 (6–20 holes) and 3 (>20 holes). These BEC groupings were based on early field and lab observations of crown and phloem tissue health and number of basal emergence holes present. The CCC and BEC were summed to yield a rapid estimation index (REI), ranging from 0 to 7 that facilitated grouping of trees into three REP infestation history classes (Table 1). Infestation history refers to colonization of trees by both current and previous red oak borer generations and incorporates duration of red oak borer infestation in a tree and decline of tree health. If a tree's REI was equal to 0 or 1, then it was considered to have a low infestation history and labeled Class I. If REI was equal to 2, 3 or 4, then infestation history was considered moderate and

Table 1
Rapid estimation procedure variables assessed in the field include crown condition and number of basal emergence holes

Crown condition	CCC	Emergence holes <2 m	BEC	REI	REP class
<1% dieback	0	0	0	0, 1	Class I
1–33% dieback	1	1–5	1		
34–66% dieback	2	6–20	2	2, 3, 4	Class II
67–99% dieback	3	>20	3		
Dead	4			>4	Class III

Summation of these variables yields indices that were used to classify trees into REP infestation history classes. *Abbreviations:* CCC, crown condition class; BEC, basal emergence hole class; REI, rapid estimation index (CCC + BEC).

labeled Class II. If REI was greater than four then infestation history was considered high with tree death imminent and REP was Class III.

2.4. Data analysis

Red oak borer population data derived from intensive and extensive sampling were used to verify accuracy of REP classes. Data were analyzed with JMP 5.1 (SAS Institute, 2004). ANOVA and Tukey–Kramer HSD means comparisons were used to test for significance between classes. Discriminant analysis was used to confirm validity of REP classes based on five red oak borer population variables: attack holes, current generation galleries, live red oak borer, emergence holes and previous generation galleries.

3. Results

Field estimation of red oak borer infestation placed 30 trees in REP Class I, 23 in Class II and 16 in Class

III. Analysis of data from intensive and extensive sampling revealed significant differences in some red oak borer population variables between REP infestation history classes (Table 2). Emergence holes and previous generation galleries clearly separated among the three classes. Attack holes, current generation galleries, and live red oak borer typically allowed only the separation of two of the three classes with Class I trees always differing significantly from Class II, but neither was always significantly different from Class III.

Class I trees had significantly fewer attack holes than Class II and III trees ($F = 8.1$; d.f. = 2, 55; $P = 0.0008$). Current generation galleries in a tree represent the sum of all galleries initiated by red oak borer larvae in the current generation and Class I trees had significantly fewer ($F = 6.28$; d.f. = 2, 39; $P = 0.0043$) of these galleries than Class II trees, but did not differ significantly from Class III trees. Class I trees had significantly fewer live red oak borer than Class II trees, but not Class III trees ($F = 4.73$; d.f. = 2, 65; $P = 0.0121$). Mean bark emergence holes and previous generation heartwood galleries per tree significantly increased from Class I to Class II to Class III, respectively ($F = 35.9$; d.f. = 2, 66; $P < 0.0001$ and $F = 32.7$; d.f. = 2, 38; $P < 0.0001$).

Discriminant analysis of REP classes for 41 trees (15 Class I, 16 Class II and 9 Class III) on which all five population variables were measured, revealed 5 misclassified trees (12.5%) (Fig. 1). Two canonical axes were interpreted with 88.3 and 11.7 proportion of variance represented by Axes 1 and 2, respectively. Class II trees were most often misclassified using the REP procedure with three trees predicted as Class I with probabilities of 60, 87 and 55% and one tree predicted to be Class III with a probability of 62%.

Table 2
Mean and standard error of red oak borer population variables measured for 69 trees in three REP infestation history classes

Population variable (<i>n</i>)	Infestation history classes		
	Class I	Class II	Class III
Attack holes (27, 19, 12)	1455 ± 230; A (116–4220)	2711 ± 198; B (684–3909)	2475 ± 360; B (867–5042)
Current generation galleries (17, 16, 9)	402 ± 71; A (14–1178)	748 ± 59; B (434–1244)	573 ± 109; AB (165–1178)
Live red oak borer (30, 23, 15)	34 ± 8; A (0–166)	118 ± 34; B (3–577)	51 ± 11; AB (0–144)
Emergence holes (30, 23, 16)	48 ± 12; A (0–256)	128 ± 22; B (10–368)	296 ± 31; C (189–694)
Previous generation galleries (16, 16, 10)	22 ± 3; A (0–42)	170 ± 35; B (21–451)	402 ± 48; C (254–790)

Different letters (A–C) within rows indicate significant differences using Tukey–Kramer HSD means comparison at $\alpha = 0.05$. Range is given after the means and number of trees sampled (*n*) is given in parentheses after each population variable for each class, respectively.

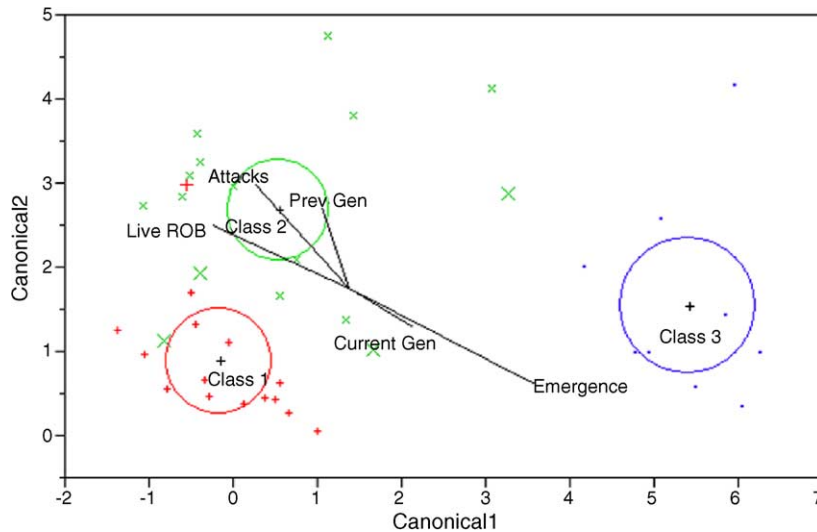


Fig. 1. Discriminant analysis of REP classes ($n = 41$ trees) based on five red oak borer population variables. Circles indicate 95% confidence limits around the mean for each class. Five trees (12.5%) were misclassified (bold symbols). Four were Class II and one was Class I.

REP Class I had one misclassified tree with an 84% predicted probability of being Class II.

4. Discussion

Population indices are useful and are often the only practical means available to estimate insect populations because of the time and expense involved in more precise measures (Knight, 1967). The most beneficial aspect of the rapid estimation procedure is that it is an extremely quick, non-destructive method for estimating within-tree red oak borer population densities at tree, stand and landscape levels. It requires less than 2 min to evaluate crown condition and basal emergence holes in the field, whereas, to fell and to intensively sample a whole tree in the lab for all five population variables requires over 100 h (Fierke et al., 2005).

Class I trees were successfully attacked by fewer red oak borers relative to Class II and III trees as indicated by fewer attack holes. Class II trees were infested by significantly higher densities of live red oak borer than Class I trees and may be serving as brood trees for further infestations. There was a trend for Class II trees to have more live red oak borer than Class III trees, but the difference was not statistically significant.

Large ranges in live red oak borer data were attributable to the fact that means were derived from dissections completed from the first quiescent life stage through adult emergence. Intensive and extensive sampling techniques, as well as data derived from them, are dependent on life stage of red oak borer within the tree. Early in the life cycle there were more live larvae present, whereas late in the life cycle there may be only a few borers surviving into pupal and pharate adult stages.

Field observations and stand data (unpublished) indicate that Class III trees are infested with a final red oak borer generation and that mortality is imminent. This knowledge, in combination with the fact that Class III trees have had significantly higher numbers of red oak borers emerge from them as indicated by numbers of previous generation galleries, strongly suggest that red oak borer are primary contributing factors to tree mortality in the current oak decline event.

Numbers of previous generations infesting a tree appear to be associated with rapid increases in within-tree populations and current levels of infestation. One possible explanation for this could be increased oviposition on natal trees from which beetles are emerging. Increased oviposition on natal trees by wood-boring insects has been documented in previous studies. Female carpenterworm, *Prionoxystus robiniae* (Peck) (Lepidoptera: Cossidae), a common

heartwood-boring insect frequently found associated with red oak borer, is known to oviposit 2/3 or more of their egg-load on trees from which they emerge prior to their first flight (Solomon and Neel, 1974). This leads to increased populations within infested trees and re-infestation in subsequent years once a tree has been successfully attacked.

Another possible explanation could be female attraction to previously infested trees. Dunn et al. (1986) demonstrated preferential attraction of two-line chestnut borer, *Agilus bilineatus* (Weber) (Coleoptera: Buprestidae), the insect most often associated with other U.S. oak decline events, within hours to induced stress in white oaks. Preliminary research into red oak borer preferential attraction indicated a trend for increased landing rates on Class II trees (unpublished data); however, because the sample size was small this trend cannot yet be considered conclusive. During times of tree stress and otherwise favorable conditions for insect survival, either of these explanations could lead to epidemic population levels within trees relatively rapidly.

Class II and III trees have higher numbers of attack holes, emergence holes and previous generation galleries than do Class I trees. Stand data collection (unpublished) reveals that some forest stands experience almost 100% oak mortality, yet there are individual Class I trees within these high mortality stands that exhibit virtually no evidence of borer attack. It may be that some Class I trees are on favorable microsites or on microsites to which they are better adapted genetically (Sork et al., 1993) and therefore able to better defend themselves, physically or chemically, from insect attack.

Alternate explanations for the occurrence of Class I trees in stands that contain predominately Class II and III trees are that these trees may be less susceptible to red oak borer if they are not infested with a forest pathogen or if they are associated with location-specific predators. *Armillaria*, a root and heart rot fungus, has been indicted as a contributing agent in other oak decline events (Manion, 1991) and is present in the Missouri Ozarks (Bruhn et al., 2000). Field observations of foraging ants (e.g., *Camponotus* species) and abundant ant populations along with our observations of ant predation led to the hypothesis that some trees might be associated with increased populations of egg/neonate predators.

The rapid estimation procedure is an effective tool for classifying infestation history of northern red oaks under outbreak conditions with misclassification of <15% of sampled trees. Further work is needed to determine reasons behind differences observed in red oak borer infestation levels between REP classes.

5. Conclusions

Depending on precision required and resources available, the rapid estimation procedure could be an appropriate and valuable survey method in stands experiencing epidemic populations of red oak borer. It is not recommended for use in stands with endemic population levels as Class I trees in this study had far higher infestation levels than previously reported in the literature (Hay, 1974; Donley and Rast, 1984). The REP can be used to compare within-tree levels and duration of infestation, estimate area-wide population levels and insect damage, and in evaluating stand and forest health. REP data may also be invaluable in designing and implementing silvicultural management for enhancing forest health and in developing landscape- and stand-level models to predict areas of high probability for infestation.

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