RESEARCH ARTICLE

Forest Management and Curculionid Weevil Diversity in Mixed Oak Forests of Southeastern Ohio

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ABSTRACT: Weevils (Coleoptera: Curculionidae) may play a role in the reduced regenerative ability of oak (*Quercus* L.) species in the hardwood forests of eastern North America. Presently, because of biome-wide regeneration failure, silvicultural treatments of prescribed fire and mechanical thinning are being implemented as a means to enhance natural oak regeneration. The effect that these treatments may have on the diversity and population structure of non-target organisms like weevils (oak seed predators) remains unclear. This study provides an evaluation of the weevil populations of two experimentally managed, mixed-oak forests in southeastern Ohio. Each of the two sites used in this study was divided into four 20 ha treatment plots consisting of: (1) untreated control, (2) thin only, (3) thinning followed by prescribed burning, and (4) prescribed burning only plots. Pyramid style traps (N = 48) were placed in each treatment unit to sample weevils. Overall, we identified 26 species of Curculionid weevils representing nine genera from five different tribes and two subfamilies. Weevil communities were generally dominated by a few highly abundant species and a moderate number of uncommon to rare species. Generally, treatments increased overall weevil diversity and influenced the abundance of certain rare species. However, there was no significant effect on number of weevils or on occurrence of the two major acorn infesting genera (*Curculio* L. and *Conotrachelus* Dejean). Based upon our findings, prescribed spring burning had little effect on overall weevil populations and is not likely to substantively aid in silvicultural endeavors to promote oak regeneration; however, effects on rare species need to be carefully considered.

Index terms: Coleoptera, Curculionidae, fire, forest management, *Quercus*

INTRODUCTION

Forest management techniques, including applications of prescribed burning and mechanical thinning, are presently being explored as a means to enhance the natural regeneration of oak species (*Quercus* spp. L.) in the eastern and central hardwood forests of North America (Brose et al. 1999; Franklin et al. 2003; Hutchinson et al. 2005; Albrecht and McCarthy 2006). One mode of action by which silvicultural treatments are thought to improve regeneration is through a reduction in the occurrence of invertebrate seed predators, particularly acorn weevils (Coleoptera: Curculionidae). It is hypothesized that a spring burn might destroy weevils emerging from the soil as well as those residing near the soil surface. Additionally, by removing the leaf litter, prescribed burning may also increase susceptibility of weevils to predation by vertebrate predators such as the white-footed mouse (*Peromyscus* leucopus) and the short-tailed shrew (*Blarina* sp.), both of which are common in the eastern deciduous forests (Anderson and Folk 1993; Semel and Anderson 1988).

Weevils, particularly those in the genus *Curculio* (L.), are the major seed predator of oak species in the eastern United States, and damage to seed crops can vary anywhere from 0-100 % based on tree species and seed crop size (Christisen 1955; Gibson 1972, 1982; Riccardi et al. 2004; Miller and Schlarbaum 2005). Gibson (1969) lists 27 species of *Curculio* as occurring in America north of Mexico. Adult *Curculio* spp. can be found from April to November in southern states with a slightly lower active period farther to the north. Toward the end of the summer, females excavate a hole into developing acorns using their extended rostrum and deposit an egg. Eggs hatch in 5-14 days and larvae feed from within the pericarp for approximately two weeks. After seed drop, larvae exit the acorn and burrow into the ground to overwinter. Diapause may last from one to five years, depending upon the species; however, one or two years is common (Gibson 1969). *Conotrachelus* (Dejean), another major genus of seed-feeding weevils, generally emerges later in the summer and oviposits in acorns at the end of August and early September. Many species in this genus require pre-existing damage to the nut as they are unable to chew through the pericarp on their own. Not all weevil species breed in seeds; many simply oviposit in or on the soil surface, or on the surface of leaves or other parts of a tree, and may feed either on the roots or the inner bark (Blatchley and Leng 1916; Evans 1959).

The purpose of this study is to determine if stand level treatments affect the diversity and abundance of adult weevils in two managed, oak dominated hardwood forests in southeastern Ohio. Specifically, we wish to address the following questions: (1) What effect do treatments have on overall diversity of weevils in the area, and how do they influence community composition? and (2) Do the treatments specifically reduce the abundance of the acorn infesting weevils, *Curculio* and *Conotrachelus*?

METHODS

Study Site

This study utilized the silvicultural treatments initiated by the U.S. Forest Service at the Ohio Hills site of the National Fire and Fire Surrogates (FFS) study (<http://www.fs.fed.us/ffs/>). The two study areas were located at the Zaleski State Forest (39°35′5″N; 82°37′0″W) and the Raccoon Ecological Management Area (REMA) (39°20′0″N; 82°39′0″W), both of which are in Vinton County, southeastern Ohio. The area lies within the unglaciated region of the Alleghany plateau and the forest type is classified as mixed-mesophytic by Braun (1950). Canopy tree basal area consists of approximately 80% oak at both the Zaleski and REMA sites (2000; data on file, USDA Forest Service, NE Research Station, Delaware, OH). The climate in this area is humid continental with a mean yearly temperature of 11.6 °C and mean annual rainfall of 97.84 cm. The warmest month is July with a mean temperature of 23.9 °C and the coldest is January with a mean temperature of 2.1 °C (NOAA 2006).

Sampling Design

Each of the two study sites was divided into four 20 ha treatment areas consisting of: (1) untreated control, (2) thinning only, (3) thinning followed by prescribed fire, and (4) prescribed fire only. Thinning was conducted in the winter of 2000-2001 and reduced total stand basal area by 30%-35%. Thinning treatments were applied from below, meaning that sub-dominant trees of non-oak species were preferentially removed. Prescribed burning treatments were conducted in the spring of 2001, and a second burning was performed four years later in the spring of 2005. Fires were low intensity, consuming mainly leaf litter and 1-hr woody fuels (Iverson et al. 2004). In early June of 2005, six pyramid style (Tedders and Wood 1995) insect traps were established within each treatment unit. Traps, neutral brown in color, were constructed from 6.4 mm fiberboard and were left unbaited. The traps were placed in areas containing a high number of apparently healthy oak trees, mainly black (*Quercus velutina* Lam.), white (*Q. alba* L.), and chestnut oak (*Q. prinus* L.) but often including some red oak (*Q. rubra* L.) and hickory (*Carya* spp.) species as well. Traps were checked for presence of adult weevils every 7-10 days for a period of 15 weeks beginning in June and continuing through September 2005. Captured Curculionids were identified to species level in the fall of 2005 using taxonomic keys. For *Curculio* species, we used Gibson (1969). For all other genera, we used Blatchley and Leng (1916) and Kissinger (1964). Where possible, species identified using the taxonomic keys were confirmed with verified specimens from the Ohio University entomological collection.

Statistical Analysis

Weevil data were assembled into a species by stands data matrix (26 × 8) and subjected to a non-metric multidimensional scaling analysis (NMDS) using the VEGAN package (Oksanen 2007) of R (v. 2.4.0, R-Project, <http://www.r-project.org/>). Species with only one occurrence in one stand were deleted from the matrix prior to analysis to prevent undue influence by very uncommon species.

Species diversity was assessed by a variety of measures so as to ensure comparability with other studies. We evaluated species richness (S), evenness (J), Shannon-Weiner (H′), Simpson's (D), Simpson's Inverse (1/D), and ACE estimator of S ± SE. The latter was used due to an anticipated moderate number of rare species and the desire to attempt an evaluation of sampling efficiency. All indices are described in detail in Magurran (2004). The DIVERSITY function of package VEGAN of R was used for all calculations.

Effects of stand level silvicultural treatments on weevil abundance were analyzed with a mixed model Analysis of Variance (ANOVA) using the NCSS statistical software package (Number Cruncher Statistical System 2004). All Curculionids captured over the 15-week period were combined into four treatments and two replicates (sites), where treatment (control, thin, prescribed burn, and thin + prescribed burn) was a fixed effect, and site (Zaleski, REMA) was a random block effect. *F*-tests were considered significant at a critical value of $P = 0.05$ or below.

RESULTS

Overall, we identified 833 individual Curculionid weevils belonging to 26 different species and representing nine genera from five different tribes and two subfamilies (Table 1). The Asiatic oak weevil (*Cyrtepistomus castaneus* Roelofs) was the most abundant species at both study sites, comprising 63% of the weevils caught at Zaleski and 64% at REMA. *Conotrachelus* spp. comprised a large proportion of the remainder. Many of the species (22) were very uncommon and found at either low abundance or in only a single stand. Overall, a greater number of weevils were caught at Zaleski (446) than at REMA (387).

Diversity analysis reveals that by most measures, the Zaleski site had slightly greater diversity than the REMA site, regardless of treatment (Table 2). Species richness (S) ranged from 7 to 14, with the lowest richness occurring in control stands. Stand level disturbance from the prescribed burning and thinning treatments increased diversity by almost all measures (S, H′, 1/D). The ACE estimator of species richness shows that there are 2-2.5 times more species likely to be present than we recovered in sampling. This was due to the large number of singletons that were recovered, and indicates that sampling intensity probably needed to be greater.

The NMDS ordination results suggest that there is a moderately strong effect on weevil community composition (Figure 1.). Replicate (site) stands respond in a similar

Table 1. List of species and number of individuals of Curculionid weevils captured at two study locations, the Zaleski State Forest (Z) and the Raccoon Ecological Management Area (R), in Vinton Co. southeastern Ohio, USA.

Species	Control		Thin		T & B		Burn		Totals	
	Z	R	Z	R	Z	R	Z	R	Z	R
Subfamily: Curculioninae										
Tribe: Cryptorhynchini										
Conotrachelus anaglypticus	16	4	9	7	16	9	26	4	67	24
Conotrachelus falli				1		1		1	0	3
Conotrachelus geminatus			1				1		2	0
Conotrachelus juglandis					1	1			1	1
Conotrachelus naso	1	5	6	28	6	6	5	7	18	46
Conotrachelus posticatus	21	22	4	7	1	5	13	3	39	37
Cryptorhynchus bisignatus								1	0	1
Cryptorhynchus fallax					1				1	0
Cryptorhynchus lapthi							1		1	0
Cryptorhynchus parochus				1					0	1
Micromastus spp.	3				1				4	0
Tribe: Curculionini										
Curculio caryae				1			1		1	1
Curculio confusor								1	0	1
*Curculio humeralis**		1	1			3			1	4
Curculio iowensis		1	1	2			2	1	3	4
Curculio neocorilus							1		1	0
Curculio pardalis	1		2		4	4	2	3	9	7
Curculio sulcatulus			1						1	0
*Curculio timidis**					1	3		1	1	4
Curculio spp.	2			1		1			2	2
Tribe: Otidocephalini										
Otidocephalus chevrolatii	1								1	0
Otidocephalus spp.	1		1		3		2		7	0
Tribe: Prionomerini										
Piazorhinus scutellaris		1							0	1
Tribe: Zygopini										
Eulechriops minutus	1								1	0
Psomus spp.			1	1				1	1	2
Subfamily: Entiminae										
Cyrtepistomus castaneus	56	61	45	42	112	49	71	96	284	248
Totals	103	95	72	91	146	82	125	119	446	387

*Indicates species not previously recorded in this area.

Table 2. Species diversity assessment of weevil community summarizing species richness (S), evenness (J), Shannon-Weiner (H'), Simpson's (D), Simpson's Inverse (1/D), and Abundance Based Coverage Estimator (ACE) of S ± SE. Details of all measures can be found in Magurran (2004). Treatments: Control (C), Burn (B), Thin (T), Thin+Burn (TB). Sites: Z = Zaleski State Forest, R = Raccoon Environmental Management Area.

	C		T		B		TB	
Measure	Z	R	Z	R	Z	R	Z	R
S	9	7	13	11	14	11	11	12
J	0.72	0.63	0.84	0.66	0.71	0.88	0.79	0.91
H'	1.59	1.22	2.15	1.58	1.88	2.10	1.91	2.25
D	0.74	0.57	0.84	0.67	0.75	0.84	0.79	0.87
1/D	3.85	2.32	6.16	3.02	4.01	6.40	4.97	8.00
ACE S	18.67	14.16	37.55	23.34	20.48	23.99	18.58	14.96
ACE SE	2.55	1.64	3.56	2.46	2.44	2.63	2.43	1.59

fashion in ordination space, suggesting that treatment effects are relevant to community composition. In fact, stand level treatment appears to be associated with an increasing abundance of certain rare *Curculio* and *Conotrachelus* species.

Overall, there was no significant effect of the silvicultural treatments on total number of weevils (F = 1.04, df = 3, P = 0.4886) found in a stand. This finding rejects our hypothesis that prescribed fire in the spring would reduce abundance. Of the nine genera indentified in this study, two – *Conotrachelus* and *Curculio* – are considered to be major predators of oak acorns. Both genera were found in all treatment plots at both study sites, and statistically the two locations were similar in their numbers, though *Conotrachelus* was more abundant than *Curculio* (Figure 2). There was no effect of silvicultural treatments on occurrence of either genus (F = 0.06, df = 3, P = 0.9767). Likewise, we observed no significant treatment × genus interaction, indicating that both genera were similarly unaffected (F = 0.41, df = 3, P = 0.7557).

DISCUSSION

Controlling seed-destroying insect populations by implementing stand-level treatments would benefit land managers attempting to promote oak regeneration. However, the prescribed burning and mechanical thinning treatments employed in our study demonstrated no significant effects on overall weevil abundance at either of the two study sites. The treatments did, however, produce a systematic measurable effect on weevil community composition. These results are similar to those of Moretti et al. (2004) who found that single and repeated fires had no significant effect on the number of Curculionids in temperate, deciduous forests of the Southern Alps, though species richness was shown to decline. Likewise, Bellocq et al. (2005) found no effect of shelterwood thinning on acorn predation by insects in central Ontario, Canada. The prescribed fire treatments used in our study were conducted in the spring, presumably during the time when weevils would be emerging from the soil. It is possible that a prescribed burn conducted early in the fall, during the period of acorn drop, may be more effective in reducing weevil occurrence by destroying larvae residing within the acorns.

Cyrtepistomus castaneus, the non-native Asiatic oak weevil, was the most abundant weevil encountered in our study. This species was introduced to North America from Japan and first detected in New Jersey in 1933. Ferguson et al. (1991) found black, white, and red oak, along with sugar maple (*Acer saccharum* Marsh.), to be the preferred host trees of this species; and additional studies by Frederick and Gering (2006) substantiate this claim. *Cyrtepistomus castaneus* weevil larvae have been reported to impact oak seedling growth by feeding on the fine roots and leaves (Sander 1990).

Species in the genus *Curculio* are regarded as primary seed infesting weevils of oaks as well as other nut tree species, since they do not require previous insect or other damage to a seed for oviposition. *Curculio* weevils are host specific, and of the more than nine species captured in our study, at least five are known to feed on oaks common to the central hardwood forest. Two of the species found in our study were not previously reported in this region. Gibson (1969) lists the northern distribution of *Curculio humeralis* as the northern Tennessee and North Carolina area, though the host tree range extends into Ohio. Our study documents the presence of this species in this region. A second species, *Curculio timidis*, is listed by Gibson (1969) as occurring only in the southwestern states, particularly New Mexico, Arizona, and Texas. This species breeds in oaks, though no information is given as to particular host species. It is possible that this species was recently introduced into the area or was previously here but remained undocumented. Furthermore, due to a lack of voucher specimens for comparison, we cannot rule out the possibility of a misidentification.

Conotrachelus weevils are also a major contributor to the destruction of acorn crops, though most species may be restricted to previously infested or damaged acorns

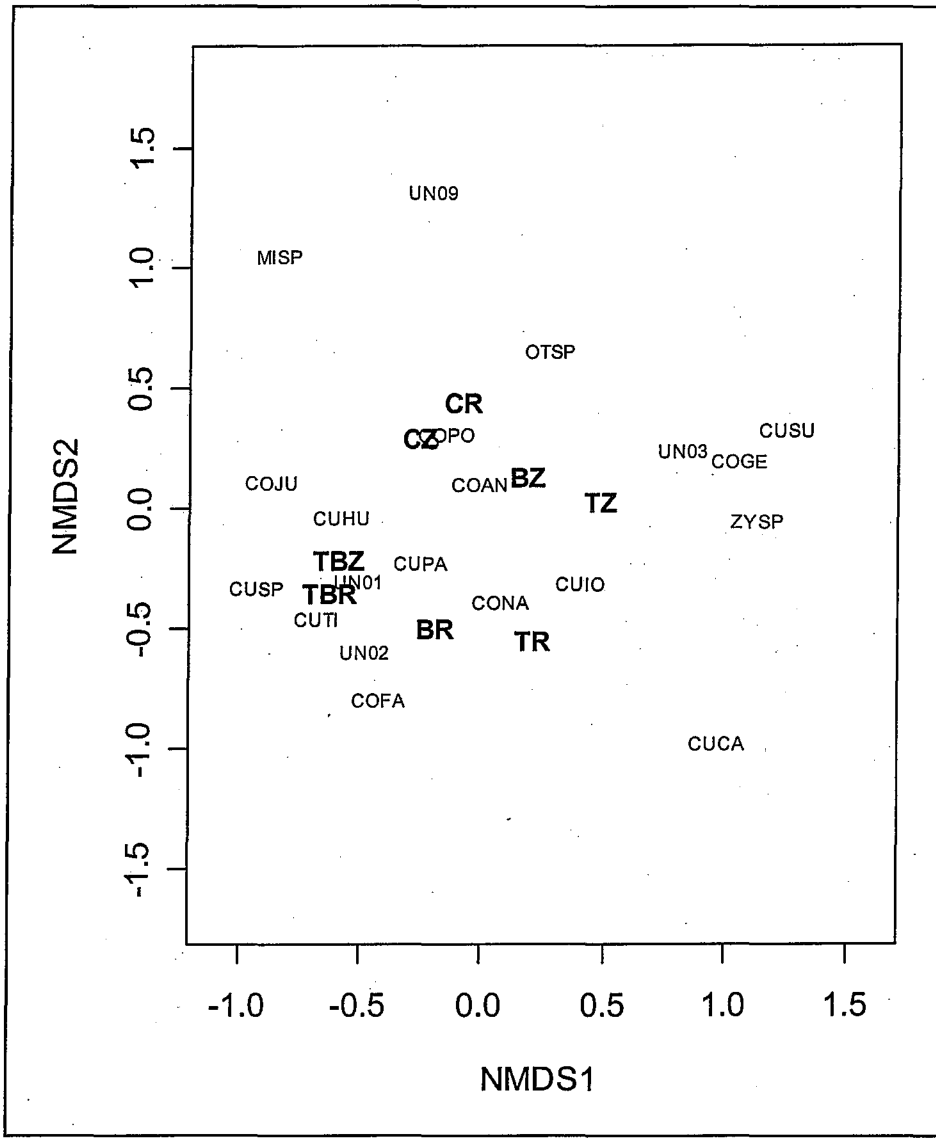

Figure 1. Non-metric multidimensional scaling (NMDS) ordination depicting species and stands. Stand acronyms (bold-face font) correspond to site (Z = Zaleski State Forest, R = Racoon Ecological Management Area; B = burn, T = thin, TB = thin+burn, C = control) and species acronyms (non-bold-face font) correspond to the first two letters of the genus and first two letters of the specific epithet (see Table 1 for complete binomials).

(Gibson 1964; Beers et al. 2003). The most abundant species, *C. naso*, is known to oviposit in acorns, particularly those of the white oak subgroup (*Leucobalanus*), in addition to *Crataegus* and *Malus* species. Larvae of the genus *Cryptorhynchus* are bark borers and adults are generally found on the bark and dead twigs of oaks, hickory, birch (*Betula* spp. L.), and others. Weevils in the genus *Otidocephalus* primarily breed in galls found on oaks and other tree species. *Piazorhinus scutellaris* is found on oaks where it is thought to mine the leaves. *Eulechriops minutus, Piazorhinus scutellaris,* and *Psomus* spp. are known to occur on oak as well as hickory and ash; however, it is not clear whether or not they breed within the seeds of any of these species (Blatchley and Leng 1916).

While the purpose of this study was not to provide a comprehensive list of all Curculionids in the region, it does give us a glimpse into the major species inhabiting oak forests and how their populations are structured and influenced by forest management activities. Species richness indicators suggest that considerably more sampling needs to be conducted to better clarify community composition. The apparent ineffectiveness of silvicultural treatments, particularly prescribed burning in the spring, in reducing seed weevil occurrence is an important preliminary finding. Additional research should examine the effect of fall burns on weevil abundance and the relationship of burn time to mast cycles. The effect of burning on rare species requires additional consideration.

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Jeffrey Lombardo was a graduate student in the Department of Environmental and Plant Biology at Ohio University. He completed this work as part of his M.S. thesis research examining the effects of fire and thinning on oak seed production and predation.

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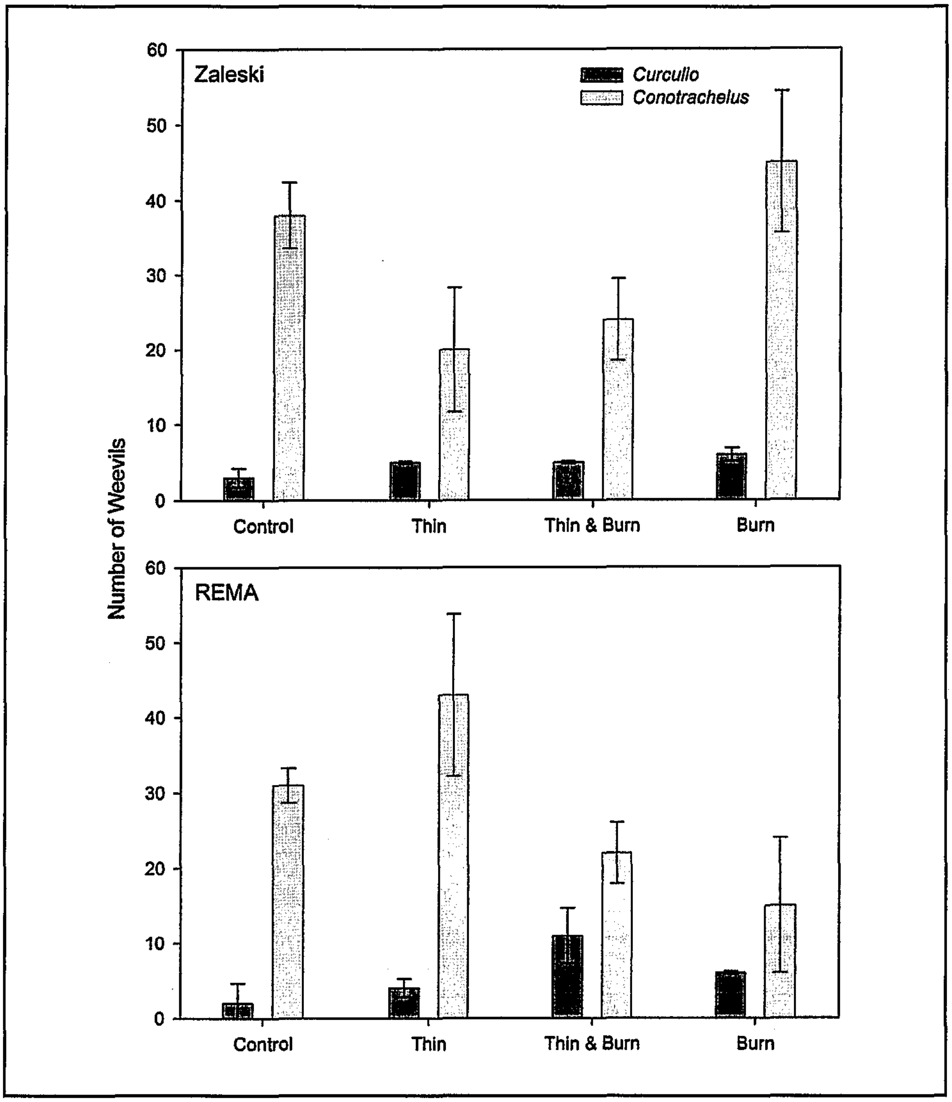

Figure 2. Mean (± SD) number of weevils in the genus *Curculio* and *Conotrachelus* captured in each of the four silvicultural treatments at the Zaleski and REMA experimental forests in southeastern Ohio.

LITERATURE CITED

Albrecht, M.A., and B.C. McCarthy. 2006. Effects of prescribed fire and thinning on tree recruitment patterns in central hardwood forests. Forest Ecology and Management 226:88-103.

Anderson, D.C., and M.L. Folk. 1993. *Blarina brevicauda* and *Peromyscus leucopus* reduce overwinter survivorship of acorn weevils in an Indiana hardwood forest. Journal of Mammalogy 74:656-664.

Beers, E.H., M.W. Klaus, A. Gebhard, S. Cockfield, R. Zack, and C.W. O'Brien. 2003. Weevils attacking fruit trees in Washington. Pp. 1-35 *in* Proceedings of the 77th Annual Western Orchard Pest and Disease Management Conference, 2003, Jan 15-17, Washington State University, Pullman.

Bellocq, M. I., C. Jones, D.C. Dey, and J.J. Turgeon. 2005. Does the shelterwood method to regenerate oak forests affect acorn production and predation? Forest Ecology and Management 205:311-323.

Blatchley, W.S., and C.W. Leng. 1916. Rhynchophora or Weevils of Northeastern America. The Nature Publishing Co., Indianapolis, Ind.

Braun, E.L. 1950. Deciduous Forests of Eastern North America. McGraw-Hill, New York.

Brose, P.H., D.H. Van Lear, and R. Cooper. 1999. Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites. Forest Ecology and Management 113:125-141.

Christisen, D.M. 1955. Yield of seed by oaks in the Missouri Ozarks. Journal of Forestry 53:439-441.

Evans, R. 1959. Notes on the biology of the Asiatic oak weevil in Maryland. Journal of Economic Entomology 52:177.

Ferguson, C.S., M.J. Linit, and G. Krause. 1991. Host-plant preference of the Asiatic oak weevil (Coleoptera, Curculionidae). Environmental Entomology 20:1427-1432.

Franklin, S.B., P.A. Robertson, and J.S. Fralish. 2003. Prescribed burning effects on upland *Quercus* forest structure and function. Forest Ecology and Management 184:315-335.

Frederick, K.H., and J.C. Gering. 2006. A field study of host tree associations of an exotic species, the Asiatic oak weevil [*Cyrtepistomus castaneus* (Roelofs 1873), Coleoptera: Curculionidae]. American Midland Naturalist 155:11-18.

Gibson, L.P. 1964. Biology and life history of acorn-infesting weevils of the genus Conotrachelus (Coleoptera: Curculionidae). Annals of the Entomological Society of America 57:521-526.

Gibson, L.P. 1969. Monograph of the genus *Curculio* in the new world (Coleoptera Curculionidae): Part I. Miscellaneous Publication, Entomological Society of America 6:241-285.

Gibson, L.P. 1972. Insects that damage white oak acorns. Research Paper NE-220, U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, Pa.

Gibson, L.P. 1982. Insects that damage red oak acorns. Research Paper NE-492, U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, Pa.

Hutchinson, T.F., E.K. Sutherland, and D.A. Yaussy. 2005. Effects of repeated prescribed fires on the structure, composition, and regeneration of mixed-oak forests in Ohio. Forest Ecology and Management 218:210-228.

Iverson, L.R., D.A. Yaussy, J. Rebbeck, T.D. Hutchinson, R.P. Long, and A. Prasad. 2004. A comparison of thermocouples and temperature paints to monitor spatial and temporal characteristics of landscape-scale prescribed fires. International Journal of Wildland Fire 13:1-12.

Kissinger, D.G. 1964. Curculionidae of America North of Mexico: a Key to the Genera. Taxonomic Publications, South Lancaster, Mass.

Magurran, A.E. 2004. Measuring Biological Diversity. Blackwell, Malden, Mass.

Miller, D.R., and S.E. Schlarbaum. 2005. Acorn fall and weeviling in a northern red oak seedling orchard. Journal of Entomological Science 40:31-38.

Moretti, M.M., K. Orbist, and P. Duelli. 2004.

Arthropod biodiversity after forest fires: winners and losers in the winter fire regime of the southern Alps. Ecography 27:173-186.

[NOAA] National Oceanographic and Atmospheric Administration. 2006. National Climactic Data Center. Available online <http://cdo.ncdc.noaa.gov>.

Number Cruncher Statistical Software. 2004. NCSS Software version 2004. Number Cruncher Statistical Software, Kaysville, Utah.

Oksanen, J. 2007. Multivariate analysis of ecological communities in R: vegan tutorial. The R-Project for Statistical Computing. Available online <http://www.r-project.org/>.

Riccardi, C.L., B.C. McCarthy, and R.P. Long. 2004. Oak seed production, weevil (Coleoptera: Curculionidae) populations, and predation rates in mixed-oak forests of south east Ohio. Pp. 10-21 *in* D.L. Yaussy, D.M. Hix, R.P. Long, and C.P. Goebel, eds., Proceedings of the 14th Central Hardwood Forest Conference, U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, Pa.

Sander, I.L. 1990. Northern red oak. Pp. 727-733 *in* R.M. Burns and B.H. Honkala, eds., Silvics of North America, vol. 2., Hardwoods. Agriculture Handbook 654, U.S. Department of Agriculture, Forest Service, Washington, D.C.

Semel, B., and D.C. Andersen. 1988. Vulnerability of acorn weevils (Coleoptera: Curculionidae) and attractiveness of weevils and infested *Quercus alba* acorns to *Peromyscus leucopus* and *Blarina brevicauda*. American Midland Naturalist 119:385-393.

Tedders, W. L., and B.W. Wood. 1995. Pyramidal traps for monitoring the presence of pecan weevils (Coleoptera: Curculionidae). Journal of Entomological Science 30:534-544.