SHORT-TERM EFFECTS OF SPRINGTIME PRESCRIBED FIRES ON ADULT POPULATIONS OF SOIL-EMERGING WEEVILS IN CENTRAL APPALACHIAN HARDWOOD STANDS

David P. McCann, David W. McGill, Thomas M. Schuler, and W. Mark Ford[1]

Abstract—Numerous biotic and abiotic factors interact to affect oak regeneration in the central Appalachians. Fire, white-tailed deer, rodents, other vertebrate seed predators, invasive plants, insects, fungi, climate, and tree physiology contribute singularly or additively to oak regeneration problems. Moreover, fire suppression has significantly enhanced the deleterious impacts of several of these biotic influences. The relationship between fire and acorn weevils is unknown, but acorn weevils are significant contributors to regeneration problems in some oak stands and may be vulnerable to fire at certain life stages. As part of a broader investigation of fire use as a silvicultural tool, we examined prescribed fire impacts on acorn weevils (genera: *Curculio* and *Conotrachelus*) that inhibit oak (*Quercus* spp.) regeneration by larval consumption of embryonic or newly dropped acorns. We prescribe burned two stands on the Fernow Experimental Forest in north-central West Virginia: One was burned April, 2002, and the other April, 2003. We placed soil emergence traps under oak and other tree species on five plots within each burn treatment and four adjacent unburned plots. Arthropod samples were collected April to October in 2003 and 2004. We collected 233 weevils representing 11 species from 9 genera. *Curculio* and *Cyrtepistomus* species predominated; *Conotrachelus* species were notable. Our preliminary data indicates that acorn weevil emergence may not be reduced following a single spring fire. Herein, we describe the pattern and intensity of acorn weevil emergence during the first 2 years of our study.

INTRODUCTION

Successful oak regeneration in the central Appalachians is currently hindered by many biotic and abiotic factors such as an absence of fire, white-tailed deer herbivory, seed predation by rodents and other vertebrates, insects, invasive plants, fungi, climate, and tree physiology. These factors probably work in both additively and synergistically, presenting managers with almost insurmountable challenges. Historical evidence suggests lack of fire is an important factor accelerating the shift from oak-dominated stands to those dominated by shade-tolerant species such as red maple, *Acer rubrum* L., and sugar maple, *A. saccharum* Marsh. (Gribko and others 2002, Oak 1998). It has been hypothesized that fire suppression has allowed acorn weevils and other insects to become a greater impediment to oak establishment and regeneration than would have occurred otherwise (Gribko and others 2002, Oak 1998, Riccardi and others 2004).

Within the central Appalachian landscape, Native Americans and European settlers routinely used fire to clear land, flush game, and increase soft fruit and forage production (Van Lear and Harlow 2002). These anthropogenic efforts aided oak establishment and maintenance, particularly in forest systems where shade-tolerant mesic species would otherwise predominate. Local and regional extirpation of white-tailed deer, black bear, and wild turkey might have somewhat ameliorated the impacts of the early fire suppression era (circa 1920). However, several decades of restocking, conservation, and hunting regulation has led to tremendous population increases of game animals—particularly deer—that impact oak through seed consumption and plant herbivory (Horsley and others 2003).

Red oaks (*Erythrobalanus*) and white oaks (*Leucobalanus*) are temporally distinct in germination. Red oaks drop acorns in early fall and need a period of dormancy interrupted by 4 to 6 weeks of cool, moist conditions to germinate, whereas white oaks drop and germinate in the same fall season (Gribko and others 2002, Olson and Boyce 1971). Accordingly, white oaks germinate during peak litter depths, whereas red oaks germinate more often on bare soils (Gribko and others 2002). Furthermore, acorns from red oaks have significantly higher tannin concentrations than white oak acorns and in some cases have been reported to have less weevil predation (Brezner 1960, Weckerly and others 1989).

Once germinated, seedling growth is dictated by several factors. Stored food reserves in the form of endosperm and cotyledon health are crucial determinates of seedling survival (Gribko and others 2002, Oliver and Chapin 1984), but sufficient soil moisture also is necessary for root development. Light becomes limiting once the carbohydrate reserves in the cotyledons, which remain below ground, are consumed (Kramer and Kozlowski 1979). Ultimately, long-term seedling success depends on competition for growing space. Seedlings must outcompete herb and shrub layers to become advance regeneration.

Insects and vertebrates inhibit acorn production and oak regeneration at all levels, from flower development through sapling survival. Vertebrates prey on acorns in the tree and on the ground (Brooks 1910, Marquis and others 1976); treehoppers (Family: Membracidae) retard flower development (Beck 1993, Gribko and others 2002); and a litany of primary and secondary insects injure acorns and shoots at all stages of development.

Deer and rodents are among the primary vertebrate acorn predators, although their impact is hard to evaluate because

[1] Graduate Research Assistant and Extension Specialist, respectively, West Virginia University, Division of Forestry, Percival Hall, Morgantown WV 26506; and Research Forester and Research Wildlife Biologist, respectively, USDA Forest Service, Northeastern Research Station, Parsons, WV 26287.

Citation for proceedings: Connor, Kristina F., ed. 2006. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640 p.

they often remove or completely consume acorns. Gray and fox squirrels and eastern chipmunks cache acorns whole or consume enough endosperm to prevent germination and radicle growth, particularly in the presence of secondary organisms such as fungi, bacteria, and insects (Edwards and others 2003, Galford and others 1988, Gribko and others 2002, Marquis and others 1976, Steiner 1995, Tryon and Carvell 1962). Any estimates of vertebrate predation will necessarily be underestimations because of missing acorns that cannot be counted.

Numerous acorn-damaging insects from various families are primary predators; they penetrate sound, undamaged acorns (Galford and others 1988, Gibson 1971, Gibson 1972, Gribko and others 2002, Murtfeldt 1894, Steiner 1995). Secondary insects and other pests only enter acorns through damage incurred physically or from primary predators feeding on acorns and developing seedlings (Galford and others 1991, Galford and others 1988, Gibson 1972, Gibson 1982, Murtfeldt 1894, Oak 1992, Winston 1956).

The most significant primary insect predators are the acorn weevils of the genus *Curculio* (Coleoptera); the filbertworm (*Mellissopus latiferreanus* Wals.: Lepidoptera) and Cynipid wasps (*Callirhytis* spp.: Hymenoptera) are also notable, but their damage is insignificant relative to *Curculio* spp. (Galford and others 1991, Gibson 1971, Gibson 1972, Gibson 1982, Gribko and others 2002, Murtfeldt 1894, Oak 1992, Oliver and Chapin 1984, Olson and Boyce 1971, Steiner 1995, Tryon and Carvell 1962, Winston 1956). The most prominent secondary insect predators are weevils of the genus *Conotrachelus* (Coleoptera)—a seedling weevil, *Barypeithes pellucidus* Boh. (Coleoptera), the acorn moth (*Valentinia glandullela* Ril.: Lepidoptera), and a nitidulid beetle, *Stelidota octomaculata* Say (Coleoptera) (Galford and others 1991, Galford and others 1988, Gibson 1964, Gribko and others 2002, Murtfeldt 1894, Oak 1992). Other scavenging insects from the order Diptera are commonly found in damaged acorns; they often are attracted by secondary fungal organisms (Winston 1956).

Adult *Curculios* emerge from the soil from spring to fall following pupation; they then oviposit eggs in acorns on the tree or ground where larvae feed on endosperm or embryo tissue before exiting to overwinter in the soil for 1 to several years prior to pupation during the growing season (Brooks 1910, Gibson 1971, Gibson 1972). *Conotrachelus* spp. adults also emerge from the soil from spring to fall, but they only oviposit in previously-damaged acorns or in the oviposition holes of *Curculios* (Brooks 1910, Gibson 1964). *Conotrachelus* larvae feed on acorn contents, exit in the fall, and pupate before overwintering in leaf litter (Brooks 1910, Gibson 1964); *Conotrachelus posticatus* Boh. may spend its first winter as a larva, pupate the following spring, and overwinter as an adult during its second winter (Brezner 1960, Brooks 1910, Gibson 1964).

Cyrtepistomus castanea Roel. and *Barypeithes pellucidus* typically do not enter acorns but feed on leaves, shoots, roots, and, more significantly, radicles of oak seedlings (Evans 1959, Ferguson and others 1991, Ferguson and others 1992, Galford 1986, Galford 1987, Triplehorn 1955). Secondary insects other than weevils also will feed on embryos, endosperm, and radicles (Galford and others 1988, Gribko and others 2002, Murtfeldt 1894). Insect infestation is not always an absolute mortality agent if cotyledons and endosperm are still somewhat intact. However, if the radicle is damaged, then acorn germination is unlikely. Furthermore, if reserves for seedling survival are diminished enough to affect seedling health, survival rates of seedlings are lowered.

Damaged portions of the acorn crop vary but generally indicate significant insect activity. Gibson (1972, 1982) reported 100 percent insect damage in stands of white oak and up to 96 percent in red oak stands. Tryon and Carvell (1962) noted approximately 30 percent damage from all insects. *Curculio* spp. can be responsible for nearly all of insect damage to acorns (Gibson 1971, Riccardi and others 2004). *Conotrachelus* spp. can infest up to 38 percent of sampled acorns (Gibson 1964, 1972) or as few as 2.8 percent (Gibson 1971).

Our knowledge on the limiting factors and controls on weevil infestations in oaks is lacking, especially about fire-weevil interactions and ecology. By sampling acorns and adult emergence, Riccardi and others (2004) found spring prescribed fires in Ohio resulted in improved acorn crops and lower weevil predation rates in the second season after burning. However, there were insignificant differences in weevil emergence among thinning and burn treatments. Wright (1987) found spring fires reduced populations of *Conotrachelus* weevils in Ohio. In Washington, growing season fires have been shown to impact ground-dwelling arthropod numbers (Rickard 1970) and in Minnesota, Wisconsin, and Michigan, spring and fall fires significantly reduced red pine cone beetle, *Conophthorus resinosae* Hopkins (Miller 1978).

Fire was an historical component in the central Appalachians and might have had a role in controlling weevil populations when it occurred at opportune times during weevil life cycles. Therefore, the objective of our study was to evaluate the impacts of spring prescribed fire on soil-emerging adult populations of weevils known to prey on acorns and oak seedlings in the central Appalachians.

SITES

Our study sites were located on the Fernow Experimental Forest (39.03° N, 79.67° W) in north-central West Virginia. The Fernow is a 1,900-ha Experimental Forest within the Monongahela National Forest administered by the Northeastern Research Station, U.S. Forest Service. The ecological land type of the Fernow is referred to as within the Allegheny Mountains of the Central Appalachian Broadleaf Forest as designated by McNab and Avers (1994). The draft landtype association is the Allegheny Front Sideslopes (DeMeo and others 1995) and is representative of over 40,000 ha on the Monongahela National Forest alone. The vegetation of the Fernow ranges from mixed mesophytic to northern hardwoods depending on elevation, aspect, and site quality.

Spring burning occured in the Stonelick and Sugarcamp Run drainages and included both a flat ridgetop (47 acres; 2,400 to 2,600 feet asl) and a lower slope (30 acres; 2,000 to 2,200 feet asl) site. The lower site had a western aspect, and both the upper and lower sites have inclusions of cove-like conditions. Study site soils were characterized by a Calvin series that were well-drained and strongly acid, moderately deep, and moderately permeable. Overall, the site index was approximately 70 for northern red oak (*Quercus rubra* L.). Overstory species in the study area include northern red oak, chestnut oak (*Q. prinus* L.), and white oak (*Q. alba* L.) in descending order of dominance as measured by basal area. Other overstory species include red maple, sugar maple, yellow-poplar (*Liriodendron tulipifera* L.), and sweet birch (*Betula lenta* L.).

METHODS

A total of 24 experimental plots were established (12 on each site, 2 of which were controls receiving no treatments) on which the effects of shelterwood harvests and accompanying fires will be evaluated. Prescribed fire was applied to the lower site in April, 2002, and the upper site in April, 2003 (excluding control plots on both sites). Shelterwood regeneration cuts have not yet been completed.

We sampled emerging adult weevils using 1 m^2 soil emergence traps placed under oak and non-oak species on 5 plots of both the upper and lower sites and the 4 control plots. In all, 60 traps were used in burned plots, 15 traps under oaks and 15 under non-oaks on each site. Additionally, 31 traps were used on control plots, 15 under oaks and 16 under non-oaks.

We collected samples from March through October in 2003 and 2004; contents were placed in plastic bags and kept frozen until examined for weevils. We examined contents ocularly and with a stereoscope to determine the number and genus of emerging weevils. Weevils trapped in 2003 were pinned by staff from the West Virginia University Entomology Department and sent to R.S. Anderson in Canada for species identification. This collection served as the source for identification of future-trapped weevils to genus.

RESULTS AND DISCUSSION

Species and Relative Frequency

Overall, we collected 233 weevils, 53 in 2003 and 180 in 2004, representing 11 species from 9 genera (table 1). Most genera occurred in negligible numbers. Three species/genera

Table 1—Species and abundance of trapped adult weevils in the central Appalachians in West Virginia in 2003 and 2004

Species	2003	2004	Total
Cyrtepistomus castanea Roel.	14	121	135
Curculio pardalis Chitt.	11	56	67
Conotrachelus posticatus Boh.	11	1	12
Contrachelus naso Lec.	1	0	1
Conotrachelus anaglypticus Say	2	0	2
Acalles carinatus Lec.	7	1	8
Eubulus bisignatus Say	2	0	2
Ithycerus noveboracense Forster	2	1	3
Epacalles inflatus Blat.	1	0	1
Cophes fallax Lec.	1	0	1
Lepidophorus setiger Ham.	1	0	1
Totals	53	180	233

dominated collections: *Curculio pardalis* Chitt. was the most commonly collected nut weevil; *Conotrachelus* spp. occurred less frequently; *Cyrtepistomus castanea*, an exotic root/seedling weevil, accounted for the majority of collections (fig. 1). As noted above, *Curculio* spp. have been observed to be responsible for the majority of acorn infestations, and *Conotrachelus* spp. significantly added to infestations or may be primarily responsible at times. While the genera *Curculio* and *Conotrachelus* were the main subjects of this study, the predominance of *Cyrtepistomus castanea* is clear (table 1; figs. 1, 2, and 3), and the species must be considered when evaluating detriments to oak regeneration. Trap locations under oak versus non-oak species did not have any influence on our results.

Cyrtepistomus castanea, the Asiatic oak weevil, is a univoltine, broad-snouted weevil that as an adult feeds on leaves

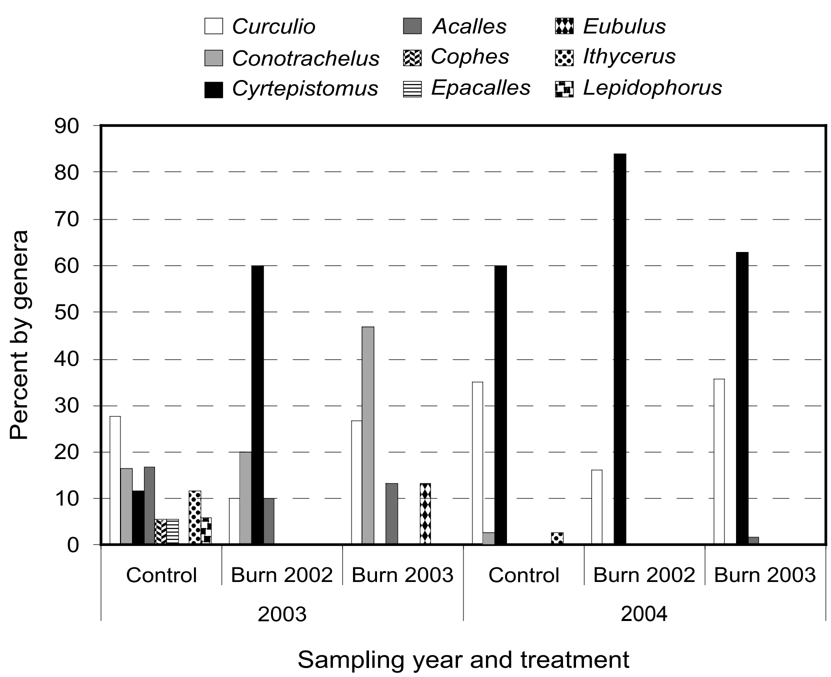

Figure 1—Proportion of weevils by genera, treatment, and sampling year.

(of seedlings most importantly) and emerging radicles. Larvae reside and overwinter in soil, feeding on roots. Pupation occurs in the summer shortly before adult emergence in the summer and fall (Evans 1959, Ferguson and others 1991, Ferguson and others 1992, Triplehorn 1955). The Asiatic oak weevil uses almost any oak species as food. The habits of this weevil and its abundance in the sampled area also indicate its potential importance as a factor affecting oak regeneration in the central Appalachians.

Emergence and Population Sizes

Emergence patterns of the three dominant genera of this study confirm findings of previous studies: *Curculio* and *Conotrachelus* adults emerge predominantly from April to July, and *Cyrtepistomus castanea* adults emerge from July to October (fig. 2). Data from our study also suggest population sizes vary substantially from year to year (figs. 2 and 3). Population sizes, as estimated from emergence, also vary from control to burn plots (fig. 3).

In 2003, more *Curculio* weevils emerged in control plots than in plots burned that year or in the previous year (2002). *Conotrachelus* weevil emergence increased in both the same year and 1-year-old burn plots, and *Cyrtepistomus castanea* emergence increased in the same year, even more so in 1-year-old burn plots relative to control plots (fig. 3). In 2004, *Curculio* weevil emergence increased in all three treatment areas (control, burn 2002, burn 2003), suggesting a secondary environmental signal, but the fewest *Curculios* appeared in the treatment area burned in 2002 (fig. 3). It may be noteworthy that this area burned more completely and with higher average temperatures than the other burn area (Schuler

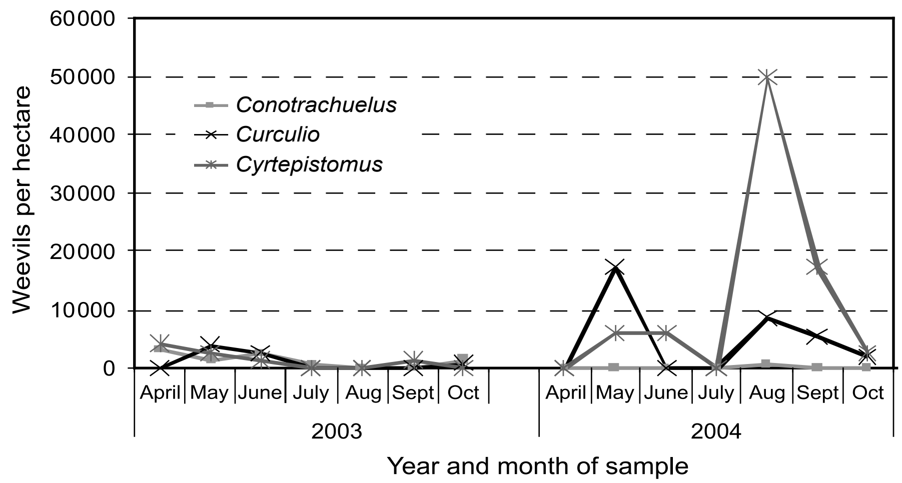

Figure 2—Emergence patterns of adult weevils of the three prominent genera collected in the central Appalachians in 2003 and 2004.

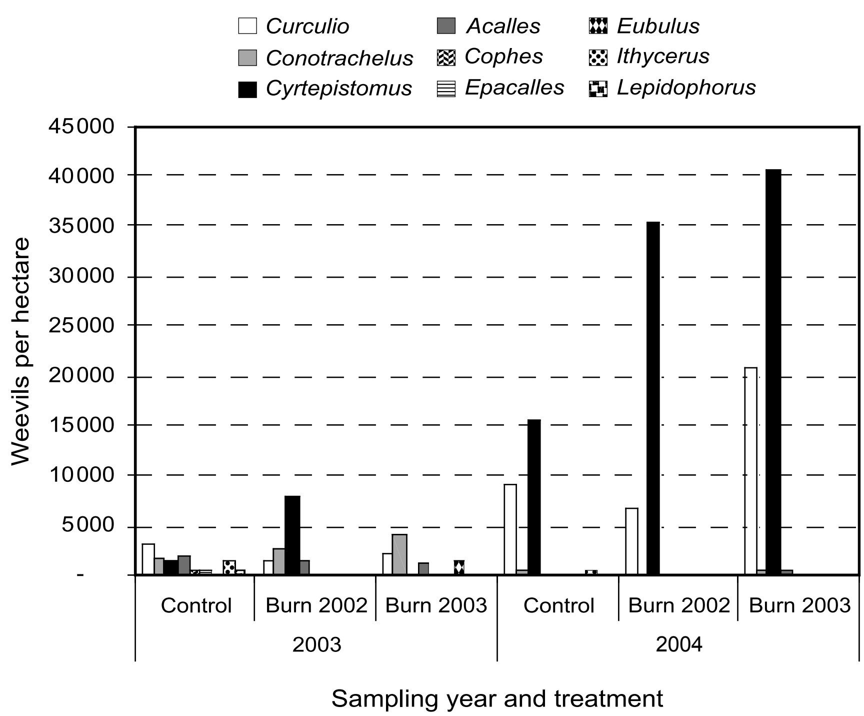

Figure 3—Number of weevils per hectare by species, treatment, and sampling year.

unpublished data). *Cyrtepistomus castanea* was the most abundant weevil in all three areas in 2004; fire either had no effect or possibly favored this species.

Overall, our results suggest spring burns do not directly reduce emerging populations of adult acorn and seedling weevils in the short term. Conversely, burning may somehow stimulate larger-than-normal emergence populations. In most comparisons, emergence on burned plots exceeded that on control plots in terms of absolute numbers and per unit area (figs. 1 and 3).

Wright (1987) obtained similar results from collections of *Conotrachelus* weevils in pitfall traps over 2 years of sampling following a spring fire. However, the use of pitfall traps could have skewed data by gathering weevils in an area greater than their emergence zone. Wright (1987) concluded that *Conotrachelus* weevil emergence was consistently reduced by spring fires when sampling from litter rather than with pitfall traps. Conversely, Riccardi and others (2004) found no difference in adult weevil emergence following fire in Ohio.

Future studies should perhaps utilize fall fires that might effectively impact insects in forest litter (Miller 1978, Wright 1987) or target late-emerging adults (fig. 2), any resident adults in litter, larvae recently emerging from acorns that have not yet burrowed into the soil, or larvae still in acorns that have dropped to the ground. *Cyrtepistomus castanea* populations in particular could be controlled more effectively with fall fires when late-season, active adults are present and larvae are preparing to overwinter. Repeated fires have not yet been assessed but may also contribute to significantly different weevil population dynamics, more so than a single prescribed fire.

Although our study suggests emerging weevil populations might be enhanced by spring fire, the increase in emergence in the short term may retard emergence in subsequent years. In figure 3, *Curculio* weevil emergence 2 years following burning is reduced on burned plots; similarly, Riccardi and others (2004) found acorn infestations 2 years after spring burns were reduced.

One of the strategies insects employ for species survival that could possibly account for variable populations from year to year (figs. 2 and 3) is diapause: Some larvae may overwinter 2 or more years, supplementing future populations. These larvae may in some cases develop more slowly and need more time to mature to where they can be significant contributors to reproduction.

If fire stimulates the emergence of weevils that would have emerged later or are not fully developed for reproduction, subsequent weevil populations might exhibit less overall fitness and survival, which could reduce numbers over the long term. To evaluate these possibilities, continuous sampling over several years to identify the long-term effects of prescribed fires (spring or fall) on weevil populations will be necessary. In addition to sampling emerging populations, acorn infestation and reproductive fitness (as determined by adult dissections) should be measured and correlated with emerging populations from previous years to investigate the long-term effects of fire on weevil populations.

Our study continues, and in the spring of 2005 all of the previously burned areas were successfully burned again. Through continued monitoring and periodic prescribed fires, we hope to gain a better understanding of how fire may have changed acorn weevil populations in the past, and whether fire has any management potential for controlling problematic weevil populations in the present.

ACKNOWLEDGMENTS

We acknowledge L. Gribko for her pioneering role early in this project; gratefully thank R.S. Anderson for weevil species identification; express gratitude to L. Butler, J. Strazanac, and the rest of West Virginia University Entomology Department for their services; and salute R. Hovatter and R. Rosier of the Northeastern Research Station for weekly insect collections and overall trap maintenance. Partial funding for this project was obtained through the USDA Forest Service, Northeastern Research Station and the West Virginia University Division of Forestry.

LITERATURE CITED

Beck, D.E. 1993. Acorns and oak regeneration. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: serious problems, practical recommendations. Symposium proceedings. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 96-104.

Brezner, J. 1960. Biology, ecology, and taxonomy of insects infesting acorns. Research Bulletin 726. Columbia, MO: Missouri Agricultural Experiment Station. 40 p.

Brooks, F.E. 1910. Snout beetles that injure nuts. Bulletin 128. Morgantown, WV: West Virginia Agricultural Experiment Station: 148-185.

DeMeo, T.; Tracy, L.; Wright, L. 1995. Landtype associations of the Monongahela National Forest. 1:250,000; UTM map projection. Elkins, WV: U.S. Department of Agriculture, Forest Service, Monongahela National Forest.

Edwards, J.W.; Ford, W.M.; Guynn, D.C. 2003. Fox and gray squirrels. In:. Feldhammer, G.A.; Thompson, B.C.; Chapman, J.A., eds. Wild mammals of North America, second edition. Baltimore, MD: John Hopkins University Press: 248-267.

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

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

Ferguson, C.S.; Linit, M.J.; Krause, G. 1992. Dispersion and density of Asiatic oak weevil (Coleoptera: Curculionidae) relative to oak density. Environmental Entomology. 21: 247-252.

Galford, J.R. 1986. The weevil *Barypeithes pellucidus* (Coleoptera: Curculionidae) feeds on northern red oak, *Quercus rubra*, seedlings. Entomological News. 97(3): 113-114.

Galford, J.R. 1987. Feeding habits of the weevil *Barypeithes pellucidus* (Coleoptera: Curculionidae). Entomological News. 98(4): 163-164.

Galford, J.R.; Auchmoody, L.R.; Smith, H.C.; Walters, R.S. 1991. Insects affecting establishment of northern red oak seedlings in central Pennsylvania. In: McCormick, L.H.; Gottschalk, K.W., eds. Proceedings of the eighth central hardwood forest conference. Gen. Tech. Rep. NE-148. Parsons, WV: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 271-280.

Galford, J.R.; Peacock, J.W.; Wright, S.L. 1988. Insects and other pests affecting oak regeneration. In: Smith, H.C.; Perkey, A.W.; Kidd, W.E., eds. Proceedings: guidelines for regenerating Appalachian hardwood stands. Publication 88-03. Bethesda, MD: Society of American Foresters: 219-225.

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

Gibson, L.P. 1971. Insects of bur oak acorns. Annals of the Entomological Society of America. 64: 232-234.

Gibson, L.P. 1972. Insects that damage white oak acorns. Res. Pap. NE-220. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

Gibson, L.P. 1982. Insects that damage northern red oak acorns. Res. Pap. NE-492. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

Gribko, L.S.; Schuler, T.S.; Ford, W.M. 2002. Biotic and abiotic mechanisms in the establishment of northern red oak seedlings: a review. Gen. Tech. Rep. NE-295. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 18 p.

Horsley, S.B.; Stout, S.L.; DeCalesta, D.S. 2003. White-tailed deer impact on the vegetation dynamics of a northern hardwood forest. Ecological Applications. 13(1): 98-118.

Kramer, P.J.; Kozlowski, T.T. 1979. Physiology of woody plants. New York: Academic Press. 811 p.

Marquis, D.A.; Eckert, P.L.; Roach, B.A. 1976. Acorn weevils, rodents, and deer all contribute to oak-regeneration difficulties in Pennsylvania. Res. Pap. NE-356. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.

McNab, W.H.; Avers, P.E. 1994. Ecological subregions of the United States: section descriptions. Publication WO-WSA5. Washington, DC: U.S. Department of Agriculture, Forest Service. 218 p.

Miller, W.E. 1978. Use of prescribed burning in seed production areas to control red pine cone beetle. Environmental Entomology. 7(5): 698-702.

Murtfeldt, M.E. 1894. Acorn insects, primary and secondary. Washington, DC: U.S. Department of Agriculture, Division of Entomology. Insect Life. 6: 318-324.

Oak, S.W. 1992. Insects and diseases affecting oak regeneration success. In: Loftis, D.L.; McGee, C.E., eds. Symposium proceedings: oak regeneration; serious problems, practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 105-111.

Oak, S.W. 1998. Insects and pathogens in eastern wilderness and natural areas. In: Kulhavy, D.L.; Legg, M.H., eds. Wilderness and natural areas in eastern North America: research, management and planning. Nacogdoches, TX: Stephen F. Austin University: 71-75.

Oliver, A.D.; Chapin, J.B. 1984. *Curculio fulvus* (Coleoptera: Curculionidae) and its effects on acorns of live oaks, *Quercus virginiana* Miller. Environmental Entomology. 13(6): 1507-1510

Olson, D.F.; Boyce, S.G. 1971. Factors affecting oak production and germination and early growth of seedlings and seedling sprouts. In: White, D.E.; Roach B.A., co-chairs. Oak symposium proceedings. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeast Forest Experiment Station: 44-48.

Riccardi, C.L.; McCarthy, B.C.; Long, R.P. 2004. Oak seed production, weevil (Coleoptera: Curculionidae) populations, and predation rates in mixed-oak forests of Southeast Ohio. In: Yaussy, D.A.; Hix, D.M.; Long, R.P.; Goebel, P.C., eds. Proceedings of the 14th central hardwood forest conference. Gen. Tech. Rep. NE-316. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 10-20.

Rickard, W.H. 1970. Ground dwelling beetles in burned and unburned vegetation. Journal of Range Management. 29: 293-294.

Steiner, K.C. 1995. Autumn predation of northern red oak seed crops. In: Gottschalk, K.W.; Fosbroke, S.L., eds. Proceedings of the 10th central hardwood forest conference. Gen. Tech. Rep. NE-197. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 489-494.

Triplehorn, C.A. 1955. The Asiatic oak weevil in Delaware. Journal of Economic Entomology. 48: 289-293.

Tryon, E.H.; Carvell, K.L. 1962. Acorn production and damage. West Virginia University Agricultural Experiment Station Bulletin 466T. 14 p.

Van Lear, D.H.; Harlow, R.F. 2002. Fire in the eastern United States: influences on wildlife habitat. In: Ford, W.M.; Russell, K.R.; Moorman, C.E., eds. The role of fire in nongame wildlife management and community restoration: traditional uses and new directions. Proceedings of a special workshop. Gen. Tech. Rep. NE-288. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 2-10.

Weckerly, F.W.; Sugg, D.W.; Semlitsch, R.D. 1989. Germination success of acorns (*Quercus*): insect predation and tannins. Canadian Journal of Forest Research. 19: 811-815.

Winston, P.W. 1956. The acorn microsere, with special reference to arthropods. Ecology. 37(1): 120-132.

Wright, S.L. 1987. Managing insects affecting oak regeneration by prescribed burning. In: Current topics in forest research: emphasis on contributions by women scientists. Proceedings of a national symposium. Gen. Tech. Rep. SE-46. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 186-192.