INSECTS AFFECTING ESTABLISHMENT OF NORTHERN RED OAK SEEDLINGS IN CENTRAL PENNSYLVANIA

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Abstract: Studies to evaluate the impact of insects on the establishment of advance oak regeneration in Pennsylvania were initiated in 1989. The populations and species of insects feeding on germinating acorns and new seedlings, their activity periods, and the damage caused by these insects were studied in relation to overstory-density (40, 60, and 100 percent relative density) and understory vegetation control (herbicided and unherbicided) at three sites on the unglaciated Allegheny Plateau in Clearfield County. These experiments showed that overstory-density levels and treatment with herbicide to eliminate the understory had negligible effects on the species of acorn-feeding insects present, their population levels, and their damage to germinating red oak acorns and new seedlings. These experiments also showed that acorn weevils (*Conotrachelus posticatus* (Boheman), nitidulids (*Stelidota octomaculata* (Say), and acorn moths (*Valentinia glandulella* (Riley) are important acorn predators, that they become active during late winter and spring, and that they destroy great numbers of germinating acorns and new seedlings in central Pennsylvania oak stands, thus affecting oak regeneration.

INTRODUCTION

"Although there seems to be a universal problem with regenerating northern red oak, there is not a universal solution. Specific requirements for local conditions will need to be developed from the general requirements for regenerating the species". These comments by Crow (1988) are supported by the large volume of literature on the problem of regenerating oak, yet this problem remains a formidable one.

One problem that is encountered in regenerating mature oak stands on good and excellent growing sites can be traced to a lack of advance oak reproduction. The oak seedlings must be of sufficient size to successfully compete with other faster growing species when the stand is regenerated (Sander 1988; Loftis 1988; Lorimer 1989).

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In 1988, the Northeastern Forest Experiment Station initiated a series of studies to identify and understand the important factors that limit the development of advance red oak reproduction on high-quality growing sites in Pennsylvania, West Virginia, Ohio, and Kentucky[2]. The effects of deer, rodents, insects, light, competition from herbaceous and woody species, site, stand composition, and acorn availability are some of the factors being evaluated.

The first research plots were established in 1988-89 on the Moshannon State Forest in central Pennsylvania. This paper reports early results from studies on the impact of insects on the establishment of northern red oak (*Quercus rubra* L.) seedlings.

DESCRIPTION OF STUDY AREA

The Moshannon State Forest is located in four counties in central Pennsylvania within the unglaciated Allegheny Plateau region. The experiments were conducted in the Clearfield County section of the Forest, where the elevation is about 2200 feet. Precipitation averages 45 inches and is distributed uniformly throughout the year. The area is usually snow covered from December through mid-March. Soil moisture is usually ample during the spring and early summer, though intermittent periods of moisture stress are common during the latter part of the growing season. The frost-free period is about 130 days.

All of the study stands originated after a complete clearcutting shortly after the turn of the century. As a result, they are even-aged and about 80+ years old. The site index for northern red oak is about 70.

Following clearcutting, many factors, including repeated fires, gave rise to the fully stocked, second-growth hardwood stands that are present today. These stands have a major component of northern red oak growing in mixture with black cherry (*Prunus serotina* Ehrh.), sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and white ash (*Fraxinus americana* L.). Other species represented include yellow-poplar (*Liriodendron tulipifera* L.), American beech (*Fagus grandifolia* Ehrh.), cucumbertree (*Magnolia acuminata* L.), bigtooth aspen (*Populus grandidentata* Michx.), hickory (*Carya* spp.), white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), and chestnut oak (*Quercus prinus* L.).

The understory on the study areas is limited in abundance and diversity, reflecting long-term browsing from the high deer population that numbers between 31 to 34 per square mile

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[2]Study Plan: Factors limiting the establishment of advance oak regeneration in mature oak stands by H. Clay Smith and L. R. Auchmoody (called Limiting Factors Study).

(Powell and Considine 1982; Pennsylvania Game Commission)[3]. Hay-scented fern (*Dennstaedtia punctilobula* L.), New York fern (*Thelypteris noveboracencis* L.), striped maple (*Acer pensylvanicum* L.), and American beech are not preferred by deer and, therefore, are the species found most frequently in the understories. Desirable hardwood regeneration also is sparse, being limited to species that are low in preference as deer browse. Virtually all oak seedling regeneration is less than 15 inches tall due to repeated browsing. The number of advance red oak seedlings ranges from about 60 to 350 per acre.

METHODS

The field design of the Clearfield installation on the Moshannon State Forest consists of six, 4-acre cutting-level plots arranged in three randomized complete blocks (a total of 18 plots). Treatments applied to these plots were: 1) three cutting levels (40, 60, and 100 percent residual relative density); 2) fencing half of the plots to exclude deer; and 3) herbicide (glyphosate) applied to one-half of each of the 18 plots to eliminate the understory vegetation. Each block (replicate) was located in a fully stocked stand in which northern red oak was a principal component, and that also was representative of the oak stands in the area. Herbicide was applied in August 1988, and the overstory treatments were made in the winter and spring of 1989.

Studies to determine the relative populations and species of insects that might be causing damage to red oak acorns were conducted in the spring of 1989 and 1990. Both experiments used pitfall traps to catch the insects. The pitfall traps consisted of pint canning jars with 10-ounce plastic cup inserts containing a paper towel, 20 ml of water, and four or five viable red oak acorns that had been cut into halves (bait). The jar sealing caps were replaced with 1/4-inch hardware cloth circles to allow entry by the insects. The wire discs were glued inside the screw caps with epoxy ribbon adhesive to prevent rodents from pulling out the wire screens. The traps were buried in the soil with the tops flush with the ground. Rain shields for the traps were provided by positioning plastic food container lids (6- to 8-inch diameter), supported on 10-inch nails, about 3 inches above the tops of the traps. The traps were checked at 7- to 10-day periods. At the end of each trapping period, the insects that were caught were identified and counted, and the traps equipped with new plastic cup inserts containing fresh acorn bait.

In 1989, the trapping period was between May 3 to June 13 and a total of five collections were made. That year, 4 pitfall traps (2 in each herbicided and unherbicided section of each cutting level) were placed in each of the 6 plots at replicates 2 and 3 and also in the two uncut (100 percent relative density) plots of replicate 1, a total of 56 traps. The 40 percent and 60 percent relative density plots at replicate 1 were not trapped in 1989 because rain

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[3]Unpublished Pennsylvania Game Commission annual estimate of winter deer population estimates by William Palmer.

delayed the completion of the cutting treatments until mid-June. In 1990, the trapping period was between May 15 and June 6 and a total of three collections were made. During 1990, two pitfall traps were placed in each herbicided and unherbicided section of all plots, for a total of 72 traps. Analysis of variance was used to determine if the insect species present or their population levels were affected by the residual stand densities on the plots and by the application of herbicide (i.e. understory removal).

In separate experiments to evaluate insect damage to germinating red oak acorns and young seedlings, direct-seeded acorns were used along with 6-inch-square, open-bottom wire boxes of 0.5- by 1.0-inch hardware cloth to protect sown acorns from chipmunks and larger mammals. The wire boxes were secured to the ground with 12-inch landscaping nails or 8-inch plastic tent stakes. As with the pitfall trap experiments, these studies also were conducted in the herbicided and unherbicided sections of the main cutting-level plots (40, 60, 100 percent relative density).

The first of the experiments began in early May 1989 and was conducted on seven plots where deer were excluded and one unfenced plot. Six wire boxes were placed in herbicided and unherbicided sections of each plot. Under each wire box, two red oak acorns were planted 1-inch deep and two acorns were placed on the soil surface. At a distance of 1 foot from each of 2 sides of the wire box, one acorn was planted 1-inch deep and one placed on the soil surface (eight acorns total per site). All acorns inside and outside the boxes were covered with leaves. The acorns, which had been collected in 1988 and kept in cold storage, were just beginning to germinate so all were viable when sown. Thus, 768 acorns were deployed; half were protected from rodents and half were surface or subsurface sown. The sites were checked in late June to determine the extent of insect and rodent damage. Differences in damage attributed to residual overstory density and to understory removed by herbicide were determined by analysis of variance (ANOVA).

The second experiment began in late October and early November of 1989. Ten wire boxes were placed in each herbicided and unherbicided section of all 18 plots. Under each wire box, five red oak acorns were placed on top of the ground and covered with leaves. The boxes were secured to the ground with 12-inch landscaping nails or 8-inch plastic tent stakes. The acorns used in this study were collected outside of the study plot boundaries and float-tested; any acorns showing signs of insect or other damage were discarded. The boxes were distributed throughout the plots and placed under acorn-bearing trees. Thus, 100 acorns were sown in each cutting-level plot (1,800 acorns total). The wire boxes were lifted and the acorns and seedlings checked for damage in May, June, and July of 1990. The heights of the seedlings were measured in July when the boxes were removed from the plots. Differences in damage between the residual overstory densities and from the removal of the understory with herbicide were evaluated by ANOVA.

The viability of the acorn crop and effects of insects thereon were determined from acorn samples taken in November inside 14- by 42-ft. fenced rodent-exclosure plots inside the fenced 4-acre plots (Auchmoody et al. - unpublished). This eliminated variation due to removal of acorns by rodents prior to sampling. A sample of 10 to 25 acorns was collected in each rodent-exclosure plot. The acorns were packed in moist peat moss in plastic bags and stored at 45 to 50°C. Several small holes were punched in each bag to allow aeration. About 3 months later the bags were placed at room temperature and a small amount of water was added to each bag. After 2 weeks the acorns were checked for germination. Inviable acorns were cut open and inspected to determine the cause of germination failure.

A final study was conducted to determine when feeding activity by acorn insects begins. A sample of 300 acorns was collected near the plots on February 13, 1990, and a second sample of 235 acorns was collected on March 15, 1990. The acorns were examined in the laboratory and insect activity associated with each of the sampling dates was determined.

RESULTS

Three important species of insects that damage germinating acorns were caught in the pitfall traps in 1989 and 1990: the weevil, *Conotrachelus posticatus* (Boheman); the nitidulid or sap beetle *Stelidota octomaculata* (Say); and the acorn moth, *Valentinia glandulella* (Riley). Table 1 gives the mean number of weevils and sap beetles caught per trap per trapping period for five periods in 1989 and three periods in 1990.

Analysis of variance revealed no significant differences in weevil or sap beetle populations associated with the overstory-density treatments or with the removal of the understory with herbicide in either years. Thus the data from all plots within a replicate were pooled and the replicate means were analyzed for differences. The weevil population in both 1989 and 1990 was significantly lower in Replicate 1 than in Replicate 2 but not significantly lower than in Replicate 3. The Replicate 2 and Replicate 3 plots did not differ significantly in 1989 but they did in 1990.

Table 1.--Mean number of weevils, *Conotrachelus posticatus*, and sap beetles, *Stelidota octomaculata*, caught per pitfall trap per trap period, 1989 and 1990[a]

Area	Weevil		Sap Beetles	
	1989	1990	1989	1990
Replicate 1	4.8 a[b]	0.3 a	0.9 a	0.1 a
Replicate 2	8.2 b	0.8 b	7.9 b	2.4 b
Replicate 3	6.2 ab	0.3 a	10.0 b	1.9 b

[a]Mean shown for each replicate is the mean of pooled plot data since ANOVA showed no significant differences in either insect population due to different overstory densities or to removal of understories with herbicide in either year.
[b]Means in the same column followed by the same letter are not significantly different at the 95 percent level.

Populations of sap beetles in Replicate 1 were significantly lower in both 1989 and 1990 than in Replicates 2 and 3. There was no significant difference in sap beetle populations between Replicates 2 and 3 in either years.

Populations of the acorn moth *V. glandulella* were not determined from pitfall traps in 1989 or 1990, but many moths were reared from the acorns used as bait in the pitfalls. However, because this insect was thought to be a minor acorn pest, no attempt was made to monitor exact numbers. Subsequently, germinating acorn samples collected on March 15, 1990, near the study plots revealed that the radicle tips of 50 percent of the acorns had been eaten by the moth larvae and laboratory rearing showed that 60 percent of the acorns were infested with moth larvae. As a result, this insect must now be considered a major pest of germinating acorns in Pennsylvania, and future studies should monitor the populations of *V. glandulella*.

Table 2 presents the 1989 results of subsurface- and surface-sown acorns inside and outside of hardware-cloth boxes. There were 192 acorns in each of the four treatments. Analysis revealed no differences due to overstory density, herbicide treatment, or plot location (replication) so the data given in Table 2 is the pooled data from all plots. Acorn placement and rodent protection did result in significant differences in numbers of seedlings, acorns taken by rodents, and acorns destroyed by insects. Rodents destroyed virtually every acorn outside of the boxes -- all of the acorns on the surface and 150 (78 percent) of those buried. Under the boxes, insects destroyed 177 (92 percent) of the acorns on the surface but only 16 (8 percent) of those buried. One hundred and seventy-six (92 percent) of the acorns buried under a wire cage produced a seedling while only 41 (21 percent) of those buried without protection from rodents produced seedlings. Seventeen of the subsurface acorns were destroyed by weevils and sap beetles which enter loose soil to feed on acorns.

Table 2.--Results of 1989 test in which 192 acorns per treatment were surface or subsurface sown, inside or outside of wire boxes -- number of acorns lost to rodents and insects and seedlings produced.*

Treatment	Seedlings	Acorns taken by rodents	Acorns destroyed by insects
		number	
A - Surface-inside	15	0	177
B - Surface-outside	0	192	0
C - Subsurface-inside	176	0	16
D - Subsurface-outside	41	150	1

*Data pooled for all study areas. T-test showed no significant differences in number of seedlings relative to overstory density, herbicide treatment, or study area. Surface treatment (A) inside and subsurface treatments (C and D) inside and outside boxes significantly increased seedling establishment ($P \leq 0.05$).

As shown in Table 3, insects destroyed 87 percent of the germinating acorns and new seedlings that resulted from 1,800 acorns placed under the wire boxes in autumn of 1989. Insects destroyed 270 (64 percent) of the 422 seedlings that established from 1139 germinating acorns. Only 152 (13 percent) of the 1,139 germinating acorns and seedlings survived insect destruction and 113 of the seedlings were in Replicate 1. The insect damage listed in Table 3 is based only on acorns that germinated since rodents destroyed some of the acorns and nonviable acorns were not subject to insect damage. The insect damage was primarily by the acorn moth and the *Conotrachelus* weevil. Laboratory rearing of the acorns removed from the wire boxes revealed that at least one-third were infested with moths and nearly all with weevils. Most of the newly rooted seedlings were killed due to heavy weevil feeding on the radicles and shoots. There also was some damage to newly rooted seedlings by *S. octomaculata* in concert with the weevils. The sap beetles ate the tender top-shoots as they formed and reproduced in the acorn cotyledons, destroying any chance for the acorn to resprout and form a seedling.

Table 3.--Fate of 1800 northern red oak acorns surface-sown under wire boxes in autumn of 1989 and checked May, June, and July 1990.[a]

	Replicate			Total	Percent
	1	2	3		
	----------------Number----------------				
A - Germinating acorns destroyed by insects	242	265	210	717	63*
B - Seedlings destroyed by insects	92	129	49	270	64*
A + B - Total number of acorns and seedlings destroyed by insects	334	394	259	987	87*
Surviving seedlings	113**	26	13	152	13

[a]Of the 1,800 surface sown acorns, 661 (37 percent) failed to germinate because of mouse predation (7 percent) and desiccation (30 percent). Plot data pooled for each replicate since ANOVA showed no significant differences within a replicate relative to overstory density or understory control.
*Percentages based on 1,139 acorns that germinated and 422 seedlings that initially established from the 1,139 acorns.
**Significantly different at 99 percent level from Replicates 2 and 3.

The acorn samples removed in November 1989, from the rodent-exclosure plots revealed that 132 of 536 (24.7 percent) were infested with insects, primarily *Curculio* sp. larvae. Less than 2 percent of the acorns were infested with the filbertworm moth, *Cydia latiferreana* (Wlsm.) and the acorn moth, *V. glandulella*. Surprisingly, larvae of *V. glandulella* were found in sound, previously undamaged acorns, having gained entry into the acorn by chewing through the micropyles on the cap end of the acorn. This is the first report of this insect being a primary invader of sound, ungerminated acorns. It is believed that the larvae are able to chew only into immature acorns. Damage to the cotyledons was confined to the cap ends and had no affect on acorn viability. Sixty-two (47 percent) of the acorns infested with *Curculio* weevils and *Cydia* moths failed to germinate while 70 (53 percent) germinated. Ideal germination conditions in the laboratory probably allowed many insect infested acorns to produce seedlings that otherwise would have desiccated under natural conditions. However, at least 12 percent of the 1989 bumper acorn crop was not viable due to insect damage.

The samples of germinating acorns collected on February 13, 1990, revealed that the acorn moth, which overwinters as an early instar larva, had just begun to feed. In this sample, only 13 of 300 acorn radicles had been damaged, but by March 15 the radicles of 118 of the 235 acorns collected had been damaged by moth larvae. Weevil damage was not observed in the February sample of acorns and by March 15 weevil feeding and oviposition had just begun. Activity by sap beetles was not detected in either of the acorn samples. Adult sap beetles were found on moth- and weevil-destroyed acorns under the wire boxes on May 7, 1990. However, sap beetle reproduction was not detected until a second check of the acorns under the boxes on June 7 revealed that reproduction probably began in late May.

DISCUSSION

The average number of weevils and sap beetles caught in the pitfall traps in 1990 appears very low compared to 1989 (Table 1). In 1990, the traps were competing with a large number of residual acorns from the 1989 bumper crop. By contrast, in 1989, wildlife had consumed nearly all of the acorn crop by June, which resulted in greater numbers of insects being attracted to the traps. Insects destroyed 987 (87 percent) of the 1,139 germinating acorns and young seedlings under the wire boxes in 1990 (Table 3). This indicates that the acorn-insect population actually was very high in 1990. Thus, the number of acorn insects trapped in pitfalls must be evaluated over time in relation to acorn food sources available in the surrounding area to accurately assess populations.

The pitfall trapping period was shorter in 1990 than in 1989 but was conducted during the ideal time for assessment of weevil and sap beetle populations that overwintered within the plots; when temperatures were below the threshold for flight of the acorn insects but high enough for the insects to readily migrate to the traps by walking. The overwintering populations of acorn insects are the most damaging and their populations within an area are best assessed before migration or emigration by flight can occur and before emergence of new adults occurs in late spring and early summer.

Mice destroyed 119 (7 percent) of the 1,800 acorns placed under the wire boxes. However, 95 acorns were eaten by mice in just two plots in Replicate 3. This demonstrates the localized effect of some species of rodents on seedling establishment. The hardware-cloth mesh allowed entry by mice. Mice usually eat off the cap ends of the acorns, leaving a nearly intact acorn hull; other rodents typically leave the acorn hull in pieces.

Of the 152 new seedlings that were established under the wire boxes in 1990, only 51 were undamaged by rodents. Rodents chewed off the tops of most seedlings emerging from the wire boxes. This type of rodent damage also was observed in Ohio (Galford et al. 1988). Seedlings not damaged by rodents ranged in height from 1 to 12 cm and averaged 5.4 cm. The smallest seedlings resulted from acorns heavily damaged by insects; none appeared vigorous.

Snowfall was less than normal during the winter of 1989-90 in the study area, and rainfall was below normal in March and April of 1990. This may account in part for the large number of acorns (30 percent) that did not germinate. Laboratory germination tests of samples of the acorns used in the study showed that 97 percent were viable. The dry conditions at the time of acorn germination also may have influenced the impact of insects on seedling establishment. Delayed acorn germination and a slow rate of radicle growth due to a moisture deficit would expose the radicle tips to insect feeding for a longer period.

The low population of sap beetles in the Replicate 1 plots (Table 1) may have been a factor in a greater number of seedlings being established under the wire boxes in 1990 (Table 3). However, the importance of the sap beetles is not completely known. Additional studies are needed to establish insect and rodent population interrelationships with respect to acorn abundance and seedling establishment.

Examination of several hundred newly established red oak seedlings in and near the plots in 1989 revealed that only two seedlings originated from surface acorns. Nearly all of the seedlings establishing in areas undisturbed by the logging operations resulted from acorns buried or otherwise cached by rodents. By contrast, in 1990 more than 70 percent of the new oak seedlings that were examined originated from surface acorns under leaf litter. Thus, the large acorn crop of 1989 allowed some unburied acorns to survive predation by both insects and rodents.

Data obtained on insect species that feed on germinating acorns and their impact on seedling establishment in central Pennsylvania parallels results from studies on acorn insects in Ohio (Galford et al. 1988).

In conclusion, insects and rodents singly or in combination can significantly limit the number of oak seedlings establishing in central Pennsylvania forests, even in years of large acorn crops. Foresters have long known that logging operations following a good acorn crop can increase oak seedling establishment. Many acorns are covered or pressed into the soil during logging. The results of this study demonstrate that buried acorns are afforded protection from insect and rodent predation and desiccation, which increases oak seedling establishment.

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LITERATURE CITED

Crow, T. R. 1988. Reproduction mode and mechanisms for self-replacement of northern red oak (*Quercus rubra*)---a review. For. Sci. 34:19-40.

Galford, J. R., J. W. Peacock, and S. L. Wright. 1988. Insects and other pests affecting oak regeneration. In: Smith, H. C., A. W. Perkey, and W. E. Kidd, Jr., eds. Guidelines for regenerating Appalachian hardwood stands: workshop proceedings. May 24-26, 1988. SAF Publ. 88-03. West Virginia University Books. p. 219-225.

Loftis, D. L. 1988. Regenerating oak on high-quality sites, an update. In: Smith, H. C., A. W. Perkey, and W. E. Kidd, Jr., eds. Guidelines for regenerating Appalachian hardwood stands: workshop proceedings. May 24-26, 1988. SAF Publ. 88-03. West Virginia University Books. p. 199-209.

Lorimer, C. G. 1989. The oak regeneration problem: new evidence on causes and possible solutions. Univ. Wisconsin Dep. For., For. Resour. Anal. No. 8. 31 p.

Powell, D. S. and T. J. Considine, Jr. 1982. An analysis of Pennsylvania's forest resources. USDA For. Serv. Resour. Bull. NE-69. 97 p.

Sander, I. L. 1988. Guidelines for regenerating Appalachian oak stands. In: Smith, H. C., A. W. Perkey, and W. E. Kidd, Jr., eds. Guidelines for regenerating Appalachian hardwood stands: workshop proceedings. May 24-26, 1988. SAF Publ. 88-03. West Virginia University Books. p. 189-198.