MEADOW VOLE-INDUCED MORTALITY OF OAK SEEDLINGS IN A FORMER AGRICULTURAL FIELD PLANTING

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Abstract--Seedling mortality due to meadow vole herbivory is an often acknowledged but relatively unstudied aspect of hardwood afforestation. Vole-induced mortality is not typically a major item of concern in afforestation attempts. However, damage has been extreme in some plantings. A total of 4,320 bare-root Nuttall oak (*Quercus texana* Buckley), Shumard oak (*Quercus shumardii* Buckley), and swamp chestnut oak (*Quercus michauxii* Nutt.) seedlings were planted in February 2008 on three Mississippi sites. All sites were of comparable soils and received above average precipitation throughout the 3-year duration of the study. One half of seedling plots were treated with a 1-year post-plant application of Oust XP®. The other half was treated for 2 years. May 2008 seedling survival was excellent at 99.7 percent. However, 76.9 percent of observed seedling mortality was directly attributable to vole damage. End-of-growing-season survival for the first three growing seasons was 98.9 percent, 97.1 percent, and 94.1 percent, respectively. While these survival rates would be considered excellent in most afforestation attempts, vole herbivory accounted for 57.6 percent of observed seedling mortality over the course of the study. If the assumption is made that vole-induced mortality had been nonexistent, third-year survival would have been approximately 97.5 percent. Fourth and fifth growing season mortality accounted for an additional 7.8 percent reduction in overall survival at one site. If vole-related seedling mortality were nonexistent, fifth-year survival would have been approximately 98.9 percent. Seedling mortality levels of this magnitude are significant and may deserve consideration in planting efforts.

INTRODUCTION

A problem that occurs infrequently in plantings across the eastern United States is seedling mortality due to the meadow vole, also known as the pine vole (*Microtus pinetorum* LeConte) (Ostfeld and Canham, 1993). Meadow voles are semifossorial, arvicoline rodents found in woodlands and other habitats across the eastern United States. Meadow vole herbivory is usually subterranean in nature, resulting in seedling taproots eaten below the root collar (Schreiber and Swihart 2009). Several studies have indicated that meadow voles may selectively feed on roots of oak seedlings (Ostfeld and Canham 1993, Rathfon and others 2008, Schreiber and Swihart 2009). Mortality levels as high as 19 percent were noted by Rathfon and others (2008) in southern Indiana for white oak, northern red oak, and black oak seedlings under mature, closed-canopy, oak-dominated forests. The highest levels of meadow vole-induced seedling mortality were found in areas that had undergone midstory removal. Other studies have shown increased frequency of meadow voles in areas with greater levels of herbaceous vegetation due to midstory and overstory removal (Perry and Thill 2005, Schreiber and Swihart 2009). Increased ground cover provides better habitat and serves to aid in increased meadow vole numbers in these settings (Birney and others 1976). Afforestation attempts on retired agriculture fields may be hindered due to the protection from predation provided by the greater levels of herbaceous vegetation typically found on these sites (Buell and others 1971, Gill and Marks 1991, Ostfeld and Canham 1993). While typically not a major concern in afforestation attempts, vole herbivory can reach levels with substantial impact to planting success.

OBJECTIVE

The objective of this study was to determine the effect of mechanical site preparation, species, and herbaceous weed control on seedling mortality attributable to meadow vole herbivory.

MATERIALS AND METHODS

Site Description

This study was located on three sites. Two sites are owned by the Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP): one site was located on Copiah County Wildlife Management Area (WMA), the other was located on Malmaison WMA. The third site was located near Arkabutla Lake on land owned by the U.S. Army Corps of Engineers.

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Citation for proceedings: Holley, A. Gordon; Connor, Kristina F.; Haywood, James D., eds. 2015. Proceedings of the 17th biennial southern silvicultural research conference. e–Gen. Tech. Rep. SRS–203. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 551 p.

Malmaison WMA

The Malmaison WMA study area was located approximately 14 miles northeast of Greenwood, MS in Grenada County. The site was formerly used in row-crop production and retired from agricultural production in the late 1990s. It was maintained as an opening for wildlife through mowing and disking from agricultural retirement until the initiation of this study. Soils were silt loams, and 40-year average yearly precipitation was 53.8 inches (NOAA 2011). Soil tests indicated that onsite pH ranged from 6.3 to 7.0.

At initiation of this project, dominant onsite herbaceous species were ryegrass (*Lolium* spp.), bermudagrass (*Cynodon dactylon* L.), Brazilian vervain (*Verbena brasiliensis* Vell.), and Carolina horsenettle *(Solanum carolinense* L). Forty other herbaceous species occurred in small quantities. Cumulative herbaceous coverage by all species was 100 percent.

Copiah County WMA

The Copiah County WMA study area was located approximately 16 miles northwest of Hazlehurst, MS in Copiah County and was retired from row crop production in the 1980s. It was maintained as an opening for wildlife through mowing and disking from agricultural retirement until the initiation of this study. Soils were silt loams, and 35-year average yearly precipitation was 59.2 inches (NOAA 2011). Soil tests indicated that onsite pH is 5.2.

At study initiation, dominant onsite herbaceous species were crimson clover (*Trifolium incarnatum* L.), ladino clover (*Trifolium repens* L.), and ryegrass (*Lolium multiflorum* Lam.). Twenty-five other herbaceous species occurred in small quantities. Cumulative herbaceous coverage by all species was 100 percent.

Arkabutla Lake

The Arkabutla Lake study area was located approximately 5 miles northwest of Coldwater, MS in Desoto County. The site was in soybean [*Glycine max* (L.) Merr.] production until September 2007. Soil series were silt loams, and 40-year average precipitation was 56.1 inches (NOAA 2011). Soil tests indicate that the site had an average pH of 6.2.

Dominant herbaceous species on site at study initiation were Brazil vervain, poorjoe (*Diodia teres* Walt.), and thorny amaranth (*Amaranthus spinosus* L.). Twenty-one other herbaceous species were observed in small quantities across the site. Cumulative herbaceous coverage of all species was approximately 5 percent.

Experimental Design

The study was completely replicated at all three sites. Each site had its own unique installment of randomized treatment combinations. This experiment utilized a split-split-plot design with whole plot factors in a randomized complete block design and sub-plot factors completely randomized within whole plot factors and sub-sub-plot factors completely randomized within sub-plot factors. The whole plot factor was site preparation treatment. The sub-plot factor was species. The sub-sub-plot factor was pre-emergent competition control. The experimental unit was a plot with its unique combination of site preparation treatment, species, and pre-emergent chemical treatment. The response variable was seedling mortality directly resulting from vole herbivory.

There were three blocks at each site that contained all possible site preparation treatment/species/pre-emergent chemical treatment combinations. Each block consisted of 12 planting rows split horizontally resulting in the creation of 24 plots. The experimental unit was the plot which was approximately 190- by 10-feet and contained 20 seedlings. For logistical reasons, site preparation treatments were applied singularly as a group; however, these groups were randomized within each block. Individual species were planted by row for each site preparation treatment. Species were randomized by site preparation treatment. Each row was divided into two plots. Each plot received different pre-emergent chemical treatments.

Mechanical Site Preparation and Herbaceous Weed Control (HWC) Treatments

Four mechanical site preparation treatments were employed: control (no site preparation), subsoiling, bedding, and combination plowing. Site preparation treatments were applied on 10-foot centers. Subsoil trenches were cut to a depth of 15 inches. Bedding was performed using a furrow plow with the blades set to pull a soil bed approximately 3 feet wide and between 8- and 10-inches deep. Combination plowing involved pulling a soil bed over the top of subsoiled trenches. Mechanical site preparation treatments were applied during the first week of November 2007.

HWC treatments included a 1-year application and a 2-year application of Oust XP®. Both treatments were applied in 5-foot-wide bands using a rate of 2 ounces of product per acre and were applied over the top of seedlings prior to budbreak. The 1-year Oust XP® application was applied during March 2008. The 2-year Oust XP® application was applied during March 2008 and March 2009. A Solo® backpack sprayer was used for herbicide application with total spray volume of 10 gallons per acre (GPA).

Seedling Establishment
Nuttall oak, Shumard oak, and swamp chestnut oak were chosen for use in this study. Seedlings were purchased from Joshua Timberlands Elberta Nursery in Elberta, AL and were lifted mid-January 2008. Seedling specifications required 1-0 seedlings of overall vigorous appearance with relatively intact root systems. Specified seedling parameters dictated that stems be 18- to 20-inches tall and possess root systems 8- to 10-inches long with a minimum of eight first-order lateral roots (FOLRs).

A total of 4,320 seedlings were planted. Across the three sites, 1,440 seedlings of each species were planted. At each site, 480 seedlings of each species were planted. Seedlings were planted at root collar depth during February 2008 by university personnel using a10-foot spacing.

Survival Measurements
Seedling survival and cause of death were determined by ocular evaluation and recorded October 2008, October 2009, and October 2010 for all sites. Seedling bases were examined to determine if vole herbivory was the causal agent for mortality. If a seedling were observed as a resprout in later observations, it was back-modified. Seedlings dying from vole herbivory were recorded as such. For logistical reasons, the Malmaison WMA and Copiah County WMA sites were not resampled in years 4 and 5. Fourth and fifth-year survival was recorded using the same measuring procedures for the Arkabutla Lake site during October 2011 and January 2013.

Data Analysis
All statistical analyses were performed using Statistical Analysis System version 9.2 (Cary, NC). Survival percentages were arcsine square root transformed for normalization purposes. This transformation was necessary to convert the binomial distribution of the data to one that is nearly normal. Repeated Measures Analysis of Variance was applied on transformed survival data using Proc Mixed and Proc Glimmix. Best covariance structure for repeated measures compared CS, AR(1), and TOEP(2) alternatives using BIC criteria. The best covariance structure was found to be TOEP(2). Full model was fit; however, no differences were detected among species, mechanical site preparation, HWC treatments, or their interactions for stems killed by voles. As such, overall survival averages are used in this paper. While transformed survival data were used for analyses, untransformed means are presented for interpretation.

RESULTS AND DISCUSSION

Overall First, Second, and Third-Year Survival
Overall seedling survival was excellent during the May 2008 evaluations (99.67 percent over all combinations) ranging from 97.78 to 100.0 percent for individual treatment combinations (table 1). Survival levels this high indicate that there was little mortality due to planting shock. Most observed initial seedling mortality resulted from vole herbivory. Of the 13 seedlings that died by the May 2008 observations, 10 died from clipping. Vole-induced mortality accounted for 76.92 percent of the total mortality for initial evaluations. Assuming that vole-killed seedlings had lived and not died from some other cause, overall survival for the May 2008 observations would have been approximately 99.9 percent.

Table 1—Yearly survival of oak seedlings on all sites by treatment

		Species					
		Nuttall oak		Shumard oak		Swamp chestnut oak	
		1 year	2 year	1 year	2 year	1 year	2 year
Mechanical	Timing	OustXP	OustXP	OustXP	OustXP	OustXP	OustXP
Control	5-2008	99.44	99.44	100.00	98.89	99.44	99.44
	10-2008	98.33	99.44	98.89	98.33	99.44	98.33
	10-2009	96.67	99.44	98.89	93.33	98.89	95.00
	10-2010	96.11	88.89	97.22	88.89	96.67	94.44
Subsoiled	5-2008	99.44	100.00	100.00	100.00	100.00	99.44
	10-2008	99.44	99.16	97.22	98.33	99.44	97.22
	10-2009	98.89	99.16	93.89	96.67	98.89	92.22
	10-2010	98.33	93.04	92.22	93.83	98.27	91.11
Bedded	5-2008	97.78	100.00	100.00	100.00	100.00	100.00
	10-2008	97.78	98.89	99.44	99.44	100.00	99.44
	10-2009	97.22	95.56	99.44	97.22	97.78	97.22
	10-2010	96.11	92.78	98.30	93.33	95.00	95.56
Combination plowed	5-2008	99.44	100.00	100.00	100.00	100.00	99.38
	10-2008	99.44	100.00	98.33	99.44	99.44	98.27
	10-2009	98.33	96.67	96.11	99.44	98.89	95.49
	10-2010	88.01	95.56	93.89	89.44	98.33	93.14

Overall, October 2008 seedling survival was 98.9 percent (table 2) and ranged between 97.22 and 100.0 percent for individual treatment combinations (table 1). Meadow vole herbivory continued to be the primary source of seedling mortality throughout the 2008 growing season. Meadow vole herbivory accounted for the death of an additional 25 seedlings during the growing season. By the time October 2008 evaluations were performed, 35 of 45 seedlings that died throughout the growing season were killed by meadow vole herbivory. Vole-induced mortality accounted for 77.78 percent of the total mortality for 2008 evaluations. Assuming that vole-killed seedlings had survived and not died from some other cause, overall survival for the October 2008 observations would have been approximately 99.7 percent.

The greatest change in seedling survival between May and October 2008 was observed in Shumard oak seedlings planted in subsoiled areas treated with a 1-year Oust XP® application (table 1). May 2008 survival was 100.0 percent for this combination, and by October, survival had dropped to 97.22 percent. This 2.78 percent difference was heavily influenced by meadow vole-induced seedling mortality. Of the five trees that died by the October 2008 evaluations, four were the result of vole herbivory. Assuming that vole-killed seedlings had not died and did not die from some other cause, overall survival for this combination would have been approximately 99.44 percent.

Table 2--Overall survival of oak seedlings on all sites by year

Year	Survival
	percent
2008	98.90
2009	97.14
2010	94.11

Overall, survival for 2009 was 97.1 percent (table 2). This 1.8 percent drop in survival between October 2008 and October 2009 was driven primarily by leaf scorch in swamp chestnut oak seedlings. Swamp chestnut oak is classed as shade intolerant (Burns and Honkala 1990) but scorches relatively easily when fully exposed to full sunlight such as that encountered in HWC treated areas. Vole herbivory was almost non-existent for the year.

Overall seedling survival was 94.1 percent ranging between 88.01 and 98.33 percent for individual treatment combinations in 2010 (table 2). Lower survival was observed for all combinations in October 2010 evaluations. While most combinations did not exhibit large differences between the October 2009 and October 2010 growing seasons, some of the differences were substantial. Meadow vole herbivory was the largest contributor to seedling mortality between the 2009 and 2010 growing seasons. Of the 129 seedlings that died between October 2009 and October 2010, 97 seedlings (75.19 percent) were killed by voles. Assuming that seedlings killed by voles had not died from some other cause, overall survival for the October 2010 observations would have been approximately 96.35 percent.

Meadow vole damage was the main factor in lower survival noted in the four combinations with the lowest survival at the end of the 2010 growing season (table 1). A drop in survival of 10.55 percent between 2009 and 2010 was observed for Nuttall oak in subsoiled areas treated with 2-year Oust XP® applications. Vole herbivory accounted for 13 (68.42 percent) of the 19 seedlings killed during 2010 for that combination. Similar survival reductions were noted in Nuttall oak planted in combination plowed areas receiving Oust XP® for 1 year, Shumard oak planted in combination plowed areas that received the 2-year Oust XP® treatment, and Nuttall oak planted in subsoiled areas treated with 2 years of Oust XP® (10.32 percent, 10.0 percent, and 6.12 percent reductions, respectively). Vole herbivory accounted for a large portion of this mortality (10, 15, and 8 seedlings, respectively). This accounted for a respective 52.63, 83.33, and 72.73 percent of the mortality observed in these treatment combinations.

Of the 255 seedlings that died over the course of the 3-year span of this study, vole herbivory accounted for 147 seedlings (57.64 percent). If the assumption is made that vole-induced mortality had been nonexistent, overall third year survival would have been approximately 97.50 percent. A 3.40 percent reduction in survival typically does not result in a change in management strategy. Seedlings should be of a size by year 3 or 4 that would serve to inhibit substantial levels of continued herbivory in the future. However, more severe vole herbivory has been noted in some studies. Rathfon and others (2008) found that vole herbivory resulted in mortality levels as high as 19 percent in southern Indiana for three species of oak seedlings under mature, closed-canopy, oak-dominated forests. The highest levels of meadow vole-induced seedling mortality were observed in areas where midstory removals had been performed. The authors surmised that increased mortality in these areas was due to the added protection from predation that increased herbaceous coverage provided.

Although statistical differences were not detected, vole herbivory was more prevalent in areas undergoing 2 years of Oust XP® treatment (table 1). Slightly lower overall seedling survival levels were observed starting with first growing season evaluations. At this point, all plots had received identical HWC treatment, and seedlings were not exhibiting any phytotoxic effects. Second year difference among treatments were similar with the gap between HWC treatments opening slightly in swamp chestnut oak for reasons previously discussed. Third year survival gaps increased among HWC treatments in all three oak species. While not significantly different, vole herbivory in areas treated with 2 years of Oust XP® treatment was noticeably greater in year 3. The likely cause for increased vole herbivory in these areas can be found in the form of increased herbaceous vegetation coverage compared to areas receiving only 1 year of HWC treatment. In the third growing season, areas treated with 1 year of Oust XP® were in their second year of herbaceous vegetation growth. Herbaceous vegetation was at a more mature growth stage compared with the vegetation observed in areas treated with 2 years of HWC. The 1-year-old vegetation in 2-year HWC areas was denser and provided better meadow vole cover. Other studies have noted that afforestation attempts on retired agriculture fields might be hindered due to protection from predation resulting from the greater herbaceous vegetation levels inherent to these sites (Buell and others 1971, Gill and Marks 1991, Ostfeld and Canham 1993).

Arkabutla Lake Fourth and Fifth-Year Survival

For logistical reasons, seedling survival of only the Arkabutla Lake site was resampled in years 4 and 5. Overall, 2010 seedling survival was 95.6 percent (table 3). At this point, meadow vole herbivory was responsible for 75 percent of overall seedling mortality on this site. Assuming that vole-killed seedlings had survived and not died from some other cause, overall survival for 2010 observations would have been approximately 99.7 percent.

Table 3--Overall third-, fourth-, and fifth-year survival of oak seedlings on the Arkabutla Lake site

Year	Survival
	percent
2008	95.6
2009	91.7
2010	87.8

Conventional wisdom dictates that upon entering the third or fourth growing season, vole herbivory should be a lessening problem regarding continued seedling/tree mortality. Vole-induced seedling mortality did not follow this more traditional trend at the Arkabutla Lake site. Overall, 2011 seedling survival was 91.7 percent (table 3). Meadow vole herbivory was responsible for 100 percent of seedling mortality observed between the 2010 and 2011 observations (3.9 percent reduction). Overall, 2012 seedling survival was 87.8 percent with vole herbivory accounting for 100 percent of seedling mortality observed between the 2011 and 2012 observations (3.9 percent reduction).

Of the 176 seedlings that died over the 5-year course of the study at the Arkabutla Lake site, vole herbivory accounted for 159 seedlings (90.3 percent). If the assumption is made that vole-induced mortality had been nonexistent, overall fifth- year survival would have been approximately 98.8 percent. Vole herbivory was directly responsible for an 11 percent reduction in oak survival on this site. A possible explanation for the increasing vole damage over time may be the amount of vegetative coverage within the plantation.

CONCLUSIONS

Meadow vole-induced mortality of planted seedlings is a known but ordinarily minor factor in afforestation attempts. We found vole herbivory can reach levels with substantial impact to planting success. Additionally, vole herbivory is typically thought to be nonexistent after the second or third growing season. Oak mortality from vole damage reached levels of concern for this study both in frequency and seedling age. Most land managers evaluate planting success during the first 3 years after plantation establishment. In some situations it is possible that the greatest levels of vole damage do not manifest until after this point. It is possible that vole herbivory plays a larger role in oak survival rates in plantation settings than is currently assumed.

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