FIRST-YEAR EFFECTS OF *MICROSTEGIUM VIMINEUM* AND EARLY GROWING SEASON HERBIVORY ON PLANTED HIGH-QUALITY OAK (*QUERCUS spp.*) SEEDLINGS IN TENNESSEE

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ABSTRACT.—Continuing difficulty in the successful natural regeneration of economically important oak species (*Quercus* spp.) on highly productive sites has led to considerable research regarding the use of artificial oak regeneration to ensure recruitment of oak as an important component of future stands. Two obstacles to the success of some oak plantings in Tennessee are herbivory by white-tailed deer (*Odocoileus virginianus* (Boddaert)) and competition from an invasive non-native grass, Nepalese browntop (*Microstegium vimineum* (Trin.) A. Camus). We examined the effects of both deer herbivory and the Nepalese browntop on the first-year growth of outplanted, high quality, locally adapted, 1-0 northern red oak (*Q. rubra* L.) seedlings on the Ames Plantation in Tennessee. Northern red oak seedlings were outplanted under four overstory treatments (no cut, high grade, commercial clearcut, and two age). Seedling growth, deer browse pressure (defined as browse on terminal or lateral shoots), and herbaceous biomass were monitored monthly through the 2002 growing season. Browse pressure accounted for approximately 67 percent of the variation in total seedling height growth, and exhibited a strong negative relationship with total growth (r = -0.82; slope= -0.48). Additionally, Tukey-Kramer multiple comparison tests detected seedling height differences between the no-harvest treatment as compared with the three harvest treatments. Herbivory was prevalent early in the growing season when the seedlings first flushed, then declined during the remainder of the growing season. Analysis indicated that seedlings with a height of 148 cm or greater escaped browse. Thus, with larger seedlings planted, it may be expected that many seedlings will surpass this "browse line" in the first or second growing seasons. Linear regression revealed a strong negative relationship between Nepalese browntop biomass production and mean seedling height growth (r = -0.74; slope= -0.0046). No differences in Nepalese browntop biomass production were found between treatments (P = 0.29) with first year results, but means ranged from 45 percent in the two-age treatment to 23 percent in the no cut treatment. This range may broaden with additional time and significant differences arise. These results still suggest that canopy disturbance may encourage a growth flush of this competitive species.

Introduction

The problem of successful oak (*Quercus* spp.) regeneration on higher quality sites (S.I. ≥ 65, base age 50) has attracted considerable attention and generated numerous research papers over past decades. However, the successional replacement of oak as a major forest component persists as a major concern in eastern deciduous forests, particularly on mesic or highly productive hardwood sites of the Central Hardwood Region (CHR). Studies indicate that promoting abundant large oak advance reproduction prior to overstory removal will aid in successfully regenerating oak on these sites (Sander 1971, Loftis 1982, 1990). However, the altered disturbance regimes of the CHR combined with short-term economic factors that constrain management options do not often produce conditions favorable to the development of such advanced reproduction. Therefore, some researchers have shifted focus to a post-harvest approach utilizing artificial means to maintain oaks on these sites.

Over the past ten years, a number of research projects have attempted to use nursery-grown seedlings to enhance post-harvest oak composition with varying results (Lorimer 1994, Demchik and Sharpe 1999, Buckley 2001, Spetich et al. 2002). Deer herbivory (Buckley et al. 1998), herbaceous competition including non-native species (Dubois et al. 2000) and competition from other woody species has hindered success. Through genetic selection, use of proper seed source, and optimal nursery techniques, high-quality

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artificial oak reproduction has been developed (Kormanik et al. 1994a, 1994b, Schlarbaum et al. 1998) to address these matters. Although initial growth results appear positive (Oswalt et al. 2003), deer herbivory and competition by nonnative vegetation still present problems. Large deer populations throughout the eastern deciduous forest continue to affect planted oak seedlings (Demchik and Sharpe 1999, Ward et al. 2000, Buckley 2001, Romagosa and Robison 2003). In addition, an invasive Asian C4 grass, Nepalese browntop (*Microstegium vimineum* (Trin.) A. Camus.), has been identified as a potentially severe problem on productive sites in the southeast (Barden 1987, Simberloff 2000, Romagosa and Robison 2003).

This study investigates the potential impacts of early season deer herbivory on the first-year growth of high-quality northern red oak (*Q. rubra* L.) seedlings developed by the University of Tennessee Tree Improvement Program, outplanted within four overstory treatments. In addition, we explore the relationships among nonnative invasive Nepalese browntop biomass, other herbaceous biomass, and first-year planted seedling height growth.

Materials and Methods

Study Site

The study site is located along an intermittent stream in the headwaters region of the North Fork of the Wolf River (NFWR) in southwest Tennessee (35°09'N, 89°13'W) on the Ames Plantation. The site encompasses approximately 100 acres of mixed bottomland and riparian hardwood forest dominated by various oak species. Two distinct landforms were identified within the study site: a minor bottom, infrequently impacted by flooding, near the confluence of the stream with the NFWR and ancestral terraces of the minor stream (Hodges 1997).

The headwaters region of the NFWR is located within the Mississippi Embayment of the Gulf Coastal Plain. The geology is dominated by the highly erodible Wilcox and Claiborne formations overlain by loess deposits common in western Tennessee (Fenneman 1938). The principal soil groups are Grenada-Loring-Memphis on the terraces and Falaya-Waverly-Collins within the minor bottom (USDA 1964). Average site index, base age 50 yr, was estimated to be 75 for oaks, 85 for yellow-poplar (*Liriodendron tulipifera* L.) and 70 for sweetgum (*Liquidambar styraciflua* L.) on both sites (Carmean et al. 1989). Average age for the dominant and co-dominant stems across the study site was 70 yr.

Study Design

In the fall of 2001, three experimental blocks were identified based on differences in average basal area ($p<0.05$), landform and position. Twelve 2-ac treatment units were designated within the experimental blocks, four units located within the minor bottom (bottom block) and eight units located within the terrace sites upstream from the minor bottom (four each within the east and west blocks). Species composition was dominated by cherrybark oak (*Q. falcata var. pagodifolia* Ell.), yellow-poplar and sweetgum in the bottom block and several species of red and white oaks on the ancestral terraces.

Four overstory treatments, including a control (no harvest), with 3 replications were randomly assigned to the 12 units using a randomized complete block (RCB) design. Harvesting for all treatments was completed in the winter of 2001-2002. Overstory treatments are described below.

• Commercial clearcut: defined by the removal of all stems greater than 6 in. diameter breast height (DBH). This treatment is designed to represent a common practice on industrial forestland.

• High-grade: standard diameter limit harvest where all stems greater then 14 in. DBH are removed. This treatment is designed to represent a common and persistent practice on NIPF lands.

• Two-age: residual stand basal area of 15-20 ft^2/ac targeted. Residual stems were chosen based on spacing criteria and the desire to leave stems of desirable species with an opportunity to increase in value. Desirable species included oaks, hickories (*Carya* spp.) and yellow-poplar.

• No-cut: no harvesting; is designed to act as the study control.

Seedlings

Northern red oak seedlings originating from acorns collected from a seed orchard on the Ames Plantation (Schlarbaum et al. 1998) were chosen for planting following harvest. The seedlings were grown at the Georgia Forestry Commission's Flint River Nursery under fertilization and irrigation protocols developed by Kormanik et al. (1994a). The seedlings were lifted in February 2002 and were graded using procedures developed by Kormanik et al. (1994a, 1994b), as modified by Clark et al. (2000). The seedlings were measured for height and root collar diameter (rcd) growth and the number of first-order lateral roots (folr) (Ruehle and Kormanik 1986) were counted. Seedlings were visually graded based on initial height, rcd and number of folr. Approximately 50 percent of the seedlings were culled. Mean initial rcd, initial shoot height and number of folr for planted seedlings (n=720) were 1.14 cm (0.45 in.), 114 cm (3.74 ft) and 19 respectively. Sixty seedlings were planted by shovel at a 6.1 by 6.1 m (20 by 20 ft.) spacing in March 2002 within each of the 12 units for a total of 720 seedlings.

The planted seedlings were monitored monthly (35-45 days) throughout the growing season for four periods (beginning = 5/02, early = 6/02, mid = 7/02 and late = 8/02). Seedling mortality, defined as lack of green tissue along the primary stem, and herbivory were monitored for all seedlings in all four periods. End-of-season mortality and shoot growth data were obtained in January 2003 for all seedlings after the onset of dormancy.

Herbivory

In order to investigate the effects of deer herbivory, a "browse pressure classification" was used (Buckley 2001). Browse pressure was classified into one of 4 categories; no browse, terminal browse, lateral browse and complete browse. No browse was defined by no visible signs of herbivory, lateral browse was defined as herbivory limited to lateral shoots only, terminal browse was herbivory limited to only the terminal shoot and complete browse was defined as observed herbivory on both lateral and terminal shoots.

Nepalese browntop

During pre-harvest sampling, Nepalese browntop was observed in all units and identified as a possible future problem. Therefore, the response, after overstory disturbance, of understory biomass production was also measured, focusing on Nepalese browntop. Five randomly placed 0.46 m^2 samples were collected in the four sample periods during the growing season and during end-of-season data collection, within each unit for a total of 60 samples per sample period. All material was clipped at ground level, divided into 12 categories (Table 1), dried and weighed according to Mueller-Dombois and Ellenberg (1974). Woody species were removed from all analyses.

Table 1.—Mean biomass (kg/ac) by category for the 12 treatment units during the 2002 growing season for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee.

Biomass Category	Mean Biomass (kg/ac)
Poison ivy	19.78
Japanese honeysuckle	73.46
Forbs (18+ spp.)	634.73
Smartweeds	52.95
Semi-woody plants	5.42
Ferns and fern allies	7.44
Sedges	42.08
Nepalese browntop	670.13
Woody shrubs and seedlings	43.64
Vines	45.09
Grasses	67.42
Rushes	14.85

Analyses

Statistical analyses were conducted using both SAS (SAS Institute Inc. 1989) and NCSS software (Hintze 2001). Mixed-model analysis of variance and Tukey-Kramer multiple comparison tests were used to discern differences in height growth, herbaceous biomass production and browse pressure among treatments. Simple linear regression was used to determine possible relationships between early growing season herbivory (calculated as percent of seedlings incurring any browse in each unit) and mean end-of-season seedling height growth with and without the control data. The category "any browse" includes pooled data from the complete, terminal and lateral browse categories. Logistic regression techniques, using pooled data of terminal browse and complete browse, referred to as terminal shoot removal, and chi-square were used to explore the possible effect of initial seedling height on observed patterns of herbivory. Stepwise variable selection and multiple regression analyses were used to test associations between mean seedling height growth and end-of-season herbaceous biomass production of the twelve different biomass categories and to select the most influential variables. Independent simple linear regression analyses were used to further explore the strongest associations with and without the control data. Statistical significance for all analyses were selected at the a = 0.05 level.

Results

Seedling Growth and Survival

First-year mortality was greatest for the no-cut treatment with mean percent mortality of 33 percent or 59 seedlings (n = 180, p = 0.004) followed by the high-grade and two-age treatments with 5 percent each. The commercial clearcut experienced no seedling mortality.

Eighty-one percent of all seedlings experienced only one growth flush. First-year end-of-season height growth was greater for the no-cut treatment (P = 0.0005). Mean total growth was observed as 12.43 cm, 13.48 cm, 9.18 cm and 22.33 cm for the commercial clearcut, high-grade, two-age and no-cut treatments, respectively (Table 2). Tukey-Kramer multiple comparison tests resulted in no differences between the three harvest treatments. No significant interactions were indicated.

Table 2.—Mean initial height, average height growth for each sampling period and mean total height growth (cm) of 1-0 high-quality northern red oak (*Quercus rubra* L.) seedlings for each sampling period during the 2002 growing season for each treatment and block for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee.

			Growing Season							
Treatment	Initial[1]		Early		Mid		Late		Total	
Commercial clearcut	110.49	(180)[2]	12.40 A[4]	(89)	3.17 A	(41)	0.92	(43)	12.43 A	(180)
High-grade	108.78	(180)	11.46 A	(91)	3.42 A	(30)	6.14	(33)	13.48 A	(171)
Two-age	109.61	(180)	8.73 A	(92)	0.00 B	(27)	-2.79	(28)	9.18 A	(170)
Control (no-cut)	110.70	(180)	26.21 B	(90)	-0.18 B	(20)	-0.20	(30)	22.33 B	(121)
	P = 0.89[3]		P < 0.001		P < 0.01		P = 0.52		P < 0.001	
Block										
East	109.69	(240)	16.68	(119)	2.87	(38)	1.00	(40)	17.72	(222)
West	110.26	(240)	15.60	(121)	1.64	(57)	0.58	(65)	16.35	(213)
Bottom	109.73	(240)	11.82	(122)	0.29	(23)	-7.74	(29)	9.00	(207)
	P = 0.92		P < 0.04		P = 0.85		P = 0.98		P < 0.001	

[1] Sample Dates – Initial = 2/08/02, Early = 6/10/02, Mid = 7/14/02, Late = 8/25/02, End = 1/04/03
[2] Sample size (n), 50% of seedlings were randomly measured at each period during the growing season with n representing the number of actual seedlings in the sample cross-referenced directly from previous sample. Total height growth was measured at the end of the growing season for all seedlings.
[3] Mixed model ANOVA results
[4] Mean separation by Tukey-Kramer multiple comparison tests. Means followed by the same letter are not significantly different at the alpha 0.05 level.

Herbivory

Herbivory was concentrated in the early part of the growing season and was not recurrent. No additional browse was observed after the May observation date. Observed browse pressure was concentrated within the harvest treatments. The three harvest treatments experienced similar pressure with 32 percent, 33 percent and 27 percent of seedlings being completely browsed for the two-age, high-grade and commercial clearcut treatments, respectively. Browse pressure was least severe for the no-cut treatments with 77 percent of seedlings experiencing no browse and only 13 percent being completely browsed. Browse levels for lateral bud browse only and terminal bud browse only were similar among all treatments. Analysis of the pooled dataset (any browse) suggested differences in observed seedling browse pressure among treatments ($P < 0.02$) primarily due to the lower amount of browse pressure experienced by the no cut treatment. No differences in browse pressure were observed between the three harvest treatments. When examined independently of all other variables and across all treatments, browse pressure (any browse) accounted for approximately 67 percent of the variation in total seedling height growth ($R^2 = 0.6720$, $P = 0.011$). Browse pressure exhibited a strong negative relationship ($r = -0.82$) with total growth. Because seedling growth differences occurred between the no-cut treatment and the three harvest treatments, and no differences were found among the harvest treatments, the data was reanalyzed without the controls. The reduced data model resulted in a slightly weaker fit ($R^2 = 0.64$), although the new model was still significant ($P < 0.01$) and a strong association was still observed ($r = -0.80$). A logistic regression model using initial seedling height indicated a relationship with terminal shoot removal ($P < 0.001$). In an attempt to identify "browse height", chi-square was used to test 4 categories of initial height and terminal shoot removal. No seedling with an initial height greater than 148 cm experienced terminal shoot removal ($P <0.001$).

Nepalese browntop

Nepalese browntop was the dominant herbaceous vegetation in most plots at the end of the growing season. Analysis of the 12 biomass categories, through stepwise variable selection and multiple regression across all treatments, revealed that Nepalese browntop appeared to be of greatest importance (Table 3). The overall model was significant ($R^2 = 0.97$, $P < 0.001$), but model fit was reduced by 83 percent with the removal of the Nepalese browntop term (Table 3). Therefore, simple linear regression techniques were used to explore the potential relationship between Nepalese browntop production and mean seedling height growth within individual units. Although a strongly negative relationship was found, Nepalese browntop biomass appeared to be a moderate to weak predictor of end-of-season seedling height growth ($R^2 = 0.63$, $P = 0.003$, $r = -0.80$).

Interestingly, with the removal of Nepalese browntop from the analysis, the relationship between herbaceous biomass production and mean seedling height growth did not exist. Simple linear regression of mean end-of-season height growth and mean herbaceous biomass production without Nepalese browntop

Table 3.—Reduction of R^2 from multiple regression of mean biomass (selected significant biomass terms from stepwise regression - kg/ac) and mean seedling height growth (cm) for the 12 individual treatment units for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee.

Term	R^2	Sum of Squares	P
Full model	0.97	2473.08	0.0009
Error	0.03	12.94	
Smartweeds	0.19[1]	90.04	0.002
Sedges	0.24	113.01	0.0012
Nepalese browntop	0.83	394.28	0.0001
Woody shrubs and seedlings	0.18	86.85	0.0022
Grasses	0.05	22.97	0.0308
Poison ivy	0.11	54.29	0.0059

[1] The reduction in R^2 when the term is removed from the model.
Example: when the Nepalese browntop term is removed, the remaining terms explain approximately 14 percent of the variation in seedling height growth.

resulted in no association (R^2 = 0.008, r = -0.09, P = 0.78). Although no differences in Nepalese browntop production occurred among treatments (P = 0.10), mean biomass production of Nepalese browntop ranged from 1422 kg/ac in the two-age treatment followed by the commercial clearcut, high-grade and no-cut treatments with 888 kg/ac, 324 kg/ac and 47 kg/ac (Figure 1), respectively. When the data were reanalyzed without controls, the reduced data model resulted in a stronger fit (R^2 = 0.75, P < 0.003), and an overall stronger association (r = -0.87). Analysis of all herbaceous material resulted in similar associations as the Nepalese browntop- only analysis. Total end-of-season herbaceous biomass production and end-of-season (total) height growth were significantly negatively related among treatments (r = -0.74, P = 0.006, R^2 = 0.55). Mean end-of-season herbaceous biomass production differed across treatments (P = 0.003).

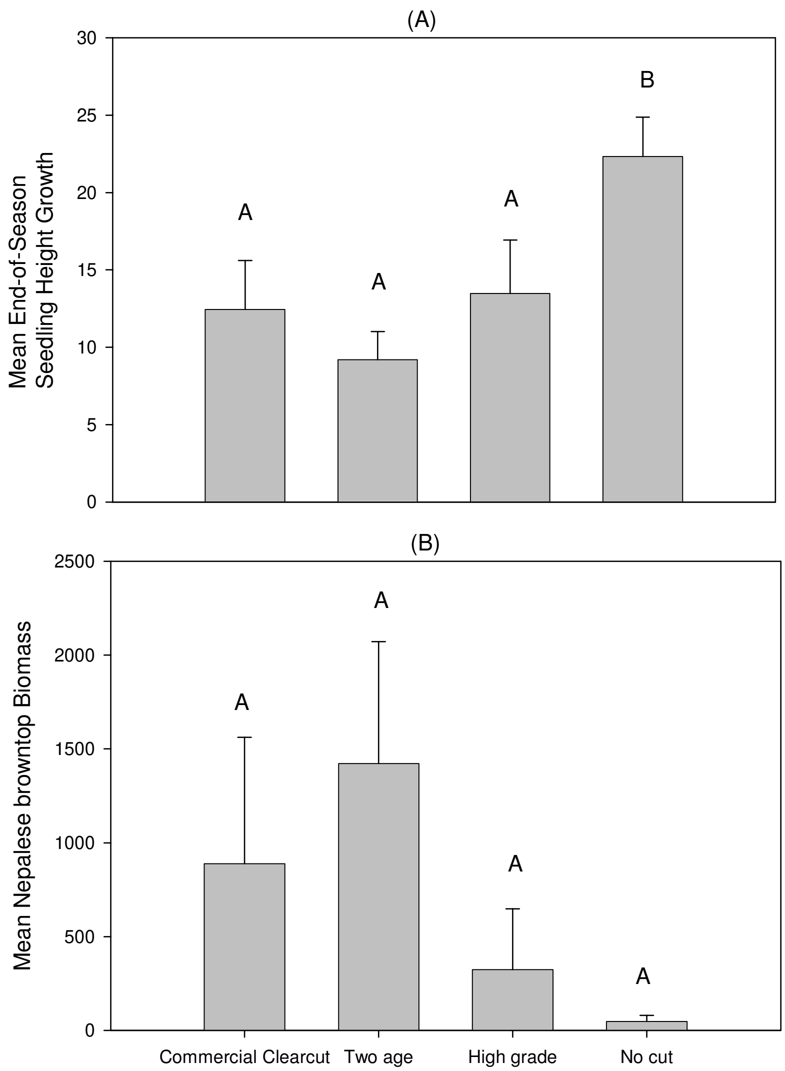

Figure 1.—Mean end-of-season height growth (cm) of 1-0 high-quality northern red oak (*Quercus rubra* L.) seedlings (a) and mean end-of-season Nepalese browntop biomass (kg/ac) (b) for each treatment for the oak regeneration study on the Ames Plantation, Fayette County, TN. Mean seperation by Tukey-Kramer multiple comparison tests. Means followed by the same letter are not significantly different at the alpha 0.05 level.

Discussion and Conclusions

Browse Pressure

In this study, browse pressure, when examined independently, significantly impacted first-year seedling shoot growth, accounting for 67 percent of variation. However, one of the key benefits in using large, high-quality seedlings with a greater initial height at the time of outplanting is the capability of these seedlings to exceed browse height rapidly, escaping damage from herbivory. Conventionally, "browse lines" have been loosely defined at approximately 137 cm (4.5 ft). Results from this study indicate the browse line for this particular site is at 148 cm (4.9 ft), slightly greater. Additionally, results from logistic regression analysis suggest that a strong relationship exists between initial planting height and browse pressure, further indicating that larger seedlings may be more likely to escape browse.

After the first growing season, heights of many seedlings have already approached or surpassed the "local browse line". If second year growth is similar to the first year, it is reasonable to suggest that a majority of seedlings will have surpassed this limiting height. Therefore, high-quality seedlings like those used in this study have a greater initial advantage over commonly available seedling stock due to the larger initial planting height.

For this study, seedlings were planted on 6.1 by 6.1 m (20 by 20 ft) spacing. Planting on such a wide spacing was consistent with enrichment plantings and was not an attempt to establish an oak plantation. Such a wide spacing was hypothesized to reduce seedling apparency and minimize herbivory. Although browse levels were greater early in the growing season, herbivory on all seedlings decreased with the onset of herbaceous vegetation growth. The measured herbaceous biomass for the mid growing season increased by approximately 300 percent from the early growing season. This marked increase in herbaceous material occurred concomitantly with a cessation of browse pressure. No detectable shoot browse was observed following the first observation period (beginning) while clear signs of herbivory were observed on surrounding herbaceous material. Therefore, the flush of herbaceous material either provided protection through concealment or offered an alternative food source for herbivores. Further empirical investigations are needed in addition to this correlative study to address the question of spacing influences on seedling apparency.

Herbaceous Biomass Production

Although herbaceous growth appeared to offer seedling protection from herbivory, herbaceous biomass production appeared to have a significant competitive effect on the development of the oak seedlings used in this study. When examined independently, herbaceous biomass production accounted for approximately 55 percent of the variation in end-of-season height growth. Herbaceous biomass production and seedling growth were also negatively correlated.

Both the stepwise variable selection and multiple regressions suggested that one particular herbaceous species had a greater influence than all other herbaceous material. Nepalese browntop, an introduced invasive, appeared to influence seedling development and at times comprised 50 percent or more of the herbaceous material sampled. Nepalese browntop, when analyzed independently, accounted for the same amount of variation as total herbaceous biomass. When Nepalese browntop was removed from the analysis, all other herbaceous material accounted for less than 1 percent of the variation in mean seedling height growth. Therefore, the results suggest that Nepalese browntop was the overwhelming competitive influence, in terms of herbaceous biomass, in this study during the first growing season. The post-harvest release of this non-native grass appeared explosive due to the species' ability to completely overwhelm the invaded site. In this study, although no significant relationship between Nepalese browntop biomass production and overstory treatment was observed, Nepalese browntop appeared to be affecting seedling growth. In treatment units where the greatest Nepalese browntop response, in terms of biomass accumulation, were observed, the lowest seedling growth was also observed. For example, the two age treatment units experienced the largest Nepalese browntop explosion and the least amount of first-year seedling growth. This suggests that Nepalese browntop could be having a significant impact and due to its growth strategies could continue to impact both artificial and natural regeneration within the study.

Trends and associations observed in the first year of this study have potential implications. It appears that seedlings herbivory by white-tail deer may be overcome by the planting of taller seedlings. Additionally, the observed relationship between seedling growth and Nepalese browntop may persist, further retarding seedling development. However, it is important to note that this is first-year data, yet the first year after planting can be viewed as very critical in establishing artificial reproduction.

Low first-year mortality and the ability to surpass browse levels were observed with seedlings in this study. As a result, these data can be seen as positive. Yet, further empirical investigations are needed to clarify the impacts of both non-native Nepalese browntop and deer herbivory on planted oak seedlings in the CHR.

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