Vegetation Response to Timing of Discing to Manage Northern Bobwhite Habitat in Texas

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Abstract: Discing is commonly recommended to improve northern bobwhite (*Colinus virginianus*) habitat. However, little information exists regarding optimal timing of discing or the duration of discing effects on semiarid rangelands. Our objectives were to evaluate vegetation response to autumn (October 2003), winter (January 2004), and spring (March 2004) discing in two ecoregions of Texas (Rio Grande Plains and Rolling Plains). Our study design was a completely randomized, two-factor (treatment and soil texture) factorial with repeated measures. We collected data on percent bare ground, forb density, visual obstruction, and non-native grass density during pretreatment (September 2003) and six sampling periods post-treatment (March, May, and July 2004 and 2005). Differences in percent bare ground, forb density, and visual obstruction differed ($P>0.05$) among treatments only during the first year post-discing in all soil textures and ecoregions. The trend was for density of non-native grasses to increase (>60%) on both control and disced plots in the Rio Grande Plains. Density of non-native grasses in the Rolling Plains exhibited no ($P<0.05$) change. Our findings suggest the positive, structural effects of discing on bobwhite habitat on semiarid rangelands can be short-lived (<1.5 years) and unintended, negative habitat changes may result from an increase of non-native grasses if additional measures such as herbicide application are not taken.

Key words: Colinus virginianus, discing, non-native grasses, northern bobwhite, Texas

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A basic principle of wildlife habitat management is that animal species are adapted to certain seral stages of ecological succession and that provision of the correct seral stage will improve resource utilization and subsequently enhance abundance (Bailey 1984, Patton 1992, Robinson and Bolen 2003). Northern bobwhites (*Colinus virginianus*) generally are considered an early successional species (Stoddard 1931, Jackson 1972), though seral stage affiliation may vary with site productivity (Spears et al. 1993). Early seral stages provide important brood-rearing and foraging habitat for bobwhites (Stoddard 1931, Rosene 1969, Jackson et al. 1987). Consequently, management practices that disturb the soil, such as discing, have been recommended to manage bobwhite habitat (Stoddard 1931, Rosene 1969, Lehmann 1984, Guthery 1986).

Discing patches of rangeland can improve bobwhite habitat by increasing percentage of bare ground (Webb and Guthery 1983, Greenfield et al. 2002), stimulating growth of important food plants (Peoples et al. 1994), and creating plant structural diversity necessary for invertebrates (Shelton and Edwards 1983, Manley et al. 1994). In semiarid rangelands, the optimal time for discing and its lasting effects on habitat structure are relatively unknown (Fulbright 1999). Recently, the value of discing for improving wildlife habitat has been questioned because soil disturbance may favor establishment of non-native grasses (Johnson and Fulbright 2008) which can be detrimental to bobwhites (Kuvlesky et al. 2002). The

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objectives of our study were to 1) compare bare ground exposure, forb density, and visual obstruction among autumn (October), winter (January), and spring (March) discing over two growing seasons, and 2) document the response of non-native grasses to soil disturbance.

Study Area

Our study was conducted in the Rio Grande Plains and Rolling Plains ecoregions of Texas (Gould 1975). Specific study areas were the James E. Daughtery Wildlife Management Area (WMA) (Live Oak and McMullen counties) and Gene Howe WMA (Hemphill County). The James E. Daughtery WMA study area is in the Rio Grande Plains ecoregion (Gould 1975). It is a 1,781-ha low-fenced multiple-use recreational area. Mean annual temperature was 21.7 C with a mean rainfall of 71.1 cm and a 289-day growing season. Rainfall during the study period exceeded the long-term mean in 2004 (99.0 cm) and approximated the long-term mean in 2005 (61.3 cm). Predominant brush species include honey mesquite (*Prosopis glandulosa*), huisache (*A. smallii*), blackbrush (*A. rigidula*), granjeno (*Celtis pallida*), and pricklypear cactus (*Optuntia lindheimeri*). Native grasses common to the area included silver bluestem (*Bothriochloa laguroides*), curly mesquite (*Hilaria belangeri*), and Arizona cottontop (*Digitaria californica*). Predominant forbs include croton (*Croton* spp.), sunflower (*Helianthus annuus*), dayflower (*Commelina erecta*), and partridge pea (*Chamaecrista fasciculata*). Three species of non-native grasses were found in our study area: King Ranch bluestem (*B. ischaeum*), Kleberg bluestem (*Dicanthium annulatum*), and bermudagrass (*Cynodon dactylon*).

The Gene Howe WMA is in the Rolling Plains ecoregion (Gould 1975). The WMA consists of 2,382 ha located along the Canadian River in Hemphill County. Mean maximum temperature was 35 C in July with a mean minimum of –5 C in January. Mean annual rainfall was 52.1 cm, and the growing season averages 204 days a year. Rainfall during the 2004 study period was well above the long-term mean and approximated in 2005 (55.4 cm) the long-term average. The Gene Howe WMA is characterized as a sand sagebrush (*Artemesia filifolia*)-mid-grass rangeland and eastern cottonwood (*Populus deltoides*)-tallgrass bottomland along the river. Vegetation consisted predominantly of sand sagebrush, sand plum (*Prunus angustifolia*), fragrant sumac (*Rhus aromatica*), eastern cottonwood, netleaf hackberry (*Celtis reticulata*), and black locust (*Robinia pseudoacacia*). Predominant grasses included little bluestem (*Schizachyrium scoparium*), sand dropseed (*Sporobolus cryptandrus*), blue grama (*Bouteloua gracilis*), big bluestem (*A. gerardii*), switchgrass (*Panicum virgatum*), indiangrass (*Sorghastrum nutans*), and alkali sacaton (*Sporobolus airoides*). Common forbs included western ragweed (*Ambrosia psilostachya*), silverleaf nightshade (*Solanum elaeagnifolium*), common sunflower, and Texas croton (*C. texensis*). Three species of non-native grasses occurred on the study site: perennial ryegrass (*Lolium perenne*), Japanese brome (*Bromus japonicus*), and cheatgrass (*Bromus tectorum*).

Methods

Experimental Design

Our study design was a completely randomized, two-factor factorial with repeated measures. The two factors were discing treatment and soil texture. We evaluated two soil textures (i.e., sandy or clay) in each ecoregion. Each soil-delineated study plot consisted of 15 experimental units (10 × 100 m) that were separated by 10-m buffer strips. Our treatments involved one control (no discing) and three seasons of discing: autumn (October 2003), winter (January 2004), and spring (March 2004). We randomly selected three experimental units within each soil texture for each discing treatment and six experimental units for control. Thus, each discing treatment had three replications within each soil-delineated plot, and the control had six replications (3 discing treatments × 3 experimental units/treatment = 9 experimental units; 1 control × 6 experimental units/control = 6 experimental units; for a total of 15 total experimental units per soil study plot). Treatment plots were disced with a heavy disc plow with two gangs of 100-cm diameter blades to a depth of about 10 cm. The disc plow was pulled by a tractor and two passes were made within each plot on each date of discing.

Vegetation Sampling

We visited each of the study areas during May–June 2003 to evaluate potential study plots and determine soil textures. Soil samples were collected with an Oakfield 36² Tube Sampler with Step soil probe (Oakfield Apparatus, Inc., Oakfield, Wisconsin). We overlaid a 50 × 50-m grid over the potential site and extracted 10 cm of soil at each grid point ($n = 18$) contained within the block (100 × 350 m). Soil samples were analyzed at the Texas A&M University-Kingsville soil laboratory to verify soil texture. Blocks meeting the soil-texture criteria were delineated and georeferenced using a Garmin eTrex Venture Global Positioning System (Garmin International, Olathe, Kansas). Coordinates were entered into a geographic information system (GIS) using ArcView (ESRI, Redlands, California) to digitize soil-type blocks.

We collected pretreatment data on percent bare ground, forb density, visual obstruction, and non-native grass density during September 2003. We also collected post-treatment data on these four variables during three sampling periods (March, May, and July) for two years post discing (2004 and 2005). One observer collected all data to minimize observer variability. We established a 100-m transect through the center of each experimental unit. We visually estimated percent bare ground within a 20 × 50-cm sampling frame (Daubenmire 1959) at 10-m intervals beginning at 10 m and terminating at 90 m (nine sampling frames/experimental unit). We also identified plants to species and recorded number of individuals for each species within each sampling frame. We used these data to estimate forb density (forbs m^{-2}) and non-native grass density (non-native plants m^{-2}).

We measured visual obstruction using a 1 m × 30.5-cm vegetation profile board (Nudds 1977) that was marked in 1-dm intervals. Initial readings were taken at a distance of 4 m and a height of 0.5 m in a random direction at 10-m intervals along the transect. Three subsequent readings were obtained at each sampling point at 90°, 180°, and 270° from the first reading. We chose this distance and height because it resulted in the greatest variability in visual obstruction readings (based on pilot study) and represented the approximate height of a mammalian predator of bobwhites, respectively. Visual obstruction was averaged over strata and the four readings for each 10-m interval and then averaged for the transect.

Statistical Analysis

We tested for treatment differences using an *F* test for each soil × time combination because of significant interactions ($P > 0.05$) between treatments, soil texture, and time. We then used Tukey's HSD mean separation test within these combinations to identify which means differed. In addition, we evaluated percent bare ground among treatments based on the bounds of habitat suitability (15%–60%) identified for bobwhites by Kopp et al. (1998).

Results

We do not discuss specific differences in percentage bare ground among treatments because it is obvious that discing will increase bare ground and that the most recent discing treatment generally will have the greatest exposure. Rather, we present data on the duration of the discing effect (i.e., when differences among treatments ceased to exist) and habitat suitability bounds.

Percentage bare ground differed ($P < 0.05$) among treatments only during the initial part (March–May) of the first growing season in both soil textures in the Rio Grande Plains (Table 1). Percentage bare ground remained within the habitat-suitability bounds of bobwhites during this time period and approached the lower bound by July 2004 (Figures 1A and 1B). Discing had a similar treatment life in the Rolling Plains. Percentage bare ground differed ($P < 0.05$) among treatments through the end of the first growing season in clay soils but only through March in sandy soils (Table 1). Suitable bare ground exposure for bobwhites lasted longer in the Rolling Plains, approximating the lower suitability bound during May of the second growing season. (Figures 1C and 1D).

Table 1. Percent bare ground pre- and post-treatment following four treatments (control, Oct discing, Jan discing, and Mar discing) on clay and sandy plots in the Rio Grande (Live Oak and McMullen Counties) and Rolling Plains (Hemphill County) of Texas, March–July 2003–2005. For each ecoregion and soil texture, means in a column accompanied by the same letter are not significantly ($P > 0.05$) different based on Tukey's test.

		2003		2004						2005					
Soil		Pretreatment		Mar		May		Jul		Mar		May		Jul	
Treatment	*n*	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Rio Grande Plains Ecoregion															
Clay															
Control	6	17.2^{B}	3.1	19.3^{B}	6.2	15.7^{B}	3.6	8.0^{A}	1.2	11.7^{A}	3.6	12.4^{A}	3.1	15.8^{A}	3.2
Oct 2003	3	30.0^{AB}	6.0	43.3^{AB}	14.7	37.4^{AB}	10.0	21.5^{A}	5.0	10.7^{A}	3.3	24.4^{A}	5.6	16.1^{A}	4.3
Jan 2004	3	51.3^{A}	11.5	62.0^{A}	11.0	30.2^{AB}	6.1	13.5^{A}	6.1	8.5^{A}	6.7	20.9^{A}	18.7	13.0^{A}	7.7
Mar 2004	3	38.5^{AB}	9.6	70.6^{A}	29.4	51.3^{A}	11.5	14.8^{A}	3.6	17.8^{A}	4.2	22.8^{A}	11.2	23.1^{A}	8.4
Sandy															
Control	6	10.8^{B}	2.0	8.8^{C}	1.4	10.8^{B}	2.0	15.5^{A}	7.7	8.4^{A}	2.8	21.3^{A}	4.4	24.0^{A}	2.4
Oct 2003	3	10.9^{B}	1.8	5.9^{C}	2.4	15.7^{B}	5.1	32.8^{A}	2.9	4.4^{A}	2.0	13.0^{A}	2.1	32.6^{A}	9.7
Jan 2004	3	54.6^{A}	10.4	43.1^{B}	3.1	10.9^{B}	1.8	14.4^{A}	6.5	8.3^{A}	5.6	16.7^{A}	2.2	19.3^{A}	8.0
Mar 2004	3	15.7^{B}	5.1	100.0^{A}	0.0	54.6^{A}	10.4	17.4^{A}	3.4	11.5^{A}	4.6	11.7^{A}	1.5	17.0^{A}	1.3
Rolling Plains Ecoregion															
Clay															
Control	6	6.9^{A}	2.9	28.7^{B}	6.4	41.7^{C}	3.2	24.5^{B}	3.1	17.1^{A}	5.6	15.5^{A}	3.5	16.8^{A}	3.5
Oct 2003	3	7.6^{A}	5.2	42.6^{A}	6.3	48.0^{BC}	8.0	21.9^{B}	5.1	16.5^{A}	9.5	10.6^{A}	0.3	12.2^{A}	1.2
Jan 2004	3	8.3^{A}	3.3	68.7^{A}	5.5	71.1^{AB}	8.7	45.6^{AB}	13.8	35.4^{A}	13.1	16.7^{A}	5.0	16.7^{A}	3.9
Mar 2004	3	5.4^{A}	3.4	71.9^{A}	11.8	73.3^{A}	1.8	50.6^{A}	4.4	24.1^{A}	14.6	20.0^{A}	7.3	20.0^{A}	7.3
Sandy															
Control	6	20.8^{A}	6.8	40.2^{A}	12.7	63.1^{A}	5.4	39.2^{A}	4.3	29.6^{A}	8.1	19.5^{A}	6.2	16.8^{A}	3.4
Oct 2003	3	28.0^{A}	15.0	50.4^{A}	18.7	56.9^{A}	11.4	35.0^{A}	8.0	38.9^{A}	6.9	8.9^{A}	1.7	10.0^{A}	2.8
Jan 2004	3	8.5^{A}	3.6	59.8^{AB}	18.2	68.3^{A}	15.0	37.8^{A}	8.3	42.0^{A}	4.0	16.3^{A}	6.0	17.0^{A}	5.2
Mar 2004	3	9.8^{A}	7.7	78.3^{B}	9.7	62.0^{A}	12.4	34.6^{A}	4.2	36.9^{A}	14.2	9.8^{A}	1.5	12.8^{A}	2.0

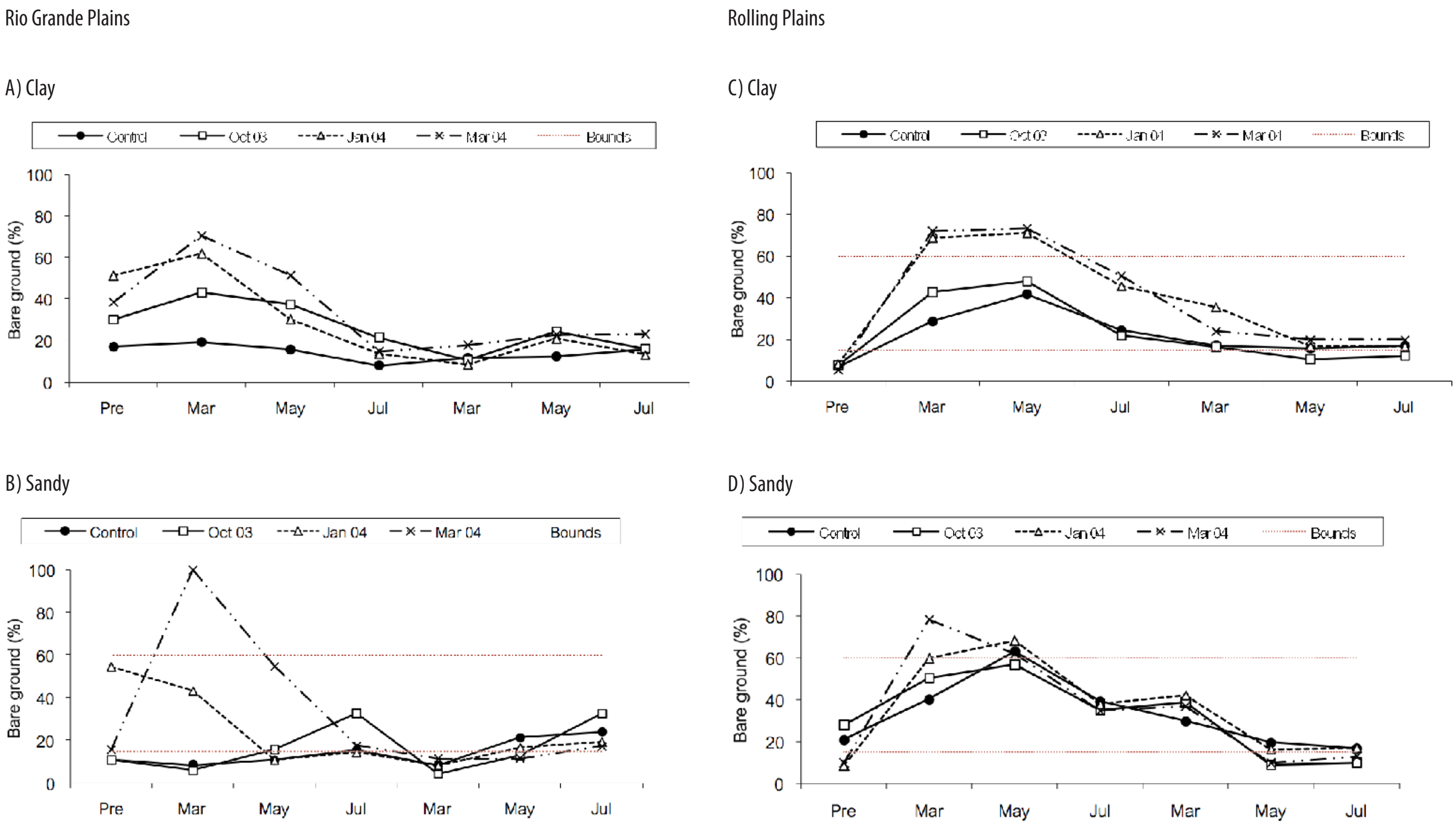

Figure 1. Bare ground exposure (%) in relation to bounds of habitat suitability for northern bobwhite among four discing treatments (control, Oct 2003, Jan 2004, and Mar 2004) on clay and sandy soils in the Rio Grande Plains (A,B) and Rolling Plains (C,D) of Texas, 2003–2005. Pretreatment data were collected on September 2003 and vegetation sampling occurred March–July 2004 and 2005.

We documented a diversity of forbs and grasses during our study (Table 2). Mean forb density (forbs m^{-2}) differed among treatments during March 2004 and March 2005 in clay-textured soils in the Rio Grande Plains (Table 3). Sandy-textured soils exhibited differences in mean forb density only in March 2004. Seasonal effects appeared to have influenced fluctuations in forb density because forb density generally peaked during March in both years independent of treatment or soil texture (Figures 2A and 2B). We observed similar trends in the Rolling Plains, except these trends were expressed about one month later than in the Rio Grande Plains. Mean forb density differed among treatments during May 2004 in clay soils and May 2005 in sandy soils (Table 3). Seasonal effects also were observed in forb density in this ecoregion; forb density generally peaked during May in both years independent of treatment or soil texture (Figures 2C and 2D).

Mean visual obstruction (%) did not differ ($P>0.05$) among treatments throughout the study in clay soils in the Rio Grande Plains (Table 4). Mean visual obstruction differed ($P<0.05$) only during the first part of the growing season (March–May 2004) in sandy soils (Table 3; Figures 3A and 3B). In the Rolling Plains, mean visual obstruction differed ($P<0.05$) during March 2004 in clay and sandy soils (Table 3; Figures 3A and 3B). Thus, across all soil textures and in both ecoregions, mean visual obstruction was similar ($P>0.05$) among treatments by the end of the first growing season (Table 4).

We observed a general, positive trend for non-native grass density from pretreatment to two years post-discing in both soil types and all treatments in the Rio Grande Plains (Table 5). Non-native grass density increased ($P<0.05$) only in sandy soils of disced plots (Table 4). We documented no significant changes ($P>0.05$) in den-

Table 2. Common forb and grass species found on clay and sandy plots in the Rio Grande (Live Oak and McMullen counties) and Rolling Plains (Hemphill County) of Texas, March–July 2003–2005.

	Clay		Sandy	
Type	Common name	Scientific name	Common name	Scientific name
Rio Grande Region				
Forb	Western ragweed	*Ambrosia psilostachya*	Western ragweed	*Ambrosia psilostachya*
	Texas thistle	*Cirsium texanum*	Texas thistle	*Cirsium texanum*
	Engelmann daisy	*Engelmannia pinnatifida*	Wooly croton	*Croton capitatus*
	Common sunflower	*Helianthus annuus*	Heart-sepal wild buckwheat	*Eriogonum multiflorum*
	Wild alfafa	*Medicago sativa*	Common sunflower	*Helianthus annuus*
	Sour clover	*Oxalis dillenii*	Horsemint	*Monarda citriodaro*
	Tallowweed	*Plantago hookeriana*	Tallowweed	*Plantago hookeriana*
	Redseed plantain	*Plantago rhodosperma*	Upright prairie coneflower	*Ratibida columnaris*
	American nightshade	*Solanum ptycanthum*	Silverleaf nightshade	*Solanum eleagnifolium*
	Fan-leaf vervain	*Verbena plicata*	Fan-leaf vervain	*Verbena plicata*
Grass	Japanese broome	*Bromus japonicus*	Japanese broome	*Bromus japonicus*
	Cheatgrass	*Bromus tectorum*	Cheatgrass	*Bromus tectorum*
	Buffalograss	*Buchloe dactyloides*	Canadian wildrye	*Elymus canadensis*
	Ryegrass	*Lolium perenne*	Sand lovegrass	*Eragrostis trichodes*
	Common witchgrass	*Panicum capillare*	Ryegrass	*Lolium perenne*
	Vinemesquite	*Panicum obtusum*	Common witchgrass	*Panicum capillare*
	Switchgrass	*Panicum virgatum*	Vinemesquite	*Panicum obtusum*
	Marsh hay cordgrass	*Spartina patens*	Switchgrass	*Panicum virgatum*
	Alkali sacaton	*Sporobolus airoides*	Alkali sacaton	*Sporobolus airoides*
	Six weeks grass	*Vulpia octoflora*	Sand dropseed	*Sporobolus cryptandrus*
Rolling Plains Region				
Forb	Western ragweed	*Ambrosia psilostachya*	Western ragweed	*Ambrosia psilostachya*
	Arkansas lazy daisy	*Aphanostephus skirrhobasis*	Horsemint	*Monarda citriodaro*
	Texas thistle	*Cirsium texanum*	Sour clover	*Oxalis dillenii*
	Wild geranium	*Geranium carolinianum*	Wooly croton	*Croton capitatus*
	Bur-clover	*Medicago polymorpha*	Dayflower	*Commelina erecta*
	Horsemint	*Monarda citriodaro*	Deer-pea vetch	*Vicia ludoriciana*
	Sour clover	*Oxalis dillenii*	Old Man's beard	*Clematis drummondii*
	Tallowweed	*Plantago hookeriana*	Tallowweed	*Plantago hookeriana*
	Upright prairie coneflower	*Ratibida columnaris*	Campherweed	*Pluchea camphorata*
	Deer-pea vetch	*Vicia ludoriciana*	Texas thistle	*Cirsium texanum*
Grass	Purple threeawn	*Aristida purpurea*	Bermudagrass	*Cynodon dactylon*
	King ranch bluestem	*Bothriochloa ischaemum*	Fescue	*Festuca versuta*
	Buffelgrass	*Cenchrus ciliaris*	Texas wintergrass	*Stipa leucotricha*
	Hooded windmill grass	*Chloris cucullata*	King ranch bluestem	*Bothriochloa ischaemum*
	Bermudagrass	*Cynodon dactylon*	Hooded windmill grass	*Chloris cucullata*
	Kleberg bluestem	*Dichanthium annulatum*	Buffelgrass	*Cenchrus ciliaris*
	Plains lovegrass	*Eragrostis intermedia*	Purple threeawn	*Aristida purpurea*
	Hall panicum	*Panicum halli*	Red lovegrass	*Eragrostis secundiflora*
	Johnsongrass	*Sorghum halepense*	Six weeks grass	*Vulpia octoflora*
	Texas wintergrass	*Stipa leucotricha*	Grassbur	*Cenchrus incertus*

sity of non-native grasses in either clay or sandy soils in the Rolling Plains (Table 5).

Discussion

Habitat changes resulting from discing were short-lived. Differences among treatments in percentage bare ground and forb density ceased to exist by the end of the first growing season. Short-term (<2 years) improvements in habitat quality for northern bobwhites following discing also appear common in mesic ecosystems (Stoddard 1931, Buckner and Landers 1979, Jones et al. 1993, Greenfield et al. 2002). Considering that our study was conducted in more xeric rangelands, we anticipated longer-lasting treatment effects resulting from slower recovery of vegetation after disturbance. The short-lived treatment effects of discing in our study were likely the result of above-average rainfall. The study sites in the Rio Grande and Rolling Plains received about 30 cm and 20 cm of rainfall, respectively, above long-term annual means during the first year post-discing and average rainfall the year after. Because rainfall exerts a profound influence on vegetation dynamics in semi-arid rangelands, this occurrence of abundant rainfall likely shortened treatment life. Fulbright (1999, 2004) documented that habitat response to discing could be variable and inconsistent from year to year in semiarid rangelands depending on rainfall.

In our study, seasonal effects appeared to have a stronger influence on forb density than discing or soil texture. We observed consistent seasonal fluctuations in forb density in both ecoregions somewhat independent of treatment or soil texture. Forb density generally peaked in March in the Rio Grande Plains and May in

Table 3. Forb density (plants m^{-2}) pre- and post-treatment following four treatments (control, Oct discing, Jan discing, and Mar discing) on clay and sandy plots in the Rio Grande (Live Oak and McMullen counties) and Rolling Plains (Hemphill County) of Texas, March–July 2003–2005. For each ecoregion and soil texture, means in a column accompanied by the same letter are not significantly (P >0.05) different based on Tukey's test.

		2003		2004						2005					
Soil		Pretreatment		Mar		May		Jul		Mar		May		Jul	
Treatment	*n*	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Rio Grande Plains Ecoregion															
Clay															
Control	6	13.1^{A}	4.8	119.1^{A}	17.1	53.0^{A}	8.6	31.3^{A}	7.2	81.9^{B}	8.1	61.5^{A}	10.8	41.9^{A}	9.5
Oct 2003	3	18.5^{A}	6.8	127.4^{A}	44.0	95.9^{A}	20.5	33.3^{A}	5.7	106.7^{AB}	28.6	48.1^{A}	14.1	43.0^{A}	9.3
Jan 2004	3	18.9^{A}	5.3	19.3^{B}	2.6	47.0^{A}	8.2	37.8^{A}	1.9	153.7^{A}	6.3	43.3^{A}	6.3	28.9^{A}	1.3
Mar 2004	3	22.2^{A}	6.3	95.9^{AB}	95.9	39.3^{A}	12.3	45.6^{A}	12.4	90.7^{B}	17.3	63.3^{A}	8.0	52.6^{A}	15.5
Sandy															
Control	6	17.2^{A}	4.3	102.4^{AB}	31.9	80.2^{A}	20.0	27.8^{A}	7.2	74.4^{A}	21.7	24.8^{A}	6.7	25.6^{A}	2.5
Oct 2003	3	13.3^{A}	1.9	144.8^{A}	12.5	94.8^{A}	11.6	37.0^{A}	6.2	55.6^{A}	12.0	28.5^{A}	3.2	39.6^{A}	10.0
Jan 2004	3	20.7^{A}	1	78.1^{B}	15.5	115.9^{A}	18.0	61.9^{A}	17.2	53.7^{A}	14.6	46.7^{A}	10.3	33.0^{A}	5.0
Mar 2004	3	19.3^{A}	3.6	0.0^{C}	0.0	57.0^{A}	4.9	62.2^{A}	17.6	96.7^{A}	52.1	31.1^{A}	5.3	20.0^{A}	4.8
Rolling Plains Ecoregion															
Clay															
Control	6	74.1^{A}	10.9	0.2^{A}	0.2	43.9^{B}	8.7	43.5^{A}	3.5	37.0^{A}	6.0	58.1^{A}	11.0	46.9^{A}	3.9
Oct 2003	3	73.7^{A}	20.2	0.0^{A}	0.0	103.7^{A}	24.3	45.2^{A}	7.8	59.6^{A}	2.4	84.1^{A}	35.3	38.9^{A}	5.9
Jan 2004	3	63.7^{A}	25.7	0.0^{A}	0.0	42.2^{B}	8.4	20.7^{A}	7.7	39.6^{A}	11.2	75.6^{A}	18.4	40.0^{A}	1.3
Mar 2004	3	81.1^{A}	25.5	0.0^{A}	0.0	67.0^{A}	2.3	53.7^{A}	3.5	29.6^{A}	1.5	71.9^{A}	14.3	50.4^{A}	8.4
Sandy															
Control	6	15.9^{A}	3.6	0.2^{A}	0.2	24.6^{A}	5.8	18.3^{A}	2.9	29.6^{A}	3.7	68.5^{A}	6.6	40.0^{A}	13.9
Oct 2003	3	11.1^{A}	4.5	0.0^{A}	0.0	79.6^{A}	46.3	55.2^{A}	18.9	35.6^{A}	9.7	25.2^{B}	10.9	19.3^{A}	7.5
Jan 2004	3	8.9^{A}	5	0.0^{A}	0.0	46.3^{A}	31.9	45.2^{A}	7.0	40.0^{A}	2.3	47.0^{AB}	22.3	20.0^{A}	7.8
Mar 2004	3	12.6^{A}	2.7	0.0^{A}	0.0	69.6^{A}	21.5	38.1^{A}	3.6	58.5^{A}	21.9	37.0^{B}	9.1	31.5^{A}	2.3

Table 4. Mean visual obstruction (%) pre- and post-treatment following four treatments (control, Oct discing, Jan discing, and Mar discing) on clay and sandy plots in the Rio Grande (Live Oak and McMullen counties) and Rolling Plains (Hemphill County) of Texas, March–July 2003–2005. For each ecoregion and soil texture, means in a column accompanied by the same letter are not significantly (P >0.05) different based on Tukey's test.

		2003		2004						2005					
Soil		Pretreatment		Mar		May		Jul		Mar		May		Jul	
Treatment	*n*	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Rio Grande Plains Ecoregion															
Clay															
Control	6	60.3^{A}	7.3	7.5^{A}	1.3	47.8^{A}	3.1	71.2^{A}	2.3	44.5^{A}	5.0	49.1^{A}	4.4	40.3^{A}	4.0
Oct 2003	3	48.4^{A}	10.6	2.2^{A}	0.5	34.6^{A}	4.5	54.8^{A}	4.1	27.6^{A}	4.5	35.8^{A}	2.1	36.7^{A}	3.9
Jan 2003	3	68.8^{A}	6.1	0.8^{A}	0.2	37.8^{A}	4.5	60.2^{A}	5.8	35.2^{A}	4.6	30.1^{A}	5.2	39.6^{A}	6.0
Mar 2004	3	70.7^{A}	6.7	3.3^{A}	1.7	20.7^{A}	2.5	83.4^{A}	7.7	48.2^{A}	9.1	38.9^{A}	7.3	32.8^{A}	2.1
Sandy															
Control	6	78.9^{A}	3.6	48.6^{A}	5.5	77.5^{AB}	4.5	79.9^{A}	3.2	42.5^{A}	6.6	84.5^{A}	5.1	87.7^{A}	3.2
Oct 2003	3	70.3^{A}	5.5	35.0^{A}	5.5	95.9^{A}	2.0	90.5^{A}	3.6	61.1^{A}	5.9	62.9^{A}	9.3	99.1^{A}	0.6
Jan 2003	3	86.6^{A}	3.9	2.5^{B}	0.2	56.1^{B}	3.9	90.2^{A}	3.7	41.8^{A}	9.5	79.8^{A}	7.6	98.8^{A}	1.3
Mar 2004	3	87.2^{A}	3.4	0.0^{B}	0.0	24.7^{C}	5.2	90.4^{A}	3.2	29.1^{A}	7.9	74.1^{A}	8.7	89.0^{A}	3.8
Rolling Plains Ecoregion															
Clay															
Control	6	83.6^{A}	5.5	52.1^{A}	5.4	17.6^{A}	2.1	37.3^{A}	3.7	28.1^{A}	1.9	31.2^{A}	1.1	68.4^{A}	4.5
Oct 2003	3	98.3^{A}	1.1	0.0^{B}	0.0	4.5^{A}	0.4	33.1^{A}	3.0	27.6^{A}	1.5	31.4^{A}	2.2	71.2^{A}	7.6
Jan 2003	3	81.6^{A}	8.9	0.0^{B}	0.0	3.5^{A}	0.4	29.3^{A}	4.3	25.3^{A}	3.3	30.9^{A}	1.7	71.1^{A}	8.1
Mar 2004	3	86.2^{A}	5.6	0.0^{B}	0.0	3.8^{A}	0.4	48.4^{A}	4.5	30.0^{A}	0.9	26.3^{A}	1.6	75.2^{A}	5.6
Sandy															
Control	6	72.8^{A}	5.7	70.6^{A}	7.6	22.7^{A}	3.6	70.2^{A}	5.1	54.6^{A}	4.5	37.6^{A}	1.3	64.7^{A}	4.8
Oct 2003	3	54.1^{AB}	10.4	0.0^{B}	0.0	6.8^{A}	0.9	75.5^{A}	6.1	32.8^{A}	4.8	34.6^{A}	0.6	64.4^{A}	5.1
Jan 2003	3	76.1^{A}	10.3	0.0^{B}	0.0	8.5^{A}	1.2	84.2^{A}	6.9	57.4^{A}	3.1	36.9^{A}	0.6	75.9^{A}	6.5
Mar 2004	3	35.9^{B}	4.0	0.0^{B}	0.0	8.3^{A}	1.2	86.2^{A}	6.2	48.1^{A}	6.1	34.4^{A}	0.7	73.7^{A}	5.3

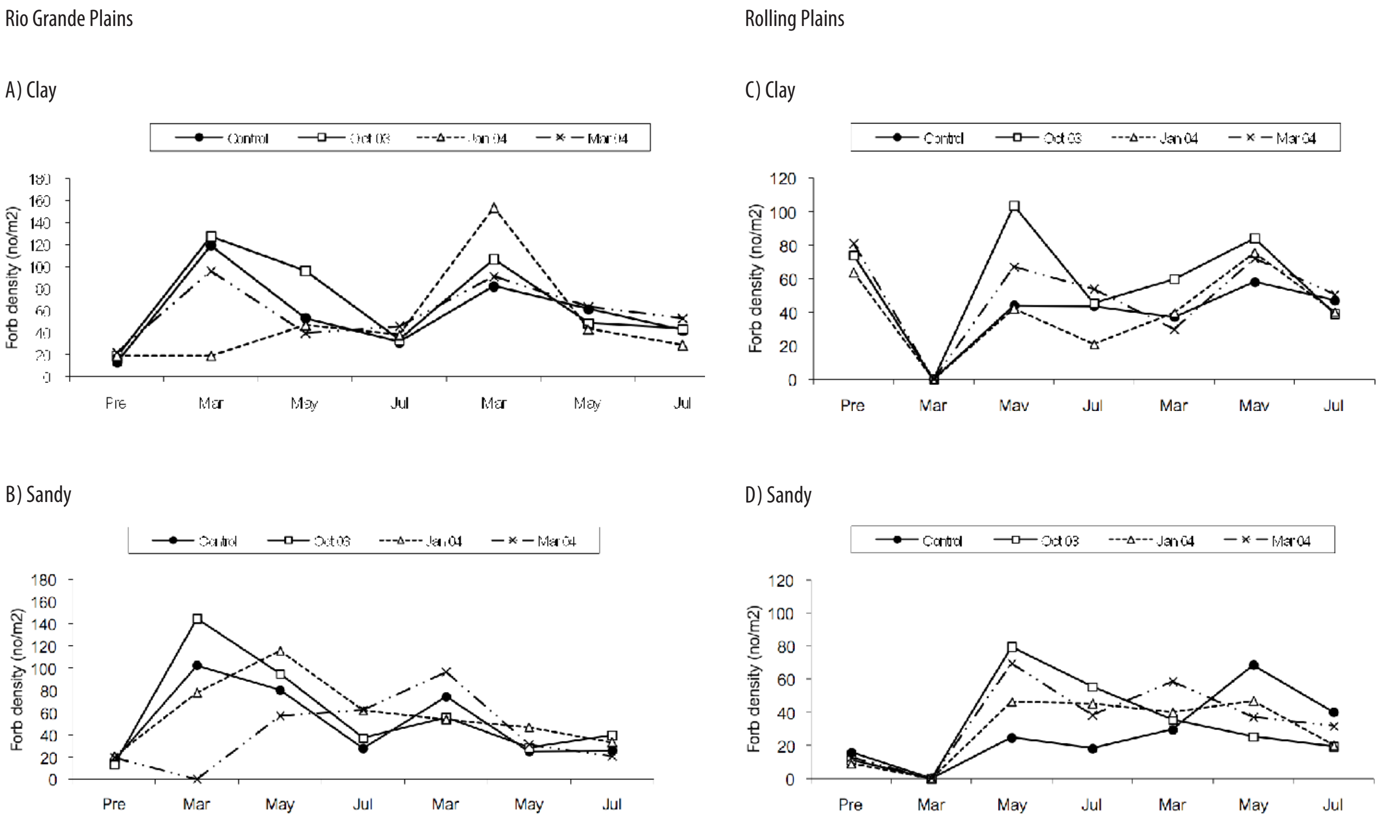

Figure 2. Forb density (plants m^{-2}) among four discing treatments (control, Oct 2003, Jan 2004, and Mar 2004) on clay and sandy soils in the Rio Grande Plains (A,B) and Rolling Plains (C,D) of Texas, 2003–2005. Pretreatment data were collected on September 2003 and sampling occurred March–July 2004 and 2005.

the Rolling Plains. Peak forb density in spring in both ecoregions resulted from response of cool-season species. The one-month delay in peak forb density in the Rolling Plains was expected because the higher latitude of this site resulted in a relatively longer and harsher winter season.

An interesting finding of our study was that discing appeared to accelerate establishment of non-native grasses in the Rio Grande Plains. Although density of non-native grasses increased on both control and disced plots, percent increase of these grasses was greater numerically on disced plots, particularly those in sandy soils. We did not observe such a pronounced response of non-native grasses in the Rolling Plains. These contrasting results may be related to ecological and physiological characteristics of the non-native species involved. Kleberg bluestem, King Ranch bluestem, and bermudagrass were the non-native species found in the Rio Grande Plains study sites. These grasses are warm-season, peren-

Table 5. Percent change in density of non-native grasses (plants m^{-2}) from pre-discing (Sep 2003) to two-years post-discing (Jul 2005) in the Rio Grande (Live Oak and McMullen counties) and Rolling Plains (Hemphill County) of Texas.

Soil		2003 Pretreatment		2005 Jul		Difference			
Treatment	*n*	Mean	SE	Mean	SE	Mean	SE	% Change	*P*-value
Rio Grande Plains Ecoregion									
Clay									
Control	6	23.9	7.8	38.9	16.4	15.0	11.2	62.8%	0.24
Disced	9	13.7	6.9	28.0	14.4	14.3	7.8	104.4%	0.10
Sandy									
Control	6	7.1	2.5	33.3	14.6	26.3	14.8	369.0%	0.14
Disced	9	10.0	2.1	54.2	14.9	44.2	14.0	442.0%	0.01
Rolling Plains Ecoregion									
Clay									
Control	6	8.9	4.0	13.9	3.9	5.0	3.1	56.2%	0.17
Disced	9	3.5	1.0	8.2	2.2	4.7	2.4	134.3%	0.08
Sandy									
Control	6	35.9	7.1	27.1	4.7	−8.9	4.2	−24.5%	0.90
Disced	9	41.9	5.8	29.5	8.5	−12.4	11.4	−29.6%	0.31

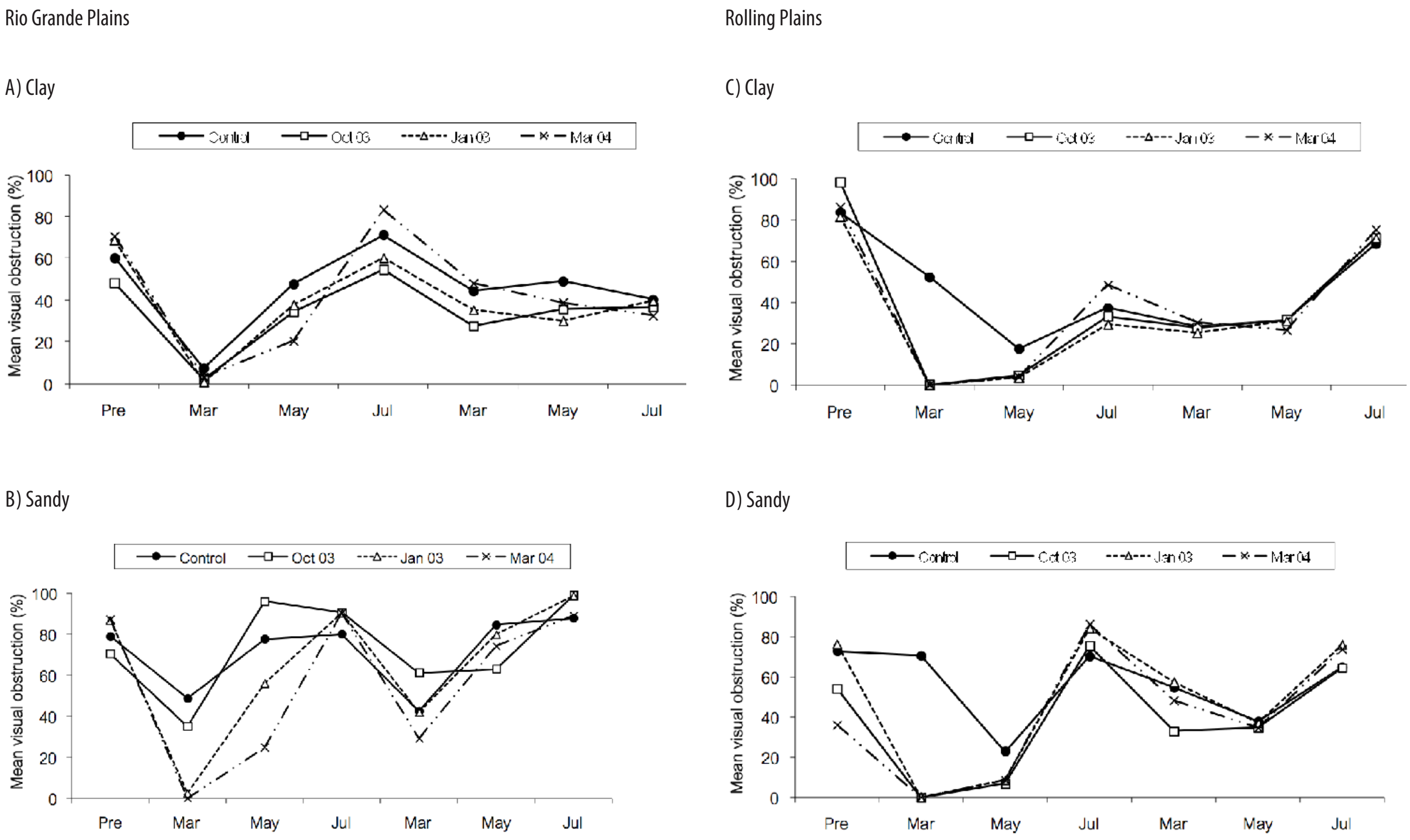

Figure 3. Mean visual obstruction (%) among four discing treatments (control, Oct 2003, Jan 2004, and Mar 2004) on clay and sandy soils in the Rio Grande Plains (A,B) and Rolling Plains (C,D) of Texas, 2003–2005. Pretreatment data were collected on September 2003 and sampling occurred March–July 2004 and 2005.

nial grasses that photosynthesize by the C_4 pathway. These C_4 species complete most of their growth during warmer portions of the year after the C_3 plants have completed their growth. The invasive grass species in the Rolling Plains study sites, cheatgrass, Japanese brome, and perennial ryegrass, are C_3 species that complete most of their growth at the same time as the period of maximum growth of cool season forbs. Additionally, cheatgrass and Japanese brome are both annuals that senesce as seeds mature during the summer. Apparent differences in the response of non-native grass species between the Rio Grande Plains and Rolling Plains may have resulted in part because of differences in season of growth relative to the timing of discing and longevity of the non-native grass species present.

Our findings are consistent with others reporting a facilitating, but variable role of soil disturbance in establishment and spread of non-native plants (Brown and Peet 2003, D' Antonio et al. 1999). Studies have reported mixed responses of invasive species to disturbance ranging from increasing (Johnson and Fulbright 2008) to decreasing (Madison et al. 2001) to no-effect (Hobbs and Atkins 1988). These mixed responses may be influenced by soil physical and chemical properties and non-native plant species involved. Johnson and Fulbright (2008) reported canopy cover of buffelgrass (*Pennisetum ciliare*) was not affected by discing on Delmita soils, but exhibited a 10-fold increase five-years post discing on Ramadero soils. The possible role discing may have in facilitating establishment of non-native grasses is of concern because non-native grasses generally do not represent suitable bobwhite habitat (Kuvlesky et al. 2002, Sands 2006). Flanders et al. (2006) reported sites dominated by non-native plants had bobwhite densities about 50% lower than sites dominated by native plants.

Management Implications

Timing of discing did not appear to have a profound impact on habitat structure or duration of treatment life in our study. Our findings indicate the structural effects of discing on bobwhite habitat can be short-lived (<1.5 years) on semi-arid rangelands, and maintaining bobwhite habitat through discing is a biennial management practice. A management concern is density of non-native grasses may increase following discing, particularly when invasive species are involved. This finding is important because non-native grasses generally do not represent suitable bobwhite habitat. In making decisions regarding habitat manipulation, managers must weigh the temporary benefits derived from discing against the potential long-term detrimental impacts on bobwhite habitat resulting from increased density of non-native grasse

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