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VEGETATION AND ARTHROPOD RESPONSES TO BRUSH REDUCTION BY GRUBBING AND STACKING

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ABSTRACT

Grubbing is a mechanical brush-reduction technique that allows targeting of mesquite (*Prosopis glandulosa*) and huisache (*Vachellia farnesiana*) and can be used to open lanes for hunting northern bobwhites (*Colinus virginianus*). Follow-up treatments of stacking allow the piling up of downed brush. We initiated this study on the Santa Gertrudis Division of the King Ranch, Inc., Texas, to determine effects of grubbing and stacking on vegetation and arthropod communities important to bobwhite. We hypothesized that grubbing and stacking would be able to selectively remove mesquite and huisache while leaving mixed brush species largely intact. We hypothesized that soil disturbance treatments would lead to improved brooding, feeding, and nesting habitat for bobwhite through an increase in herbaceous food plants, arthropods, and nesting cover. We sampled vegetation prior to treatment during July 2012 and posttreatment during November 2012, March 2013, and July 2013. We sampled arthropods before treatment in July 2012 and monthly posttreatment until July 2013, a year marked by extreme drought in South Texas. We detected a positive response of bobwhite food grasses and/or sedges 1 year after initial treatments but detected no treatment effect on bobwhite food forbs. We detected no effects of treatments on nesting cover. Grubbing and stacking did not affect total Insecta abundance; however, Insecta biomass and Arachnida abundance and biomass responded both positively and negatively to treatments. To better understand the effects of grubbing and stacking, replication of this study during years of average and above average precipitation should be conducted.

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Key words: *Vachellia farnesiana*, Arthropoda, D-Vac, honey mesquite, huisache, grubbing, *Prosopis glandulosa*, stacking, sweep net

Woody-plant encroachment is common and widespread throughout rangelands in much of the United States (Van Auken 2000). Such encroachment could be caused by many factors including livestock grazing, changes in fire frequencies, and elevated levels of CO₂; such encroachment is likely a combination of many factors (Van Auken 2000). Smith and Rechenstien (1964) reported that 93% of the Rio Grande Plains and 34% of

the Coastal Prairie in Texas have some brush infestation. This is not necessarily detrimental for northern bobwhite (*Colinus virginianus*), given that woody plants provide them with basic habitat resources (Stoddard 1931, Rosene 1969, Lehmann 1984, Schroeder 1985). Opinions vary on the ideal percentage of woody cover for bobwhites. Lyons and Ginnet (1998) suggest 15–25% woody cover of short stature, typically <1 m tall. In Wilbarger County, Texas, bobwhites selected areas that averaged 29% woody canopy cover (Ransom et al. 2008) but selected for areas of 20–60% woody cover and avoided areas with <20% in South Texas (Kopp et al. 1998). This illustrates that

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bobwhite often use areas with high percentage of brush cover at the landscape level. What further complicates these relationships is the concept of habitat slack (Guthery 1999), which postulates that different habitat configurations may be equally suitable for bobwhites. Tall herbaceous cover can partially take the place of woody cover by providing screening and loafing cover, and different amounts of woody cover may be equally inhabitable (Hernández and Guthery 2012).

Although woody cover is a crucial habitat component for bobwhites, woody plants can outcompete grasses and forbs that provide nesting cover and food for bobwhites (Guthery 1986, Hernández and Guthery 2012). As a result of this competition, excessive woody cover can limit the amount of usable habitat space available to bobwhites (Guthery 1999, Hernández and Guthery 2012). Brush management of thick stands can increase edge and interspersed habitat types (Guthery and Rollins 1997) and reduce the competitive effect of woody plants on important grasses and forbs (Fulbright 1997). Soil disturbance through brush management also favors many species of bobwhite food forbs and grasses (Guthery 1986). However, although brush management may be beneficial in certain situations, food produced by herbaceous plants is often not a limiting factor for bobwhites (Guthery 1997). Therefore, a brush management technique that increases bobwhite food plants will not necessarily increase bobwhite numbers.

Arthropods provide an important food resource for bobwhites, particularly chicks and laying females. Insects help satisfy high protein requirements of growing chicks (Nestler 1940) and laying females have been shown to consume 2.3–4.0 times more invertebrates than nonlaying females (Harveson et al. 2004). Yates et al. (1995) documented that bobwhites selected areas with a greater abundance of arthropods for brooding habitat. In South Texas, arthropods may be important year round in the bobwhite diet. Insects made up the highest percentage of the bobwhite diet during a dry winter and the lowest during a period of average spring precipitation on King Ranch from 1949 through 1951 (Lehmann 1984). In southwestern Texas, arthropods were found in 100% of bobwhite and scaled quail (*Callipepla squamata*) crops collected during June and September, and in 96% of crops collected during autumn and winter (Campbell-Kissock et al. 1985).

Grubbing is a mechanical treatment for brush management that land managers can use to combat brush encroachment (Bontrager et al. 1979). Unlike some other methods of brush management (e.g., root-plowing or chaining), grubbing is an individual plant treatment that allows for selectively removing woody plants. After grubbing, individual plants are left in place but stacking can be used in combination with grubbing to pile up downed brush left from grubbing.

We tested 3 hypotheses: 1) grubbing and stacking will leave mixed brush species (woody cover excluding mesquite and huisache) largely intact while removing mesquite and huisache; 2) the soil disturbance related to grubbing and stacking will improve brooding and feeding

habitat by increasing canopy coverage of food-producing forbs, grasses, and/or sedges, as well as forb species richness, bare ground, arthropod abundance and biomass, which are all resources that are important to growing chicks and adult bobwhite; and 3) grubbing and stacking will improve nesting habitat by increasing the number of suitable nesting clumps for breeding bobwhites.

STUDY AREA

This study was conducted on the Santa Gertrudis Division of King Ranch, Inc. near Kingsville, Texas in Kleberg County (27.30°N, 97.51°W). The grubber and stacker work totaled 1,456 ha on cleared strips. A nontreated site was established on a 650-ha section of a pasture located at a maximum of 8,567 m from the treated sites. The most common soil type on the study area was Palobia fine sandy loam (fine-loamy, mixed, active, hyperthermic Typic Natrustalfs; Natural Resources Conservation Service 2011). Common woody species on the study area included honey mesquite (*Prosopis glandulosa*), huisache (*Vachellia farnesiana*), brasil (*Condalia hookeri*), and granjeno (*Celtis ehrenbergiana*). Common forbs included palafoxia (*Palafoxia texana ambigua*), crotons (*Croton* spp.), and sidas (*Sida* spp.). Common native grasses include sandbur (*Cenchrus* spp.), hooded windmillgrass (*Chloris cucullata*), tanglehead (*Heteropogon contortus*), gramas (*Bouteloua* spp.), and threeawns (*Aristida* spp.). Common nonnative grasses include guinea grass (*Megathyrsus maximus*), Durban's crowfoot (*Dactyloctenium aegyptium*), buffelgrass (*Cenchrus ciliaris*), Kleberg bluestem (*Dichanthium annulatum*) and other Old World bluestems (*Dicanthium* and *Bothriochloa* spp.). Prior to treatments, the nontreated site was more open than the treated sites because of more regrowth running mesquite, which was likely a result of historical management practices. Grazing consisted of a cow-calf grazing operation (King Ranch, Inc., personal communication). Stocking rate was 13.4 ha/animal unit in 2012 and 24.3 ha/animal unit in 2013 in the pasture with the nontreated site and 10.9 ha/animal unit in 2012 and 17.8 ha/animal unit in 2013 in the pasture with the treated site. Stocking rates were reduced in treated and untreated sites in 2012 to compensate for the effects of the drought on forage availability.

Weather

Precipitation data were obtained from King Ranch, Inc. from a rain gauge 4,612 m from the farthest treated transect post and 3,970 m from the farthest nontreated transect post. Rain gauges were checked after each rain event by ranch personnel. Total precipitation was 46.5 cm during the study (Aug 2012–Jun 2013), far drier than the average annual precipitation of 65.5 cm from 1985 to 2012 on the Santa Gertrudis Division (King Ranch, Inc., personal communication). September 2012 and June 2013 had the most precipitation with 13.08 and 10.16 cm, respectively. October and December 2012, and March 2013, had no measurable precipitation (King Ranch, Inc.,

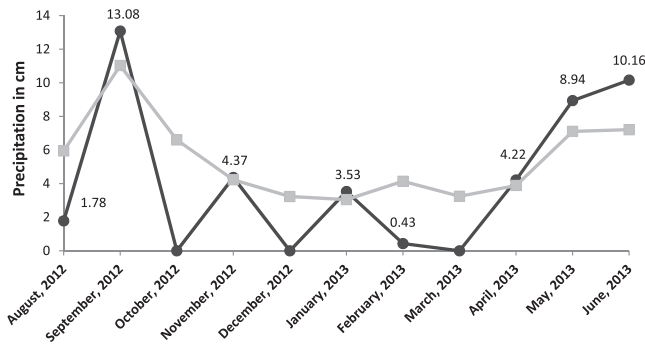


Fig. 1. Precipitation data obtained from King Ranch, Inc. The blue line represents the observed precipitation from August 2012 to June 2013 recorded at the Canelo Pens rain gauge (located between the treated and nontreated sites). Observed monthly precipitation totals included. The gray line represents the long-term monthly average over the entire Santa Gertrudis Division of the King Ranch, Inc., from 1985 to 2012 (Kleberg County, TX, USA).

personal communication; Fig. 1; Appendix A.). This study took place during an extreme drought.

METHODS

Study Design

Grubber work was completed in 10 seismic strips beginning in early August 2012. Seismic strips are cleared strips in a grid system used for oil and gas exploration. A Komatsu (Komatsu American Corp., Rolling Meadows, IL, USA) excavator was used to clear a width of 50-m strips on both sides of the seismic strips. The treatments were applied by the ranch and did not follow a systematic approach, but did follow treatment guidelines. The grubber operator targeted small to medium-sized (≤ 3 to ~ 5 -m) honey mesquite and huisache and attempted to leave the mixed brush species intact. If there was no mixed brush around, one or two large mesquite or huisache were left intact to provide some shade and/or loafing cover. During November–December 2012, a stacker was used to push all the downed brush into piles along strips that had previously been grubbed. Brush piles were burned within 1 month of stacking. The main purpose of treatments was to clear brush and create strips to provide quail hunters access to areas that were too brushy to hunt effectively. However, treatments also were applied with the hope of improving bobwhite brooding, feeding, and nesting habitat.

Ten, 25-m permanent transects were established on the treated and nontreated site. On the treated site, transects were placed randomly within 5–40 m from the seismic strips, so that they were located in the treated site and not in the seismic strip itself. On the nontreated site, we limited transects to 300 m within the interior of the designated site and within 5–40 m of dirt roads to make it comparable to the treated site. Within these restrictions, permanent transects were placed randomly using Geographic Information System (ESRI, Redlands, CA, USA)

Vegetation Sampling

The percentage canopy cover of woody plants was measured using the line intercept-method (Canfield 1941). We measured the combined absolute canopy coverage of mesquite and huisache, as well as the combined absolute canopy of mixed brush (woody cover excluding mesquite and huisache) species. We measured availability of nesting cover by the number of suitable nest clumps that occurred within a plot of a 4-m-diameter circle, with the center of the circle occurring at the start and end of each transect. The 2 circles were added to obtain the total nesting clumps within an area of 6.28 m² at each transect. We described a suitable nest clump as a bunchgrass clump or multiple smaller clumps growing together with a base of $\geq 22.9 \times 22.9$ cm and a height of ≥ 22.9 cm (Lehmann 1984). We set the maximum number of clumps in the circle to 10 (20/6.28 m² at each transect) because of the difficulty of reliably counting clumps at higher densities than this. We used a 20 $\times$ 50-cm quadrat placed every meter along the permanent transect for 25 total quadrats/transect. We placed the quadrat randomly on the right or left of the transect at a distance of 0.5, 1.0, 1.5, or 2.0 m (Alvarez 2011). We used quadrats to estimate percent canopy cover of bare ground, bobwhite food forbs, and bobwhite food grasses and/or sedges. We estimated percent canopy cover to the nearest percent if it was between 1% and 10% and to the nearest 5% if it was $> 10\%$. We considered a dicot to be a bobwhite food forb if it was 1) a croton or legume (Guthery 1986), 2) listed in Larson et al. (2010) as a bobwhite food forb, and/or 3) listed as a bobwhite, scaled quail, or passerine bird food in Everitt et al. (1999). We considered a monocot to be a bobwhite food grass and/or sedge if it was a *Cenchrus*, *Panicum*, *Paspalum*, *Scleria*, *Setaria*, or *Urochloa* (Larson et al. 2010) excluding liverseed grass (*Urochloa panicoides*), an invasive grass species. We determined forb species richness at each transect by the number of species of broad leafed plants found in 25 quadrats. We collected vegetation data prior to treatments in July 2012 and posttreatment in November 2012, March 2013, and July 2013.

Arthropod Sampling

We used 2 methods to sample a more representative assemblage of the arthropod community (Buffington and Redak 1998, Standen 2000, Moir et al. 2005). Sweep-net and D-Vac sampling provide a more accurate representation of the taxonomic assemblage of arthropods than using only one method (Buffington and Redak 1998). Although there is some overlap in catch, the 2 methods differ in arthropods sampled by favoring different sizes and taxa (Buffington and Redak 1998, Doxon et al. 2011). This combination of sampling techniques allowed us to quantify several insect orders important in the bobwhite diet in South Texas, such as Coleoptera, Hemiptera, Hymenoptera, Lepidoptera, and Orthoptera (Lehmann 1984, Campbell-Kissock et al. 1985). We used a 39.4-cm sweep net of muslin cloth and a D-Vac Vacuum Insect Net Model 122 (D-Vac Sales Inc., Massapequa, NY,

USA), with a 10.2-cm converter on the end (converter was included with the D-Vac) for sampling (Rincon-Vitova Insectaries, Ventura, CA, USA). With the sweep net, we walked 25 m, 4 paces to the right of the transect. We averaged 35 sweeps/transect with each sweep just above ground level. Then at a slow pace we walked back the length of the transect 4 paces to the right of the other side of the transect with the D-Vac on full throttle. We used 8 paces between sampling paths to avoid affecting one sampling method with the other while still sampling a path with a similar vegetation composition. Both sweep-net samples and D-Vac samples were collected within 1 minute for each transect. The same person sampled each time to avoid differences in pace and sampling technique between researchers. While sampling, we held the opening of the vacuum just above soil level except when going over thick vegetation. If brush was too dense to walk through with the sweep net or D-Vac, we walked around while staying as close to the line as possible. After sampling, we transferred arthropods to a plastic bag with cotton balls soaked in ethyl acetate and then froze them. In the lab, we sorted and counted arthropods. We sorted arthropods to class, and we sorted class Insecta to order. After sorting, we dried the samples for 24 hours at 105–110° C and weighed them to obtain biomass estimates for classes Arachnida and Insecta.

We estimated abundance and biomass for classes Arachnida and Insecta prior to treatment in July 2012, and monthly following treatments through July 2013, with the exception of August and December 2012 because of the mechanical treatment application during these months. We began sampling around sunrise unless the herbaceous vegetation was wet or the temperature was below 7.5° C, in which case we started once the vegetation dried and the temperature increased. We began and ended sampling at the same transects every month, starting with the 10 treated transects and then moving to the 10 nontreated transects.

STATISTICAL ANALYSIS

Design Considerations

The treated and nontreated sites served as experimental units. We averaged all vegetation data collected for each transect and combined arthropod samples collected using both sweep nets and the D-Vac for each transect. In each site (treated and nontreated), we sampled 10 transects with sampling time analyzed as a repeated-measures effect. Treatments were not replicated; therefore, we estimated within-treatment variation with transect-to-transect variation, and thus inferences are limited to the particular experimental units in this study (Wester 1992). We combined data from treated and nontreated sites in a single analysis following Kempthorne (1952) with a statistical model that included 1) treatment as a main plot factor, 2) transect nested within treatment as a random effect used as an error term for the treatment effect (see above), 3) date and the interaction between treatment and date as subplot (repeated measures) effects, and 4) the crossed interaction between date

and plot nested within treatment as the error term for date and its interaction with treatment.

Analysis Considerations

Residuals were nonnormally distributed and heteroscedastic; therefore, we analyzed all response variables with PERMANOVA+ (Anderson et al. 2008) using the model described above. For each dependent variable, if treatments differed ($P < 0.10$) for pretreatment data, we used analysis of covariance (ANCOVA) with pretreatment values as a covariable; otherwise, we used analysis of variance (ANOVA). For vegetation variables we analyzed, mesquite and huisache canopy cover, mixed brush canopy cover, forb species richness, and nesting clump density with ANOVA, while we used ANCOVA for bobwhite food grasses and/or sedges canopy, canopy cover of bobwhite food forbs, and bare ground cover. For the arthropod variables, we analyzed abundance and biomass of class Arachnida and class Insecta with ANOVA. We selected an alpha of 0.10 as the significance level because of high variation of arthropod variables. We tested treatment $\times$ date interactions first, and if there was an interaction ($P \leq 0.10$) treatment effects within dates were tested; if we detected no interaction ($P > 0.10$), we tested main effects of treatment (grubbing and stacking) and date, followed by a protected least significant difference test when appropriate (Kirk 2013). We used 10,000 permutations for all analyses.

RESULTS

Effects on Woody Cover

Differences between treatments depended on date for both mesquite and huisache cover ($P < 0.001$, $F_{3,54} = 10.518$) and mixed brush cover ($P < 0.001$, $F_{3,54} = 7.102$). Mesquite and huisache cover did not differ prior to treatments in July 2012 ($P = 0.289$, $F_{1,18} = 1.265$). Mesquite and huisache cover was 10.99% lower on the treated site 3 months after grubbing in November 2012 and approximately 12.4% and 14.72% ($P = 0.03$, $F_{1,18} = 6.955$) lower on treated sites following stacking in March ($P = 0.084$, $F_{1,18} = 3.759$) and July 2013 ($P = 0.052$, $F_{1,18} = 5.128$; Fig. 2). Mixed brush cover did not differ prior to treatments in July 2012 ($P = 0.888$, $F_{1,18} = 0.433$). Mixed brush cover was 6.48% lower on the treated site than the nontreated site 3 months after grubbing treatments in November 2012 ($P = 0.043$, $F_{1,18} = 5.346$), and it was 7.1% lower 3 months after stacking in March 2013 ($P = 0.037$, $F_{1,18} = 6.276$) and 8.96% lower 7 months after stacking in July 2013 ($P = 0.036$, $F_{1,18} = 5.913$; Fig. 3).

Herbaceous Response

Differences of treatment for bare ground depended on date ($P < 0.001$, $F_{2,36} = 10.37$) and the adjusted mean was $>22.22\%$ greater on the treated site than the nontreated site 3 months after stacking in March 2013 ($P = 0.086$, $F_{1,17} = 3.836$; $49.25\% \pm 3.41\%$ on the treated site compared with $27.03\% \pm 3.41\%$ on the nontreated site). Bare ground

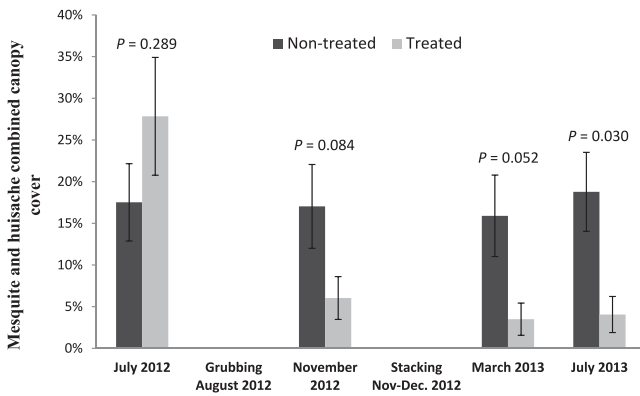


Fig. 2. Mesquite and huisache absolute combined canopy cover (Mean $\pm$ SE) estimated on 10 permanent transects using the line-intercept method. Treated represents grubbed and stacked sites and nontreated represents nontreated sites on the Santa Gertrudis Division of King Ranch, Inc. (Kleberg County, TX, USA). P -values obtained by analysis of variance tests of treatment effects within date. Treatment $\times$ date ($F = 10.518$), treatment within date effects: July 2012 ($F = 1.265$), November 2012 ($F = 3.759$), March 2013 ($F = 5.128$), July 2013 ($F = 6.955$).

cover was not different between treatments 3 months after grubbing in November 2012 ($P = 0.441$, $F_{1,17} = 0.634$) and 7 months after stacking in July 2013 ($P = 0.44$, $F_{1,17} = 0.638$). Differences in treatments of forb species richness depended on date ($P < 0.001$, $F_{3,54} = 8.048$). Forb species richness did not differ prior to treatment in July 2012 ($P = 0.214$, $F_{1,18} = 1.794$). Forb species richness was 4.7 species greater in the treated site 3 months after stacking in March 2013 ($P = 0.005$, $F_{1,18} = 13.608$) but was not different 3 months after grubbing in November 2012 ($P = 0.473$, $F_{1,18} = 0.574$) and 7 months after stacking in July 2013 ($P = 0.941$, $F_{1,18} = 0.016$; Table 1). We did not detect an effect

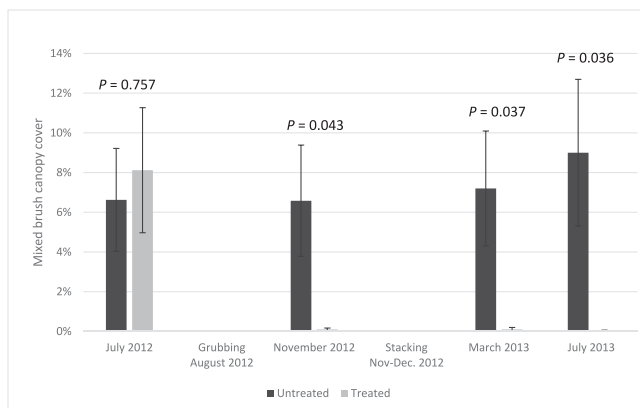


Fig. 3. Mixed brush absolute combined canopy cover (Mean $\pm$ SE) estimated on 10 permanent transects using the line-intercept method. Treated represents grubbed and stacked sites and nontreated represents nontreated sites on the Santa Gertrudis Division of King Ranch, Inc. (Kleberg County, TX, USA). P -values obtained by analysis of variance tests of treatment effects within date. Treatment $\times$ date ($F = 7.102$), treatment within date effects: July 2012 ($F = 0.096$), November 2012 ($F = 5.346$), March 2013 ($F = 6.276$), July 2013 ($F = 5.913$).

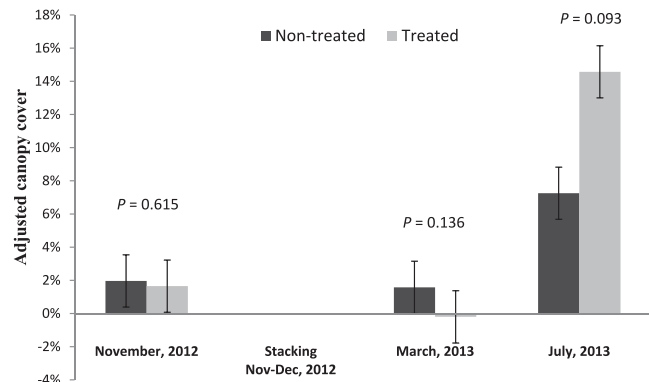


Fig. 4. Adjusted bobwhite food grasses and/or sedges canopy coverage (Mean $\pm$ SE) estimated on 10 permanent transects using 25 quadrats/transect. Canopy coverage adjusted because of the use of analysis of covariance. Treated represents grubbed and stacked sites and nontreated represents nontreated sites on the Santa Gertrudis Division of King Ranch, Inc. (Kleberg County, TX, USA). P -values obtained by analysis of covariance tests of treatment effects within date. Treatment $\times$ date ($F = 5.5023$), treatment within date effects: November 2012 ($F = 0.277$), March 2013 ($F = 2.729$), July 2013 ($F = 3.729$).

of treatment ($P = 0.256$, $F_{1,17} = 1.482$) or a treatment $\times$ date interaction on canopy cover of bobwhite food forbs ($P = 0.106$, $F_{2,36} = 2.388$; Table 1). There was a date effect on canopy cover of bobwhite food forbs ($P < 0.001$, $F_{2,36} = 42.116$): cover ranged from $2.86\% \pm 0.65\%$ in March 2013 to $22.00\% \pm 1.59\%$ in July 2013. Differences of treatments for bobwhite food grasses and/or sedges depended on date ($P = 0.008$, $F_{2,36} = 5.502$), and adjusted canopy coverage was 7.32% greater in the treated site 7 months after stacking in July 2013 ($P = 0.093$, $F_{1,17} = 3.729$), but did not differ 3 months after grubbing in November 2012 ($P = 0.615$, $F_{1,17} = 0.277$) or 3 months after stacking in March 2013 ($P = 0.136$, $F_{1,17} = 2.729$; Table 1; Fig. 4). We did not detect a treatment effect ($P = 0.245$, $F_{1,18} = 1.551$) or treatment $\times$ date interaction ($P = 0.249$, $F_{3,54} = 1.405$) on the number of nesting clumps, but the number of nesting clumps changed with date ($P < 0.001$, $F_{3,54} = 7.583$). We measured the lowest density of nesting clumps in March 2013 and the highest density of nesting clumps in July 2013.

Arthropod Response

We collected 6,736 arthropods in the grubbed and stacked site and in the nontreated site from 11 months of sampling. Samples consisted of 2 classes of Arthropoda and 12 orders of Insecta (Table 2). Differences in Arachnida abundance between treatments depended on date ($P < 0.001$, $F_{10,180} = 4.814$): for example, abundance was 10 individuals/transect lower on the treated sites 1 month after grubbing in September 2012 ($P < 0.001$, $F_{1,18} = 25.568$) and 7.1 individuals/transect lower 1 month after stacking in January 2013 ($P = 0.039$, $F_{1,18} = 5.679$), but we detected no difference in the other 9 months ($P \geq 0.116$, $F_{1,18} \leq 2.928$; Table 3; Fig. 5). Differences in treatments in Arachnida biomass also depended on date ($P = 0.07$, $F_{10,180} = 1.722$), and Arachnida biomass was

Table 1. Summary of vegetation results^a following grubbing and stacking on the Santa Gertrudis Division of King Ranch, Inc. (Kleberg County, TX, USA). We used analysis of variance unless treatments were different ($P < 0.10$) for pretreatment values, in which case we used analysis of covariance with pretreatment values as the covariable. We tested treatment $\times$ date interactions first and, if there was an interaction ($P \leq 0.100$), treatment effects within dates were tested. If no interaction was detected ($P > 0.100$), main (treatment and date) effects were tested. Ten thousand permutations were used for all analyses.

Response variable	Grubbing Aug 2012	Nov 2012	Stacking Nov–Dec 2012	Mar 2013	Jul 2013
Bare ground		ND		+	ND
Forb species richness		ND		+	ND
Food forbs canopy		No treatment effect or Treatment $\times$ date interaction ($P \geq 0.106$)			
Food grasses and/or Sedges canopy		ND		ND	+
Nesting clumps		No treatment effect or Treatment $\times$ date interaction ($P \geq 0.245$)			

^a + if grubbed and stacked site was greater than nontreated site ($P \leq 0.100$), and ND if there was no difference ($P > 0.100$).

0.007 g/transect lower on the treated site 1 month after grubbing in September 2012 ($P = 0.032$, $F_{1,18} = 6.70$) 3 as well as 0.011 g/transect and 0.024 g/transect higher on the treated site 6 and 7 months after stacking in June ($P = 0.061$, $F_{1,18} = 4.618$) and July 2013 ($P = 0.066$, $F_{1,18} = 4.412$). We detected no difference in the other sampling months ($P \geq 0.296$, $F_{1,18} \leq 1.281$) but January 2013 was just below the alpha cut-off ($P = 0.101$, $F_{1,18} = 3.016$; Table 3; Fig. 6). We detected no effect of treatment ($P = 0.504$, $F_{1,18} = 0.486$) or treatment $\times$ date interaction ($P = 0.372$, $F_{10,180} = 1.092$) on Insecta abundance (Table 3) but there was a date effect ($P < 0.001$, $F_{10,180} = 22.814$) on Insecta abundance ($P < 0.001$). Insecta abundance ranged from 3.95 ± 0.56 individuals/transect in April 2013 to 75.7 ± 8.78 individuals/transect in October 2012. Difference of treatments for Insecta biomass depended on date ($P = 0.002$, $F_{10,180} = 3.002$). Insecta biomass was 0.139 g/transect lower on the treated sites 1 month after grubbing in September 2012 ($P = 0.029$, $F_{1,18} = 6.36$) but 0.345 g/transect higher on the treated site than the nontreated site 2 months after grubbing in October 2012 ($P = 0.079$, $F_{1,18} = 3.934$). Insecta biomass was also lower on the treated site 1, 2, 4, and 5 months after stacking in January ($P = 0.066$, $F_{1,18} = 4.444$), February ($P = 0.09$, $F_{1,18} = 3.548$), April ($P = 0.088$, $F_{1,18} =$), and May 2013 ($P = 0.054$, $F_{1,18} = 4.875$). We detected no difference in Insecta biomass in the other 5 sampling months ($P \geq 0.119$, $F_{1,18} \leq 2.867$; Table 3; Fig. 7).

Table 2. Summary of number of arthropods collected during 11 sampling months on treated site and nontreated site on the Santa Gertrudis Division of King Ranch, Inc. (Kleberg County, TX, USA). Samples collected with sweep net and D-Vac were pooled.

Order	No.
Arthropoda	6,736
Unknown	137
Arachnida	858
Insecta	5,741
Coleoptera	1,749
Hemiptera	1,449
Hymenoptera	587
Lepidoptera	293
Orthoptera	1,195
Other	468

DISCUSSION

Impacts on Woody Cover

Contrary to our initial hypothesis, grubbing and stacking did not leave mixed brush species intact but led to significant decreases in mixed brush cover. It should be noted that mixed brush was not eradicated on the study area even though it decreased on the permanent transects. Mesquite serves as a nursery plant for many species of woody plants (Archer et al. 1988). This association of mixed brush species with mesquite may make it difficult to remove one without damaging the other. Canopy coverage of brush following treatment on the treated strips was lower than bobwhite typically prefer to use (Kopp et al. 1998, Ransom et al. 2008); however, because of the strip treatment applications denser woody cover was available nearby.

Arthropod Response

We saw some positive responses from the arthropod community, as we hypothesized; however, contrary to what we expected, this positive response was short-lived and somewhat unpredictable. Contrary to what we hypothesized, we also saw negative responses for arthropod variables. However, these negative effects also appeared to be short-lived because variables returned to control levels or exceeded control levels the next month, with the exception of Insecta biomass, which remained lower in the treated site 2, 4, and 5 months poststacking. These quick rebounds of both abundance and biomass may be a result of the resiliency of the arthropod community. One potential limitation in a study like this is that weather and times of day are factors that have been shown to affect results obtained by sweep-net sampling (DeLong 1932, Romney 1945, Hughes 1955, Dumas et al. 1962).

Brooding, Feeding and Nesting Habitat

As we hypothesized, we detected some increases in canopy cover of bobwhite foods, forb species richness, and bare ground, which are resources that are important for brooding and feeding habitat. However, the results were mixed and, for many variables measured, the treatments did not have any effects. It should be noted that although the treated site had more bare ground cover

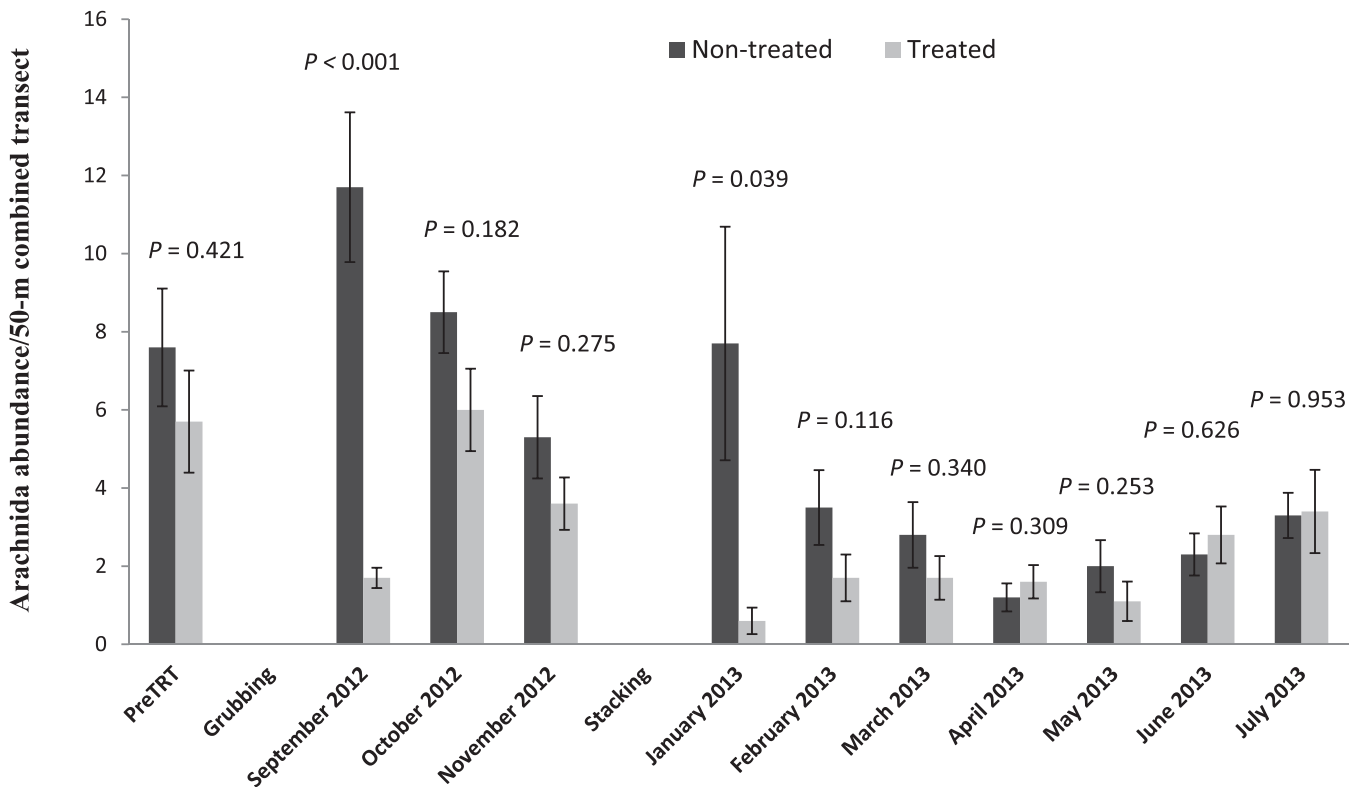


Fig. 5. Arachnida abundance (Mean $\pm$ SE)/50-m combined transect (25-m sampled with a sweep net and 25-m sampled with a D-Vac on 10 transects in each site). Treated represents grubbed and stacked sites and nontreated represents nontreated sites on the Santa Gertrudis Division of King Ranch, Inc. (Kleberg County, TX, USA). P -values obtained by analysis of variance tests of treatment effects within date. Treatment $\times$ date ($F = 4.814$), treatment within date effects: July 2012 ($F = 0.697$), September 2012 ($F = 25.568$), October 2012 ($F = 2.111$), November 2012 ($F = 1.34$), January 2013 ($F = 5.679$), February 2013 ($F = 2.928$), March 2013 ($F = 0.948$), April 2013 ($F = 1.161$), May 2013 ($F = 1.554$), June 2013 ($F = 0.26$), July 2013 ($F = 0.006$).

than the nontreated site in March 2013, this increase in bare ground cover may not have led to improved brooding habitat because both sites fell within the recommended range (Schroeder 1985, Guthery 1986). Contrary to what we hypothesized, we did not observe improved nesting habitat through increased nesting clump density following treatments. Although grubbing did not have an overall positive effect on many variables it did not appear to have much of a negative effect on bobwhite habitat and food sources either. Both vegetation and arthropod response variables rebounded to control levels quickly. This was the case even though the area was in a severe drought.

Even during drought conditions, the treatments appeared to have only minor short-term negative effects and some positive effects.

Although we saw some positive and some negative responses, for most variables in the majority of months we detected no difference between treated and nontreated. The overall neutral effects we documented are not uncommon in semiarid environments. Habitat, arthropods, and bobwhite populations tend to respond positively to treatments in mesic environments (Stoddard 1931, Hurst 1971, Cram et al. 2002, Yarrow et al. 2009). However, the response in more xeric environments is much less

Table 3. Summary of arthropod results^a following grubbing and stacking on the Santa Gertrudis Division of King Ranch, Inc. (Kleberg County, TX, USA). We used analysis of variance for the analysis unless treatments were different ($P < 0.10$) for pretreatment values, in which case we used analysis of covariance with pretreatment values as the covariable. We tested treatment $\times$ date interactions first and, if there was an interaction ($P \leq 0.100$), treatment effects within dates were tested. If no interaction was detected ($P > 0.100$), main (treatment and date) effects were tested. Ten thousand permutations were used for all analyses.

Response variable	Grubbing	Sep 2012	Oct 2012	Nov 2012	Stacking	Jan 2013	Feb 2013	Mar 2013	Apr 2013	May 2013	Jun 2013	Jul 2013
Arach. abundance	—	—	ND	ND	—	—	ND	ND	ND	ND	ND	ND
Arach. biomass	—	—	ND	ND	—	ND	ND	ND	ND	ND	+	+
Insecta abundance	—	—	—	—	—	—	—	—	—	—	—	—
Insecta biomass	—	—	+	ND	—	—	—	ND	—	—	ND	ND

^a + if grubbed and stacked site was greater than nontreated site ($P \leq 0.100$), — if nontreated site was greater than grubbed and stacked site ($P \leq 0.100$), and ND if there was no difference ($P > 0.100$).

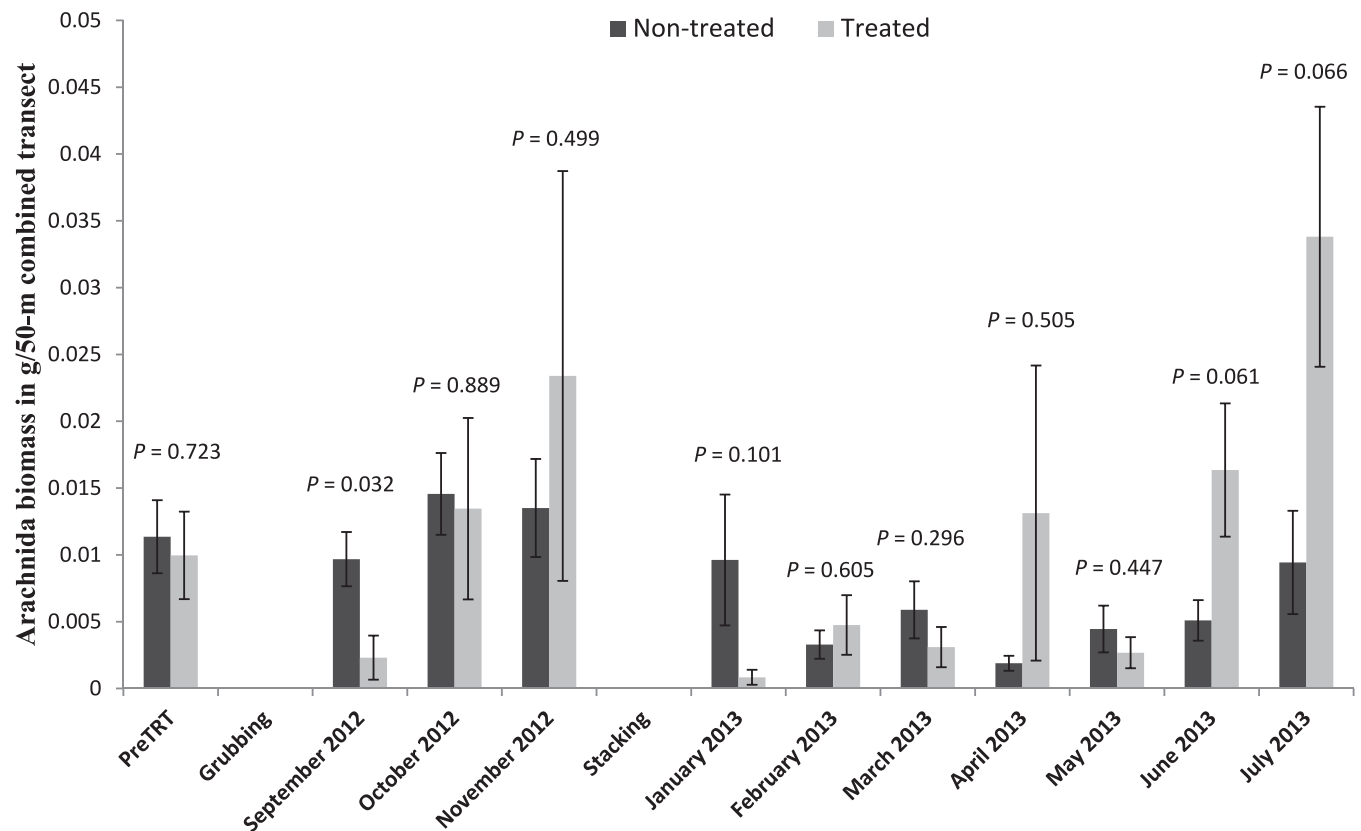


Fig. 6. Arachnida biomass (Mean $\pm$ SE)/50-m combined transect (25-m sampled with a sweep net and 25-m sampled with a D-Vac on 10 transects in each site). Treated represents grubbed and stacked sites and nontreated represents nontreated sites on the Santa Gertrudis Division of King Ranch, Inc. (Kleberg County, TX, USA). *P*-values obtained by analysis of variance tests of treatment effects within date. Treatment $\times$ date ($F = 1.722$), treatment within date effects: July 2012 ($F = 0.135$), September 2012 ($F = 6.7$), October 2012 ($F = 0.017$), November 2012 ($F = 0.523$), January 2013 ($F = 3.016$), February 2013 ($F = 0.3$), March 2013 ($F = 1.281$), April 2013 ($F = 1.011$), May 2013 ($F = 0.669$), June 2013 ($F = 4.618$), July 2013 ($F = 4.412$).

predictable (Wilson and Crawford 1979, Kane 1988, Leif 1993, Rollins and Lyons 2009) and largely dependent on rainfall (Bozzo et al. 1992). As site productivity decreases, optimal seral stage for bobwhites may increase (Spears et al. 1993). In some sites, mid- to late-seral stage may be better habitat for bobwhites (Hernández and Guthery 2012). If this is the case, habitat management practices that set back seral stage in sites with low productivity would likely have a neutral or negative effect as opposed to the predictable positive response in mesic areas.

Our conclusions are constrained in 2 senses: we lacked spatial replication (because of the logistic difficulties of replicating experimental units that exceeded 650 ha) and temporal replication. This study was also conducted during a historic drought and results should be interpreted with that in mind. Replication of this study during years of average and above-average precipitation should be conducted to better understand the effects of grubbing and stacking on the herbaceous and arthropod communities important to northern bobwhite. We also did not have control over grazing or past management practices on our 2 study sites, both of which likely affected our results. Heavier grazing in the untreated site during the study may have promoted early successional

grasses and forbs, as well arthropods (Guthery 1986), which may have affected our results.

MANAGEMENT IMPLICATIONS

The combination of grubbing and stacking is a management tool that can drastically decrease brush cover and open up the area while showing greater selectivity than some other mechanical methods. However, it is quite expensive, because management costs averaged \$444.79/ha for this brush management application (King Ranch, Inc., personal communication).

The main benefit of grubbing, in comparison with other brush management treatments, is the ability to leave mixed brush species intact while being able to selectively remove problem species. The association of mixed brush with mesquite on South Texas rangelands may make it difficult for the grubber operator to remove mesquite without unintentionally damaging or removing mixed brush. Operators should be well-trained in identifying woody species and able to carefully remove the mesquite or huisache without damaging mixed brush. If an operator is unable to do this efficiently, it may be far more cost-effective to use a cheaper, less selective practice of brush management.

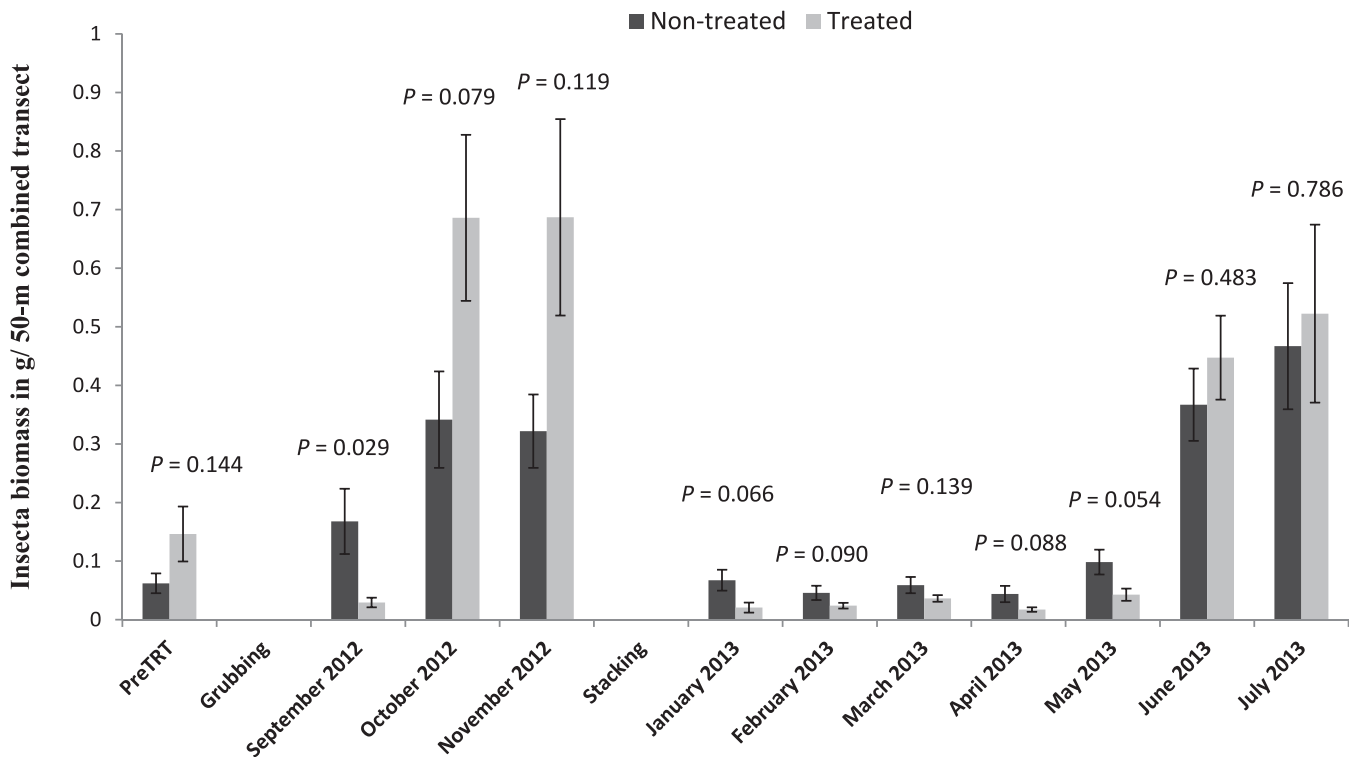


Fig. 7. Insecta biomass (Mean $\pm$ SE)/50-m combined transect (25-m sampled with a sweep net and 25-m sampled with a D-Vac). Treated represents grubbed and stacked sites and nontreated represents nontreated sites on the Santa Gertrudis Division of King Ranch, Inc. (Kleberg County, TX, USA). *P*-values obtained by analysis of variance tests of treatment effects within date. Treatment $\times$ date ($F=3.002$), treatment within date effects: July 2012 ($F=2.607$), September 2012 ($F=6.36$), October 2012 ($F=3.934$), November 2012 ($F=2.867$), January 2013 ($F=4.444$), February 2013 ($F=3.548$), March 2013 ($F=2.644$), April 2013 ($F=3.789$), May 2013 ($F=4.875$), June 2013 ($F=0.538$), July 2013 ($F=0.078$).

Grubbing and stacking can be used to alter habitat and food sources for bobwhite. However, we have little evidence that it changes the habitat drastically during drought conditions. Treatments were applied in strips, so thick brush cover is left adjacent to these open strips. The more open area is far easier to navigate for hunters and the visibility of bird dogs has been increased so treatments may allow hunters to access thicker brush areas that were more or less unhuntable, prior to treatment.

ACKNOWLEDGMENTS

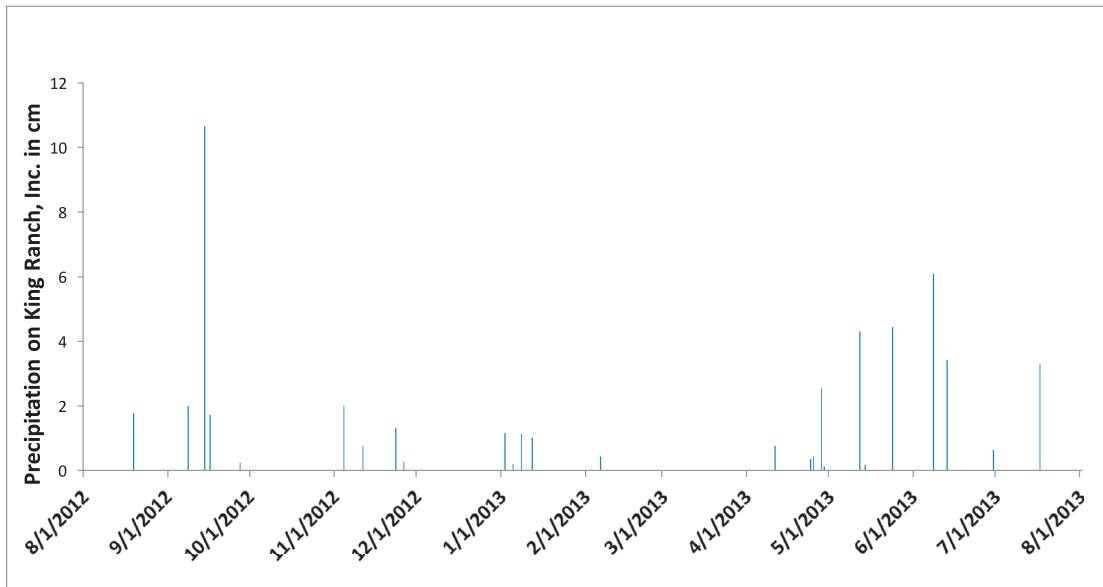
We would like to thank the Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville, and King Ranch, Inc. for all funding and support for this project; and the San Antonio Livestock Exposition and René Barrientos for the scholarships provided for Crouch, the main author. This is Caesar Kleberg Wildlife Research Institute publication number 16-127.

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Appendix A. Precipitation data obtained from King Ranch, Inc., Kleberg County, Texas, USA. The blue bars represent daily precipitation totals in cm from 1 August 2012 to 1 August 2013 recorded at the Canelo Pens rain gauge (located between the treated and nontreated sites).