Effects of site characteristics, pinyon-juniper management, and precipitation on habitat quality for mule deer in New Mexico

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**Abstract:** Wildlife enterprises are increasingly important to ranch income in the western United States. Habitat management practices that facilitate wildlife are needed for optimal management of multiple-use ranches, particularly for economically important species, such as mule deer (*Odocoileus hemionus*), that are declining throughout much of their range. We tested the effects of vegetation cover type, site characteristics, pinyon-juniper management treatments, and precipitation on body condition and size of spring-summer-autumn (SSA) home ranges of mule deer to assess habitat quality on the Corona Range and Livestock Research Center (CRLRC), a multiple-use research ranch in eastcentral New Mexico. Accrual of lean tissue and body fat reserves in does was positively associated with use of mechanically cleared juniper, pinyon-juniper woodland, and savannah and increased annual and spring (April to June) precipitation. Size of SSA home ranges of does was negatively associated with use of pinyon-juniper woodland and savannah and mechanically cleared pinyon-juniper stands, indicating that habitat quality was positively associated with use of these types. Conversely, size of SSA home ranges was positively related to use of short grass prairie (does), proportion of short grass prairie in SSA ranges (bucks), and areas of low forage production classes (does, bucks). Overall, habitat quality for deer on CRLRC was most positively associated with a mix of thinned and unmanaged pinyon-juniper habitat. Conversely, habitat quality was negatively associated with use of short grass prairie, which is the most common (77%) vegetation cover type on CRLRC. Management for deer habitat should focus on increasing forage, particularly shrub communities, by opening pinyon-juniper communities while maintaining sufficient area in unmanaged woodland for cover. Deer responses are likely to be greater if management focuses on sites of higher forage production potential within 200 m of unmanaged pinyon-juniper stands.

**Key words:** condition, habitat, human–wildlife conflicts, mule deer, New Mexico, pinyon-juniper

**Wildlife enterprises** are increasingly important to ranch income in the western United States, and, thus, habitat management practices that facilitate wildlife are needed for optimal management of multiple-use ranches, particularly for economically important species, such as mule deer (*Odocoileus hemionus*; Figure 1), which are declining throughout much of their range (Heffelfinger and Messmer 2003). The mission of New Mexico State University's Corona Range and Livestock Research Center (CRLRC) wildlife enterprises program is to produce and maintain viable mule deer and pronghorn (*Antilocapra americana*) populations that contribute economically toward the support of the CRLRC, a multiple-use, working ranch located in eastcentral New Mexico. Significant declines in size of the mule deer population on CRLRC (539 during 2005 to 191 in 2008; Bender et al. 2011) and throughout the West present an economic and ecological challenge for managers.

Declines in mule deer are likely associated with decreases in habitat quality (Heffelfinger and Messmer 2003; Wakeling and Bender 2003; Bender et al. 2007a,b; Hoenes 2008; Bender et al. 2011, 2012). On both public and private lands, changes in composition and structure of vegetation, including expansion of pinyon (*Pinus edulis*)-juniper (*Juniperus* spp.), invasion of other noxious or exotic plants, or responses to repeated or prolonged droughts are common.
range management challenges that can strongly affect the quality of habitat for mule deer (Lutz et al. 2003, Heffelfinger et al. 2006, Bender et al. 2007a). Managers typically use mechanical, herbicide, and prescribed fire treatments to manipulate pinyon-juniper and other habitats for free-ranging herbivores (Lutz et al. 2003). However, results of these treatments have emphasized responses of plant communities (Wood et al. 1970, Clary et al. 1974, Short et al. 1977, Severson and Medina 1983, Lutz et al. 2003), while fundamental responses of wildlife, such as mule deer, have rarely been rigorously evaluated (but see Bender et al. 2007a,b; Lomas and Bender 2007; Hoenes 2008; Lomas and Bender 2007; Hoenes 2008; Bender et al. 2011, 2012). Consequently, our specific objectives included assessing the effects of: (1) habitat characteristics and management practices on condition of mule deer; (2) habitat characteristics and management practices on size of spring-summer-autumn (SSA) home ranges of mule deer; and (3) precipitation on condition, productivity, and size of SSA home ranges of mule deer.

**Study area**

The CRLRC (34° 15’ 36” N, 105° 24’ 36” W) is an 11,290-ha working research ranch owned and operated by New Mexico State University. Located approximately 22.5 km east of the village of Corona, New Mexico, CRLRC has an average elevation of 1900 m; mean annual precipitation across the research center is 40 cm, most of which occurs in July and August during high-intensity, short-duration convectional thunderstorms. A number of soil associations are present; valley floor soils have been classified as Sampson loams (0% to 5% slope) and are deep and well-drained. Gently sloping soils (2 to 15% slope) included in the Penistaja-Travessilla, Plack-Dioxice, and Plack-Penistaja associations dominate the uplands and tend to be shallow to moderately deep. The Stroupe-Deama association includes the steep (30 to 75% slope) mesa sides and rock outcrops.
Vegetation is composed primarily of perennial grassland interspersed with sparse to dense pinyon pine (*Pinus edulis*) and 1-seed juniper (*Juniperus monosperma*) woodlands and limited, scattered shrublands (Figure 2).

**Methods**

**Deer capture**

We captured ≥1.5-year-old mule deer each December, 2005 to 2007, and April, 2006 to 2007. Deer were captured by aerial darting and net-gunning from a Bell 206B Jet Ranger helicopter. We immobilized individuals using 1.5 to 1.8 mg carfentanil citrate and 50 to 75 mg xylazine hydrochloride per deer. We blindfolded deer to minimize stress during handling and treated them intramuscularly with penicillin G procaine (3 ml), vitamin B (3 ml), MUSE (vitamin E and selenium, 1 ml), and subcutaneously with an 8-way *Clostridium* bacterin (i.e., a solution of killed or weakened bacteria used as a vaccine; 1 ml). Upon completion of processing, we antagonized immobilants with 3 ml of naltrexone (1/2 subcutaneously, 1/2 intravenously) and 4 ml of tolazoline or 2 ml atipamezole intravenously.

We aged deer as yearling or adult based on tooth wear and replacement (Robinette et al. 1957) and fit deer with mortality-sensitive radio-collars (Advanced Telemetry Systems, Asanti, Minnesota).

**Individual condition**

We collected a variety of size and condition indices that spanned the continuum from most readily mobilized (subcutaneous fat) to least (structural lean tissue). We measured subcutaneous rump fat thickness at its thickest point immediately posterior to the cranial process of the tuber ischium (pin bone; MAXFAT) using a SonoVet 2000 portable ultrasound with a 5-mHz probe. Approximate body fat (BF) was estimated for does only (predictive equations have not been developed specifically for bucks) using BF = 5.68 + 5.93 × MAXFAT (cm; Stephenson et al. 2002). Because the above equation can predict body fat down to only 5.7%, we also used a rump body condition score (rBCS; Bender et al. 2007a) to predict BF when no subcutaneous rump fat was present, where BF = 3.444 × rBCS – 0.746 ($r^2 = 0.83; n = 27$; Bender et al. 2007a). This relationship was derived from Rocky Mountain mule deer captured in northcentral and eastcentral New Mexico (Bender et al. 2007a) and allowed determination of levels of BF below levels where subcutaneous fat is fully catabolized. We estimated rBCS by palpating the sacral ridge and soft tissue of the rump near the base of the tail and scored measurements on a scale of 1 to 5 in intervals of 0.25, where 1 = emaciated and 5 = obese (Cook 2000, Bender et al. 2007a).

We measured the depth of the longissimus dorsi (loin) muscle at the thickest part between the twelfth and thirteenth ribs (LOIN) and estimated a withers body condition score (wBCS; Cook 2000; Bender et al. 2007a) to index catabolism of lean muscle tissue. Last, we also measured body mass using a spring scale and heart girth (GIRTH) to index size of deer. We compared condition indices among captures using ANOVA (Zar 1996), specifically testing the year × lactation interaction for adult does because of the negative impacts of lactation on accrual of condition (Hoenes 2008) and using only year as an effect for bucks. Condition of deer converges over winter so that individuals enter spring in similar condition regardless of lactation status the previous autumn (Clutton-Brock et al. 1982, Hoenes 2008, Figure 2. Major vegetation types present on the Corona Range and Livestock Research Center, eastcentral, New Mexico.
Thus, we were able to treat does as independent samples annually, regardless of recapture history.

**Habitat delineation and mapping**

We used a vegetation association map of the CRLRC area (U.S. Geological Survey ReGAP vegetation classification), which identified 13 vegetation associations on the study site, of which six showed coverage of >0.1%: North American desert active and stabilized dune (0.6%); southern Rocky Mountain pinyon-Juniper woodland (0.8%); southern Rocky Mountain juniper woodland and savannah (19.7%); Colorado Plateau mixed low sage shrubland (0.2%); Intermountain Basins semidesert shrub-steppe (1.9%); and western Great Plains short grass prairie (76.7%).

We derived forage production classes and pinyon-juniper management practices for CRLRC pastures from GIS coverages developed by McDaniel et al. (2002). Pinyon-juniper treatments included mechanical clearing of approximately 1,619 ha prior to 1989 and broadcast herbicide (tebuthiuron) treatments at 0.57 kg/ha in autumn on an additional 712 ha in 1995.

Forage production classes were similar to Natural Resources Conservation Services forage production classes used in soil surveys (http://soils.usda.gov) and classified potential forage production based on soils given average precipitation, where F1 = 0–150 kg/ha; F2 = 150–300 kg/ha; F3 = 300–450 kg/ha; F4 = 450–600 kg/ha; and F5 = 600–750 kg/ha (McDaniel et al. 2002).

**Precipitation**

We used precipitation data collected from 3 automated and 7 manual weather stations which six showed coverage of >0.1%: North American desert active and stabilized dune (0.6%); southern Rocky Mountain pinyon-Juniper woodland (0.8%); southern Rocky Mountain juniper woodland and savannah (19.7%); Colorado Plateau mixed low sage shrubland (0.2%); Intermountain Basins semidesert shrub-steppe (1.9%); and western Great Plains short grass prairie (76.7%).

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**Precipitation**

We used precipitation data collected from 3 automated and 7 manual weather stations distributed across CRLRC. We summed annual precipitation (e.g., total amount received from January of year, through December of year,) and cumulative precipitation during each of 4 seasons based on biological relevance to deer (Bender et al. 2007a; Hoenes 2008; Bender et al. 2011, 2012). These seasons included (1) conception–parturition (January to June), when deer need to minimize overwinter condition

**Table 1.** Mean and SE of condition indices for adult doe and buck mule deer at the peak of condition in late-autumn on the Corona Range and Livestock Research Center, New Mexico. Indices are presented by lactation status for adult does.

<table>
<thead>
<tr>
<th>Year</th>
<th>Dry does Mean ± SE</th>
<th>Lactating does Mean ± SE</th>
<th>Bucks Mean ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>rBCS 2.21 ± 0.20</td>
<td>1.88 ± 0.13</td>
<td>2.80 ± 0.37</td>
</tr>
<tr>
<td></td>
<td>wBCS 3.27 ± 0.24</td>
<td>3.31 ± 0.28</td>
<td>3.70 ± 0.34</td>
</tr>
<tr>
<td></td>
<td>MAXFAT 0.23 ± 0.10</td>
<td>0.00 ± 0.00</td>
<td>0.56 ± 0.30</td>
</tr>
<tr>
<td></td>
<td>LOIN 3.64 ± 0.15</td>
<td>3.81 ± 0.12</td>
<td>4.10 ± 0.14</td>
</tr>
<tr>
<td></td>
<td>GIRTH 87.3 ± 1.10</td>
<td>87.3 ± 0.5</td>
<td>100.0 ± 4.40</td>
</tr>
<tr>
<td></td>
<td>BF 7.06 ± 0.59</td>
<td>5.68 ± 0.35</td>
<td>— —</td>
</tr>
<tr>
<td>2006</td>
<td>rBCS 2.22 ± 0.13</td>
<td>1.83 ± 0.08</td>
<td>3.63 ± 0.33</td>
</tr>
<tr>
<td></td>
<td>wBCS 3.71 ± 0.92</td>
<td>3.58 ± 0.30</td>
<td>4.19 ± 0.12</td>
</tr>
<tr>
<td></td>
<td>MAXFAT 0.17 ± 0.08</td>
<td>0.00 ± 0.00</td>
<td>1.45 ± 0.34</td>
</tr>
<tr>
<td></td>
<td>LOIN 3.68 ± 0.08</td>
<td>3.70 ± 0.15</td>
<td>4.30 ± 0.13</td>
</tr>
<tr>
<td></td>
<td>GIRTH 87.6 ± 1.0</td>
<td>88.7 ± 2.7</td>
<td>106.0 ± 3.30</td>
</tr>
<tr>
<td></td>
<td>BF 6.69 ± 0.48</td>
<td>5.61 ± 0.23</td>
<td>— —</td>
</tr>
<tr>
<td>2007</td>
<td>rBCS 2.10 ± 0.26</td>
<td>1.67 ± 0.33</td>
<td>3.92 ± 0.30</td>
</tr>
<tr>
<td></td>
<td>wBCS 3.58 ± 0.21</td>
<td>3.58 ± 0.17</td>
<td>4.42 ± 0.83</td>
</tr>
<tr>
<td></td>
<td>MAXFAT 0.28 ± 0.12</td>
<td>0.00 ± 0.00</td>
<td>1.67 ± 0.32</td>
</tr>
<tr>
<td></td>
<td>LOIN 3.94 ± 0.09</td>
<td>3.67 ± 0.09</td>
<td>4.37 ± 0.19</td>
</tr>
<tr>
<td></td>
<td>GIRTH 89.2 ± 0.9</td>
<td>84.0 ± 1.0</td>
<td>103.3 ± 3.00</td>
</tr>
<tr>
<td></td>
<td>BF 7.32 ± 0.73</td>
<td>4.99 ± 1.15</td>
<td>— —</td>
</tr>
</tbody>
</table>

1rBCS = rump body condition score; wBCS = withers body condition score; MAXFAT = maximum subcutaneous rump fat thickness (cm); LOIN = depth of the longissimus dorsi muscle (cm); GIRTH = heart girth (cm); and BF = approximate body fat (%).
loss and later require increased nutritional quality as the fetus begins to grow (Wakeling and Bender 2003); precipitation during this period has been strongly linked to survival in cervids (Bender 2007; Hoenes 2008, Bender et al. 2011, 2012); (2) late-gestation-parturition (April to June), when energy requirements associated with late-gestation greatly increase deer nutritional requirements (Wakeling and Bender 2003); (3) lactation (July to September), the period of greatest nutritional demand on does (Wakeling and Bender 2003); and (4) post-lactation (October to December), when does need to recover energy reserves prior to winter and bucks enter the rut. We used totals from the nearest station for each individual deer’s SSA range in analyses of precipitation effects on habitat quality.

Deer locations

We visually located deer using ground tracking as frequently as possible with the goal of obtaining locations on a weekly basis with emphasis on SSA locations because of the importance of this period in accrual of endogenous energy reserves (Verme and Ullrey 1984; Wakeling and Bender 2003; Bender et al. 2007a,b). We recorded locations using a hand-held Geographic Positioning System (GPS), and we mapped locations using the Geographic Information System (GIS) software package ArcGIS 9.3 (Environmental Systems Research Institute, Redlands, California). We recorded date, time, group size, sex, and age composition, cover type, habitat type, and observed behavior (i.e., foraging, bedded, etc.) for each observation of radio-collared deer.

SSA home ranges

Because we were interested in the influences of environmental and management practices on the ability of mule deer to accrue endogenous energy reserves, we analyzed only SSA ranges of deer with the SSA period defined as following the early spring capture (late March, when deer are at their seasonal low in terms of body condition (Bender et al. 2007a,b; Hoenes and Bender 2012) and immediately prior to the late autumn capture (early December, when deer are at their seasonal peak in condition; Bender et al. 2007a,b; Hoenes and Bender 2012). We built 95% minimum convex polygon (MCP) SSA home ranges (Kie et al. 1996) after determining the minimum number of locations to adequately estimate seasonal home range size by plotting size as a function of number of locations (Bender et al. 2007b).

Habitat quality

We used analysis of covariance (ANCOVA; Zar 1996) to identify the effects of home range composition (proportion of habitat types within SSA home ranges), habitat use (proportion of locations of deer during the SSA period by habitat type), precipitation, forage production class, and pinyon-juniper management history (for the latter two, proportion of SSA locations in each site class or management category) on doe condition in autumn while accounting for the influence of lactation status (Bender et al. 2007b, Hoenes 2008). We used linear regression (Zar 1996) to identify the effects of these same variables on buck condition. Because size of home ranges is also a surrogate for quality (Bender et al. 2007b), we similarly modeled sizes of SSA home ranges as a function of these same variables. For significant relationships, we present normalized parameter coefficients to allow relative comparison of effect size within sexes.

Results

Health and condition

We captured, recaptured, and assessed for condition of 63 individual adult mule deer (53 individually radio-collared [46 does and 7 bucks]; the remainder were used only for condition data and were released without a radio collar), from December 2005 to 2007. Numbers of radio-collared deer annually (2006 to 2008) were 18, 27, and 19 does, and 5, 6, and 5 bucks, respectively. Mean annual body condition of does and bucks was poor (Table 1; Bender et al. 2007a; Bender et al. 2011, 2012). Although lactating does were consistently in poorer condition than dry does for most condition indices each year (Table 1), no indices of condition varied among does by year × lactation status ($F_{5,46} < 1.1; P > 0.37$), likely because all does were in extremely poor condition each year (Table 1) and consequently sample sizes of lactating does were low (3 to 4 annually). Bucks had significantly more subcutaneous fat (MAXFAT [$F_{2.9} = 3.4; P = 0.08$])
in 2006 and 2007 as compared to 2005, while all other indices did not differ among years ($F_{1,9} \leq 2.8; P \geq 0.12$).

Modeling of doe condition indicated that only GIRTH was associated with cover type composition of SSA ranges. GIRTH was negatively related to the amount of desert dunes ($F_{1,8} = 4.7; P = 0.06; \text{effect} = -0.41$), mixed low sage shrubland ($F_{1,8} = 4.5; P = 0.066; \text{effect} = -0.36$), and mixed salt desert scrub ($F_{1,8} = 7.5; P = 0.03; \text{effect} = -0.58$) in doe SSA ranges. The proportion of SSA locations in dunes ($F_{1,8} = 6.9; P = 0.03; \text{effect} = -0.57$), mixed low sage shrubland ($F_{1,8} = 7.5; P = 0.03; \text{effect} = -0.58$), and semi-desert shrub steppe ($F_{1,8} = 3.4; P = 0.10; \text{effect} = -0.49$) was similarly negatively related to GIRTH in mule deer does, while the proportion of locations in semi-desert shrub steppe was also negatively related to wBCS ($F_{1,8} = 5.7; P = 0.05; \text{effect} = -0.72$) and LOIN ($F_{1,8} = 3.4; P = 0.10; \text{effect} = -0.56$) in adult does. Conversely, proportion of locations in juniper woodland and savannah was positively related to GIRTH ($F_{1,8} = 4.7; P = 0.06; \text{effect} = 0.55$) in mule deer does. No other detectible relationships between vegetation cover types and doe condition were present. We were unable to model buck condition as a function of SSA range characteristics because of small (3) sample sizes.

Among site characteristics, GIRTH of mule deer does was positively related to high forage production class ($F_4: F_{1,8} = 7.4; P = 0.026; \text{effect} = 0.58$). Approximate BF of adult does was negatively related to low forage production class ($F_2: F_{1,8} = 6.4; P = 0.04; \text{effect} = -0.52$). No condition indices of adult does were related to use of areas of herbicide-treated juniper ($F_{1,8} \leq 2.2; P \geq 0.18$). Proportion of locations in SSA ranges in areas of mechanically cleared juniper were positively related to GIRTH ($F_c: F_{1,8} = 3.7; P = 0.09; \text{effect} = 0.31$) and BF ($F_{2,8} = 4.7; P = 0.06; \text{effect} = 0.39$). No other condition indices were associated with use of mechanically cleared juniper in SSA ranges ($F_{1,8} \leq 0.2; P \geq 0.67$).

### Table 2. Relationships between use of habitat types and the composition of home ranges with size of spring-summer-autumn (SSA) home ranges on the Corona Range and Livestock Research Center, New Mexico. Presented are normalized coefficients and direction of effect of habitat types on size of SSA home ranges ($= -$ negatively related to size of SSA home ranges; $+$ = positively related to size of SSA home ranges; ns = nonsignificant effect at $P = 0.10$).

<table>
<thead>
<tr>
<th>Home range attribute</th>
<th>Habitat type</th>
<th>Buck</th>
<th>Doe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active and stabilized dunes</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Pinyon-juniper woodland</td>
<td>–</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Mixed low sage shrubland</td>
<td>–</td>
<td>+0.24</td>
</tr>
<tr>
<td></td>
<td>Juniper woodland and savannah</td>
<td>ns</td>
<td>-0.38</td>
</tr>
<tr>
<td></td>
<td>Semi-desert shrub steppe</td>
<td>ns</td>
<td>+0.34</td>
</tr>
<tr>
<td></td>
<td>Shortgrass prairie</td>
<td>ns</td>
<td>+0.28</td>
</tr>
<tr>
<td></td>
<td>Active and stabilized dunes</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Pinyon-juniper woodland</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Mixed low sage shrubland</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Mixed salt desert scrub</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Juniper woodland and savannah</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Semi-desert shrub steppe</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Shortgrass prairie</td>
<td>+0.22</td>
<td>ns</td>
</tr>
</tbody>
</table>

### Home range modeling

We were able to adequately model (minimal number of locations for SSA home ranges = 15 based upon plots of home range size as a function of number of locations) complete SSA home ranges for 32 does and 9 bucks. Size of doe SSA ranges was not related to habitat type composition of SSA home ranges ($F_{1,30} = 0.8; P = 0.39$; Table 2). Size of SSA home ranges was positively related to the proportion of locations in mixed low sage shrubland ($F_{1,30} = 3.8; P = 0.060$), semi-desert shrub steppe ($F_{1,30} = 3.9; P = 0.07$), and shortgrass prairie ($F_{1,30} = 2.8; P = 0.10$). Conversely, size of doe SSA ranges was negatively related to proportion of locations in pinyon-juniper woodland and savannah.
Size of buck SSA ranges was positively related to the proportion of short grass prairie ($F_{1,30} = 4.6; P = 0.07$) in SSA ranges, but was not related to the proportion of locations within cover types comprising SSA ranges ($F_{1,7} < 1.7; P > 0.24$; Table 2).

Size of deer SSA ranges was positively related to very low herbaceous forage production class ($F_{1,30} = 3.8; P = 0.06$; bucks: $F_{1,7} = 6.4; P = 0.04$; Table 3). Only relatively high forage production class (F4) was associated with decreasing size of SSA ranges of does ($F_{1,30} = 3.5; P = 0.07$), and no site characteristics were related to decreasing SSA home range size for bucks ($F_{1,7} < 1.4; P > 0.28$; Table 3).

Neither adult doe ($F_{1,30} = 0.3; P = 0.59$) or adult buck ($F_{1,7} = 0.5; P = 0.50$) SSA home range size was related to use of herbicide-treated juniper. Size of adult doe SSA home ranges was negatively related to the proportion of SSA locations in areas of mechanically cleared juniper ($F_{1,30} = 3.9; P = 0.06$). No bucks were ever located in areas of mechanically cleared juniper. Last, neither sizes of SSA home range of adult does ($F_{1,30} < 0.7; P > 0.42$) or adult bucks ($F_{1,7} < 0.5; P > 0.50$) were related to any measures of seasonal or annual precipitation.

### Discussion

The nutritional status of individuals is the first parameter affected by resource limitations (Hanks 1981, Gaillard et al. 2000). On CRLRC, lactating does were never able to accrue $>5.7\%$ BF in any year, well below condition levels that mule deer are capable of accruing ($>20\%$ BF; Oliver 1997). Even dry does were able to accrue only $>7\%$ BF in only 2 of 3 years, highlighting the nutritional stress faced by adult does on CRLRC. In contrast, bucks were able to accrue much more subcutaneous fat and other reserves in all years (Table 1). These differences occurred despite bucks entering SSA in poorer condition than does (Bender et al. 2011) and were likely related to different habitat use patterns and lower nutritional quality requirements of adult bucks (Wakeling and Bender 2003, Hoenes 2008).

Commonalities among SSA home range composition and use, modeling of condition, and modeling of SSA home range size indicated that cleared pinyon-juniper and pinyon-juniper woodlands and savannahs provided the best habitat for mule deer on CRLRC, whereas short grasslands and xeric shrublands provided the least value for mule deer. Precipitation also influenced the quality of habitats on CRLRC, although timing of precipitation was important; does showed slightly increased muscle mass (LOIN) as spring (April to June) precipitation increased. However, the effect of existing vegetation on deer condition was likely more important than precipitation, as adult does continued to exhibit poor body condition and population performance even during years of adequate and well-timed precipitation (Table 1) and the effect size of habitat influences on condition were $\geq 1.5$ times greater than the effect of precipitation. Similarly, bucks were able to achieve higher condition than does despite experiencing the same precipitation patterns.

### Table 3.

Relationships between use of ecological site characteristics and pinyon-juniper treatments on spring-summer-autumn (SSA) home range size on the Corona Range and Livestock Research Center, New Mexico. Presented are normalized coefficients and direction of effect of attribute on size of SSA home ranges ($-$ = negatively related to size of SSA home ranges; $+$ = positively related to size of SSA home ranges; ns = nonsignificant effect at $P = 0.10$).

<table>
<thead>
<tr>
<th>Range attribute</th>
<th>Class</th>
<th>Buck Class</th>
<th>Doe Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecological site class</td>
<td>Forage production class 1</td>
<td>$+0.21$</td>
<td>$+0.29$</td>
</tr>
<tr>
<td></td>
<td>Forage production class 2</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Forage production class 3</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Forage production class 4</td>
<td>ns</td>
<td>$-0.32$</td>
</tr>
<tr>
<td>Pinyon-juniper treatments</td>
<td>Herbicide</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>Mechanical</td>
<td>$-$</td>
<td>$-0.47$</td>
</tr>
</tbody>
</table>

(\(F_{1,30} = 3.5; P = 0.070\)).
Home range, habitat use, and condition

Pinyon-juniper woodlands and savannas comprised only 20% of the landscape of CRLRC but comprised approximately 25% of SSA ranges, and use of these types was associated with increased condition of does and decreased size of SSA home ranges. Further, doe use of mechanically cleared juniper sites, which are savannah-like, was also positively associated with increased condition of does. Although production of high-quality herbaceous forages is frequently low in pinyon-juniper woodlands, they typically show relatively high diversity and availability of browse species as compared to most other vegetation types in eastern and southern New Mexico (Bender et al. 2007b; Hoenes and Bender 2012). Browse is the main constituent of mule deer diets (Boeker et al. 1972, Krausman et al. 1997), and diversity and abundance of key browse species is a critical component of mule deer habitat (Wallmo 1981, Heffelfinger et al. 2006). Browse is of even greater importance for mule deer in arid environments, such as the CRLRC, due to high annual variability associated with the production of forbs (Kemp 1983, McKinney 2003, Hoenes and Bender 2012). On CRLRC, cover of browse species preferred by mule deer was greatest in pinyon-juniper woodlands (11%), pinyon-juniper savannah (17%), and short grasslands (16%). Similarly, positive associations of mechanically cleared pinyon-juniper with habitat quality, as opposed to herbicide-treated pinyon-juniper, likely reflected forage availability, as mechanically cleared stands had greater cover of preferred browse species (10% versus 2%; Bender 2012).

Size of SSA home ranges of adult does was inversely related to the proportion of locations in pinyon-juniper woodlands and savannas in SSA home ranges. In general, smaller home ranges are usually associated with better habitat quality (Robinson and Bolen 1984), and this relationship is often attributed to food availability, with individuals in food-rich habitats being able to meet energetic requirements over smaller areas (Harestad and Bunnell 1979, Widmer et al. 2004). This is especially pronounced in ungulate species that are primarily browsers and located in woodland-shrubland communities dominated by browse species (Saïd and Servanty 2005). Consequently, use of open pinyon-juniper stands and mechanically cleared juniper resulted in does on CRLRC accruing greater size and muscle mass, which was positively related to their survival (Bender et al. 2011). Overall, however, condition of adult doe mule deer was poor (Table 1); despite the positive associations with open pinyon-juniper types, deer were not able to acquire diets approaching optimal quality in pinyon-juniper communities on CRLRC.

The role of pinyon-juniper woodlands in providing cover for mule deer has been well documented (Clary et al. 1974; Short et al. 1977; Wallmo and Regelin 1981; Lutz et al. 2003; Bender et al. 2007b), and >88% of locations of radio-collared mule deer were < 200 m from unmanaged pinyon-juniper stands that averaged 62% cover of pinyon-juniper (L. Bender, unpublished data). Densities and cover of woody species associated with pinyon-juniper demonstrate that pinyon-juniper woodlands provide the best cover attributes of any habitat type for mule deer in the Southwest (Bender et al. 2007b, Hoenes and Bender 2012). Further, doe-use of pinyon-juniper in SSA ranges coincides with fawning, and hiding cover for fawns is an attribute of mule deer habitat that does consistently select (Wallmo 1981, Short et al. 1977, Severson and Medina 1983, Heffelfinger et al. 2006). The ability of pinyon-juniper woodlands and savannas to provide cover and, thus, minimize disturbance likely contributed to their positive relationship with doe condition and habitat quality as indexed by size of SSA home ranges on CRLRC.

Size of SSA home ranges of deer increased as use of short grass prairie and xeric shrublands increased. Short grasslands on CRLRC were dominated by stands of perennial gramas (Bouteloua spp.) and were the most common vegetation type on our study area, covering approximately 77% of the site. Because of its abundance, the negative association between short grasslands and deer habitat quality was particularly relevant. While short grasslands produce forage species used by mule deer (cover of preferred browse = 16% on CRLRC; L. Bender, unpublished data), often in significant quantities (Bender et al. 2007, Hoenes and Bender 2012), cover is lacking (Bender et al.
Cover is an important component of mule deer habitat (Short et al. 1977, Wallmo 1981, Wallmo and Regelin 1981, Severson and Medina 1983, Heffelfinger et al. 2006). Cover minimizes energy expenditures associated with disturbances and also reduces vulnerability to predation (Smith and LeCount 1979, Severson 1981, Lutz et al. 2003, Bender et al. 2007b, Lomas and Bender 2007). Lack of cover provided by trees and shrubs in grasslands is a likely explanation for their positive association with increasing size of SSA home range size and hence negative association with habitat quality (Bender et al. 2007b, Hoenes 2008).

Hoenes (2008) found that mule deer showed increased use of grama grasslands that were associated with deciduous shrublands and pinyon-juniper woodlands, both of which provided cover and browse and were consistently used in excess of their availability in his study area in the San Andres Mountains of southcentral New Mexico. Use of grasslands by mule deer, thus, may be increased in areas where cover is available in adjacent habitat types, similar to relationships seen in northcentral New Mexico (Bender et al. 2007b). On CRLRC, virtually all use of short grass prairie by mule deer was within 200 m of pinyon-juniper or other cover.

Negative associations with condition of deer and positive associations with increased SSA home range sizes indicated that xeric shrublands (i.e., mixed low-sage shrubland, mixed salt-desert scrub, semi-desert shrub-steppe) were of low quality for deer. Many xeric shrublands are characterized by poor forage and cover characteristics (Bender 2007, Hoenes and Bender 2012) that likely limits their value to mule deer. However, some of these cover types (i.e., semi-desert shrub-steppe, mixed low-sage) often have useful browse species (i.e., winter fat [Krascheninnikovia lanata], apache plume [Fallugia paradoxa], fourwing saltbush [Atriplex canescens], etc.) as important components of their flora. Thus, we are unsure of the reasons behind the negative relationships with deer habitat quality on CRLRC. Most of the mixed low sage and semi-desert shrub steppe was associated with poorer soils on CRLRC, possibly contributing to their negative association with mule deer habitat quality.

**Influence of precipitation**

Condition of adult does was positively, albeit weakly, related to increased precipitation during spring (April to June), and survival of adult does was likewise benefited by increased precipitation during winter and spring (January to June and April to June; Bender et al. 2011). Adult does face increased energetic requirements at the onset of late-gestation (Verme and Ullrey 1984, Wakeling and Bender 2003). If precipitation and consequently green forage is absent during this period, a doe mobilizes its body reserves in an attempt to provide the fetus with adequate nourishment (Verme and Ullrey 1984, Landete-Castillejos et al. 2003), thus, lowering her condition. Increasing nutritional requirements associated with late-gestation likely accounted for the positive relationship between autumn condition of does and cumulative precipitation during late-gestation (April to June). In most regions where mule deer are found, forage availability is limited during late winter months, and individuals must rely primarily on fat reserves for energy through winter (Mautz 1976). However, winters in central New Mexico are relatively mild compared to winters in more northern climates, with snow accumulation typically low and most precipitation occurring as rainfall. Consequently, some annual forb species (winter annuals) germinate and grow in response to precipitation during late winter and early spring (Guo and Brown 1997, Hoenes 2008). Production of winter and early-spring annuals may provide mule deer in CRLRC with a forage resource that allows them to slow condition losses, which may be particularly important given that deer entered winter in extremely poor condition on CRLRC (Table 1).

**Management implications**

Poor condition of adult doe mule deer on CRLRC indicated that overall habitat quality for mule deer was poor, as further evidenced by low survival and poor productivity of mule deer on CRLRC (Bender et al. 2011). Of existing habitat attributes on CRLRC, only pinyon-juniper woodlands and savannas were positively associated with condition and habitat quality of doe mule deer on CRLRC, and most deer use was <200 m from pinyon-juniper stands. Consequently, management strategies should be aimed at enhancing forage
attributes of these cover types to increase the productivity of mule deer on CRLRC. Mechanical thinning (Van Hooser et al. 1993, Stevens and Monsen 2004) and prescribed burns (Hobbs and Spowart 1984, Monsen et al. 2004, Stevens and Monsen 2004) are 2 strategies that can increase the quantity and quality of forage species associated with woodland communities to benefit mule deer by freeing nutrients for herbaceous and shrub species, and decreasing the successional status of shrub communities. However, treatments must be carefully designed to maintain adequate cover attributes, or deer-use may actually decline (Bender et al. 2007b, Hoenes and Bender 2012, Bender 2012). Management strategies that maintain 25% of home ranges in unmanaged (high cover, i.e., >60% on CRLRC) pinyon-juniper and provide a mixture of thinned stands of 10 to 30% cover likely provide an acceptable balance between cover and forage, particularly if unmanaged stands are within 200 m of any point on thinned stands (Bender 2012). Additionally, treatments associated with areas of higher forage production classes would likely show greater positive effects on mule deer habitat. In contrast, herbicide treatment of pinyon-juniper had no positive benefit to mule deer habitat quality on CRLRC, likely because treatments also killed other woody vegetation and, thus, lowered both forage and cover attributes of treated stands.

Short grasslands contain significant quantities of palatable herbaceous forages and browse, but were of low overall quality for mule deer likely because they lacked cover. Management actions to enhance the quality of grasslands for mule deer include prescribed burns to enhance the forb component (Ford and McPherson 1996) and establishment of woody shrub patches near or adjacent to locally rugged topography (Severson 1981, Bender et al. 2007b) to provide a cover component. Treatment areas are likely to see a greater response from deer if located <200 m from areas providing cover for mule deer. Because many carpeted shrubs are present through much of CRLRC’s short grasslands, grazing exclosures may also be useful to encourage expansion and increased vertical growth of these shrubs, particularly because establishment of shrub communities is often more difficult than enhancing existing shrub communities (Stevens and Monsen 2004).

Regardless of treatments or habitat types managed, increasing cover of palatable shrubs on CRLRC should be a priority to maintain or increase mule deer numbers. Because of the effect of precipitation, particularly during January to June and April to June on deer survival, mule deer on CRLRC require an environmental buffer that can mitigate the negative impacts of drought years (Bender et al. 2007a, Bender et al. 2011). An abundant and diverse browse community is less susceptible to drought than are forbs (Hoenes and Bender 2012), and establishing such resources throughout CRLRC will make mule deer habitats far more drought tolerant, thereby reducing the severe declines seen in mule deer numbers in response to a combination of extremely low body condition and drought, particularly during late winter and spring (Bender et al. 2011).

Despite taking these measures, we are unsure to what degree these activities can increase condition and productivity of mule deer on CRLRC. Consistent positive relationships between deer survival and precipitation on CRLRC (Bender et al. 2011) indicated that deer are sensitive to seasonal precipitation patterns. However, the causal mechanism that this would operate through (i.e., increased individual condition) was only weakly detected on CRLRC during the same period. Possibly habitat quality had declined to levels where it was largely unresponsive to the amount and timing of precipitation seen during our study, or perhaps the timing and quantity of precipitation during our study were insufficient to be generate a response in mule deer condition (although survival was influenced). If the former is true, then activities short of extensive feeding may not enhance nutrition sufficiently to compensate for extant habitat conditions or dry years, and, thus, have little overall affect on condition. However, management actions, such as listed above, may increase survival and productivity during average or above average precipitation years, accelerating recovery of populations lowered by frequent drought (Bender et al. 2011).

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