**Abstract:** Introduced oryx (*Oryx gazella gazella*) have expanded into the San Andres Mountains of south-central New Mexico, but little is known of concurrent habitat used by oryx and desert mule deer (*Odocoileus hemionus crooki*); the latter in New Mexico is a species of special concern that has declined significantly since the introduction of oryx. We used fecal-pellet and browse surveys in combination with presence modeling to identify differences in relative use of habitat types, distribution, and browsing of highly palatable, highly preferred (hereafter, key) plant species during 2004 to 2006 to assess the potential for direct competition in use of resources in the San Andres Mountains. Numbers of pellet groups per transect (hereafter referred to as relative use) of oryx was greatest in sandsage (*Artemisia filifolia*) shrublands and alkali sacaton (*Sporobolus airoides*) grasslands, whereas mule deer-use was greatest in oak-(*Quercus* spp.) mountain mahogany (*Cercocarpus montanus*) shrublands, and pinyon-(*Pinus edulis*) juniper (*Juniperus* spp.) woodlands. Use of key mule deer browse species was low (<4.0% of current annual growth browsed) in all habitat types. Relative use of oryx accounted for 42% of the variation in browse percentages in pinyon-juniper woodlands and 58% of the variation in mesquite (*Prosopis glandulosa*) shrublands, whereas mule deer-use accounted for 79% of the variation in oak-mountain mahogany shrublands and 27% in pinyon-juniper woodlands. Presence models similarly indicated that deer distribution was most positively associated with oak-mountain mahogany shrublands and pinyon-juniper woodlands, while oryx distribution was most positively associated with alkali sacaton grasslands, mixed lowland scrub, and sandsage shrublands. Presence models also indicated that areas closer to roads were positively associated with presence of mule deer and oryx, as were southern aspects for oryx and higher elevations for mule deer. Relationships with roads were likely driven by other attributes (e.g., water sources, arroyos, and canyons) associated with these areas in the San Andres Mountains. Current management strategies aimed at limiting oryx numbers in woodland and shrubland habitat types located in mountainous areas of the San Andres Mountains that show highest use by mule deer should continue to aide in recovery of mule deer populations.

**Key words:** competition, desert mule deer, habitat-use, herbivory, human–wildlife conflicts, New Mexico, oryx
that provide cover for them (Boeker et al. 1972, Krausman et al. 1997, Dye 1998, Hoenes 2008). In contrast, oryx are classed as intermediate feeders (Hofmann 1985) and feed primarily on grasses but also use palatable browse extensively when it is present (Reid and Patrick 1983, Smith et al. 1998, Dye 1998, Hoenes 2008). Because of the potential high use of browse by both species and the relative scarcity of high-quality browse on the San Andres Mountains (Hoenes 2008), the potential for exploitative competition between oryx and mule deer would be greatest in areas frequented by and having habitat attributes most preferred by mule deer, i.e., relatively abundant browse communities. This may be particularly true in desert environments subject to frequent drought, such as found in the San Andres Mountains, as browse is less susceptible to short-term drought than are other foods, such as forbs, which are preferred by oryx and mule deer (Hoenes 2008).

Interference competition occurs primarily due to social interactions among species (Birch 1957). Extremely aggressive behavior has been associated with oryx (Walther 1980, 1988), increasing their potential to interfere with mule deer. Regardless of the type of competition, a concurrent use of the same habitats is a prerequisite for competition between native mule deer and oryx.

Our goal was to determine the relative use of habitat types (as indexed by numbers of pellet groups per species; Neff 1968, Leopold et al. 1984) in the San Andres Mountains by mule deer and oryx to evaluate whether the potential for competition exists, and if so, to what degree. Our specific objectives included: (1) determine relative use of habitat types by mule deer and oryx; (2) identify landscape attributes that affected distribution of mule deer and oryx; and (3) compare relative use of forage resources within habitat types by mule deer and oryx.

![Figure 1. Exotic bull oryx in San Andres Mountains, New Mexico. (Photo courtesy Mara Weisenberger, San Andres National Wildlife Refuge)](image1)

![Figure 2. Buck mule deer in San Andres Mountains, New Mexico.](image2)
Human–Wildlife Interactions 4(1)

Methods

Study area

The greater San Andres Mountains area encompasses ~11,000 km² (approximately 165 km north to south and 64 km east to west), including joint-use and management areas of San Andres National Wildlife Refuge, WSMR, the North American Air and Space Administration’s White Sands Test Facility, White Sands National Monument, Holloman Air Force Base, and the U.S. Department of Agriculture’s Jornada Experimental Range. The San Andres Mountains and surrounding terrain include playas, rugged mountain peaks, canyons, rolling grasslands, sand dunes, lava flows, and scattered springs and ponds (Muldavin et al. 2000). Precipitation averaged 200 to 350 mm annually, with the bulk of moisture occurring as short, intense rainstorms during July through September. Snowfall averaged <100 mm, was short-lived, and occurred only at high elevations. Temperatures of the area ranged from −23 to 41°C. Three principal seasons occurred in the study area: warm-wet (July–October); cool-dry (November–February); and warm-dry (March–June).

Major vegetation communities of the San Andres Mountains included semidesert grassland, Chihuahuan Desert scrub, and Great Basin conifer woodland (Muldavin et al. 2000). Vegetation was typical of the Chihuahuan Desert shrublands and grasslands, with characteristic plant species including grama grasses (Bouteloua spp.), dropseeds (Sporobolus spp.), bristlegrass (Setaria leucopila), soaptree yucca (Yucca elata), banana yucca (Yucca baccata), Mormon tea (Ephedra spp.), creosotebush (Larrea tridentata), tarbush (Flourensia cernua), mesquite (Prosopis glandulosa), and 4-wing saltbush (Atriplex canescens). Pinyon- (Pinus edulis) juniper (Juniperus spp.) woodlands occurred at the higher elevations in association with mountain mahogany (Cercocarpus montanus) and oak (Quercus spp.) shrublands.

Habitat delineation and mapping

We used a vegetation association map of WSMR (Muldavin et al. 2000) and condensed the original 32 vegetation associations into 9 major habitat types based on relevance of their characteristics to mule deer (Hoenes 2008; Table 1). The other shrublands habitat type consisted of shrubland habitat types present within the

### Table 1. List of 9 major habitat types delineated for the San Andres Mountains in New Mexico and the original associations determined by Muldavin et al. (2000).

<table>
<thead>
<tr>
<th>Major Habitat Type</th>
<th>Original Associations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Oak (Quercus spp.)-mountain mahogany (Cercocarpus montanus) shrublands.</td>
<td>Montane scrub. Interior chaparral.</td>
</tr>
<tr>
<td>3. Creosotebush (Larrea tridentata) shrublands.</td>
<td>Creosotebush shrubland.</td>
</tr>
</tbody>
</table>
San Andres Mountains that comprised only a small percentage of total land cover (<9.0% combined). Habitat types in this group included, but were not limited to, fourwing saltbush, pickleweed (*Allenrolfea occidentalis*), tarbush, and acacia (*Acacia* spp.) shrublands (Table 1).

**Relative use**

We conducted fecal-pellet surveys within habitat types concurrent with browse surveys to assess relative use of habitats, not population trends (Neff 1968, Connolly 1981). We randomly selected 10 (2004 and 2005) and 15 (2006) stands per habitat type for surveys, with each stand being the experimental replicate. We randomly selected stands annually from vegetation association maps of the San Andres Mountains that delineated all 9 habitat types in Table 1 using a random point generator in ArcGIS 9.0 (Environmental Systems Research Institute, Redlands, Calif.). Surveys consisted of a single 6-m × 500-m belt transect per stand. We tallied all fecal-pellet groups encountered and identified them to species. Oryx pellets were larger and more spherical in shape and were deposited typically in much larger conical piles than those of mule deer. A minimum of 15 pellets had to be present to be considered a group, and we counted only groups in which >50% of the pellets were inside the transect boundary. Scarcity of ground cover made absolute enumeration of all groups present possible, and we tallied all groups present (excluding extremely dry, white chalky pellets, which were >1 year old in the San Andres Mountains (L. Bender, personal observation) to assess use within the past year. We determined a pooled mean for each species over all 3 years to increase the power of differentiating true preference for habitat types irrespective of annual variations. We compared yearly mean browse percentages for each habitat type and determined differences among habitat types using Kruskal-Wallis ANOVAs (Zar 1996). We related the percentage of browse-use of each species on each transect to the number of deer and oryx pellet groups per transect using Pearson correlations and Stepwise Multiple Regression (Zar 1996) for each habitat type.

**Presence modeling**

We modeled distribution of oryx and mule deer using Maximum Entropy 2.3 (MaxEnt; Phillips et al. 2006). This technique utilized only locations where a species was known to be present (i.e., presence on a transect), thereby eliminating the need for absence data (Phillips et al. 2006) and providing a less-biased alternative to other techniques (Baldwin and Bender 2008). We used 6 structural and physiographic variables to model distribution: (1) vegetation type (Table 1); (2) aspect; (3) slope (0–90°); (4) elevation (m); (5) distance to water (m); and (6) distance to roads (m). We extracted values for all 6 variables using ArcGIS 9.0. We classified aspect as: north = 316 to 45°; east = 46 to 135°; south = 136 to 225°; and west = 226 to 315°.

We assessed relative performance of competing models using receiver operating characteristic (ROC) plots (Phillips et al. 2006). The ROC plot consists of sensitivity (true
positive rate represents absence of omission error) plotted on the y axis and 1-specificity (false positive rate represents commission error) on the x axis (Fielding and Bell 1997; Phillips et al. 2006). We then used the area under curve (AUC) in the ROC plot to assist in selecting the most appropriate model. The AUC served as an index of model accuracy, with values ranging from 0.5 to 1.0; a value of 0.5 indicated use by a species is random with respect to the variables in the model (Fielding and Bell 1997; Phillips et al. 2006), and AUC > 0.7 indicated a significant fit (Swets 1988). We calculated standard errors (SE) for AUC values using 30% of pellet transects as test data (Phillips et al. 2006).

Because AUC values frequently are greatest for models with many variables, we used the critical ratio test of Pearce and Ferrier (2000) to compare AUC values of competing models to determine if the increase in explanatory value was significant at \( \alpha = 0.05 \) following Baldwin and Bender (2008). If AUC values of competing models were not different, we used the percentage contribution of variables as an indicator of variable importance. We selected the more parsimonious model if variables contributed little to overall model performance and increases in AUC values were minimal.

We also estimated log thresholds for probability of oryx or mule deer presence at a site to convert probabilities to binary responses (presence-absence) and then incorporated the equal test sensitivity and specificity threshold to calculate classification percentages and corroborate results from ROC curves (Fielding and Bell 1997, Phillips et al. 2006). Lastly, we constructed response curves (Phillips et al. 2006) to identify thresholds and illustrate the effect that variables had on the probability of an area being used by mule deer or oryx (Baldwin and Bender 2008). Upward-downward trends indicated a positive-negative relationship, while the strength of the relationship was represented by the slope of the trend line.

**Results**

**Relative use**

The mean number of oryx fecal-pellet groups per transect varied among habitat types \( (H_8 = 125.9, P < 0.01) \). Oryx consistently used sandsage \((Artemisia filifolia)\) shrublands \((\bar{x} \pm SE = 38.1 \pm 3.8)\) groups per transect) and alkali sacaton \((Sporobolus airoides)\) grasslands \((17.3 \pm 2.1)\) most (Table 2), while the number of oryx pellet groups per transect was consistently lowest in other shrubland \((1.6 \pm 0.7)\), oak-mountain mahogany shrubland \((3.5 \pm 1.7)\), and pinyon-juniper woodland \((2.1 \pm 0.7)\) habitat types (Table 2). The mean number of deer-pellet groups per transect were greatest in oak-mountain mahogany shrublands \((1.6 \pm 0.7)\), oak-mountain mahogany shrubland \((3.5 \pm 1.7)\), and pinyon-juniper woodland \((2.1 \pm 0.7)\) habitat types (Table 2). The mean number of deer pellet groups per transect were greatest in oak-mountain mahogany shrublands \((1.8 \pm 0.5)\) and pinyon-juniper woodlands \((1.2 \pm 0.3)\). Deer-pellet groups were always absent from mixed lowland scrub and alkali sacaton grasslands (Table 2).

**Browse surveys**

Due to absence or small sample sizes of other

<table>
<thead>
<tr>
<th>Habitat type</th>
<th>Oryx</th>
<th>Mule deer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkali sacaton ((Sporobolus airoides)) grassland</td>
<td>17.3 ± 2.1 B*</td>
<td>0.0 ± 0.0 D</td>
</tr>
<tr>
<td>Grama ((Bouteloua spp.)) grassland</td>
<td>10.0 ± 2.8 C</td>
<td>0.7 ± 0.2 B, C</td>
</tr>
<tr>
<td>Creosote ((Larrea tridentata)) shrubland</td>
<td>7.0 ± 1.6 C, D</td>
<td>0.3 ± 0.2 C, D</td>
</tr>
<tr>
<td>Mesquite ((Prosopis glandulosa)) shrubland</td>
<td>7.8 ± 1.8 C, D</td>
<td>0.4 ± 0.2 C, D</td>
</tr>
<tr>
<td>Mixed lowland scrub</td>
<td>9.1 ± 1.7 C</td>
<td>0.0 ± 0.0 D</td>
</tr>
<tr>
<td>Sandsage ((Artemisia filifolia)) shrubland</td>
<td>38.1 ± 3.8 A</td>
<td>0.7 ± 0.3 B, C</td>
</tr>
<tr>
<td>Other shrublands</td>
<td>1.6 ± 0.7 E</td>
<td>0.3 ± 0.2 C, D</td>
</tr>
<tr>
<td>Oak ((Quercus spp.))-mountaint mahogany ((Cercocarpus montanus)) shrubland</td>
<td>3.5 ± 1.7 D, E</td>
<td>1.8 ± 0.5 A</td>
</tr>
<tr>
<td>Pinyon ((Pinus edulis))-juniper ((juniperus spp.)) woodland</td>
<td>2.1 ± 0.7 E</td>
<td>1.2 ± 0.3 B</td>
</tr>
</tbody>
</table>

*A, B, C, D, E = Values that share a letter within a column do not differ \((P > 0.10)\).*
shrubland, grama grassland, creosotebush shrubland, and sandsage shrubland habitat types, mean browse percentages were not estimated. Yearly means were pooled for analysis because browse percentages were not different among years ($H_2 \leq 2.0, P \geq 0.37$) for the other 5 habitat types except for mixed lowland scrub ($H_2 = 5.5, P = 0.06$), which had browse species present in only 2 transects in 2006 and 2007.

For all habitat types, mean browse percentages were low (Table 3) and differed among habitat types ($H_4 = 12.4, P = 0.01$). Mixed lowland scrub (4.0% ± 1.2) and mesquite shrubland (3.1% ± 1.7) habitat types had the greatest use, while oak-mountain mahogany shrublands (1.5% ± 0.3), pinyon-juniper woodlands (1.6% ± 0.5), and alkali sacaton grasslands (1.5% ± 0.8) had the least.

Mean browse-use in pinyon-juniper woodlands was positively related to relative use by deer ($r = 0.61, P < 0.01$) and oryx ($r = 0.65; P < 0.01$). The best model ($F_{3,27} = 27.4, P < 0.01$) included both oryx ($\beta = 0.4 \pm 0.1$) and deer-use ($\beta = 0.8 \pm 0.2$), with oryx accounting for 42% of the variation in browse-use and deer accounting for an additional 27%. Relative deer use was also positively related ($r = 0.89, P < 0.01$) to browse-use in oak-mountain mahogany shrublands. The best model ($F_{1,31} = 110.6, P < 0.01$) included only deer-use ($\beta = 0.5 \pm 0.05$) and accounted for 79% of the variation in browse-use.

### Table 3. List of mean percentage (±SE) of twigs browsed for key mule deer browse species by habitat type and year in the San Andres Mountains, New Mexico, 2004–2006.

<table>
<thead>
<tr>
<th>Habitat type</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>Pooled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkali sacaton (Sporobolus airoides) grassland</td>
<td>0.7±0.3</td>
<td>3.5±2.8</td>
<td>0.8±0.5</td>
<td>1.5±0.8 A*</td>
</tr>
<tr>
<td>Mesquite (Prosopis glandulosa) shrubland</td>
<td>6.6±6.4</td>
<td>1.4±0.5</td>
<td>2.1±0.8</td>
<td>3.1±1.7 B</td>
</tr>
<tr>
<td>Mixed lowland scrub</td>
<td>1.8±0.2</td>
<td>9.0±0.7</td>
<td>3.4±1.1</td>
<td>4.0±1.2 B</td>
</tr>
<tr>
<td>Oak (Quercus spp.)-mountain mahogany (Cercocarpus montanus) shrubland</td>
<td>1.3±0.3</td>
<td>1.3±0.5</td>
<td>1.7±0.6</td>
<td>1.5±0.3 A</td>
</tr>
<tr>
<td>Pinyon (Pinus edulis)-juniper (Juniperus spp.) woodland</td>
<td>1.4±0.4</td>
<td>2.6±1.3</td>
<td>1.0±0.5</td>
<td>1.6±0.5 A</td>
</tr>
</tbody>
</table>

*A, B = Values that share a letter within a column do not differ ($P > 0.10$).

### Table 4. Maximum entropy models for each subset of parameters for relative use of habitat types by deer and oryx in the San Andres Mountain, New Mexico, 2004–2006. Values reported include the area under curve (AUC) and respective standard errors (SE), Z scores and associated P-values comparing the model with the highest AUC to each model, and successful classification percentage (Class %). Preferred models are in bold.

<table>
<thead>
<tr>
<th>Species</th>
<th>Model†</th>
<th>AUC</th>
<th>SE</th>
<th>Z</th>
<th>P</th>
<th>Class %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deer</td>
<td>asp, ele, veg, slp, rds, wtr</td>
<td>0.781</td>
<td>0.040</td>
<td>-2.45</td>
<td>0.007</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>asp, ele, veg, rds, wtr</td>
<td>0.818</td>
<td>0.039</td>
<td>-0.64</td>
<td>0.261</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>ele, veg, rds, wtr</td>
<td>0.828</td>
<td>0.040</td>
<td>0.15</td>
<td>0.440</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td><strong>ele, veg, rds</strong></td>
<td><strong>0.831</strong></td>
<td><strong>0.040</strong></td>
<td><strong>80</strong></td>
<td>75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ele, veg</td>
<td>0.825</td>
<td>0.041</td>
<td>0.25</td>
<td>0.401</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>veg</td>
<td>0.789</td>
<td>0.054</td>
<td>1.32</td>
<td>0.093</td>
<td>65</td>
</tr>
<tr>
<td>Oryx</td>
<td>asp, ele, veg, slp, rds, wtr</td>
<td>0.676</td>
<td>0.032</td>
<td>-0.57</td>
<td>0.284</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>asp, ele, veg, slp, rds</td>
<td>0.654</td>
<td>0.035</td>
<td>-3.44</td>
<td>&lt;0.001</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>asp, ele, veg, rds</td>
<td>0.668</td>
<td>0.036</td>
<td>-2.38</td>
<td>0.009</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td><strong>asp, veg, rds</strong></td>
<td><strong>0.687</strong></td>
<td><strong>0.033</strong></td>
<td><strong>62</strong></td>
<td>62</td>
<td></td>
</tr>
<tr>
<td></td>
<td>veg, rds</td>
<td>0.679</td>
<td>0.033</td>
<td>1.21</td>
<td>0.113</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>veg</td>
<td>0.662</td>
<td>0.032</td>
<td>3.80</td>
<td>&lt;0.001</td>
<td>64</td>
</tr>
</tbody>
</table>

† Variable abbreviations: asp = aspect, ele = elevation, veg = habitat type, slp = slope, rds = distance to road, and wtr = distance to water.
was positively related \( (r = 0.76, P < 0.01) \) to relative oryx-use. The best model \( (F_{1,22} = 28.8, P < 0.01) \) of browse-use included only relative oryx-use \( (\beta = 0.5 \pm 0.1) \) and accounted for 58% of the variation in browse-use. Relationships between mean browse-use and relative use by oryx or mule deer were not significant in alkali sacaton grassland \( (r < 0.22, P > 0.43) \) or mixed lowland scrub \( (r < |0.41|, P > 0.42) \) habitat types.

**Presence modeling**

For deer, the best supported model included elevation, habitat type, and distance from roads (Table 4) and fit data well \( (AUC = 0.831 \pm 0.040, \% \text{ successful classification} = 80\%) \). Response curves indicated that relative use increased as elevation increased, decreased with distance from roads, and was positively associated most strongly with oak-mountain mahogany shrubland, sandsage shrubland, and pinyon-juniper woodland habitat types (Figures 3 and 4). Conversely, relative use by mule deer was slightly negatively associated with creosotebush shrublands.

No model of oryx presence had an \( AUC \geq 0.7 \) (Table 4), suggesting that oryx presence was nearly random with respect to all variables we measured; consequently, results may be spurious and should be interpreted with caution (Swets 1988). Based on parsimony, we selected the model including aspect, habitat type, and distance from roads as the preferred model of relative oryx-use \( (AUC = 0.687 \pm 0.03, \% \text{ successful classification} = 62\%) \). Response curves indicated that relative use decreased with distance from the nearest road and was most positively associated with sandsage shrublands. Other positive associations included alkali sacaton grasslands, mesquite shrublands, mixed lowland scrub, pinyon-juniper woodlands, and south-facing slopes (Figures 5 and 6).

**Discussion**

Distribution patterns and relative use of resources suggested low potential for direct competition between mule deer and oryx in the San Andres Mountains, assuming that patterns of mule-deer use reflected patterns seen prior to introduction of oryx. Differing relative habitat-use patterns (Table 2) reflected differing life-history strategies of each species. Although opportunistic in their use of habitat types, mule deer tended to select areas that provided cover and adequate forage (Peek and Krausman 1996). Mule deer are primarily browsers and thus also prefer habitat types that contain woody browse species (Heffelfinger et al. 2006, Hoenes 2008). This was particularly true in the San Andres Mountains, where highly erratic and spatially patchy precipitation in combination with frequent drought limited availability of forbs for deer, increasing their dependence on browse communities (Hoenes 2008). Moreover, females with young in desert habitats may show preference for mountainous areas that provide escape terrain and cover during the fawning season (Ordway and Krausman 1986, Fox and Krausman 1994). These tendencies were reflected in both distribution models and relative-use surveys; both showed greater relative use of more wooded habitat types, particularly oak-mountain mahogany shrublands and pinyon-juniper woodlands. These 2 habitat types were located at higher elevations, commonly associated with rugged terrain, had the greatest abundance of key browse species (Hoenes 2008), and provided the best cover attributes of any habitat type.

![Figure 3. Map depicting the probability of desert mule deer presence in the greater San Andres Mountains, New Mexico, 2004–2006. Roads are depicted by lines.](image-url)
in the San Andres Mountains. In the flats and foothills, deer used sandsage shrublands, which similarly provided food and cover.

Conversely, oryx are associated with short grassland and open shrub-savanna habitat types in their native range (Williamson and Williamson 1988, Bergstrom and Skarpe 1999). Although classed as an intermediate feeder, oryx were primarily grazers in New Mexico (Saiz 1975, Smith 1994, Dye 1998, Smith et al. 1998). Oryx would therefore be expected to use areas with significant grass cover and possibly a browse component. Habitat types in the San Andres Mountains that possess these characteristics include alkali sacaton grasslands, grama grasslands, and sandsage shrublands (Hoenes 2008), and these habitat types generally received greater relative use by oryx. While distribution models indicated that oryx presence was negatively associated with grama grasslands, this was likely due to topographical features often associated with grama grasslands in the San Andres Mountains. With the exception of grama grasslands found on northern ranges, which received heavy use by oryx, the majority of grama grasslands were associated with mountainous terrain and steep slopes. Conversely, both distribution models and fecal-pellet data indicated that oak-mountain mahogany shrublands received little use by oryx.

Differences in relative use of habitat types by both oryx and mule deer were also reflected in relative browsing pressure. Deer-use accounted for 79% of the variation in browse-use in oak-mountain mahogany shrublands, while oryx-use accounted for 58% of the variation in browse-use in mesquite shrublands. While oryx-use accounted for more of the variation (42%) in browse-use in pinyon-juniper woodlands, both deer- and oryx-use were included in the best model, and deer-use also accounted for a substantial amount of the variation (27%). Observations during pellet surveys and past research suggested that oryx-use of pinyon-juniper woodlands was low and primarily associated with juvenile males, which occupy this habitat type in low densities (Krueger et al. 2006). Regardless of habitat types, however, browse-use was low, suggesting little competition for preferred browse species between mule deer and oryx, given present distribution preferences.

Paradoxically, distribution models for both oryx and deer also indicated that both species

Figure 4. Relationships between the exponential contribution (cont.) of elevation (A), distance to roads (B), and habitat type (C) to the raw prediction (pred.) score and the observed value for deer presence in the San Andres Mountains, New Mexico, 2004–2006. Habitat type abbreviations: alk = alkali, creo = creosote, gra = grama, mes = mesquite, mix = mixed lowland scrub, oak = oak-mountain mahogany, oths = other shrublands, pj = pinyon-juniper, and san = sandsage.
were associated with areas closer to roads. Typically, roads are avoided by ungulates because of increased disturbance and vulnerability to harvest by humans (Conner et al. 2001, Keegan and Wakeling 2003), although the degree to which roads alter habitat-use is largely a factor of traffic volume, associated structures and developments, and level of harvest by humans (Conner et al. 2001). In the San Andres Mountains, most roads were secondary and received minimal use, were present in major drainages and canyons, had very few associated human structures and very low levels of human disturbance because most areas were closed to the general public. Consequently, low levels of disturbance likely resulted in little avoidance of most roads in the San Andres Mountains by oryx and mule deer. Further, many of the roads in the San Andres Mountains were located in major arroyos and canyons. Arroyos often contained distinctly different forage attributes than the surrounding landscape (Marshall et al. 2005) and were important habitat components for mule deer inhabiting desert environments (Hefelfinger et al. 2006). They often contained high-quality browse species and a greater quantity of forbs. These areas were also likely important to oryx, especially in habitat types, such as creosotebush shrublands and mixed lowland scrub, where the presence of high-quality, highly-palatable forages were limited (Hoenes 2008). Moreover, past research has shown that oryx moved through the San Andres Mountains (Krueger et al. 2006), and canyons (or roads) that bisect the mountains served as ideal travel corridors for these individuals.

It was likely of more importance, however, that all permanent water developments (e.g., dirt tanks, guzzlers, etc.) in the San Andres Mountains were associated with roads. Additionally, many of the springs, seeps, and ephemeral streams that provide permanent or ephemeral water sources were also associated with established roads. The ability of permanent water sources to influence the distribution and movements of mule deer has been well-documented (Wood et al. 1970, Ordway and Krausman 1986, Fox and Krausman 1994). Although oryx evolved in arid landscapes and adapted well to areas that receive minimal precipitation, they also selected areas with permanent water sources (Williamson and Williamson 1988, Knight 1991). Thus, positive associations with areas closer to roads by both species were likely influenced by permanent water sources.

Although declines in mule deer numbers paralleled increases in the number of oryx, a cause-and-effect relationship associated with competitive exclusion given present distribution of the 2 species was not supported based on relative patterns of habitat-use or browse levels of key species in the San Andres Mountains, which were low (≤4%). This did not preclude a competitive impact in the past, although we feel that this was unlikely because the higher elevation habitat types most used by deer in the San Andres Mountains were the last colonized by oryx. Oryx in these higher elevation areas had only recently (i.e., after the significant declines in mule deer) become abundant. However, other factors, such as persistent drought and disease (Bender et al. 2006), may have negatively affected mule deer but not oryx. Additionally, productivity of mule deer in the San Andres
Mountains is presently low, likely due to a lack of high-quality forages, most browse species being in late seral stages, further limiting forage availability and subsequent poor recruitment of juveniles (Hoenes 2008). Conversely, Roeder et al. (2006) found that oryx had high productivity rates within the San Andres Mountains. Oryx were well-adapted to areas that received limited rainfall and experienced extended periods of drought (Sinclaire et al. 2000). Consequently, current resource limitations within the San Andres Mountains were less likely to affect oryx than mule deer. For example, Bender et al. (2007) reported a 33% decline in a single year for a mule deer herd in northcentral New Mexico when their study area experienced a significant annual drought. Similar drought conditions in the San Andres Mountains could result in similar declines in mule deer (Logan and Sweanor 2000, Hoenes 2008) and oryx populations that exceed those of mule deer in only a few years.

**Management implications**

Dye (1998) felt that there was minimal potential for exploitative competition between mule deer and oryx because of little dietary overlap between the 2 species. Our data only partially supports this. Although oryx are considered primarily grazers in New Mexico (Saiz 1975, Smith et al. 1998) and mule deer are primarily browsers (Boeker et al. 1972, Krausman et al. 1997, Wakeling and Bender 2003), oryx-use accounted for the majority of browse-use in 2 of 3 habitat types that had a significant browse component, indicating that oryx and mule deer may compete for similar resources, especially because key browse species are relatively rare in the San Andres Mountains (Hoenes 2008). However, our data also suggest minimal potential for interference because of the distinct differences in relative use of habitat types and because levels of browse-use were low.

Pinyon-juniper woodlands, oak-mountain mahogany shrublands, and mesquite shrublands appear to be extremely important to mule deer. Thus, given the possibility of competition for browse, which is a particularly important food source of mule deer in arid environments (Krausman et al. 1997, Hoenes 2008), steps should be taken to minimize the use of these habitat types by oryx. WSMR and SANWR currently have hunts that are limited to mountainous areas and specifically target these individuals. We recommend the continuation of this management strategy.

**Acknowledgments**

We thank the U.S. Army White Sands Missile Range, U.S. Fish and Wildlife Service–San Andres National Wildlife Refuge, U.S. Bureau of Land Management, New Mexico Department of Game Resources, and New Mexico State University for their collaboration, support, and advice on this project. We also express our appreciation to the many individuals who provided field assistance and who were instrumental in the completion of this study.
and Fish, and New Mexico State University Agricultural Experiment Station for funding this project. We thank J. Barnitz, J. Boren, A. Cibils, P. Morrow, C. Rodden, and M. Weisenberger for their contributions to field and logistic needs.

**Literature cited**
Dye, J. L. 1998. Gemsbok and mule deer diets in southern New Mexico. Thesis, New Mexico State University, Las Cruces, New Mexico, USA.
Hoenes, B. 2008. Identification of factors limiting desert mule deer populations in the greater San Andres Mountains of southern New Mexico. Thesis, New Mexico State University, Las Cruces, New Mexico, USA.
Krausman, P. R., A. J. Kuenzi, R. C. Etchberger, K. R. Rautenstrauch, L. L. Ordway, and J. J.
cyclopedia of mammals. V. X. Kindler GmbH, Munich, Germany.


Wood, J. E., T. S. Bickle, W. Evans, J. C. Germany, and V. W. Howard Jr. 1970. The Fort Stanton mule deer herd. New Mexico State University Agricultural Experiment Station Bulletin 567, Las Cruces, New Mexico, USA.

Wyoming Game and Fish Department. 1982. Biological techniques. Wyoming Game and Fish Department, Cheyenne, Wyoming, USA.


Brock D. Hoenes (photo unavailable) is a wildlife biologist with the Washington Department of Fish and Wildlife. Previously, he was a wildlife specialist with the New Mexico Cooperative Fish and Wildlife Research Unit. He received his B.S. degree in fisheries and wildlife management from the University of Missouri and his M.S. degree from New Mexico State University. His primary interests include ungulate ecology and management.

Louis C. Bender (photo unavailable) is a specialist with Extension Animal Sciences and Natural Resources at New Mexico State University, where his research and management programs emphasize ungulate and carnivore ecology and management, integrated wildlife and livestock habitat management, and wildlife enterprises in the Southwest and Mexico.