Diet of pumas (*Puma concolor*) in Sonora, Mexico, as determined by GPS kill sites and molecular identified scat, with comments on jaguar (*Panthera onca*) diet

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DIET OF PUMAS (PUMA CONCOLOR) IN SONORA, MEXICO, AS DETERMINED BY GPS KILL SITES AND MOLECULAR IDENTIFIED SCAT, WITH COMMENTS ON JAGUAR (PANTHERA ONCA) DIET

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ABSTRACT—We documented puma (Puma concolor) and jaguar (Panthera onca) prey consumption in northeastern Sonora, Mexico, by investigating global positioning system cluster sites (n = 220), and conducting molecular analyses of scat (n = 116) collected between 2011 and 2013. We used camera trap data (n = 8,976 camera days) to estimate relative abundances of pumas and jaguars. Deer (Odocoileus virginianus) was the most frequent prey for puma found at kill sites (67%) and identified from scat (74%), although based on relative numbers of prey consumed, deer represented 45% and lagomorphs 20% of the proportion of all individuals eaten. A variety of small prey (weighing <15 kg) compromised the majority (52%) of the jaguar kill sites. From prey found at kill sites, jaguars killed calves (Bos taurus) at a lower frequency than previously reported, whereas pumas preyed on calves at a higher frequency than previously reported in the same area. In our study area, jaguars preyed on calves at approximately the same rate as pumas (jaguars 3.7 calves per year, pumas 4.9 calves per year). Calculated predation rates were limited only to collared animals within our study area and therefore should not be considered applicable to all pumas and jaguars in Sonora.

RESUMEN—Documentamos el consumo de presas de puma (Puma concolor) y jaguar (Panthera onca) en el noreste de Sonora, México, mediante la investigación de agrupamiento de sitios obtenidos a través de sistema de posicionamiento global (n = 220) y la realización de análisis moleculares de heces colectadas (n = 116) entre 2011 y 2013. Utilizamos datos de trampas cámara (n = 8,976 días cámara) para estimar la abundancia relativa de pumas y jaguares. El venado (Odocoileus virginianus) fue la presa con mayor frecuencia encontrada en sitios de caza de puma (67%) y identificada en heces (74%), aunque basándose en los números relativos de presas consumidas, los venados representaron 45% y lagomorfos 20% de la proporción de todas las presas consumidas. Una variedad de presas pequeñas (peso <15 kg) conformó la mayoría (52%) de los sitios de caza de jaguares. De las presas encontradas en sitios de caza, los jaguares mataron becerros (Bos taurus) a una frecuencia más baja que la reportada anteriormente, mientras que los pumas depredaron becerros a una frecuencia mayor a la reportada previamente en la misma zona. En nuestra área de estudio, los jaguares depredaron becerros aproximadamente a la misma tasa que los pumas (jaguares 3.7 becerros por año, pumas 4.9 becerros por año). Los cálculos de las tasas de depredación estuvieron limitados a los animales con collar dentro del área de estudio y por lo tanto no debe considerarse su aplicación a todos los pumas y jaguares en Sonora.

The grizzly bear (Ursus arctos) and wolf (Canis lupus), once extant throughout northern Sonora, Mexico, were extirpated because they were perceived as a threat to livestock production (Brown and Murray, 1988). Percep-
tions about jaguar and puma predation are the reason they are illegally killed and is the primary cause for the declining population of jaguars in Sonora (Brown and Lopez-Gonzalez, 2001; Rosas-Rosas et al., 2010).

Although researchers believe puma populations to be stable in Mexico, jaguars are classified as endangered by Mexico’s environmental ministry (Secretaría de Medio Ambiente y Recursos Naturales, 2010). Sonora has the northernmost population of jaguars, which has been estimated by researchers at a density of 1.05–1.1/100 km$^2$ (Gutierrez-Gonzalez et al., 2012; Rosas-Rosas and Bender, 2012) and is considered to be one of the lowest reported in the literature for all jaguar distribution (Maffei et al., 2011). A few jaguars still disperse into the southwestern United States, where they are legally protected as an endangered species (Fish and Wildlife Service, Interior, 1997). International collaboration between both countries is essential for effective conservation of not only jaguars and pumas, but also a wide variety of other species (Medellin, 1998).

Determining accurate prey proportions, including livestock, in the diets of pumas and jaguars in Sonora is essential for understanding the economic impacts of predation for livestock producers and essential to managing habitat and prey of pumas and jaguars. However, studies examining the ecology and conservation needs of coexisting jaguars and pumas and their prey are limited and they typically have been carried out in tropical areas, considered as the core habitats of jaguars (Weckel et al., 2006; Cavalcanti and Gese, 2010; Foster et al., 2010). This is the first study of puma and jaguar diet composition in the Sinaloan thornscrub using GPS cluster investigations and molecular analyses of scat.

The purpose of this study was to determine the diet of pumas and jaguars using GPS satellite collars to locate kill sites, to conduct molecular analyses of scat, and to estimate annual predation rates on cattle by both apex predators.

**MATERIALS AND METHODS—Study Area**—The study area was approximately 700 km$^2$ (Fig. 1) and partially overlapped that of a previous diet study by Rosas-Rosas et al. (2008). It was located in the Sierra Madre Occidental, in northeastern Sonora, approximately 250 km south of the United States-Mexico border. We defined boundaries by confirmed kill site locations of our study animals within the neighboring municipalities of Los Granados, Divisaderos, and Nacori Chico, inclusive of portions of the Rio Bonito, Rio Bavispe, and Rio Aros. The entire study area was within the Rio Yaqui watershed. Elevation ranged from 500 to 1,500 m, and the average annual precipitation was 480 mm (National Meteorological Service, Base de datos climáticos del Noroeste de México, http://peac-bc.cicese.mx/datosclim/dcbc.php#). The study area has a large diversity of vegetation including Sinaloan thornscrub, Sinaloan tropical deciduous forest, and Madrean evergreen woodland (Brown, 1982). Dominant vegetation includes zamota (*Corsetia glandulosa*), mauto (*Lysiloma divaricata*), mesquite (*Prosopis juliflora*), torote (*Bursera* spp.), tarachique (*Dononaea viscosa*), palo blanco (*Piscidia mollis*), catclaw (*Mimosa* spp.), organ pipe cactus (*Lemaireocereus thurberi*), and quelite (*Amaranthus palmeri*).
Livestock operations in the region consist of year-round cow-calf production without synchronized breeding. Cattle were documented previously by Rosas-Rosas et al. (2008) as prey for both pumas and jaguars in the study area. Other potential prey species included white-tailed deer (Odocoileus virginianus), collared peccary (Pecari tajacu), white-nosed coati (Nasua narica), opossum (Didelphis virginiana), and three species each of lagomorphs and skunks as determined from our camera traps.

Captures—Between February 2011 and February 2013 we captured or recaptured two jaguars and seven pumas. We used modified Aldrich foot snares (Logan et al., 1999) approximately 1 m in length staked to the ground in line with double swivels and heavy-duty springs. We monitored active snare sites every 4 h using VHF trap-site transmitters and a VHF receiver (Telonics® Inc., Mesa, Arizona). We immobilized study animals with either a combination of ketamine (5 mg/kg, Ketanil®, Wildlife Pharmaceuticals Mexico, Mexico; 200 mg/mL) and medetomidine (0.08 mg/kg, Wildlife Pharmaceuticals Inc., Fort Collins, Colorado; 20 mg/mL), antagonized with atipamezole (0.35 mg/kg, Wildlife Pharmaceuticals Inc., 20 mg/mL); or a mix of butorphanol (0.4 mg/kg, Wildlife Pharmaceuticals Inc., 30 mg/mL) combined with medetomidine (0.08 mg/kg) and azaperone (0.15 mg/kg, Wildlife Pharmaceuticals Inc., 50 mg/mL), antagonized with atipamezole (0.35 mg/kg) and naltrexone (3 mg/mg of butorphanol used, Trexonil®, Wildlife Pharmaceuticals Mexico; 50 mg/mL). We fitted all captured adult animals with up-linking Iridium (Advanced Telemetry Systems, Isanti, Minnesota; collars n = 8) or Global Star (North Star, King George, Virginia; collars n = 4) satellite GPS collars programmed to download locations six times during each 24-h period (1200h, 1800h, 2100h, 0100h, 0400h, and 0600h).

Camera Traps—We placed 42 camera traps over approximately 100 km² to estimate relative abundances of pumas and jaguars. The size of the area sampled was limited by the number of cameras available; however, we stratified placement of cameras between the major vegetation types on animal trails (70–250 cm in width) and secondary roads (approximately 400 cm wide). We placed 22 cameras within approximately 50 km² from February 2011 to March 2012 and 20 cameras within the remaining 50 km² from April 2012 to June 2013. Minimum distance between cameras was 0.32 km and maximum distance was 12.58 km, which corresponded to the distance between two different noncontiguous grazing ranches in our study area (mean = 4.97 km). We collected photos at least every 6 weeks, relabeled them with their date and time, sorted them by species, and analyzed them monthly to establish frequency of occurrence and abundance of predators using the camera trap analysis program “ReName” (Harris et al. 2010). Any two-camera site stations were considered independent from each other due to the distance and/or different stratification placement. The program assumes independent pictures of a species at a site after each 60-min period and uses the maximum number of individuals photographed in subsequent sequential pictures. We also calculated a relative abundance index (O’Brien et al., 2003; Monroy-Vilchis et al., 2011) with the program.

Kill Site Investigations—Between February 2011 and June 2013 we identified potential kill sites as two or more consecutive GPS locations <200 m apart occurring between 1800h and 0600h to avoid day-bedding activity (Anderson and Lindzey, 2003) and to save costly field time. We investigated potential kill sites within a 2-week period after the animal had departed. At sites where we found prey remains, we searched for evidence of a large felid responsible for the kill, such as bite marks by large canines, drag marks, signs of struggle (broken branches, turned-over rocks), and blood stains. When we found such evidence, we classified the site as a kill site. If the prey remains were fed upon, but no evidence associated with the act of killing was observed, we classified the site as a scavenging site. We described potential kill sites with no prey item located as possible bedding or ambush hunting sites (sites in close proximity to water, game trails, peccary bedding grounds, and fence crossings). At kill sites, we confirmed the predator species as either a puma (evisceration and caching of the carcass) or jaguar (canine bites to the skull, no evisceration, and noncaching of the carcass; Childs, 1988). For prey items we recorded species and age class (we considered cattle less than 1 year of age as calves).

Molecular Analysis of Scats—DNA Extraction—We opportunistically collected scat samples from felids throughout the study area from October 2012 to June 2013. We extracted predator DNA by obtaining sloughed epithelial cells from the scat, and extracted prey DNA from bones and hair found in the scat. We performed DNA extractions in a dedicated ancient-DNA facility located in a separate building from the post–polymerase chain reaction (PCR) laboratory to avoid contamination. We extracted depositor DNA by swabbing the surface of the scats with cotton-tipped applicators saturated with 10× phosphate-buffered saline (Thermo Fisher Scientific Inc., Waltham, Massachusetts). We placed applicators in 2.0-mL microcentrifuge tubes with 300 μL of ATL buffer (Qiagen Inc., Valencia, California) and 30 μL of proteinase K (Qiagen Inc.) and incubated at 57°C for 24 h. After incubation, we used a Qiagen DNeasy® blood and tissue extraction kit (Qiagen) and followed the manufacturer’s protocol for DNA extraction and purification from animal tissue.

We selected a major bone from each scat and pulverized it in a freezer mill (Spex 6770 freezer mill from Spex SamplePrep, Metuchen, New Jersey). We decalcified up to 50 mg of bone powder for 5 days with 400 μL of 0.5 M EDTA (Promega Corporation, Madison, Wisconsin) at 4°C with agitation. In order to remove ions accumulated during decalcification, we washed bone pellets four times with 1.5 mL of sterile deionized water prior to DNA extraction. After the wash steps, we added 300 μL of ATL buffer and 30 μL of proteinase K and incubated samples at 55°C for 24 h on a rocking platform. After incubation, we used a Qiagen DNeasy® blood and tissue extraction kit and followed the manufacturer’s protocol for animal tissue DNA extraction and purification.

We cut hair shafts into fragments of approximately 2 mm and placed them in 2.0-mL microcentrifuge tubes with 200 μL of lysis buffer X1 (10 mM Tris-Cl, pH 8.0 [Teknova, Hollister, California], 10 mM EDTA, 100 mM NaCl [Promega], 40 mM dithiothreitol [Amresco, Solon, OH], 2% sodium dodecyl sulfate [Amresco], and 250 μg/mL Proteinase K [Qiagen]). We incubated samples overnight at 55°C with agitation. Following incubation, we used a Qiagen DNeasy® blood and tissue extraction kit and followed the manufacturer’s protocol for animal tissue DNA extraction and purification.

PCR Amplification—We amplified a segment of approximately 470 base pairs of the mitochondrial cytochrome-b gene region using the primers mcb598 and mcb869, designed by Verma and Singh (2003) for mammalian species. PCR amplifications were performed in a total volume of 20 μL containing 1× PCR Buffer
Table 1—Number and proportion of independent pictures for jaguar and puma detected by camera traps from February 2011 to June 2013 and the relative abundance index (RAI) in the study area in Sonora, Mexico.

<table>
<thead>
<tr>
<th>Species</th>
<th>No. of pictures</th>
<th>%</th>
<th>RAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puma (Puma concolor)</td>
<td>240</td>
<td>4.32</td>
<td>2.67</td>
</tr>
<tr>
<td>Jaguar (Panthera onca)</td>
<td>54</td>
<td>0.97</td>
<td>0.60</td>
</tr>
<tr>
<td>Other species</td>
<td>5,286</td>
<td>94.7</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>5,560</td>
<td>100</td>
<td>—</td>
</tr>
</tbody>
</table>

We calculated the annual rate of prey consumption (SPSS, version 16.0, Chicago, Illinois). We reported these results as frequency of occurrence, which is the percentage of scats in which an item was found. Since proportionately more collectible scats are produced when pumas consume smaller prey (Ackerman et al., 1984), we used the correction factor developed by Ackerman et al. (1984): $Y = 1.98 + 0.035X$, where $Y$ is the mass of prey consumed per scat and $X$ is prey body mass. We used this regression to convert prey occurrence to an estimate of the relative biomass and relative abundance index (Shapiro-Wilk), resulting in a parametric distribution of prey consumed.

RESULTS—Camera Data—We obtained a total of 8,476 photos with a camera trap effort of 8,976 camera days, which is considered adequate sampling for establishing inferences at a community level (Cusack et al., 2015). From these, we obtained 5,560 independent pictures. Comparing the relative abundance index between puma (2.67) and jaguar (0.67; Table 1), we detected a ratio of one jaguar per 4.5 pumas in our study area.

Kill Site Investigations—We captured and radio-collared seven adult pumas (four males, three females) and two adult jaguars (one male, one female). The radio collars of three pumas failed shortly after release for unknown reasons and therefore provided limited data. One female puma was killed and eaten by a noncollared male puma prior to providing any prey data. We obtained 231 GPS clusters meeting our definition of a potential kill site. We did not investigate 11 of these sites due to personal safety reasons or lack of permission to access the area. From the remaining 220 potential kill sites, we discovered prey remains at 107 (46%), 84 of which were for pumas (Table 2) and 23 for jaguars (Table 3). Of the 107 sites with prey remains, six were determined to be scavenging sites. Based on the GPS data, three of the scavenging sites were solely fed on by puma, two only by jaguar, and one by both puma and jaguar. Feeding activity at the shared site was temporarily separated, with puma feeding prior to the arrival and feeding by jaguar as shown by the GPS data.

Scat Analyses—We collected 116 scats and determined the predator species by molecular analysis for 85 (73%); 75 (88%) deposited by pumas and 10 (12%) deposited by jaguars. Using molecular methods as previously described, we identified the prey species in 71 scats (84%); 66 from puma (Table 2) and five from jaguar (Table 3). We could not determine age classes of cattle from scat analyses, nor could we determine if the animal was killed or scavenged.

Predation and Puma Kill Sites—Puma diet included at least 12 species (Table 2). White-tailed deer was the most frequent prey killed (67%) by pumas as determined by the investigations of GPS clusters, followed by calves (16%) and peccaries (6%). The majority of prey killed by our collared pumas (89%) were species weighing >15 kg. We calculated that collared pumas in our study area killed approximately 4.9 calves per year and approximately 20.9 white-tailed deer per year. Male pumas killed 5.2 calves per year, whereas females killed calves at a lower rate of 1.6 calves per year. Collar-days were 163 ± 138.5 ($P = 0.752$).

Puma Scat Analyses—We identified white-tailed deer to be 74% of the puma diet, followed by cattle at 12%. However, applying the Ackerman’s correction factor, white-tailed deer accounted for 43% of the diet and calves for 4%. Prey weighing <15 kg represented 48% of the diet while the majority of the diet (52%) was comprised of species weighing >15 kg.

Jaguar Kill Sites—We identified a minimum of nine prey species at jaguar kill sites. The majority (52%) of prey included white-tailed deer, followed by cattle (19%); both species had a larger prey size than any other species (Table 3). We did not determine age classes for cattle or the identity of the animal that was killed or scavenged.
killed by jaguars in the study area were species weighing <15 kg (bird, coati, skunk [Mephitidae], opossum, grey fox [Urocyon cinereoargenteus], and bobcat [Lynx rufus]). Scavenging represented 13% of the sites inspected (Table 3). Although calves were the single most frequent prey species found at jaguar kill sites (17%), the frequency of occurrence was similar to that of calves in the diet of pumas (16%) as determined from the investigation of kill sites. Collared jaguars in our study area killed 3.7 calves per year and 2.8 white-tailed deer per year. Collar-days were 197.5–45.9 (P = 0.752).

### TABLE 2—Frequency (percentage) of species identified at 84 kill or scavenging GPS cluster sites from six pumas (Puma concolor), and frequency of occurrence, relative biomass, and relative number of individuals consumed of species identified by DNA analysis of 66 scat of pumas in the study area in Sonora, Mexico, between October 2012 and June 2013.

<table>
<thead>
<tr>
<th>Prey species</th>
<th>Frequency (%)</th>
<th>Frequency of occurrence (%)</th>
<th>Relative biomass consumed (%)</th>
<th>Relative number of individuals consumed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;15 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odocoileus virginianus</td>
<td>67</td>
<td>74</td>
<td>72</td>
<td>45</td>
</tr>
<tr>
<td>Bos taurus^</td>
<td>16</td>
<td>12</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>Pecari tajacu</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Canis latrans</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Equus asinus</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&lt;15 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mephitidae</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Birds (Catharidae, Melleagris gallopavo, Corvus spp.)</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nasua narica</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lagomorph (Sylvilagus spp., Lepus spp.)</td>
<td>1</td>
<td>3^b</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Tortoise (Gopherus agassizii)</td>
<td>0</td>
<td>6</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>Squirrel (Otospermophilus variegatus)</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Scavenge sites (cow or deer carcass)</td>
<td>4</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

^ Bos taurus was identified as calf at all kill sites but age could not be established through scat analysis.

b Sylvilagus floridanus identified by DNA analysis.

### Table 3—Frequency (percentage) of species identified at 23 kill or scavenging GPS cluster sites from two jaguars (Panthera onca), and prey items identified by DNA analysis of five jaguar scats, in study area in Sonora, Mexico, between February 2011 and June 2013.

<table>
<thead>
<tr>
<th>Prey species</th>
<th>Frequency (%)</th>
<th>Number of scats with prey item</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;15 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odocoileus virginianus</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Bos taurus^</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>Pecari tajacu</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>&lt;15 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mephitidae</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Birds (Catharidae, Melleagris gallopavo, Corvus spp.)</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Nasua narica</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Lynx rufus</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Urocyon cinereoargenteus</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Didelphis virginiana</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Scavenge sites (cow or deer carcass)</td>
<td>13</td>
<td>—</td>
</tr>
</tbody>
</table>

^ Bos taurus was identified as calf at all kill sites but age could not be established through scat analysis.

**Jaguar Scat Analyses**—Since a minimum sample size of 40 scats has been shown to adequately characterize jaguar diet (Nuñez et al., 2000), we did not consider our jaguar scat sample size (n = 5) as adequate to establish any conclusions.

**DISCUSSION**—During a previous scat-based diet study of jaguars and pumas in the same study area (Rosas-Rosas et al., 2008), cattle accounted for 58% of the total biomass consumed by jaguars and 9% by pumas (in contrast to 20% by pumas in our study). In that study, researchers assigned scat to either a jaguar or a puma based on observations of associated tracks and scrapes, and on the size, color, and shape of the scat, rather than DNA analyses. Scat diet studies unsupported by modern molecular techniques present three problems: 1) the possibility of misidentification of the species depositing the scat, as described by Farrel et al. (2000) and Rueda et al. (2013) (Rueda et al. [2013] found that only 64% and 36% of the scat assigned to puma and jaguar, respectively, were accurate); 2) scat collected could be from a few or even a single unknown jaguar or puma, as described by Cavalcanti and Gese (2010), who noted that three of their 10 collared jaguars accounted for most of the predation of livestock in their study area; and 3) diet cannot be differentiated as either prey killed or food obtained by scavenging (Bauer et al., 2005). The consequence of not determining actual scavenging frequencies could assign higher frequencies of depredation of livestock to puma or jaguar than are actually occurring. In our study, we

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estimated 13% of the diet of jaguars and 4% of the diet of pumas to be from scavenging. If we had used only scat analyses, these scavenging percentages would have been added into their diets and, thus, we would have wrongly assumed that jaguars and pumas were killing more livestock than they actually were.

This study, however, brings together two scientific methods for detecting and quantifying prey use by apex carnivores. The prey killed most frequently by pumas in this study was white-tailed deer (67%), a finding similar to long-term puma diet studies based on kill sites by Shaw (1981), Anderson and Lindzey (2003), and Knopff et al. (2010). Scat analyses, however, when applying the Ackerman's correction factor, can show a better numerical estimation of the different species in the diet. Although white-tailed deer remained as the most frequent prey killed by pumas, species weighing <15 kg represented 48% of the diet as determined by scat analysis compared to 11% as determined from our kill site investigations. These results suggest there is a bias toward finding larger prey items at potential kill sites. Despite the difficulty of finding prey weighing <15 kg, 52% of our kill sites for jaguar (n = 12) had medium prey species. Unfortunately, due to the low density of jaguars in the area and the difficulty in finding jaguar scat, we could not thoroughly describe jaguar diet. We acknowledge that jaguar scat was undersampled based on the results of our opportunistic collection of scats, followed by molecular identification of the depositing predator. Jaguar scats are, for unknown reasons, difficult to detect on a landscape with a low density of jaguars. Our kill site results, however, suggest that prey species weighing <15 kg might be of great importance in the maintenance or growth of a population of Sonoran jaguars.

Although our sample size of two jaguars with GPS collars was too low to adequately describe jaguar diet in the Sinaloan thornscrub, it is an important sample when considering the low density of jaguars known currently to be extant in Sonora. In 2005, Rosas-Rosas and Bender (2012) estimated a density of 1.1/100 km² in a location near our study area. However, since then, the jaguar population might have decreased. From 1999 to 2004, Rosas-Rosas et al. (2010) documented “>11 jaguars” known to have been killed, or approximately 0.6 jaguars killed per year/100 km². In a portion of our study area of approximately 200 km², we documented the killing of three jaguars in a 3-year period (2011–2013; 0.5 jaguars killed per year/100 km²). In a parallel ongoing camera trap study in our research area we documented a decrease in the detection rates for jaguars from 0.95 to 0.28 jaguars/100 camera days from the beginning to the end of the period (2009–2014). Therefore, this jaguar subpopulation in Sonora might not only be one of the lowest densities recorded, but could now be a subpopulation sink (i.e., annual mortality exceeds recruitment; Logan and Sweanor, 2001).

To a rancher, the most important information about a predator’s diet is to know how many calves are killed and what can be done to reduce or eliminate predation. Despite being vulnerable, calves were consumed at a lower frequency than white-tailed deer by pumas or small mammals by jaguars. Frequency of peccaries found at kill sites from both jaguars and pumas was less than 7%. Peccaries are an important prey for jaguar, as determined in several diet studies of jaguars in Mexico (Nuñez et al., 2000; Lopez-Gonzalez and Miller, 2002; Rueda et al., 2013). Peccaries existed in low numbers in our study area due to illegal poaching or disease die-offs, as described by ranchers; hence, the only animals of similar size available as prey for jaguars were white-tailed deer and calves. Calves were clearly more vulnerable than deer or peccary. If white-tailed deer and peccaries were more abundant, livestock predation might be reduced. Prey switching could be tested experimentally as an alternative adaptive wildlife management option in an effort to reduce livestock losses from pumas and jaguars by translocating peccaries captured in areas where their population is stable and they are considered a problem.

When managing both livestock and wildlife in a multiple-prey system for economic and conservation and management reasons, it is important to understand predation as “offtake” (Murphy et al., 2011) of prey. This occurs at a constant minimum rate that rises and falls with climate and subsequent responding seasonal and annual numbers of prey and predators as well as their composition and population sizes (Logan and Sweanor, 2001). In order to calculate prey offtake, biologists and livestock owners must work together to determine or designate what kind and how much prey are available within their area of management responsibility for a known population of predators. Attempting to manage livestock where there is a constant unregulated illegal removal of preferred wild prey likely results in costly unintended consequences for ranchers.

This study provides additional management tools to consider for improving wildlife management programs. Wildlife professionals must be precise in working with local communities that are dependent on livestock and ultimately responsible for the fate of both predator and prey. This is truer now than before, as cattle prices exceed the highest values ever recorded (U.S. Department of Agriculture, http://www.ers.usda.gov/topics/animal-products/cattle-beef/statistics-information.aspx). The wolf and grizzly were extirpated in response to past real or perceived impacts of apex carnivores on the ranching industry (Brown, 1982), yet livestock husbandry practices have not substantially changed in the Sierra Madre Occidental. Predators are still preying on cattle and predators are still killed in retaliation by ranchers. At the end of our study, both of our collared jaguars were poisoned or shot, despite this being a crime in Mexico.
**Recommendations**—Our study shows that pumas and jaguars kill and consume cattle at rates that might be mitigated with synchronized calving concurrent with the fawning season and/or by maintaining healthy populations of native prey species. In our study both predators consumed a majority of native wildlife species. Therefore, a sustainable and healthy native prey population, combined with the management of cattle within proper range carrying capacities that also considers wildlife habitat and forage needs, may decrease livestock depredation. Maintaining white-tail deer and peccary populations at levels that mitigate predation on cattle by pumas and jaguars might be warranted. We hope this study will provide the incentive for future change in the perceptions by, and practices of, ranchers; and that such changes have the potential for positive landscape and economic impacts.

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relationships. Pages 41–70 in Managing cougars in North America (J. A. Jenks, editor). Jack H. Berryman Institute, Utah State University, Logan, Utah.


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