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Do Young Calves Influence Movement Patterns of Nursing Raramuri Criollo Cows on Rangeland?☆

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ABSTRACT

We compared movement patterns of nursing versus non-nursing cows and characterized cow-calf proximity patterns over 2 years in two herds of Raramuri Criollo (RC) cattle that grazed either desert rangeland of southern New Mexico, United States, or woodlands of west-central Chihuahua, Mexico. At each site, 9–14 randomly selected mature cows were fitted with Global Positioning System (GPS) collars configured to record animal position at 5-min intervals. Four to five GPS-collared nursing cows and their calves were also fitted with proximity loggers that recorded initiation time and duration of dam-calf contact events (< 1 m logger-to-logger distance). All calves were < 2 wk old at the onset of the study. Collared animals grazed with a herd of 30 and 35 cows at the NM site and with 68 and 87 cows at the Chihuahua site in 2015 and 2016, respectively. Non-nursing RC cows exhibited straighter travel paths and explored larger daily areas than their nursing counterparts. However, nursing and non-nursing RC cows in this study traveled similar distances each day, moved at comparable velocities, spent similar amounts of time close to drinkers, and did not differ in daily time spent grazing, resting, or traveling. A higher number of cow-calf contact events occurred during day versus nighttime hours, but total day versus night contact time was similar. As calves became older, the number of both day and nighttime contact events, as well as dam-offspring contact time, decreased significantly. Relative to their calves, dams explored larger areas of the pasture each day; however, cow-calf contact events occurred throughout the entire area grazed by the dams including areas surrounding the drinkers. Cow-calf interactions of RC cows resembled those of a *strong follower* regardless of the grazing environment and differed from previously reported mother-offspring relations in mainstream British beef cattle breeds.

Introduction

There is increasing interest worldwide in raising heritage livestock breeds as a means of reducing the environmental footprint of animal agriculture and increasing human adaptation to climate change (Peinetti et al. 2011 and references therein). Raramuri Criollo are 1 of 33 known biotypes of heritage Criollo cattle that exist throughout the Americas today (De Alba Martínez 2011). The Tarahumara communities of the Copper Canyon of Chihuahua, Mexico have raised Raramuri Criollo cattle in fairly isolated locations for close to four centuries (Anderson et al. 2015). These cattle have undergone natural selection to adapt to the harsh and variable environment of the Sierras while receiving minimal modern-day animal husbandry inputs (Anderson et al. 2015). Studies comparing grazing behavior of mainstream beef cows with Raramuri Criollo counterparts in the Chihuahuan Desert of New Mexico and Sierra Madre foothills of Chihuahua, Mexico have shown that during times of the year when forage is scarce or

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dormant, Raramuri Criollo cows explore larger areas of a pasture (Roacho Estrada et al. 2008; Peinetti et al. 2011; Spiegal et al. 2019), distributing grazing pressure across the landscape rather than creating hotspots of intensive use that are frequently observed in mainstream improved beef breeds (Spiegal et al. 2019). Feeding habits (Ortega-Ochoa et al. 2008; Anderson et al. 2015), heat tolerance (Nyamuryekung'e et al. 2017), and/or mothering style (De Alba Martínez 2011) could explain the observed differences in spatial distribution patterns of Raramuri Criollo versus mainstream beef breeds. Our study sought to describe the behavior of nursing Raramuri Criollo cows and to compare their mothering style with that of well-studied mainstream beef breeds.

Newborn and young ungulates exert a significant influence on their dam's movement and resource use patterns (Costelloe and Rubenstein 2015 and references therein). This phenomenon is relatively well understood in wild ungulates (Alados and Escos 1988; Bangs et al. 2005; Grignolio et al. 2007; Costelloe and Rubenstein 2015; Viejou et al. 2018) but has been scarcely documented in rangeland-raised cattle. Even though beef cows spend roughly 6 mo of most yrs raising a calf, seminal conceptual models of rangeland livestock behavioral ecology have largely overlooked this potential source of movement constraints (Bailey et al. 1996; Launchbaugh and Howery 2005). The lack of adequate tools to assess mother-offspring interactions in large rangeland pastures is perhaps the reason for the paucity of studies in this area of research. The advent of more sophisticated and less expensive wearable sensors that can monitor animal movement and position (Fogarty et al. 2018) opens opportunities to explore these less well-known aspects of livestock grazing behavior on rangeland. We used GPS and proximity loggers to study cow-calf proximity patterns on rangelands of New Mexico (United States) and Chihuahua (Mexico).

To date, influence of newborn and young calves on their dams' resource use in rangeland pastures has been assessed indirectly by comparing activity patterns of lactating and nonlactating beef cows. Rouda et al. (1990) reported no differences in distance traveled by nursing versus non-nursing cows in the Chihuahuan Desert of southern New Mexico, whereas Bailey et al. (2001) found that nonlactating cows that grazed Montana rangeland used steeper slopes and traveled similar or shorter horizontal distances from water but moved through more rugged terrain than their lactating peers. Black Rubio et al. (2008) reported that nursing cows explored smaller areas and traveled shorter daily distances than their nonpregnant non-nursing counterparts that grazed New Mexico woodland pastures. Differences in cattle breeds, the physical grazing environment, or, more likely, the age of calves at the time of the study may explain the apparent inconsistencies among studies.

Mother-infant interactions typically change as the offspring grows older and, according to Lent (1974), usually include three phases. The first, known as the *postpartum phase,* takes place during the first hours/day surrounding parturition and is characterized by transient isolation from the herd (Lidfors and Jensen 1988; von Keyserlingk and Weary 2007; Black Rubio et al. 2008) and intense mother-offspring contact expressed by smelling, licking, rubbing, and vocalization, all of which play an important role in dam-infant bonding (Lent 1974; von Keyserlingk and Weary 2007). The second phase occurs between ~2 and 100 d (Lent 1974) and, in cattle, is characterized by initiation of social play among calves and interaction of the newborn with other dams in the herd (Lent 1974; Wood-Gush et al. 1984). Differences among ungulates in mothering style are often expressed during this phase; depending on whether dams conceal their young while foraging (most cervids) or whether offspring follow their dam at all times (most bovids), they are classified as being either *hiders* or *followers* (Lent 1974; Ralls et al. 1986). During the third phase (from ~4 mo until weaning), due to the infant's growth and increased mobility, offspring typically behave as true "followers," so, presumably, constraints imposed by the offspring on its mother's mobility begin to decrease (Lent 1974).

Ralls et al. (1986) reported many instances of *intermediate* mothering styles and suggested that an additional subcategory of *weak* and *strong* was required within the original *hider-follower* classification. Their analysis of mother-offspring proximity indices across 22 species confirmed that four clusters (*strong hider, weak hider, weak follower, strong follower*) accounted for most of the mother-offspring variation they observed along the *hider-intermediate-follower* continuum (Ralls et al. 1986). Preliminary analyses of limited GPS data sets obtained on New Mexico rangeland (Wesley 2008; Sawalhah et al. 2014) suggested that Angus × Hereford cows exhibit elements of the *hider* mothering style even though cattle are usually classified as *followers* (Lent 1974). Although these studies monitored a limited set of cow-calf pairs (Cibils et al. 2011; Sawalhah et al. 2014), results were consistent with those reported earlier by Rouda et al. (1990). In both cases, cattle appeared to exhibit a *weak follower* mothering style (*sensu* Ralls et al. 1986). Other studies conducted in Europe also suggested that some cattle breeds can exhibit *intermediate* mother-offspring interactions (Wood-Gush et al. 1984; Vitale et al. 1986).

Anecdotal observations of Raramuri Criollo cattle in the Copper Canyon area of Chihuahua, Mexico, suggest that young calves of this cattle biotype follow their mothers closely at all times, often traveling through rugged terrain (De Alba Martínez 2011). This apparently *strong follower* mothering style (*sensu* Ralls et al. 1986), which has been linked to successful predator deterrence and high calf survival rates (De Alba Martínez 2011), differs from mother-offspring proximity patterns observed in mainstream British crossbred cows in New Mexico (described earlier) and could conceivably set lower levels of movement constraints on nursing Raramuri Criollo dams. Nonetheless, no mother-infant tracking data are available to date that would support observations made by De Alba Martínez (2011).

The objectives of this study were to document movement patterns of nursing and non-nursing Raramuri Criollo cows and to describe free ranging cow-calf proximity patterns in relation to the age of the calf. We hypothesized that if mother-offspring interactions in Raramuri Criollo cattle conformed to the strong *follower* behavioral type, movement patterns of nursing cows would be minimally constrained by their offspring and therefore exhibit spatial grazing behaviors that would not differ from those of non-nursing peers. Furthermore, because some have speculated that mothering style could strategically switch from *hider* to *follower* depending on the physical environment (Lidfors and Jensen 1988), we sought to test our hypothesis at two rangeland sites with contrasting topography and vegetation structure.

Materials and Methods

Study Sites

The study was conducted at two rangeland sites, the Jornada Experimental Range (JER) and Rancho Teseachi (RTE), and was replicated over 2 yr (2015–2016). The JER is located in southern New Mexico (32°37'N; 106°40'W), 23 miles north of Las Cruces, New Mexico and encompasses 78 266 ha of relatively flat terrain (1 300–1 600 m) within the northern Chihuahuan Desert. Climate of this site is typical of hot desert grassland with a long-term mean annual precipitation of 247 mm with 53% occurring between July and September. Mean ambient temperature is highest in June and lowest in January, averaging 36°C and 13.3°C, respectively (Koppa 2007). Vegetation at JER is dominated by honey mesquite (*Prosopis glandulosa* Torrey) intermixed with perennial grasslands dominated by black grama *(Bouteloua eriopoda),* dropseeds

(*Sporobolus* spp.), and threeawns (*Aristida* spp.). Our study was conducted in a 4 355-ha pasture with five watering points adjacent to the fence line distributed across the pasture.

RTE covers 11 000 ha east of the Sierra Madre Occidental (28°48'N; 107°25'W), 10 miles from the Colonia Oscar Soto Maynez, municipality of Namiquipa, Chihuahua, Mexico. The climate of RTE is characteristic of mountainous regions with cold winters and hot summers with elevations that vary between 1 900 m and 2 800 m and topography characterized by soft, broken slopes. Average annual rainfall is 580 mm, and the average annual relative humidity is 60%. Mean ambient temperature is highest in June and lowest in December, averaging 26°C and 10°C, respectively. Vegetation types of RTE include 1) disturbed forest, 2) pine forest, 3) oak forest with grassland, 4) oak forest, 5) open grassland, and 6) shrublands. The experiment took place in a 623-ha pasture located at the center of RTE with three dirt tanks (earthen runoff rainwater catchments) and two ephemeral streams (arroyos) traversing the pasture.

Animals and Collars

All animal handling protocols were approved by the New Mexico State University Institutional Animal Care and Use Committee (2015-021). Both the JER and RTE Raramuri Criollo herds were built from animals originally obtained from the same area of the Sierra de Tarahumara in Chihuahua, México, and are therefore considered to be genetically similar. At both sites, nursing and non-nursing cows (body weight ~350 kg/animal) were randomly selected from a herd of mature cows that had been raised at that ranch. All selected nursing cows had calves that were < 2 wk of age. We monitored animals for 21 consecutive d during the beginning of phase 2 of the mother-infant interaction progression (Lent 1974), when calves approximately 15–35 d old have reduced mobility and are expected to exert a higher level of constraint on their dam's movement and activity patterns. Each cow (nursing and non-nursing) was fitted with a Global Positioning System (GPS) collar (Lotek 3300, Lotek Wireless, New Market, Ontario). An additional proximity collar (Proximity data logger systems, Sirtrack Tracking Solutions, New Zealand) was fitted on the nursing cows and their calves (Fig. S1, available online at https://doi.org/10.1016/j.rama.2019.08.015). GPS collars were programmed to record point locations at 5-min intervals throughout the deployment period. The proximity loggers were programmed to record time of contact initiation and duration of contact with another logger. Contacts were recorded any time two or more loggers came within a radius of 1 m of each other and terminated when a separation time set at 30 sec was attained. Thus, any given contact was recorded by all loggers involved in the event.

Deployments at JER took place on 14 March to 6 April, 2015 and 19 March to 14 April, 2016. At RTE, deployments took place on 13 April to 9 May in 2015. In 2016, calving season at RTE occurred later in the spring, so sampling was conducted from 26 May to 26 June. In 2015, nine cows (four non-nursing and five nursing) were fitted with GPS collars at each site. One of the GPS collars deployed on a nursing cow at RTE failed. In 2016, fourteen cows (seven non-nursing and seven nursing) were collared at each site. Three collars deployed at JER (two nursing and one non-nursing) failed during this year. Ten proximity loggers were deployed on five cow-calf pairs in 2015 at both JER and RTE. In 2016, proximity loggers were deployed on eight cow-calf pairs at JER (16 loggers total) and nine cow-calf pairs at RTE (18 loggers total). Because a portion of our collared cows fitted with GPS collars also carried a proximity logger, we were able to determine the approximate spatial locations of cow-calf contact events. Details about number of collars per deployment, including collar failures, are provided in Table S1 (available online at https://doi.org/10.1016/j.rama.2019.08.015).

Collared cows grazed with a herd of either 30 or 35 cows at JER and 68 or 87 cows at RTE in 2015 and 2016, respectively. At both sites, pastures were rested and were used only during the experimental period. Stocking rates were calculated as the ratio of forage production available on the pastures to the animal unit equivalent. During the 21 d sampling period, the stocking rates were ≈216 ha/animal unit month (AUM) at JER and 13 ha/AUM at RTE. At both sites, grazing intensity was calculated to be light to moderate on the basis of ocular estimates of key species utilization (Holechek and Galt 2000).

Data Processing

GPS data were downloaded using GPS3000 Host (V2.062; Lotek Wireless Inc.) after each deployment and projected using the Universal Transverse Mercator coordinate system (Zone 13 N) with the North American Datum of 1983. The point vector files were screened for missing records or duplicates before analysis. Data from days of collar deployment and collar retrieval were excluded. In 2015, one non-nursing and two nursing cows at JER, as well as four non-nursing and two nursing cows at RTE, escaped the experimental pastures for a short time. Data from the days that these nine cows had GPS locations outside the pasture were also excluded from analysis.

Distance to water raster maps (30-m spatial resolution) were created using all drinkers in the experiment pastures (five at JER and three at RTE), where each pixel value represented Euclidean distance to nearest drinker. This allowed us to extract a distance-to-water value for each GPS location point. The projected GPS coordinates were used to calculate distance traveled and path sinuosity using a Java code described in Sawalhah et al. (2016). Movement velocity for each GPS point was calculated and used to classify points into activity categories (resting, grazing, or traveling). Velocity values ranging from 0 to 2.34 m/min were classified as resting, values ranging from 2.34 to 25 m/min as grazing, and values between 25 and 500 m/min were classified as traveling. These threshold values for velocity (distance traveled in 5 min) were adapted from velocity thresholds used in a classification tree model developed by Augustine and Derner (2013).

Daily area explored and time spent daily within 100, 50, and 15 m of drinking water were also calculated. The Minimum Bounding Geometry tool (ESRI 2018, ArcMap Desktop v. 10.6) was used to calculate daily area explored by each collared animal. This tool creates a polygon with the minimum area enveloping all GPS coordinate points (typically 288 points $\bullet$ animal^{-1} $\bullet$ day^{-1}) for a given set of data. Time spent close to the drinker was calculated by counting the daily number of GPS points within each designated buffer zone.

Accuracy of Sirtrack proximity logger data can be affected by either reflection, refraction, or absorption of the radio waves by other proximal objects (Swain and Bishop-Hurley 2007). Height, density of animal bodies, or naturally occurring vegetation and water can also affect logger radio signals (Swain and Bishop-Hurley 2007). Furthermore, loss of battery power can exacerbate these problems causing diminishing distance for contact detection and diminishing reliability of contact duration estimates due to broken contact events (Drewe et al. 2012). Therefore, before each deployment, routine maintenance of devices was performed including battery voltage checking and wire connection inspection. To ensure systematic errors were accounted for, we followed data quality control guidelines proposed by Drewe et al. (2012) and eliminated contact events with duration $\leq$ 1 s and merged consecutive events separated by time intervals $\leq$ 47 s. In this study we used 30 s as the user defined separation time following Prange et al. (2006).

Swain and Bishop-Hurley (2007) found a strong correlation between pairs of proximity collars involved in a contact ($R^2 > 0.95$), justifying the use of either the dam's or the calf's logger in data analysis. In our experiment, we consistently used data from the dam's proximity loggers for analysis. As with GPS data, logger data from deployment and retrieval days were excluded from analysis. We analyzed the number of contact events and duration of each event for the 24-h time periods (DAY + NIGHT), as well as for daytime (DAY) and nighttime hours (NIGHT). Sunrise and sunset times for each location and day of the study were used to determine daytime versus nighttime hours.

GPS data from the dam's collar and proximity logger data were processed jointly to assign a GPS coordinate to each contact event and to map location of contact events in a pasture. To do this, we paired the start time of each proximity event with the closest 5-min interval time stamp of the dam's GPS collar to derive the location of each cow-calf contact event. Contact location coordinates were used to calculate area explored by each calf. Daily area explored by a calf was calculated using a Minimum Bounding Geometry for all contact points in a given day. We also quantified the number of contacts that occurred while the dam was grazing versus resting versus traveling and the spatial distribution of contact events within 100 and 50 m of the watering points.

Data Analysis

All daily movement variables (distance traveled, path sinuosity, average movement velocity, percentage time spent resting, grazing and traveling) and landscape use variables (daily area explored, time spent daily close to watering points) were calculated for each dry and nursing collared animal (GPS collars). Overall number of cow-calf contacts, number of cow-calf contacts classified by dam activity and proximity to the drinker, duration of events, and area explored by calves were calculated for all collared nursing cow-calf pairs (GPS collars and proximity logger). A weighted average of all variables was calculated for 3 periods (wk) of 7 consecutive d each using the MEANS procedure in SAS 9.3 (SAS Institute, Cary, NC). Grouping data in this way allowed us to account for the unequal number of sampling days that resulted from the elimination of animal/days of cows that got out of the pasture. Data were then analyzed assuming a randomized block design with repeated measures where *yr* • *site* was the blocking factor. Mixed repeated measures analyses of variance (ANOVAs), including site (JER or RTE) and yr (2015 or 2016) as fixed effects, were conducted using the MIXED procedure in SAS 9.3 (SAS Institute, Cary, NC). Our ANOVAs modeled *week* as a repeated measure using the "REPEATED" statement and fitting the AR (1) covariance structure in PROC MIXED of SAS 9.3 (SAS Institute, Cary, NC).

A first model determined the effects of cow physiological state (whether nursing or non-nursing), week (calf age), and their interaction (fixed effects) on distance traveled (km/day); path sinuosity (Sinuosity Index; 1 = straight path; 0 = most sinuous); average movement velocity (m/min); activity (% time spent resting, traveling, or grazing); and daily area explored (ha). Site-by-yr, site-by-yr-by-wk, and animal ID nested within site-by-yr were considered random effects in this model. A second model was used to determine the effect of night or day, wk, and their interaction (fixed effects) on number of mother-offspring contacts and total mother-offspring contact time (min). Again, site, yr, and animal ID were considered random effects in this model. A third model was used to determine the influence of animal category (dam or offspring), wk (calf age), and their interaction (fixed effects) on daily area explored. Random effects were the same as in previous models. A fourth and final model was used to determine the influence of wk (calf age) on the number of cow-calf contact events that occurred while the dam was grazing versus resting versus traveling, as well as the contact events that occurred within 100 and 50 m of the watering points.

ANOVA assumptions were tested for all models to detect deviations from normality and presence of outliers. Violations to assumptions were detected in all cases with the exception of daily movement variables (distance traveled, path sinuosity, percentage time spent resting and traveling). With all other response variables, a log transformation was done before analysis. Estimates on both the analysis scale and postanalysis back transformed estimates that are on the original data scale are reported. Because log transformation normalized data that were skewed on the original data scale, back transformed estimates correspond to estimates of medians rather than means (Ramsey and Schafer 2002). Means were compared via LSMEANS in SAS 9.3 (SAS Institute, Cary, NC), and differences were declared statistically detectable at $P \leq 0.05$.

Results

Medians of back transformed results are reported in this section. We found no effects of year or site on mother-offspring contact patterns, nor were the differences between nursing and non-nursing cows affected by year or site. No effects of week (calf age) on movement patterns of nursing cows were detected for any of the movement variables analyzed (Table 1). Non-nursing and nursing Raramuri Criollo cows traveled similar distances each day (7.98 vs. 8.10 km, $P = 0.77$), exhibited similar movement velocities (5.43 vs. 5.52 m. min^{-1}, $P = 0.73$), and spent similar time resting (53.01 vs. 50.18%, $P = 0.35$), grazing (41.04 vs. 43.85%, $P = 0.32$), or traveling (4.91 vs. 4.70%, $P = 0.48$) during 24-h periods (see Table 1). However, nursing cows followed significantly ($P < 0.01$) more sinuous movement paths (SI = 0.14) compared with their non-nursing counterparts (SI = 0.18, see Table 1).

We found no effect of week (calf age) on daily area explored or daily time spent near water for either nursing or non-nursing cows (Table 2). However, non-nursing cows explored significantly larger areas than their nursing counterparts during all 3 wk of the study ($P < 0.01$, see Table 2, Fig. 1). Both groups spent similar amounts of time within 100 ($P = 0.72$), 50 ($P = 0.95$) and 15 m ($P = 0.34$) of water drinkers (see Table 2, Fig. 1).

Calves spent on average 39.38 min, 34.34 min, and 25.74 min/d (DAY + NIGHT) within 1 m of their dam during wks 1, 2, and 3, respectively, distributed over 39.44, 34.10, and 25.52 daily contacts (DAY + NIGHT). A higher number of cow-calf contact events occurred during daytime versus nighttime hours ($P = 0.03$, Table 3); however, total contact time during daytime and nighttime hours were similar ($P = 0.98$, see Table 3). As calves became older, we observed a detectable decrease in the number of both daytime and nighttime contact events ($P < 0.01$), as well as dam-offspring contact time ($P < 0.04$, see Table 3). Dams explored a larger area of the pasture than did their calves ($P < 0.01$) regardless of the age of the calf (see Table 3). Cow-calf contact events occurred throughout the entire area grazed by the dams including areas surrounding the drinkers (Fig. 2, see Table 3, Video 1, available online at https://doi.org/10.1016/j.rama.2019.08.015). Most cow-calf contact events occurred while the dam was presumed grazing or resting (see Table 3); these contact patterns were not affected by calf age (see Table 3).

Discussion

Nursing and non-nursing Raramuri Criollo cows in this study traveled similar distances each day, moved at comparable velocities, spent similar amounts of time close to drinkers, and did not differ in daily time spent grazing, resting, or traveling. However, non-nursing cows followed less sinuous travel paths and explored larger areas of our study pastures per day compared with their nursing peers. Presence of young nursing calves did not influence a dam's daily activity routines but apparently altered their resource

Table 1
Movement pattern variables for non-nursing and nursing Raramuri Criollo cows while grazing rangeland sites in southern New Mexico and west central Chihuahua, Mexico during late winter and early spring.

Variables	Overall mean		Wk						SEM[1]		*P* value[2]	
			1		2		3		Phys.	Wk	Phys.	Wk
Distance traveled (*km*)												
Non-nursing	7.98		7.96		7.91		8.09					
Nursing	8.10		7.94		8.34		8.03		0.39	0.19	0.77	0.66
Sinuosity (*SI*)[3]												
Non-nursing	0.18		0.19		0.19		0.17					
Nursing	0.14		0.15		0.15		0.14		0.01	0.02	< 0.01	0.65
Velocity (*m/min*)[4]												
Non-nursing	1.72	(5.43)	1.72	(5.41)	1.71	(5.38)	1.73	(5.49)				
Nursing	1.74	(5.52)	1.72	(5.41)	1.77	(5.72)	1.73	(5.45)	0.05	0.02	0.73	0.61
% Time Resting												
Non-nursing	53.01		53.65		52.73		52.65					
Nursing	50.18		51.73		49.75		49.06		3.01	1.16	0.35	0.36
% Time grazing[4]												
Non-nursing	−0.54	(41.04)	−0.56	(40.30)	−0.54	(41.49)	−0.54	(41.34)				
Nursing	−0.50	(43.85)	−0.52	(42.52)	−0.49	(44.05)	−0.48	(45.00)	0.05	0.02	0.32	0.40
% Time traveling												
Non-nursing	4.91		4.92		4.82		4.99					
Nursing	4.70		4.54		5.00		4.56		0.29	0.29	0.48	0.81

[1] Standard error of the means for physiological state of the cow (nursing vs. non-nursing) and week.
[2] *P* values for physiological state of the cow (nursing vs. non-nursing) and week.
[3] Straightness index values range between 0 (sinuous path) and 1 (straight path).
[4] Values expressed as natural logarithm transformation used in analysis. Back-transformed mean estimates given in parenthesis.

use patterns over the course of the 21 d of our study. Our hypothesis that no differences in spatial grazing patterns of nursing versus non-nursing Raramuri Criollo cows would exist was only partially supported by our data.

Because mother-offspring interactions change significantly as calves grow older (Walker 1962; Lent 1974; Wood-Gush et al. 1984; Lidfors and Jensen 1988; Sawalhah et al. 2014), our results cannot be compared with the Rouda et al. (1990) and Bailey et al. (2001) studies that monitored cow-calf pairs on rangeland during summer months. Calf ages in those two studies ranged from ≈ 55 to 160 d. In our study, calves were roughly 14 d old at the beginning of our 21-d spring monitoring periods, an age range and time of year that are more comparable with Black Rubio et al. (2008), who also used GPS to monitor cow movement patterns as in our study. Nursing cows in both our study and the Black Rubio et al. (2008) experiment explored smaller areas of the pasture each day compared with their non-nursing counterparts. However, numerical differences between nursing and non-nursing cows were greater for the Angus × Hereford black baldies in the Black Rubio et al. (2008) study (30.4 vs. 54.8 ha, a 48% reduction) than those observed in Raramuri Criollos at our research sites (103.86 vs. 141.82 ha, a 27% reduction, see Table 3). Contrary to what we observed in this study, Black Rubio et al. (2008) reported that nursing black baldy cows traveled shorter distances and spent less time at the drinker than their non-nursing peers. Movement and activity patterns of nursing Raramuri Criollo cows are perhaps less constrained by their young calves compared with what was reported for mainstream British beef cows by Black Rubio et al. (2008). However, a formal test of this hypothesis comparing heritage and improved beef breeds under controlled conditions is necessary to confirm this observation.

Proximity logger data confirmed De Alba Martinez's (2011) observation that young Raramuri Criollo calves follow their mothers closely at all times from a relatively young age. This mothering style was exhibited regardless of the grazing environment, both in the large and fairly flat desert shrubland pasture at JER, as well as in the somewhat smaller rugged oak woodland pasture at RTE. Thus, the Raramuri Criollo cows we monitored did not appear to switch mothering styles in response to changing pasture conditions as suggested by Lidfors and Jensen (1988). The mothering style observed in Raramuri Criollo cattle in this study differs from patterns documented in an Angus × Hereford black baldy herd in central New Mexico (Wesley 2008; Sawalhah et al.

Table 2
Area explored and time near water drinker of non-nursing and nursing Raramuri Criollo cows while grazing rangeland sites in southern New Mexico and west central Chihuahua, Mexico during late winter and early spring. All variables are expressed as natural logarithm with back-transformed mean estimates shown in parentheses.

Variables	Overall mean		Wk						SEM[1]		*P* value[2]	
			1		2		3		Phys.	Wk	Phys.	Wk
Area explored (*ha*)												
Non-nursing	14.16	(141.82)	14.14	(137.89)	14.25	(154.36)	14.11	(134.03)				
Nursing	13.85	(103.86)	13.78	(96.88)	13.96	(114.97)	13.82	(100.61)	0.31	0.14	< 0.01	0.54
Water 100 m (*min*)												
Non-nursing	3.85	(46.80)	3.94	(51.04)	3.95	(51.53)	3.67	(38.97)				
Nursing	3.92	(50.45)	3.79	(43.96)	4.20	(66.34)	3.79	(44.01)	0.21	0.41	0.72	0.72
Water 50 m (*min*)												
Non-nursing	3.16	(23.40)	3.37	(28.77)	3.18	(23.92)	2.93	(18.62)				
Nursing	3.15	(23.07)	2.94	(18.71)	3.52	(33.66)	2.98	(19.47)	0.24	0.61	0.95	0.82
Water 15 m (*min*)												
Non-nursing	1.76	(5.65)	2.09	(7.91)	1.79	(5.82)	1.41	(3.91)				
Nursing	1.47	(4.16)	1.67	(5.13)	1.56	(4.59)	1.17	(3.06)	0.31	0.76	0.34	0.75

[1] Standard error of the mean for natural logarithm transformed variables for physiological state of the cow and week.
[2] *P* values of the natural logarithm of physiological state of the cow and week.

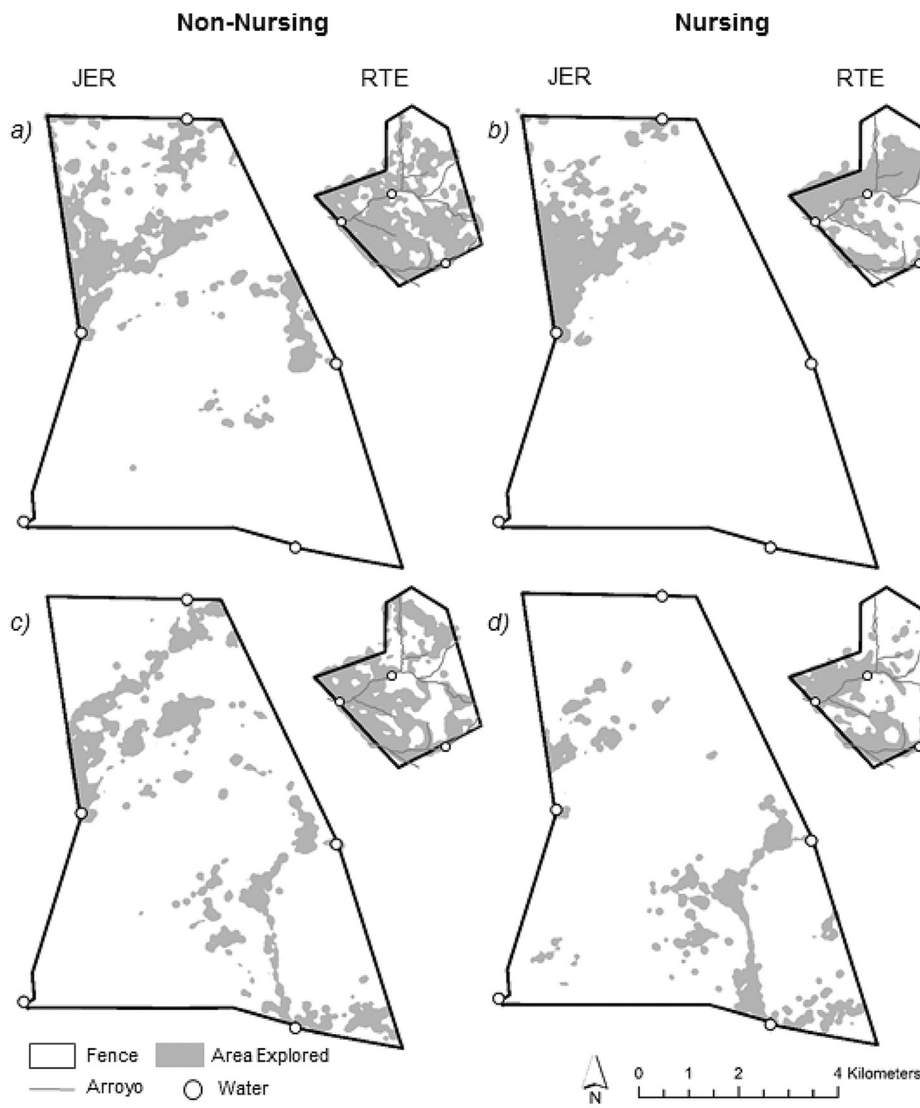

Figure 1. Spatial distribution of non-nursing (**a, c**) and nursing (**b, d**) Raramuri Criollo cows grazing the Jornada Experimental Range (JER) and Rancho Teseachi (RTE) pastures for 21 d during the spring 2015 (**a, b**) and 2016 (**c, d**). Global Positioning System locations were converted into point density maps, with radius search per unit area set at 100 m and classification based on four quantile groupings with the first group muted from visual representation. Number of non-nursing collared cows were **a,** four at JER and four at RTE and **c,** six at JER and seven at RTE. Number of nursing collared cows was **b,** five at JER and four at RTE and **d,** five at JER and seven at RTE.

2014). Although most mother-offspring contacts in our study occurred during daytime hours, Wesley (2008) and Sawalhah et al. (2014), who monitored GPS positions of both dams and their calves, reported that contact events between mother and offspring (~2 wk–2 mo of age) occurred predominantly at night. Cow-calf contact events in our study frequently occurred while the dam was grazing, yet young Angus × Hereford calves in the Wesley (2008) and Sawalhah et al. (2014) studies spent most daytime hours close to a guard cow and did not travel with their dam during morning and afternoon grazing bouts. Mother cows apparently returned to the calf nursery several times a day, presumably to nurse their calves (Wesley 2008). Relative to their dams, black baldy calves in the Wesley (2008) study explored smaller areas of the pasture each day, as was observed in this study. It is worth noting, however, that the area explored by Raramuri Criollo dams in this study may have been overestimated due to autocorrelation of 5-min interval GPS points used to calculate this metric (Perotto-Baldivieso et al. 2012). Collectively, these results suggest that mother-offspring interactions in Raramuri Criollo cow-calf pairs are substantially different from those observed in mainstream British beef breeds commonly used in the Southwest and provide additional support for the hypothesis that movement of nursing Raramuri Criollo cows is likely less constrained than that of lactating British beef cows. Again, a formal comparison of Raramuri Criollo and British breeds under controlled conditions is necessary to confirm this hypothesis.

Mother-offspring contact events in our study occurred throughout a cow's daily grazing area, including the zone surrounding drinkers. Rouda et al. (1990) reported that Hereford × Santa Gertrudis nursing cows in their study went to water without their calves and, although not directly observed, speculated that calves were possibly "left in the charge of a *guard cow*" (p. 227), a pattern similar to that observed by Wesley (2008) and by Arnold and Dudzinski (1978). Collared cows in our study traveled to water with their collared calves, suggesting that calf crèches or nurseries observed in other breeds that presumably exhibit *intermediate* or *weak follower* mothering styles (Arnold and Dudzinski 1978; Sato et al. 1987; Rouda et al. 1990; Wesley 2008) were not present in either herd of Raramuri Criollo cattle. Interestingly, nursing and non-nursing Raramuri Criollo cows in our study spent similar

Table 3
Cow-calf interaction variables expressed as natural logarithm with back-transformed mean estimates given in brackets for Raramuri Criollo cows while grazing rangeland sites in southern New Mexico and west central Chihuahua, Mexico during late winter and early spring.

Variables	Overall mean		Wk						SEM[1]			*P* value[2]		
			1		2		3		Wk	Time	Stage	Wk	Time	Stage
Prox. events *(#)*[3]														
Day	2.89	(17.84)	3.07	(21.37)	2.94	(18.81)	2.66	(14.12)						
Night	2.71	(14.83)	2.9	(18.07)	2.75	(15.53)	2.47	(11.62)	0.07	0.05		< 0.01	0.03	
Prox. time (*min*)														
Day	6.88	(16.25)	7.07	(19.62)	6.91	(16.62)	6.67	(13.17)						
Night	6.88	(16.22)	7.08	(19.76)	6.96	(17.48)	6.61	(12.35)	0.13	0.08		0.04	0.98	
Area explored (*ha*)[4]														
Calf	13.18	(53.12)	13.34	(62.44)	13.31	(60.07)	12.9	(39.96)						
Dam	13.87	(105.78)	13.85	(103.51)	13.96	(115.97)	13.8	(98.60)	0.27		0.07	0.54		< 0.01
Proximity events in relation to the dam's activity *(#)*[5]														
Resting	2.58	(13.05)	2.88	(17.58)	2.51	(12.15)	2.36	(10.39)	0.27			0.17		
Grazing	2.67	(14.23)	2.84	(17.01)	2.63	(13.76)	2.52	(12.32)	0.17			0.28		
Traveling	0.81	(2.08)	0.94	(2.38)	0.81	(2.08)	0.68	(1.81)	0.19			0.62		
Water 100 m	0.27	(1.14)	0.41	(1.34)	0.28	(1.16)	0.11	(0.95)	0.39			0.83		
Water 50 m	−0.32	(0.55)	−0.23	(0.62)	−0.31	(0.57)	−0.43	(0.48)	0.52			0.96		

1 Standard error of the means for the natural logarithm of means of week, time (day vs. night), and stage (calf vs. dam)
2 *P* values for the effects of week, time (day vs. night), and stage (calf vs. dam).
3 Proximity event count and Proximity time between calf and dam for a detection radius of 1m.
4 Area explored was calculated using minimum bounding geometry; daily cow-calf proximity locations were used for the calf calculation whereas daily nursing cow GPS locations were used for the dam calculations.
5 Number of proximity events that occurred while the dam was resting vs. grazing vs. traveling and contact events that occurred within 100 m and 50 m of the watering point.

amounts of time close to the drinker, in contrast to observations of Angus × Hereford cows by Black Rubio et al. (2008). In that study, non-nursing cows spent almost twice as much time close to the drinker compared with their nursing peers who were presumably at water without their calf (Wesley 2008) and were perhaps motivated to return to the nursery as soon as possible. Our results therefore suggest that Raramuri Criollo cow-calf interactions in this study resembled those of a *strong follower* (*sensu* Ralls et al. 1986).

A decrease in the number of daily cow-calf contacts and in the time spent by calves in the proximity of their dams as calves grew older likely reflected age-related changes in calf suckling behavior, a phenomenon that has been thoroughly documented in beef cattle (Walker 1962; Wood-Gush et al. 1984; Lidfors et al. 1994). Lidfors and Jensen (1988) reported that the weight and sex of the calves also influenced mother-offspring proximity patterns. Heifer calves in their study tended to spend more time in the proximity of their dam compared with bull calves. Limitations in the number of proximity loggers in this study precluded the possibility of calf sex comparisons. Further research including a larger number of monitored cow-calf pairs is necessary to determine whether Raramuri Criollo mothers of heifer and bull calves exhibit similar behaviors.

Differences in daily area explored by nursing and non-nursing cows in this study perhaps reflected a shift in resource selection patterns associated with either increased nutritional demands of lactation or the need to minimize calf predation risk, or both. In wild ungulates that exhibit *strong follower* mother-infant interaction styles, such as woodland caribou, nursing dams are known to select habitats that minimize predation risk and forgo sites with higher food availability (Viejou et al. 2018). Similar shifts in habitat selection have been documented in a large number of wild mammals (Costelloe and Rubenstein 2015, and references therein). The fact that nursing cows in this study showed more sinuous travel paths may suggest that they adopted a more concentrated search pattern or selected plant communities with increased vertical structure (e.g., higher woody cover). Bailey et al. (2001) suggested that compared with nonlactating peers, nursing cows selected feeding sites in flatter areas and avoided traveling through more rugged terrain, presumably seeking to minimize energy expenditure while foraging. Black Rubio et al. (2008) reported that although nursing cows explored smaller daily areas and traveled shorter distances compared with their non-nursing peers, all cows in their study showed similar patterns of habitat and diet selection, except during the days (≤ 1 wk) surrounding parturition. Incomplete information about vegetation cover at one of our research sites precluded a more in-depth analysis of nursing versus non-nursing resource selection patterns. It is also worth noting that this and previous studies comparing nursing and non-nursing peers (Bailey et al. 2001; Black Rubio et al. 2008) monitored animals that grazed the same pasture in a single herd and did not account for possible social interactions among nursing and non-nursing cows. Further research is necessary to determine whether Raramuri Criollo cows exhibit a shift in feeding site preference during lactation.

Management Implications

Raramuri Criollo cows exhibited a mother-offspring interaction style that differs from what has been previously described for British beef breeds on rangeland (Black Rubio et al. 2008). Raramuri Criollo cow-calf pairs appear to have higher levels of mobility than their mainstream British beef breed counterparts. This trait could conceivably allow them to cover larger rangeland areas and better adapt to heterogeneous grazing environments.

Social learning of foraging behaviors from the dam appears to depend in part on the mother-offspring interaction style. In *strong followers* such as sheep, learning from the mother is an important mechanism through which lambs develop diet preferences and aversions (Mirza and Provenza 1990; Provenza and Burritt 1991; Provenza et al. 1993). In *hiders* such as white-tailed deer, social learning of diet selection from the dam is either weak or nonexistent (Spalinger et al. 1997). We hypothesize that social learning of foraging behaviors from the dam is likely to be stronger in Raramuri Criollo calves *(strong followers)* that are close to their dams at all times than in calves born to mainstream British beef breed cows *(intermediate* or *weak followers)* that apparently spend a large portion of daytime hours close to a guard cow (Arnold and Dudzinsky 1978; Wesley 2008). Such differences could, again, allow Raramuri Criollo calves to exhibit higher levels of adaptation to changing forage conditions on rangeland. Further research is

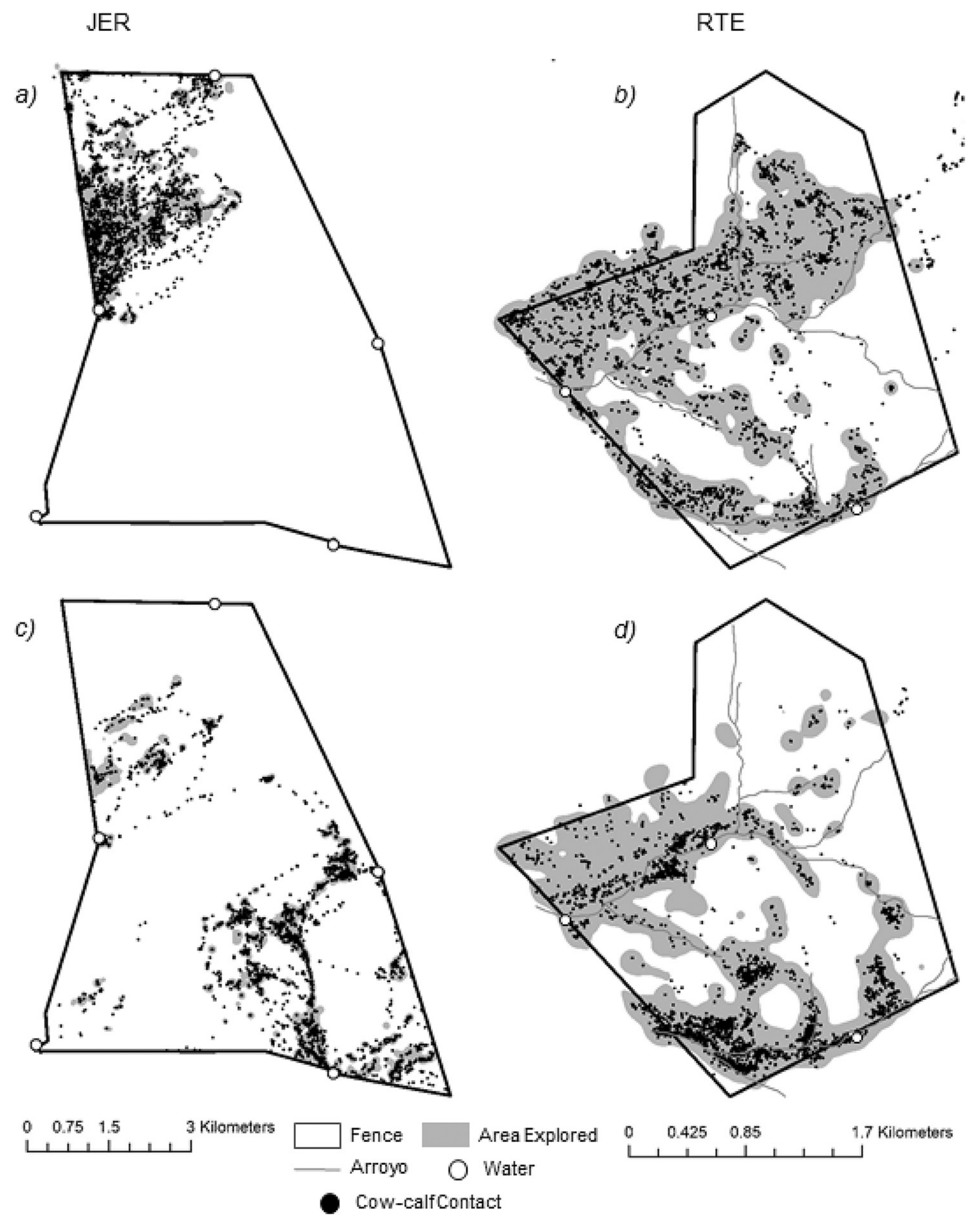

Figure 2. Spatial location of cow-calf contact events (points) mapped on point density maps developed from GPS locations of nursing Raramuri Criollo cows with radius search per unit area set at 100 m and classification based on four quantile groupings with the first group muted from visual representation. Cow-calf interactions were monitored at the Jornada Experimental Range (JER) (**a, c**) and Rancho Teseachi (RTE) (**b, d**) during spring of 2015 (**a, b**) and 2016 (**c, d**) for 21 d. Number of monitored cow-calf pairs included either five (**a**) or four (**c**) at JER and either four (**b**) or seven (**d**) at RTE for 2015 and 2016, respectively.

necessary to test this hypothesis in a controlled experimental setting.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rama.2019.08.015.

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