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Factors influencing the movement of livestock guardian dogs in the Edwards Plateau of Texas: implications for efficacy, behavior, and territoriality

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Abstract: Livestock guardian dog (*Canis lupus familiaris*; LGD) breeds of domestic dog worldwide provide a degree of control over predation losses. The application of LGDs as a wildlife damage management tool evolved as a cultural practice in the Old World. In the 1970s, this tool emerged in North America. Despite several decades of science and application, gaps still exist in our knowledge regarding applications for LGDs. From February 2016 to November 2017, we deployed global positioning system transmitters on 4 LGDs on a 20-km^2 ranch in Menard County, Texas, USA operated by Texas A&M AgriLife Research to investigate their fine scale movement and activity patterns, site fidelity to livestock management units (i.e., pastures), and fidelity to anthropogenic features, such as feed and water locations. The LGDs remained within study site boundaries for 90% of the study period. Additionally, daily activity patterns differed for dogs associated primarily with sheep (*Ovis aries*) and goats (*Capra aegagrus hircus*). All of the LGDs we studied were active throughout the 24-hour day. We determined that feed and water locations concentrated LGD activity to an extent, likely reflecting a livestock affinity for water sources, and provide an additional method by which to distribute them over the landscape. Our results, based on a small sample size, suggest that LGDs may provide effective association with livestock management areas, maintain a high fidelity to area perimeter boundaries, and distribute themselves across the area of use.

Key words: *Canis lupus familiaris*, livestock guardian dog, nonlethal predator control, site fidelity, Texas, wildlife damage management

Livestock guardian dogs (*Canis lupus familiaris*; LGDs) are an ancient tool for managing wildlife damage on livestock (Andelt 2004). Used since antiquity in the regions of present-day Israel, Syria, Palestine, Turkey, France, Spain, and beyond, early livestock raisers developed dog breeds to bond with livestock, live with them, and to some degree, actively protect them from predation by wildlife (Espuno et al. 2004, Gingold et al. 2009, OrhanYilmaz 2012, Yilmaz et al. 2015, Akyazi et al. 2017). Worldwide, users recognize LGDs as a cost-effective, constant-action tool for protecting livestock against a variety of predatory threats (Marker et al. 2005, Zarco-González and Monroy-Vilchis 2014, McManus et al. 2015, Yilmaz et al. 2015).

The use of LGDs in the United States increased following its introduction during the 1970s (Coppinger et al. 1987, Coppinger and Coppinger 2014). The reasons for the increased interest include a desire for increased tool diversity with less-than-lethal ends to native wildlife, 24-hour protection of livestock, a decline in landscape-scale trapping of carnivores due to decreasing small ruminant production and declining fur markets, and banning of certain toxicant methods (Green and Woodruff 1980). As of 2014, nearly a quarter of U.S. sheep producers use LGDs to guard their livestock, a sharp increase from 10 years prior (U.S. Department of Agriculture

[USDA] 2015). Nevertheless, sheep (*Ovis aries*) and goat (*Capra aegagrus hircus*) raisers in some regions continue to exhibit resistance to use the method, despite some empirical studies on the ways in which LGDs perform their task (Espuno et al. 2004, Lescureux and Linnell 2014, van Bommel and Johnson 2015, Allen et al. 2017). However, questions remain regarding aspects of LGD behavior, such as use of space, extent of movements, and influence of human features (Gipson et al. 2012, van Bommel and Johnson 2014). Given the reasons why LGDs are deployed, it is difficult to evaluate whether they present an appropriate solution to wildlife damage concerns without basic data on their movements. Without such an evaluation in a variety of systems worldwide, it seems less likely that LGDs will gain widespread adoption by livestock producers.

To expand the understanding of LGD use of space, we implemented a study in the Edwards Plateau of Texas, USA, a region that supports most of the production of sheep and goats in Texas. During this study, we explored how LGDs distributed themselves upon the landscape and the features that may influence these paradigms. Although important considerations in the use of this technique, we do not seek to address if LGDs actively protect livestock (i.e., via agonistic interactions with carnivores) or work to create territorial exclusion against livestock predators. The objectives of our study were to determine: (1) LGDs space use, including property and pasture fidelity, (2) daily patterns of movement and inter-LGD interactions, and (3) the influence of anthropogenic features, such as feeding stations, water sources, and fences on their distribution.

Methods

Study area

We conducted this study on a ~20-km^2 ranch in Menard County, Texas operated by Texas A&M AgriLife Research. The property sits within the Edwards Plateau Ecological Region of Texas that averages an elevation of 722 m above sea level between subtle rolling hills scattered throughout the countryside. Climate is characterized by semi-arid conditions, a mean annual temperature of 18°C, and a mean annual precipitation of 58 cm over a 30-year average. January is the coldest month (0–16°C) of the year and July is the hottest (21–35°C). Live oak (*Quercus virginiana*), Ashe juniper (*Juniperus ashei),* and honey mesquite (*Prosopis glandulosa*) woodlands dominate the overstory of the site, with an understory comprised of various native and introduced grasses, cacti, and forbs (Natural Resource Conservation Service [NRCS] 2015). Four ecological sites occupy the property: Low Stoney Hill, Clay Loam, Shallow, and Draw. Vegetation occurs on clay loam soils with shallow limestone bedrock, often exposed by periodic flooding.

Managers divided the ranch into 9 fenced pastures that average 224 ha each, with a surrounding perimeter fence. The ranch supported roughly 300 sheep, 200 goats, and 4 LGDs throughout the study period. We deployed the Great Pyrenees breed that were bonded, trained, and deployed with livestock according to a standardized procedure used by Texas A&M AgriLife Research (Redden et al. 2015). An attending, licensed Texas veterinarian either spayed or neutered each of the dogs. Ranch staff separated livestock into different pastures on a decision-deferred rotational grazing system pending management priorities. The 4 resident LGDs were 5–7 years of age by the end of the sampling period. Researchers raised and bonded these LGDs with a number of the sheep residing on the ranch soon after weaning. The LGDs roamed freely on the study site, and we consistently found them alongside the livestock they protect, with dogs 1–3 (Alfred, a male; Elizabeth, a female; Nigel, a male) primarily associated with sheep, and dog 4 (Reggie, a male) primarily associated with the goat herd. Ranch staff initially stocked all dogs with sheep, but later dog 4 shifted his activity to primary association with goats. Ranch staff provided dry food at free choice feeders located throughout the ranch at livestock water sites; staff kept feeders full when livestock were stocked into those pastures. There was no free water on the property; water troughs drawn from wells, distributed throughout the 9 pastures of the ranch, support water needs of livestock and wildlife. Research staff visited the ranch several times a week to check on the livestock, and hunters used the ranch during hunting seasons. However, no humans permanently reside on the property.

Data collection and analyses

We fitted the 4 LGDs on the ranch with global positioning system (GPS) locating Vertex collars manufactured by Vectronic Aerospace, GmbH (Carl-Scheele-Straße 12, 12489 Berlin, Germany). The GPS collars were programmed to record the location of each of the 4 dogs once every 3 hours, yielding 8 time-delineated locations per day, per dog. Collars collected data from February 26, 2016 until November 14, 2017. We fitted livestock with ultra-high frequency (UHF) transponders that relayed proximity data to GPS collars of LGDs to determine temporal association of LGDs to livestock. Bromen et al. (2019) provide a detailed description of the process and data. We downloaded LGD positions and livestock proximity data from the collars into a relational database.

We estimated LGD site fidelity based on utilization distribution (UD) estimates for each individual. We used a fixed kernel density estimator with reference smoothing parameters (Worton 1989). We conducted this estimate using the *adehabitatLT* package (Calenge et al. 2009) in Program R (R Development Core Team 2018). This method estimates the intensity of space use based on the spatial distribution of telemetry locations. This produces a 2-dimensional distribution, the height of which represents the relative amount of time an animal spent at any given location over the observation period (Van Winkle 1975). The volume of this distribution within ranch boundaries represents the proportion of time an LGD spent within its intended area.

We used autocorrelation functions (ACF) of movement speed (Dray et al. 2010) to examine cyclicity in LGD movement activity. Movement speed was quantified as the distance traveled between successive relocations, divided by the time lag between them. This produces a time series of animal movement speed. The ACFs estimated the degree of relatedness between any 2 points in a time series separated by a time lag, t. By graphing the ACF of a series over many time lags, one may reveal behavioral patterns, such as diurnal, nocturnal, or crepuscular rhythms, not easily apparent in the original series (Boyce et al. 2010). We utilized the methods of Dray et al. (2010), again using the *adehabitatLT* package (Calenge et al. 2009). One can test significance of autocorrelation at a given lag by permutation and interpret graphically based on empirical confidence intervals. In this implementation, ACF values below the confidence region imply significant positive autocorrelation, while values above the confidence region are considered significantly negatively autocorrelated. We followed the qualitative interpretations outlined by Boyce et al. (2010) and Dray et al. (2010) to determine whether LGDs exhibited crepuscular, daily, or acyclic patterns in movement activity.

We analyzed co-activity patterns of LGD dyads using the Dynamic Interaction index (DI) proposed by Long and Nelson (2013). This statistic estimates the degree of movement coordination, based on correlation in bearing and travel distance between concurrent movement vectors. The DI does not incorporate information on the distance between 2 individuals, merely the coordination of their movements. Because we evaluated DI at a temporally local level, it can be averaged for a dyad to derive a net interaction term, a mean velocity correlation. Treated as a time series, this affords a better way to evaluate patterns than as an aggregation of locations. We generated DI series for each dyad, then evaluated ACFs for each of them to look at patterns in movement correlation between dogs.

We utilized a cross k-function to test for a meaningful aggregation effect of LGD movements around food and water stations over a range of spatial scales (Cressie 1991). This extension of Ripley's K (Ripley 1976) is used to examine whether objects in space are distributed randomly, over-dispersed, or aggregated with respect to another object in space (Harkness and Isham 1983). We tested if food and water stations resulted in a clumping effect of LGD effort. These resources co-occur within 10 m of each other on our study site, and the centroid between them was considered the location of the station. Graphical interpretation is analogous to that of the ACF. If the observed curve lies above the confidence region of the null curve, the LGDs were aggregated around food and water stations at that scale. If the observed curve falls below the confidence region, the LGDs avoided the resource at that scale.

Results

LGD pasture fidelity

We found LGDs demonstrated high fidelity to pasture and ranch boundaries, with an average

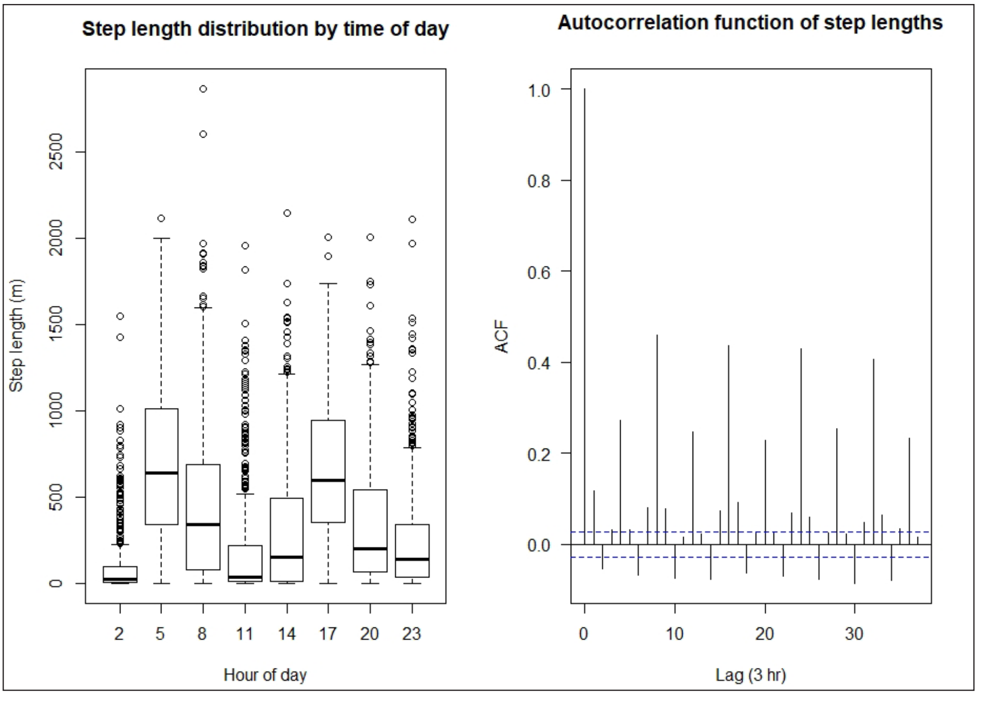

Figure 1. Step length distribution by time of day (on left) and autocorrelation function (ACF; on right) for Alfred, livestock guardian dog 1 (*Canis lupus familiaris*), February 2016 to November 14, 2017, Texas A&M AgriLife Research Ranch, Menard County, Texas, USA.

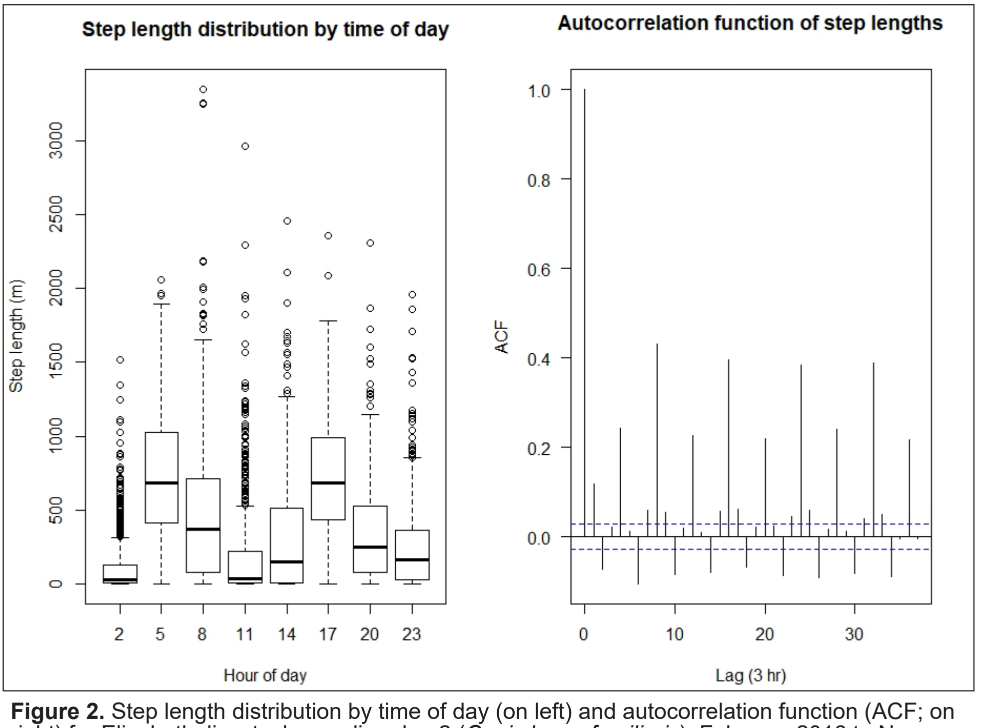

Figure 2. Step length distribution by time of day (on left) and autocorrelation function (ACF; on right) for Elizabeth, livestock guardian dog 2 (*Canis lupus familiaris*), February 2016 to November 14, 2017, Texas A&M AgriLife Research Ranch, Menard County, Texas, USA.

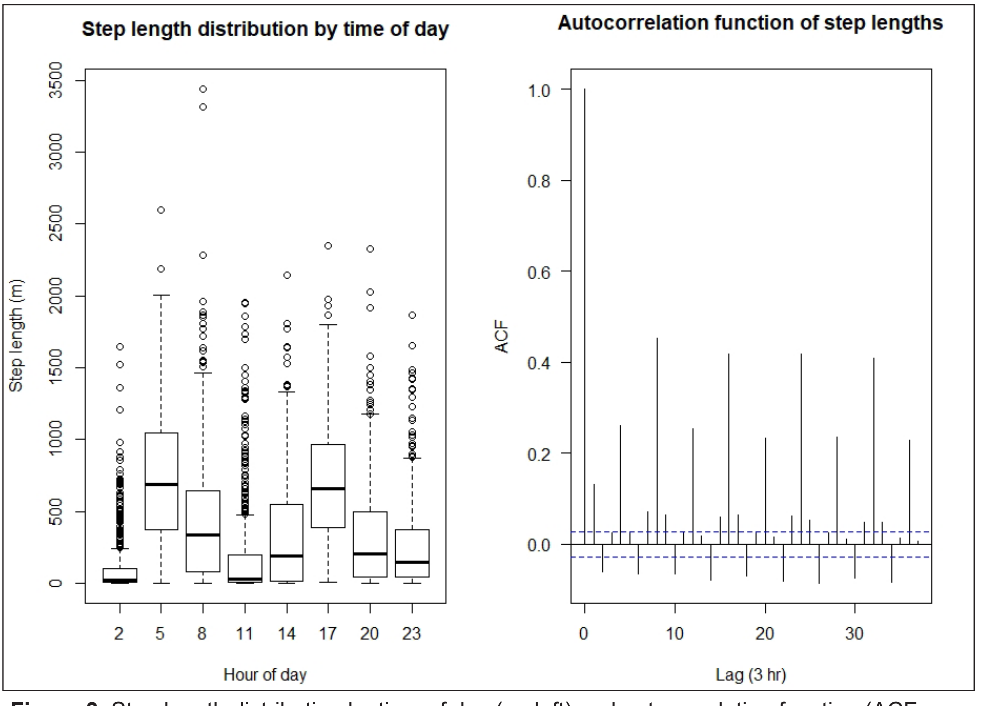

Figure 3. Step length distribution by time of day (on left) and autocorrelation function (ACF; on right) for Nigel, livestock guardian dog 3 (*Canis lupus familiaris*), February 2016 to November 14, 2017, Texas A&M AgriLife Research Ranch, Menard County, Texas, USA.

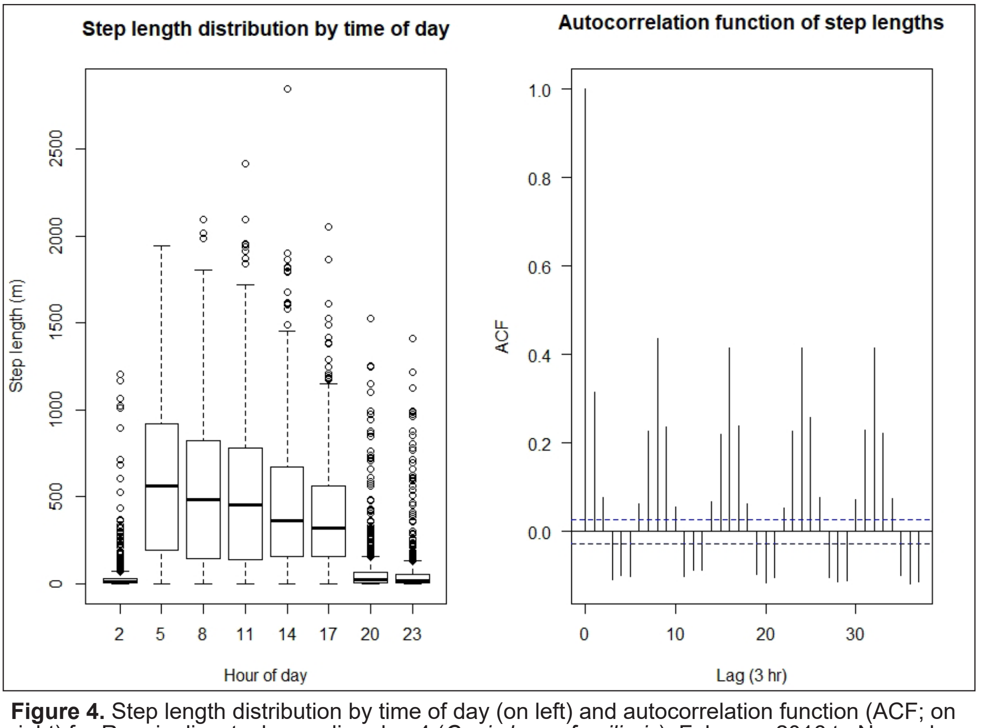

Figure 4. Step length distribution by time of day (on left) and autocorrelation function (ACF; on right) for Reggie, livestock guardian dog 4 (*Canis lupus familiaris*), February 2016 to November 14, 2017, Texas A&M AgriLife Research Ranch, Menard County, Texas, USA.

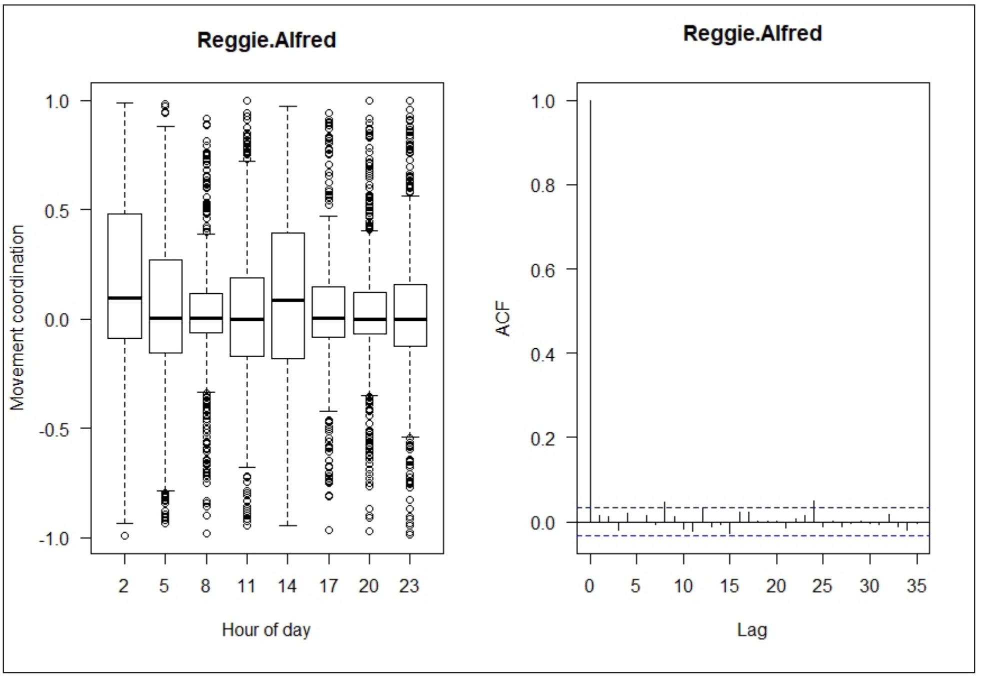

Figure 5. Dynamic interaction distribution by time of day (on left) and autocorrelation function of movement coordination (ACF; on right) for livestock guardian dogs (*Canis lupus familiaris*) Reggie and Alfred, February 2016 to November 14, 2017, Texas A&M AgriLife Research Ranch, Menard County, Texas, USA.

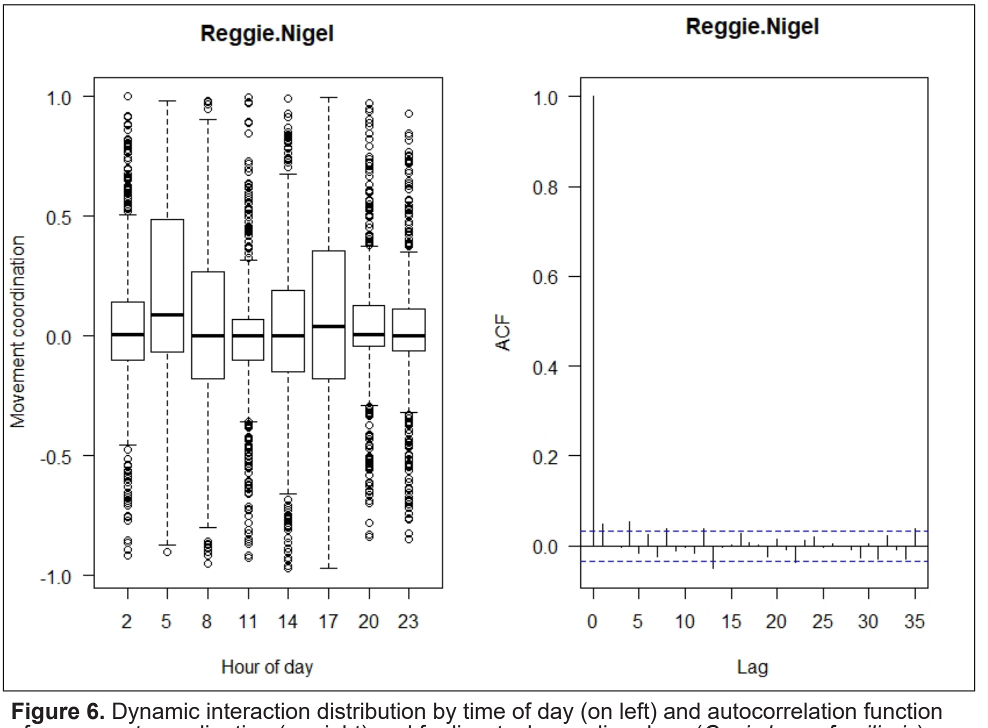

Figure 6. Dynamic interaction distribution by time of day (on left) and autocorrelation function of movement coordination (on right) and for livestock guardian dogs (*Canis lupus familiaris*) Reggie and Nigel, February 2016 to November 14, 2017, Texas A&M AgriLife Research Ranch, Menard County, Texas, USA.

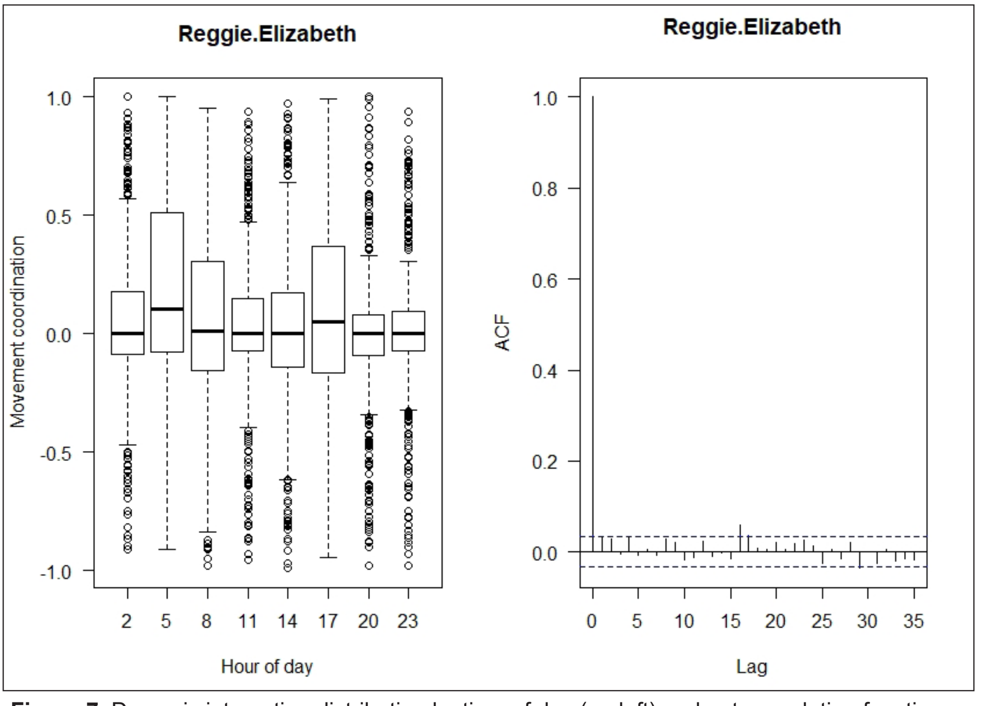

Figure 7. Dynamic interaction distribution by time of day (on left) and autocorrelation function of movement coordination (on right) and for livestock guardian dogs (*Canis lupus familiaris*) Reggie and Elizabeth, February 2016 to November 14, 2017, Texas A&M AgriLife Research Ranch, Menard County, Texas, USA.

of ≥89% of locations inside property boundaries. No LGD spent >92% of their time inside property boundaries. Nevertheless, LGDs regularly crossed interior fences to move among livestock groups, despite a lack of open crossing locations. Extra-property movements were few, despite the same fence type used for perimeter fences as for interior fences. Occasional extra-property movements were attributed to occurrences that breached property boundary fences, such as a storm destroying a section of fence, thus creating an opening that LGDs investigated.

Daily activity cycles

We detected clear patterns of activity in the LGDs studied. Three of the 4 LGDs exhibited a clearly crepuscular daily cycle (Figures 1, 2, and 3). The fourth LGD exhibited a diurnal cycle of daily movement (Figure 4). All LGDs moved somewhat throughout a 24-hour daily cycle. The diurnally patterned LGD co-occurred most times when goats were present on the study site, whereas the other 3 LGDs tend to co-occur with sheep.

Association among LGDs

We found little coordination between Reggie and the other LGDs (Figures 5, 6, and 7) more than would be expected by chance and similar biological realities. The other 3 dogs showed marked periodicity in movement coordination. The ACF of Alfred and Nigel (Figure 8) shows appreciable correlation at short time intervals (within a day; 8 lags), and possibly a crepuscular pattern with positive correlation on a daily interval, and weak but significant positive correlation at 12-hour intervals (4 lags). The boxplots show that, while quite variable, their movements were coordinated at 0200 and 1400 hours. While not crepuscular in the true sense, this does reflect a bimodal daily pattern of movement coordination. We see nearly identical results for Alfred and Elizabeth (Figure 9). Elizabeth and Nigel (Figure 10) show a stronger pattern that is shifted 3 hours later in the day. The peak ACF for any LGD pair was 0.25, thus demonstrating that at least 75% of movements were independent despite clear coordination among the LGDs.

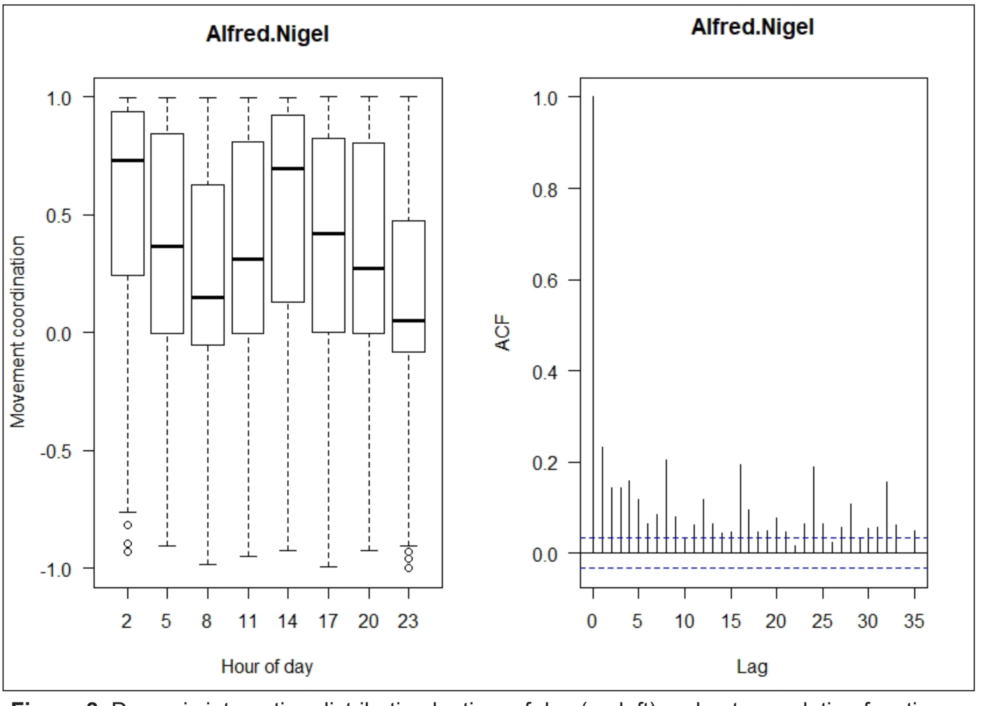

Figure 8. Dynamic interaction distribution by time of day (on left) and autocorrelation function of movement coordination (on right) and for livestock guardian dogs (*Canis lupus familiaris*) Alfred and Nigel, February 2016 to November 14, 2017, Texas A&M AgriLife Research Ranch, Menard County, Texas, USA.

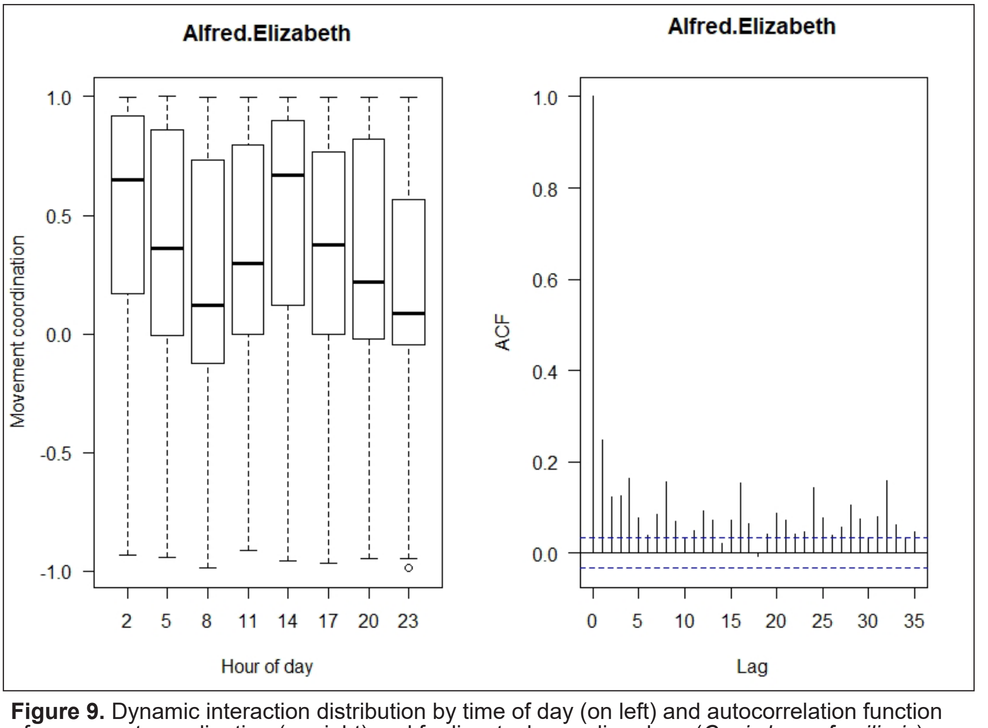

Figure 9. Dynamic interaction distribution by time of day (on left) and autocorrelation function of movement coordination (on right) and for livestock guardian dogs (*Canis lupus familiaris*) Alfred and Elizabeth, February 2016 to November 14, 2017, Texas A&M AgriLife Research Ranch, Menard County, Texas, USA.

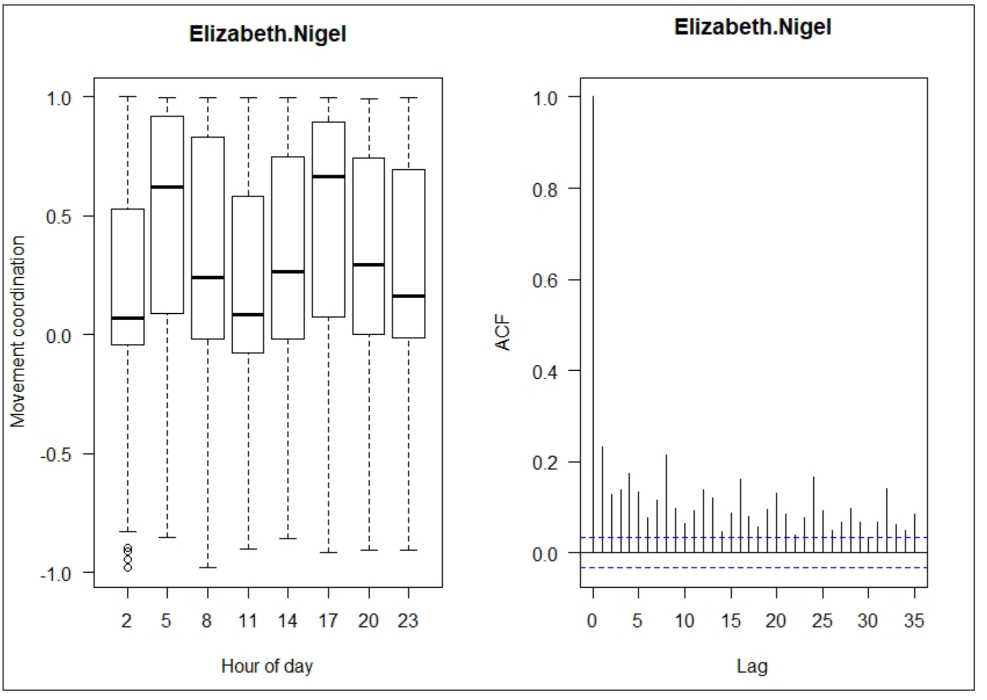

Figure 10. Dynamic interaction distribution by time of day (on left) and autocorrelation function of movement coordination (on right) for livestock guardian dogs (*Canis lupus familiaris*) Elizabeth and Nigel, February 2016 to November 14, 2017, Texas A&M AgriLife Research Ranch, Menard County, Texas, USA.

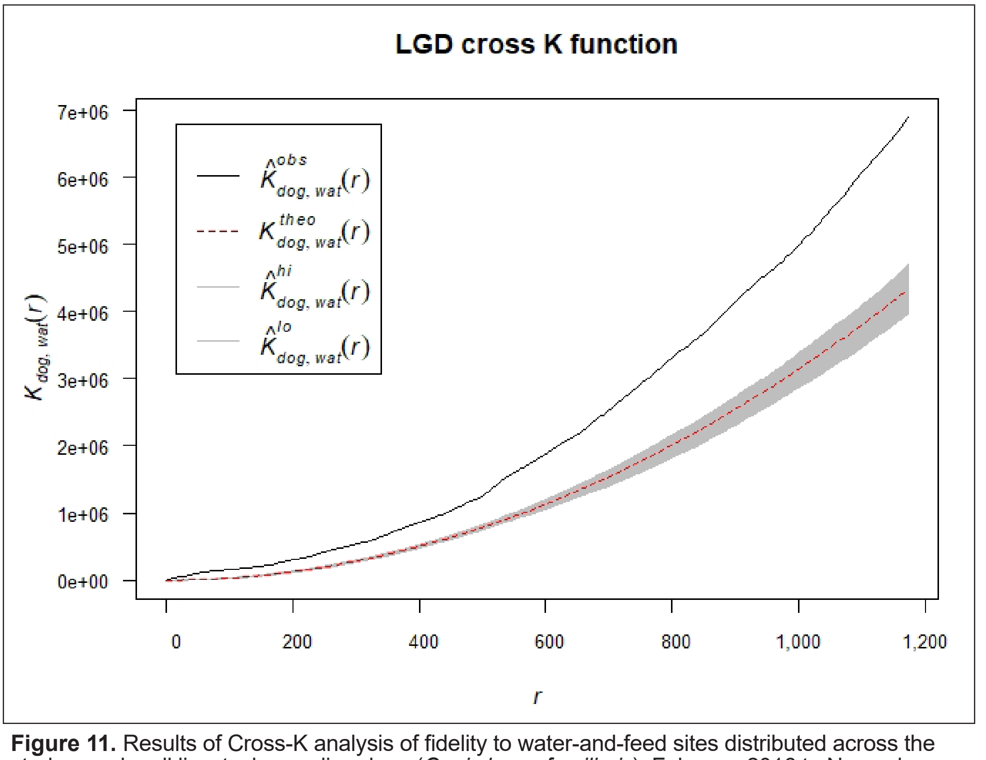

Figure 11. Results of Cross-K analysis of fidelity to water-and-feed sites distributed across the study area by all livestock guardian dogs (*Canis lupus familiaris*), February 2016 to November 14, 2017, Texas A&M AgriLife Research Ranch, Menard County, Texas, USA. Black line indicates observed aggregation of points, versus theoretical value with high and low estimates (red line and gray polygon).

Association with food and water

Analyses of association of LGD activity with regard to food and water stations revealed aggregation of points near food and water stations above values expected by chance, suggesting an attraction to these locations (Figure 11). The LGDs tended to aggregate somewhat at food and water stations, with fewer points as distance from stations increases. The LGDs in our study dispersed throughout the pastures where livestock were placed. Thus, based at our scale of management, we could not detect the maximum distance from water and feed stations that an LGD would move.

Discussion

The LGDs in our study limited themselves to pasture boundaries but use space disproportionately within pastures in relation to food and water stations. In cases where livestock were split between 2 pastures, LGDs moved across woven-wire fencing pasture boundaries. Contrary to the experience of Vercauteren et al. (2008), these fences did not limit LGD movements. These results suggest a positive result for livestock producers primarily concerned with the ability of LGDs to cover the pastures. Our LGDs exhibited a high fidelity to their home property, similar to that of van Bommel and Johnson (2015).

We also detected a difference in daily activity patterns of LGDs potentially related to livestock association. Those commonly associated with sheep exhibited strong crepuscular cycles, and 1 LGD typically associated with goats exhibited a strongly diurnal cycle. The LGDs we studied demonstrated a variable amount of cooperation, whereas the goat-associated dog acted independently, and the other 3 interacted with each other in a regular, bimodal pattern. Interestingly, Elizabeth, the female dog, showed nearly identical cooperative movements with the 2 sheep-bonded male dogs (Alfred and Nigel), shifted in time 3 hours later. In these cases, coordination is clearly bimodal, suggesting the dogs interact at 2 peak times of day. Thus, our LGDs coordinated their movements in predictable patterns but still maintained their own independent actions. While such anecdotal evidence cannot definitively answer whether LGDs adapted activity patterns to their livestock, these data raise essential questions for future research.

Conversely, this pattern is not conserved across other studies, notably van Bommel and Johnson (2014), where dogs that associated with both goats and sheep exhibited crepuscular patterns. Regardless of livestock species to which LGDs were bonded, a high degree of affinity was assessed, similar to Gipson et al. (2012), who reported LGDs keeping ≤120 m of livestock. A question raised by practitioners is the concept of "constant protection" aspects of an LGD while humans are otherwise busy or sleeping. In our study, LGDs remained with livestock nearly all the time, as demonstrated by UHF data collected by Bromen et al. (2019). These results agree with other studies, with varied breeds of LGDs (McGrew and Blakesley 1982, van Bommel and Johnson 2015, Akyazi et al. 2017, Allen et al. 2017).

To assess the degree of protection actually afforded by LGDs, however, is a more complicated question. Simply mirroring the activity patterns of livestock might be insufficient to provide adequate protection. Further considerations related to the efficacy of LGDs may address whether such activity patterns complement those of predators of concern. For example, Andelt (1985) documented the tendency of coyotes (*Canis latrans*) to function according to crepuscular activity patterns, whereas bobcats (*Lynx rufus*) tend to exhibit more diurnal patterns (Rockhill et al. 2013). Although undocumented, the risk of predation from various carnivores may be to some degree influenced by the activity pattern synchrony of both livestock and predator. Within that dynamic, an LGD that is most active when livestock are inactive may provide the most protection. Conversely, one must exercise caution, as less frequent, shorter movements could indicate either vigilance or resting periods.

Vigilance demonstrated upon an entire group of livestock substantiates the ultimate goal of those using LGDs to manage wildlife damage (Gehring et al. 2010, Allen et al. 2017). Excessive spatial aggregation may result in fewer livestock within the defensive purview of the LGD, thus limiting optimal performance. Some causal factors for excessive spatial aggregation from previous studies and technical reports claimed LGDs rarely venturing from food stations

(Andelt 2004), and not closely associating with livestock away from food stations.

We further examined the fidelity of our LGDs to food and water stations distributed throughout the property and found strong evidence of aggregation to these stations. van Bommel and Johnson (2014) found strong aggregation around dog feeding sites on at least 1 study property. While such aggregation may reduce the efficacy of LGDs, the behavior reflects an affinity to certain resource sites, which can be subsequently incorporated into management. In our study, feeding stations occurred with water sources. Thus, we cannot determine to what extent LGD aggregation at feeding stations was independent of livestock behavior. The pastures at our study site were not large enough to determine LGD maximum movements. Although we did not examine the relationship of habitat factors on LGD use of space, further research should address whether certain land cover classes inherently reduce or increase LGD efficacy.

Management implications

The objectives of our study were to provide new information regarding factors that influence the movement of LGDs. We determined that feed and water locations concentrated LGD activity. Our results, based on a small sample size, suggest that LGDs may provide effective association with livestock management areas, maintain a high fidelity to area perimeter boundaries, and distribute themselves across the area of use. Although great strides have been made in the science regarding the use of LGDs, further research is needed to assess their applications, including landscape, breed, and training influence on performance, to determine where and when agricultural producers should implement this tool.

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