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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: The problem of managing predation from carnivorous wildlife on livestock is as old as livestock husbandry itself. Over the centuries, livestock raisers developed livestock guardian dog (LGD) breeds of domestic dog breeds to provide a degree of control on predation losses. The application of LGDs as a wildlife damage management tool evolved as a cultural practice, and entered into the body of traditional knowledge. In the 1970s, however, this tool emerged in North America, a place without the tradition of LGDs. Introduced by some early wildlife damage management scientists, the North American public required significant convincing to attempt this tool. In a place without traditional, oral transmission of LGD application techniques, scientists and conservation educators must develop materials to convey proper use of a new technique. Despite several decades of science and application, significant gaps still exist in our knowledge of LGDs. Some of the most basic are questions of movement and activity patterns, site fidelity to livestock management units (i.e. pastures), and fidelity to anthropogenic features, such as feed and water locations. We used 4 LGDs to investigate these questions about the function of LGDs.

We determined that LGDs remained within study site (i.e. ranch) boundaries roughly 90% of the study period. Additionally, daily activity patterns differed significantly between dogs associated primarily with sheep, and those associated with goats. Nevertheless, all LGDs were somewhat active throughout the 24-hour day. Finally, we determined that feed and water locations do concentrate LGD activity to an extent. This likely reflects livestock affinity for water sources, and provides an additional method by which to distribute LGDs on the landscape. These results suggest that LGDs can provide effective association with livestock management areas, maintain a high fidelity to area perimeter boundaries, and distribute themselves across the area of use. Moving forward with expanding the use of LGDs, it will be important to further investigate critical aspects of behavior that can drive efficacy as a wildlife damage management tool, particularly the influence of LGD presence of species of predation concern. Research must also answer salient questions of the non-target impacts of LGDs on other native wildlife within their area of use.

Key words: Livestock guardian dog, mesocarnivore, wildlife damage management, nonlethal predator control

The problem of predation on livestock from carnivorous wildlife coevolved livestock husbandry (Frank & Conover 2015). For millennia, people engaged in the production of food and fiber animals required methods to manage this damage. Wildlife damage management traditionally employed whatever techniques deemed most efficacious, and often with an outlook for the eradication of the offending species (Miller 2007). To wit, many livestock producers since the earliest days of animal husbandry would have difficulty enumerating any benefits arising from the existence of carnivores. Nevertheless, today most ecologists and wildlife damage management technicians alike accept that carnivores fulfill an important role in the ecosystem, and that many damage-causing species that persist today cannot be easily extirpated across broad extents (Johnson & Wallach 2016; Van Bommel & Johnson 2014a).

To manage damage in this milieu, an integrated approach to the management of wildlife damage requires both lethal and non-lethal tools to be employed, based on a combination of science and situation (McManus et al. 2015). Not every efficacious tool stands up under social scrutiny, but socially acceptable tools may not necessarily manage the damage (Bruggers et al. 2002). The modern wildlife damage manager must resourcefully use all effective and acceptable tools. To that end, science must constantly develop new tools, and reevaluate and redesign old tools to fit new problems. Today, stakeholders increasingly express interest in management tools that predate the industrial revolution, perceiving them as somewhat more traditional, natural, and from a simpler time (Gehring et al. 2010).

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

Use of LGDs in the United States of America (hereafter USA) increased following its introduction during the 1970s (Coppinger & Coppinger 2014; Coppinger et al. 1987). Although an ancient technique throughout much of Europe and Asia, this tool arrived in the New World for a variety of reasons. These included 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, among a host of other drivers, precipitated the importation of LGDs to USA (Green & Woodruff 1980). This importation brought several breeds of LGD, rearing, bonding, training, and management practices, and general husbandry techniques in the context of LGDs (Coppinger & Coppinger 2014). Although this tool passed the test of time in its point of origin, early North American adopters stepped into a brave new world.

As of 2014, nearly a quarter of USA sheep producers use LGDs to guard their livestock, a sharp increase from 10 years prior (USDA-APHIS-WS 2015*b*). Nevertheless, sheep and goat raisers in some regions continue to exhibit resistance to use of the method, due perhaps to limited access to rigorous data on the ways in which LGDs perform their task (Allen et al. 2017; Espuno et al. 2004; Lescureux & Linnell 2014). Despite a few studies detailing LGD movements, relatively limited quantitative data exists to characterize basic aspects of LGD behavior, such as use of space, extent of movements, and influence of human features (Gipson et al. 2012; van

Bommel & Johnson 2014b). Given the nature of the task set before LGDs, it seems difficult to evaluate whether or not 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 experience widespread adoption by livestock raisers, and that their further implementation may be stymied by a lack of data.

To expand the understanding of LGD use of space, we implemented a study in the Edwards Plateau of Texas. This region, synonymous for over a century with production of sheep (*Ovis aries*) and goats (*Capra aegagrus hircus*), supports most of the production of these species in Texas, although relatively few livestock operations there use LGDs. Thus, it is an excellent candidate to produce rigorous, yet applicable data regarding LGD space use. During this study, we explore the ways in which LGDs distribute 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 (i.e. via agonistic interactions with carnivores) or work to create territorial exclusion against carnivorous wildlife. Before such questions may be asked, however, more basic concepts must be well understood. Thus, we seek to understand (1) LGD space use, including property fidelity, (2) daily patterns of movement, and (3) the influence of anthropogenic features, such as feeding stations, water sources, and fences, on LGD distribution.

Methods

Study area

Field data were collected in the rangelands of Menard County, Texas on a ~20 km^2 ranch operated by Texas A&M AgriLife Research. The property is situated in 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) (National Oceanic and Atmospheric Administration 2016). The dominant overstory vegetation found across the site is live oak (*Quercus virginiana*), Ashe juniper (*Juniperus ashei),* and honey mesquite (*Prosopis glandulosa*) woodlands with an understory comprised of various native and introduced grasses, cactus, and forbs (Natural Resource Conservation Service 2015). The 4 prevailing ecological sites found on the ranch (Low Stoney Hill, Clay Loam, Shallow, and Draw; Fig. 1 and Table 1) exhibit more heterogeneity as one approaches the draws, and support varied aggregations of vegetation (NRCS 2015). Vegetation occurs on clay loam soils atop limestone bedrock, often exposed in the arid draws carved by periodic flooding. Draws do not flow perennially, but rather during times of high precipitation.

The ranch is divided into 9 fenced pastures that average 224 ha each. The ranch supported roughly 300 sheep, 200 goats, and 4 LPDs throughout the study period. Ranch staff separated livestock into different pastures on a decision-deferred rotational grazing system pending management priorities. The four resident LPDs were aged 5–7 by the end of the sampling period. Researchers raised and bonded these LPDs with a number of the sheep residing on the ranch soon after weaning. The LPDs live freely on the study site, and were consistently found alongside the livestock they protect, with three dogs primarily integrated among the sheep, and the fourth integrated with the goat herd. The dogs were sustained on a diet of kibble placed at free choice feeders located throughout the ranch at livestock water sites. Water troughs distributed throughout the nine pastures of the ranch support water needs of all residing livestock. Research staff visit 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

We fitted the 4 LPDs on the ranch with Global Positioning System (hereafter GPS) locating Vertex collars manufactured by Vectronic Aerospace, GmbH. (hereafter GPS collars or collars) 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 26 Feb 2016 until 14 Nov 2017. We downloaded LPD positions from the collars into a relational database.

Analyses

We estimated LGD property 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. 2010) in Program R (R Core Team 2018). This method estimates the intensity of space use based on the spatial distribution of telemetry locations. The result is 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 of movement speed (hereafter ACF; 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. ACFs estimate 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. 2010). Significance of autocorrelation at a given lag is tested by permutation and interpreted 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 utilized a cross k-function to test for a meaningful aggregation effect 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 & Isham 1983). Thus, we tested if food and water stations lead to a clumping effect of LGD effort. These resources co-occur within 10m of one another 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 are significantly aggregated around food and water stations at that scale. If the observed curve falls below the confidence region, the LGDs avoid the resource at that scale.

Results

LGD Pasture Fidelity

We found LGDs to demonstrate high fidelity to pasture and ranch boundaries (Table 2), rarely leaving property boundaries. 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 such as when a storm felled an oak tree, destroying a section of fence, thus creating an opening which LGDs investigated.

Daily Activity Cycles

We detected clear patterns of activity in our study LGDs. Three of the 4 LGDs in this study exhibited a clearly crepuscular daily cycle (Figs. 2–4). The fourth LGD exhibited a diurnal cycle of daily movement (Fig. 5). One should note, however, that all LGDs move somewhat throughout a 24-hour daily cycle. The diurnally-patterned LGD co-occurred most times with the goats present on the study site, whereas the other 3 LGDs tend to co-occur with sheep

Association with Food and Water

Analyses of association of LGD activity with regard to food and water stations revealed significant aggregation of points near food and water stations above expected values from a random arrangement of points, suggesting an attraction to these locations (Fig 6). Predictably, LGDs tend to aggregate somewhat at food and water stations, with fewer points as distance from stations increases. It should be noted that LGDs in our study thoroughly used livestock management units in which livestock were placed, thus at our scale of management, we could not detect the maximum distance from water and feed stations that an LGD would venture.

Discussion

LGDs in our study generally limit themselves to pasture boundaries, but use space disproportionately within pastures in relation to food and water stations. These results suggest a positive result for livestock producers primarily concerned with the ability of LGDs to cover the functional livestock management units (i.e. pastures) at our study site, as well as the fidelity of

LGDs to their home property. 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 one LGD typically associated with goats exhibited a strongly diurnal cycle. While such anecdotal evidence cannot definitively answer whether or not LGDs adapt activity patterns to their livestock charges, these data raise essential questions for future research. Among these questions, one raised by practitioners is the fallacy of the "constant protection" aspects of an LGD. By definition, no animal can be constantly vigilant, but many cite the ability of LGDs to protect livestock while the livestock raiser is otherwise busy or sleeping as a key component in their desirability as a wildlife damage management tool.

To assess the degree of protection actually afforded by LGDs, however, is a more complicated question. Simply mirroring the activity patterns of livestock, however, 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 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, one may consider an LGD that is most active when livestock are inactive to 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. Excessive spatial aggregation may result in fewer livestock within the defensive purview of the LGD, thus limiting critical performance.

Some causal factors for excessive spatial aggregation from previous studies and technical reports claimed LGDs rarely venturing from food stations (Andelt 2004b), 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 LGD aggregation to these stations. While such aggregation may reduce efficacy of LGDs, one must also elucidate if such behavior reflects LGD affinity to certain resource sites, or if they, again, mirror the space and resource use of their livestock charges. For all animals, preferential space use exists for one resource or another. Moving forward, researchers and practitioners alike must determine the critical threshold for LGD fidelity with resource sites. Livestock management units at our study site did not present a large enough area that maximum LGD venturing from such sites could be determined. 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 the defensive purview of the LGD with livestock.

When considering resource sites, those using LGDs must also consider: are LGDs obtaining nutrition from food stations? LGD users, wildlife conservationists, and hunters commonly express concerns over potential impact of LGDs on native wildlife. To wit, it is possible that an LGD not obtaining nutrition from food stations at regular intervals finds its meals elsewhere. While livestock raisers may experience predation upon livestock from improperly trained LGDs, one must also consider the potential impacts to wildlife, particularly those that also comprise economic inputs to ranching operations, such as hunting of various deer, upland gamebirds, and others. If such issues exist, researchers must further investigate whether this behavior results from poor training and husbandry (e.g. adequate feed interspersion), or if it is an inherent, randomly occurring behavior of LGDs. A tool that is considered generally non-lethal to predatory species may have unintended consequences that limit other conservation efforts. Just as wildlife damage managers today must consider which tools still find acceptability with the general public, lest management be outlawed, we must also critically evaluate aspects of currently-acceptable tools to determine nontarget impacts not traditionally considered. Doing so will help ensure that decision and policy-makers may choose wisely among when regulating wildlife damage management.

Despite centuries of use, this tool still lacks much of the scientific evaluation common in other forms of wildlife damage management today. Studies of wildlife ecology, and even livestock movement, commonly provide a more detailed understanding of animal habits and movements that those known for LGDs. Moving forward, it will be critical to further assess the efficacy of LGDs, including landscape, breed, and training influence on performance, to determine where and when agricultural producers should implement this tool. Naturally, every situation requires different solutions to problems, and the successes of one site do not guarantee successes at another. We implore researchers and practitioners to continue a rigorous evaluation of this tool in the future to better refine the science of LGDs.

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Table 1. Prevailing ecological site composition across the Martin Ranch in Menard County, Texas listed by rank in terms of area in hectare and percent cover of total area.

Ecological Site	Area (ha)	% Area
Low Stony Hill	1458.75	71.98
Clay Loam	306.47	15.12
Shallow	148.21	7.31
Draw	113.27	5.59
Total	2026.7	100.00

Table 2. Site fidelity of LGDs to study area boundaries during the study period.

Dog	Bonded Species	% Site Fidelity
1 (Alfred)	Sheep	87.5
2 (Elizabeth)	Sheep	89.6
3 (Nigel)	Sheep	90.4
4 (Reggie)	Goats	92.1
Mean		89.9

Figure 1: The Martin Ranch study site delineated by pasture boundaries and ecological sites.

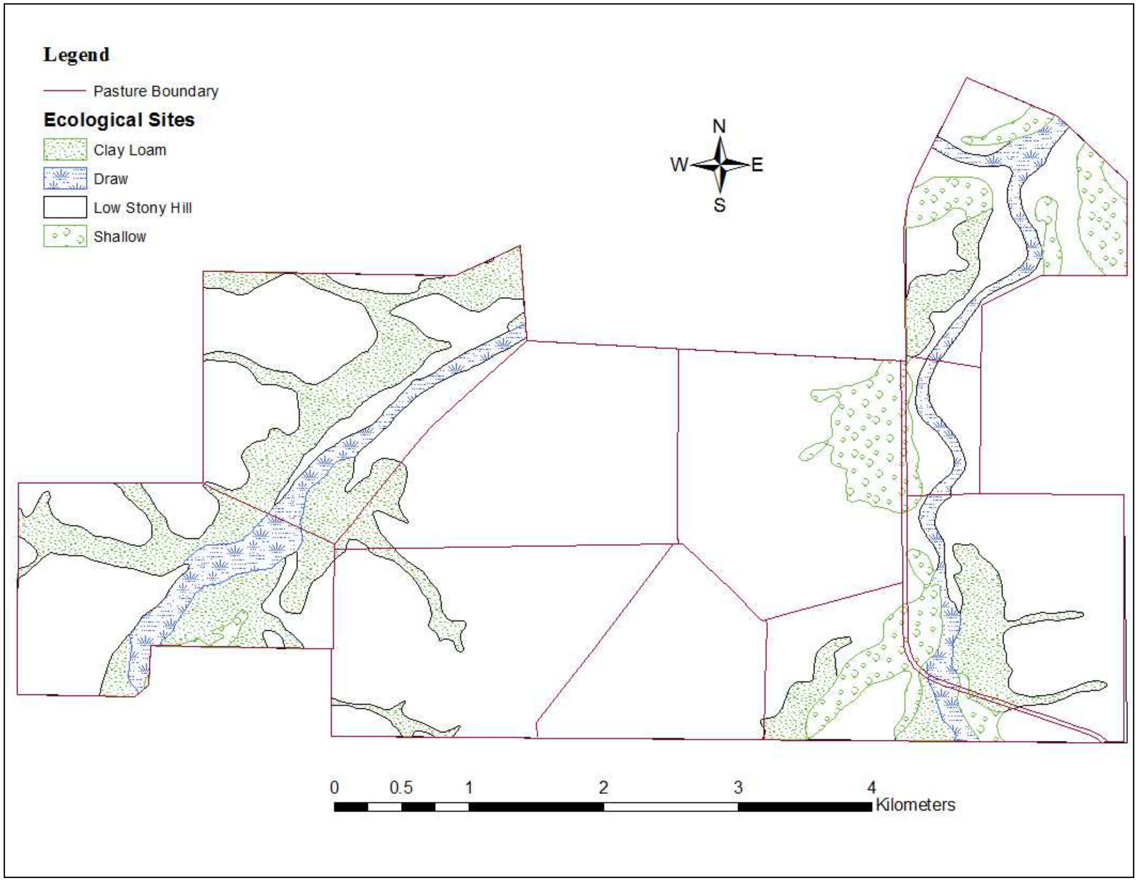

Figure 2. Autocorrelation function (on right) and step length distribution by time of day (on left) for Dog 1 (Alfred).

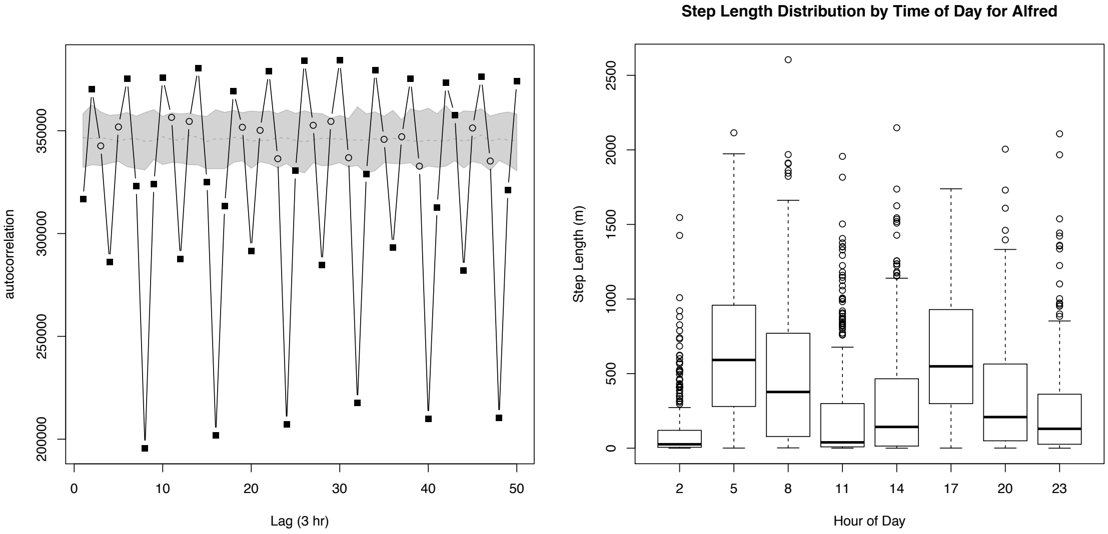

Figure 3. Autocorrelation function (on right) and step length distribution by time of day (on left) for Dog 2 (Elizabeth).

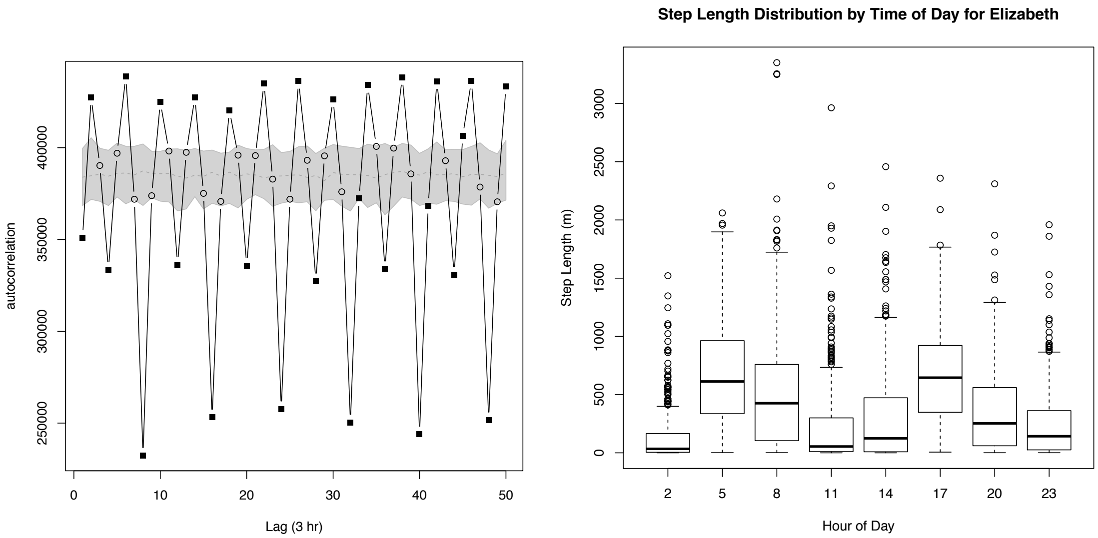

Figure 4. Autocorrelation function (on right) and step length distribution by time of day (on left) for Dog 3 (Nigel).

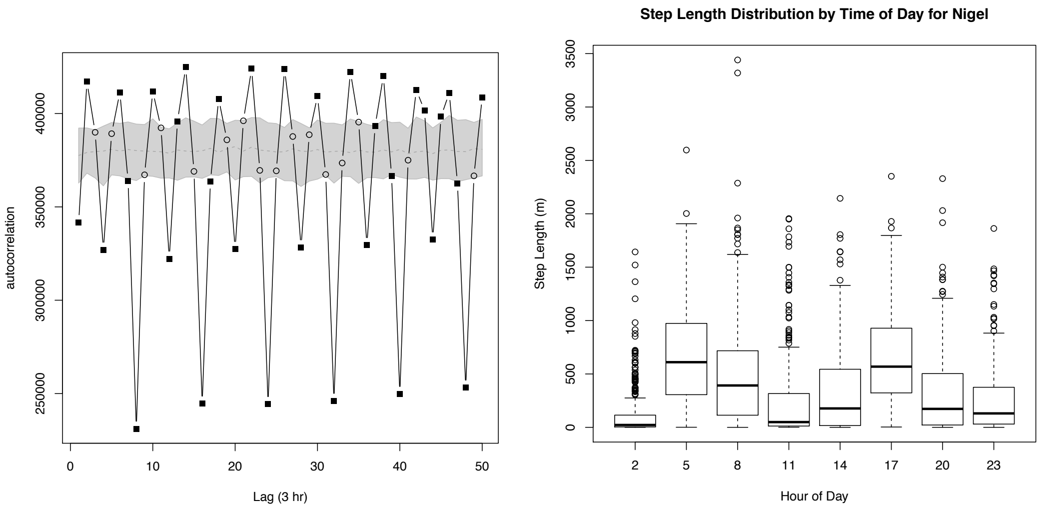

Figure 5. Autocorrelation function (on right) and step length distribution by time of day (on left) for Dog 4 (Reggie).

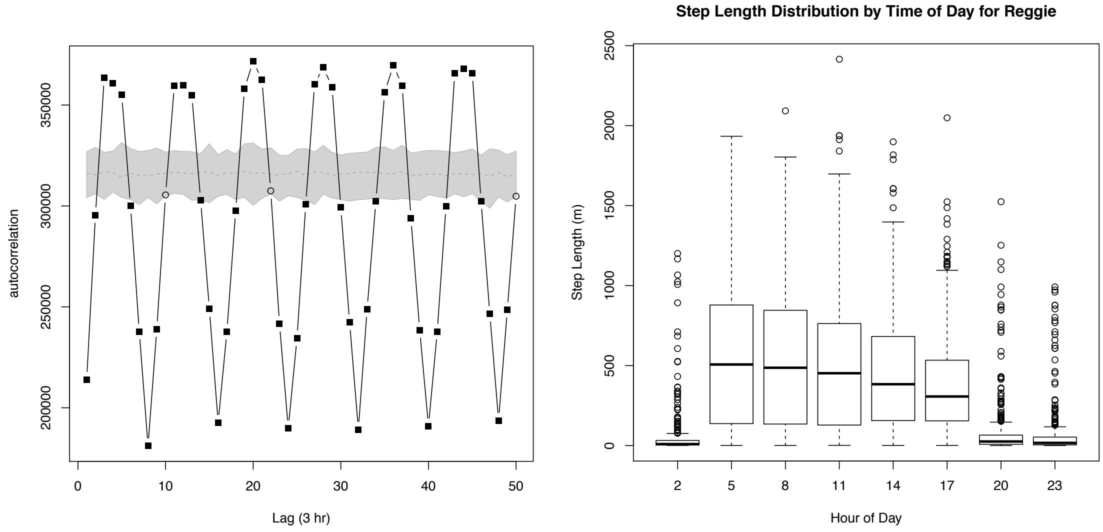

Figure 6. Results of Cross-K analysis of dog fidelity to water-and-feed sites distributed across the study area.