

Comparative movement analysis for a sympatric dhole and golden jackal in a human-dominated landscape

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Abstract. GPS tracking enables the collection of large quantities of data on animal movements which can help guide conservation efforts. Using movement data from a dhole (*Cuon alpinus*) and a golden jackal (*Canis aureus*), we demonstrate the efficacy of movement analysis techniques to explore and contrast the movement patterns of these two individuals. The jackal used a 151 km² local convex hull home ranged covering mostly agricultural lands during the monitoring period, but the dhole restricted its movements to protected forest and a home range size of 33 km². Autocorrelation functions demonstrated consistent nocturnal activity for the jackal and diurnal activity for the dhole. K-means cluster analysis of step lengths and turning angles along with semi-variograms showed that the jackal utilised larger areas and traveled longer distances than the dhole. By combining a comparative approach with simple movement analysis techniques, insights into the space use strategies of canids can be gained in order to enhance our ability to develop effective conservation strategies for these largely persecuted species.

Key words. Animal movement, Canids, daily activity, K-means cluster analysis, local convex hull, semi-variograms

INTRODUCTION

Conservation biologists and wildlife managers incorporate the study of movement ecology to develop conservation strategies and ensure species' survival in the wild. Movement analyses can help biologists determine the probability of population persistence by identifying animal dispersal and recolonisation pathways across the landscape. Such analyses, for example, could aid the understanding of metapopulation dynamics (Pittman et al., 2014) or migration patterns (Hanski et al., 2004). To identify areas with vital resources that could benefit reserve design, animal movement data provides knowledge of how animals select and use their habitat (McLane et al., 2011). Animal movement analyses can also help managers explore current threats [e.g., disease spread (Hosseini et al., 2006) or estimates of collision risk with man-made structures (Tracey et al., 2014)] and the potential impact of human interventions [e.g., the addition of artificial water holes or fences (Loarie et al., 2009)].

Because animal movements can be used to answer a variety of ecological questions, there has been a rapid growth in technologies that allow biologists to collect such data. Specifically, satellite-enabled GPS tracking allows the collection of large quantities of data on animal movements that can be used to answer conservation questions and study elusive species (Cagnacci et al., 2010; Moorcroft, 2012). However, with rapid changes in spatial statistics it can be confusing for researchers to understand options for data analysis. We offer a case study to demonstrate the efficacy of simple movement analysis techniques to explore and contrast individual animal movement patterns.

Thailand faces rising human-wildlife challenges, including the expansion of urban areas, agriculture, and livestock management, which increasingly bring humans and wildlife into contact with each other (Woodroffe, 2000; Donnelly et al., 2006; Bateman & Fleming, 2012). Some species thrive in newly-created, human-dominated habitats (Laist & Reynolds, 2005; Bateman & Fleming, 2012), but others face lethal consequences from increased contact with humans (Woodroffe, 2000; Donnelly et al., 2006; Northrup et al., 2012). This is especially true for species that are persecuted based on conflicts over livestock, belief of dangerousness to people (rarely based on facts), and traditional stereotypes (Fox, 1984; Ballard et al., 1987; Fuller, 1989; Ballard et al., 1997; Smith et al., 2010).

In Southeast Asia, the sympatric canid species dholes (*Cuon alpinus*) and golden jackals (*Canis aureus*) are often viewed as pests, and very little is known about their habitat use and movements. Dholes are a social, pack-living species that prefer to hunt large to medium sized prey and therefore must

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occupy areas with a large enough prey base to support an entire pack of obligate hunters (Humphrey & Bain, 1990; Acharya, 2007; Borah et al., 2009). Unlike the endangered dhole (Durbin et al., 2008), the golden jackal is considered a species of least concern by IUCN (Jhala & Moehlman, 2008). Jackals seem to be more adaptable, living solitarily or in small family groups and foraging opportunistically (Admasu et al., 2004; Lanszki et al., 2006). Based on these differences we propose that space use and movement trajectories of the dhole and jackal will reflect these ecologically diverse strategies. Dholes should be more likely to use areas with little to no human impact, where the habitat is relatively unfragmented. Jackals should occupy areas closer to human settlements where resources are abundant.

Our case study uses telemetry data from a dhole and golden jackal to explore differences in their movement behavior using relatively simple but powerful analytical tools. Due to difficulty obtaining research permits and lack of funding we were only able to collar one dhole and one golden jackal. Despite the small sample size, the data are still relevant as a spatial statistics example and useful because any publication of data related to these understudied canids is greatly needed to shed light on their ecology. Furthermore, we believe that it can be used as a stepping-stone for further research on these two understudied canids. Our objectives are to (1) demonstrate the use of K-means cluster analysis, semi-variograms, and autocorrelation functions to explore movement patterns using telemetry data, (2) determine if each canid species used distinct habitats during different types of behavioral movement states, and (3) contrast the space use strategies of dholes and jackals.

METHODS

The capture and collaring of both canids took place in the northern portion of Khao Ang Rue Nai Wildlife Sanctuary (KARN; 1,079 km²; 13°00'–13°32'N, 101°40'–102°09'E). Located in the eastern part of Thailand, KARN encompasses low-lying evergreen forest and a combination of deciduous dipterocarp, mixed deciduous forest, and grasslands (Jenks et al., 2010). The climate is monsoonal, with distinctive wet (Jun–Sep), cool (Oct–Jan), and dry (Feb–May) seasons. Average annual rainfall is 1,500 mm, and average temperature is 28°C (Thai Meteorological Department, 2015). Human activity varies throughout the sanctuary and is influenced by ranger patrols, tourist groups, and villagers with domestic dogs entering the protected area. Illegal hunting and logging occurs occasionally throughout the sanctuary. A mosaic of agricultural lands and village settlements surrounds the wildlife sanctuary boundary. Large fauna includes elephants (*Elephas maximus*), gaur (*Bos gaurus*), and banteng (*Bos javanicus*). There are no tigers (*Panthera tigris*) or leopards (*Panthera pardus*) remaining in the sanctuary. Prey species include sambar deer (*Rusa unicolor*), barking deer (*Muntiacus muntjak*), wild pigs (*Sus scrofa*), and a small population of reintroduced hog deer (*Axis porcinus*).

To capture the dhole and jackal we used Onedia Victor #1 ½ soft catch leg-hold traps (Minnesota Trapline Products,

Pennock, MN, USA) baited with cattle meat. Prior to handling and measuring age, sex, weight and body size, we anesthetised individuals with a 10 mg kg⁻¹ mixture of tiletamine and zolazepam (Telazol). The dhole was an adult male (19 kg) in generally good condition estimated to be 5–6 years of age based on tooth wear. He had numerous ectoparasite bite marks, a missing right maxillary canine, premolar 3 maxilla missing, and fractures to the left maxillary and right mandibular canines. The jackal was an adult female (15.5 kg) in excellent condition estimated to be less than 3 years of age and greater than 6 months of age with adult dentition. She had no missing or damaged teeth, very few fleas, and no ticks. Her mammae were not swollen, but palpation of her belly indicated a possible pregnancy. All animal capture, handling, and collaring procedures were approved by Institutional Animal Care and Use Committees at the Smithsonian Institution and the University of Massachusetts. We fitted the jackal with a 350 g Tellus Basic 3H2A GPS/GSM collar (TVP Positioning, Lindesberg, Sweden), set to collect location data every 30 minutes for a total of 37 days. This schedule was chosen to collect fine-scale data with the intention of identifying clusters that could represent den or kill sites. For the remaining 105 days of data collection, we employed a less frequent sampling regime of 4–10 relocations per day to reserve battery life, but continue to collect fixes that would allow us to calculate home ranges and analyse movements. We used the same model of Tellus GPS collar with similar sampling schedule for the dhole. However, the total relocations for the dhole (n=492) was considerably shorter than the jackal (n=2111), due to the dhole possibly traveling more frequently in areas outside GSM range and collar malfunction.

We calculated fixed number of points local convex hull (*k*-LoCoH) home ranges for the dhole and jackal using the adehabitatHR package in R (Calenge, 2006; R Core Team, 2012). We used a *k* of 65 (following the “minimum spurious hole covering” rule) and defined the home range as the area bounded by the 100% isopleth of the utilisation distribution (Getz & Wilmers, 2004; Getz et al., 2007). We were also interested in exploring whether we could differentiate movement types undertaken by each collared animal. For example, can we distinguish travelling versus resting at a den site? This could have a conservation application to identify critical resource areas (Barraquand & Benhamou, 2008). To partition canid movement paths into distinct movement types, we applied K-means cluster analysis (25 random starts, 10 iterations, 2 clusters) on step lengths and turning angles (VanMoorter et al., 2010). Cluster analysis allows us to identify groups with similar movement characteristics that may correspond to different behaviors; for example, travelling versus resting. We arbitrarily chose two clusters because we were broadly interested in two movement states; however, there could potentially be more than two states. For this analysis we first determined step lengths and turning angles from all relocation data based on a 30-min lag time using the adehabitatLT package in R (Calenge, 2006). Prior to the K-means analysis, we log transformed step lengths and then standardised the transformed values based on minimum and maximum values, following methods

RESULTS

described in VanMoorter et al. (2010). Turning angles did not need to be transformed but were also standardised via the same methodology.

K-means clusters represented two behavioral movement states: a) an encamped state with short step lengths and variable turning angles centered around 180°; and b) an exploratory state with much larger step lengths and small changes in turning angle (i.e., a turning angle centered around 0°; Morales et al., 2004). To visualise our results, we plotted histograms fitted with Weibull distributions using the MASS package in R (Venables & Ripley, 2002). We displayed turning angles with polar plots, created using the Plotrix package in R (Lemon, 2006), and fitted these plots with Wrapped Cauchy distributions using the CircStats package in R (Lund & Agostinelli, 2001).

To determine if each canid species used distinct habitats during different movement modes, we overlaid trajectory lines for encamped and exploratory movement modes on top of a land cover map. The land cover map was created in eCognition version 8.8 (Trimble Navigation Limited, 2010) by applying an object-based classification algorithm to screen captured images from Google Earth (Google Inc., 2005). We delineated four major habitat categories: forest, early successional and open forest, agriculture, and cloud (= no data). To quantify habitat type traversed by each trajectory, we created a 50-m buffer around each trajectory and extracted the majority habitat type for further analysis. Differences in habitat use between the dhole and jackal were compared using Fisher's exact tests with Bonferroni corrections. All GIS analyses were performed using ArcGIS 10.0 (ESRI, 2010) and Geospatial Modeling Environment (Beyer, 2010).

In addition to understanding variations in space use patterns of each canid, we also examined temporal differences in movement activity. We analysed step-length data from the GPS telemetry of the dhole and jackal using temporal autocorrelation functions (ACFs). ACFs can be used to discern patterns of movement from stochastic movements and can yield insights into behavior such as detecting differences in foraging behavior or identifying specific rhythms in areas of human disturbance (Boyce et al., 2010). All temporal analysis was performed in R using the stats package (R Core Team, 2012) and the cts package (Wang, 2013).

We also conducted a semi-variance comparison of dhole and jackal positions, which gives a better understanding of their movement process (such as the ability to identify migration) and indicates whether you have enough data to make conclusions about an animal's movements (Fleming et al., 2014). Semi-variograms are a useful movement metric, since they are relatively simple and do not rely upon an equally spaced GPS sampling schedule, which is often arbitrarily chosen. Standard error from the mean semi-variance was used to calculate 95% confidence intervals. To facilitate the ease of visual interpretation of our semi-variograms, the semi-variance and their corresponding 95% confidence intervals (CI), were smoothed by a moving average over 20 lags.

The overlaid movement trajectories on top of a land cover map indicated that dhole relocations occurred almost exclusively within KARN, while jackal relocations were found both within and outside of KARN (Fig. 1). The jackal had a local convex hull home range of 151 km² and occurred mostly within agricultural landscapes, but also occasionally used early successional habitat and forest (Fig. 2). The dhole never utilised agriculture and occurred only in forest and open, early successional habitats within a home range of 33 km² size (Fig. 2). The dhole and jackal's exploitation of agricultural habitats was significantly different, as was their utilisation of forested landscapes (two-sided Fisher's exact test with Bonferroni correction: $P < 0.001$ for both agriculture and forest habitat tests).

The two individuals also showed temporal differences in the periodicity of their movements, as well as their daily activity patterns. The jackal had a very pronounced cyclical pattern in its step length ACF (Fig. 3). Periods of high autocorrelation corresponded to night and early morning when step lengths were large, then as autocorrelation became negative, step lengths became shorter during daytime resting (Fig. 3, 4). The dhole had no clear pattern in step length autocorrelation (Fig. 3) and was generally more active during the day than at night (Fig. 4).

Although our results are highly limited by our sample size and monitoring duration, our K-means cluster analysis demonstrated the individual dhole and jackal had distinctly different movement patterns. Larger proportions of the dhole's movements were classified as encamped and are characterised by small step lengths and variable turning angles (Fig. 5). In contrast, the jackal displayed a larger amount of exploratory movements that are characterised by large step length and minimal variation in turning angle (Fig. 5).

As a result of these differences in movement patterns, the jackal and the dhole showed distinct differences in their semi-variance (Fig. 6). The dhole's semi-variance flattened out quickly and reached an asymptote after approximately 15 days, indicating a reduction in diffusion and a transition to movement within a home range (Fig. 6, top panel). This indicates that the dhole reached a stable home range and we probably collected data indicative of the animal's full use of its range. The jackal's semi-variance initially increased more rapidly than the dhole, during which time the jackal moved from KARN into an agriculturally dominated landscape. For the next 15 days, the jackal's semi-variance remained constant, before experiencing another rapid increase that lasted 20 days and then finally oscillating about an asymptote for the remaining 60 days (Fig. 6, bottom panel). This indicates that we may not have collected enough information on the jackal to represent a stable home range.

DISCUSSION

There are few studies devoted to understanding and conserving wild Asian canids in the face of changing

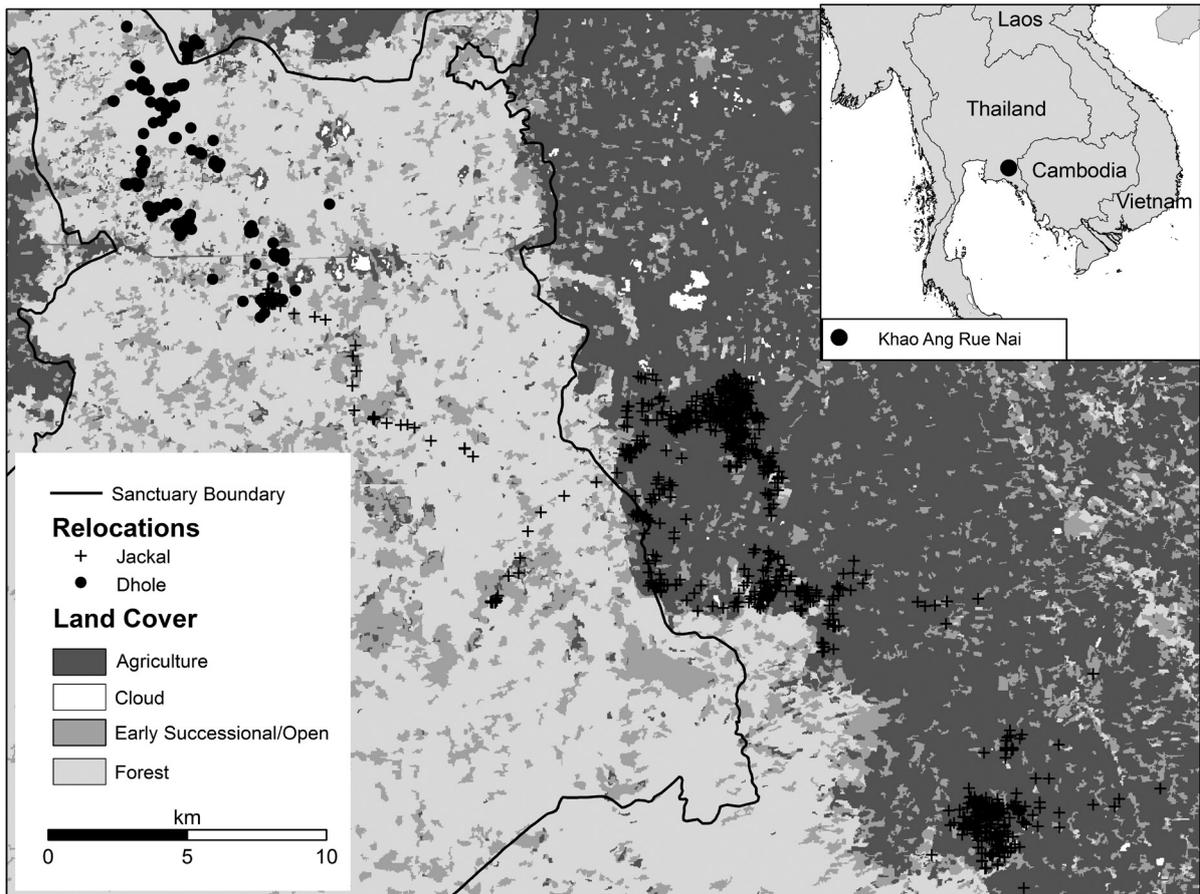


Fig. 1. Dhole and jackal relocations overlaid on a land cover map of Khao Ang Rue Nai Wildlife Sanctuary, Thailand.

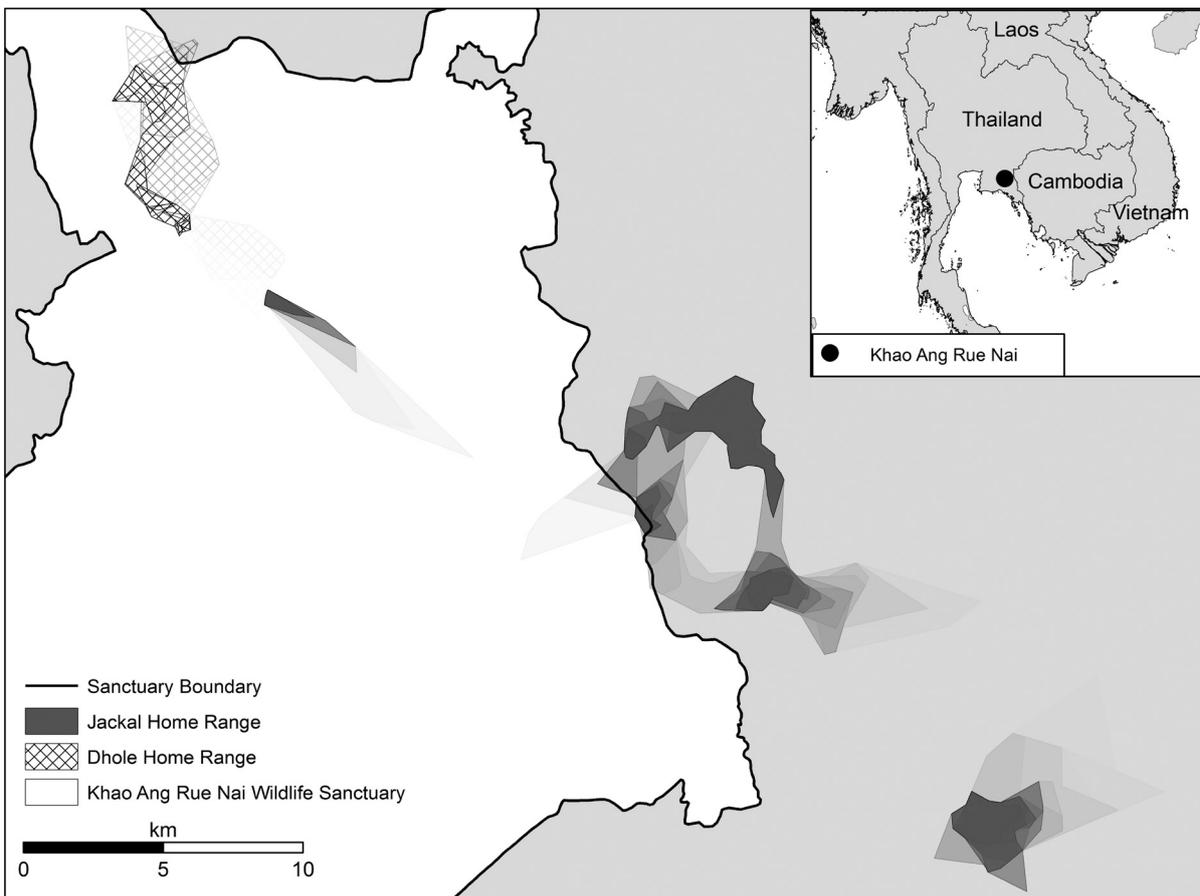


Fig. 2. Decile-shaded isopleths of convex hull home ranges for the dhole and jackal in Khao Ang Rue Nai Wildlife Sanctuary, Thailand.

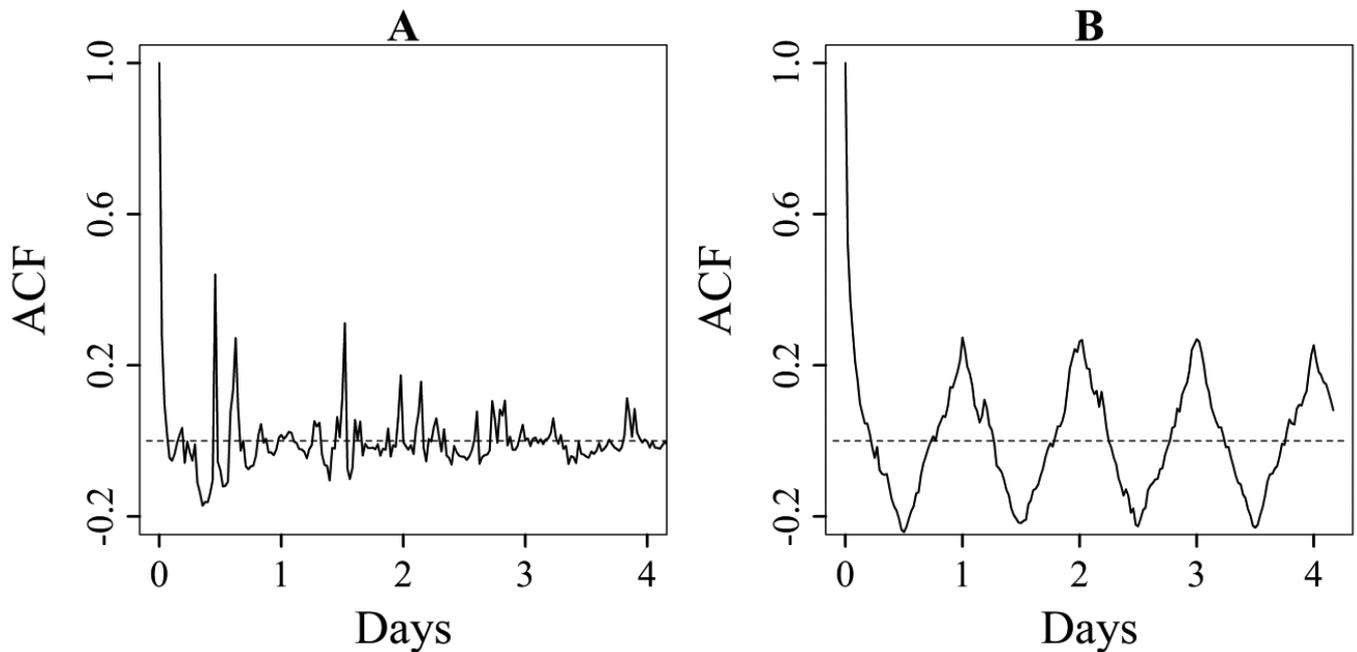


Fig. 3. Autocorrelation function (ACF) of: A, the dhole; and B, the jackal step length. Data points above the dotted line are classified as autocorrelated.

environments, human persecution, and habitat degradation. Tracking data demonstrated that the individual dhole and jackal showed distinct differences in their movements, space use, and activity patterns. The life history traits of our two study species offer insights that should be considered as potential explanations of these differences. For example, social structure (i.e., pack species versus solitary species) and prey preferences likely influence movement, space use and activity patterns. Such life history traits may also determine the degree to which a species can adapt to land use changes, such as increased use of agricultural land in response to decreased availability of natural forest and grassland habitats. These results indicate a potentially different degree of risk associated with encountering people for each species, if these results can be replicated with a larger sample size.

The dhole and jackal showed a significant difference in their exploitation of agricultural versus forested landscapes. Our results suggest that the dhole pack completely avoided areas with high human densities and restricted their movements to a home range within the boundaries of the protected area. Dhole activity patterns deduced from autocorrelation functions and analysis of step lengths also were much less cyclical, with higher activity during the day. Dholes are a highly social species and consequently, tend to prefer large prey (Humphrey & Bain, 1990; Acharya, 2007; Borah et al., 2009). As a result, home range size for dholes may be limited by prey availability or inter-pack territoriality (Johnsingh, 1982; Grassman et al., 2005). The large prey such as sambar deer, which dholes target, are unlikely to be found within agricultural areas but are abundant within protected areas, and may be more concentrated around watering holes. In fact, the dhole tracked in this study had a watering hole at the northern and southern boundary of its range and previous studies have demonstrated that proximity to watering holes is influential in den site selection and dry season range size

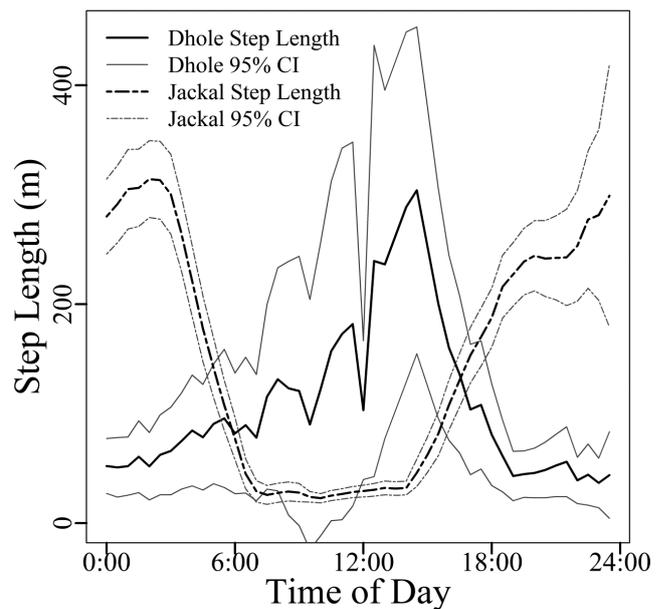


Fig. 4. Comparison of both species' daily activity patterns. Smoothing was achieved by averaging over 4 hour time intervals. The 95% confidence intervals were estimated from the standard error of the mean step length.

(Johnsingh, 1985; Venkataraman et al., 1995). Due to their pack hunting behaviors and reliance on large prey, dholes and other highly social canids may be more vulnerable to land use change and increased contact with humans.

The jackal used the agricultural matrix surrounding the sanctuary boundary, spending more time in human-dominated landscapes which thus increased its human-conflict potential. Jackals are highly adaptive, with group sizes varying in relation to resource availability and distribution (Macdonald, 1979; Admasu et al., 2004; Jaeger et al., 2007). The flexible social system of jackals seems to allow this species to

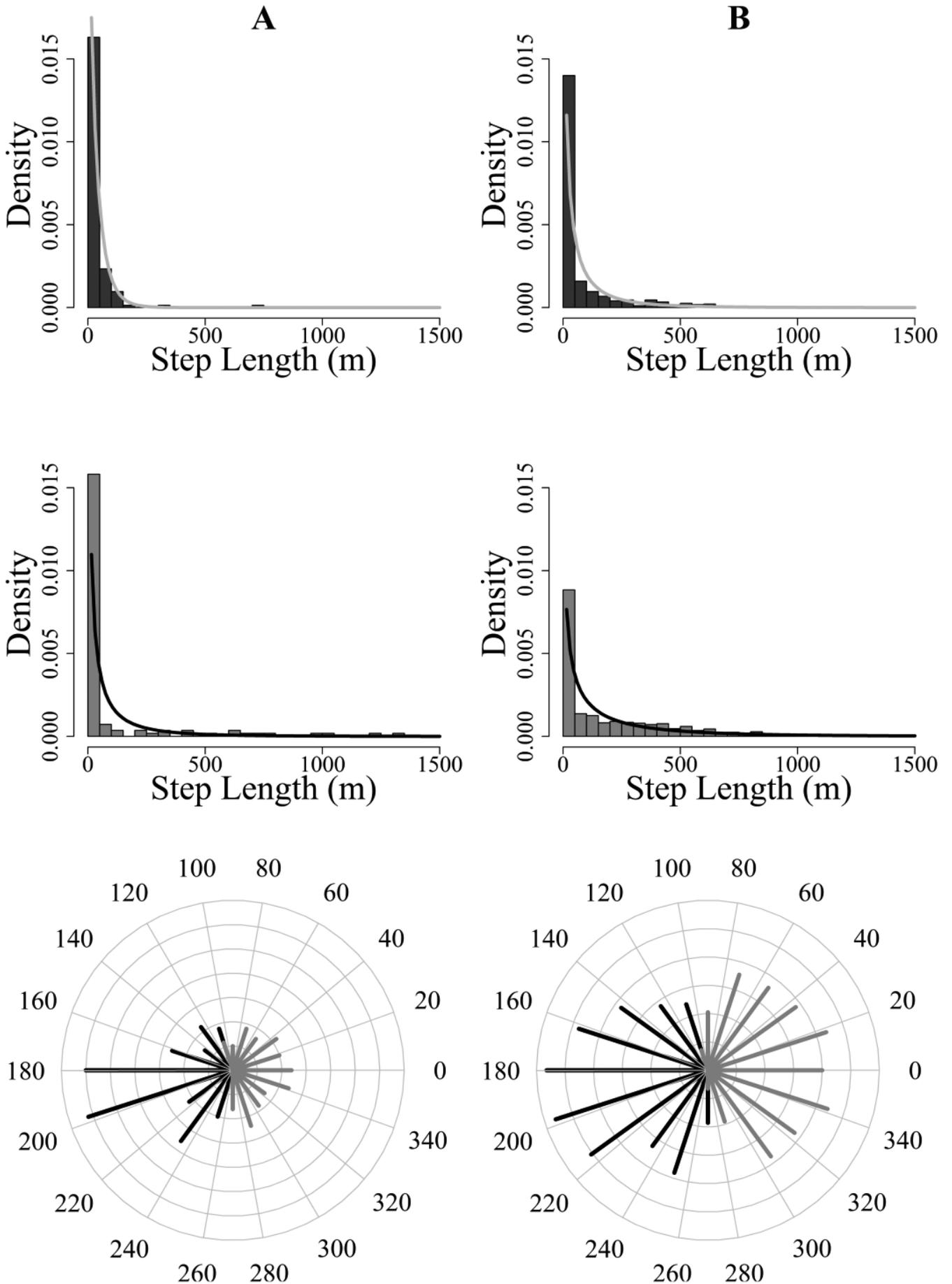


Fig. 5. Dhole (column A) and jackal (column B) step length and turning angle distributions of encamped (black) and exploratory (grey) behavioral states. Turning angles (in degrees) for both the encamped and exploratory states are plotted on the same polar plot for each species.

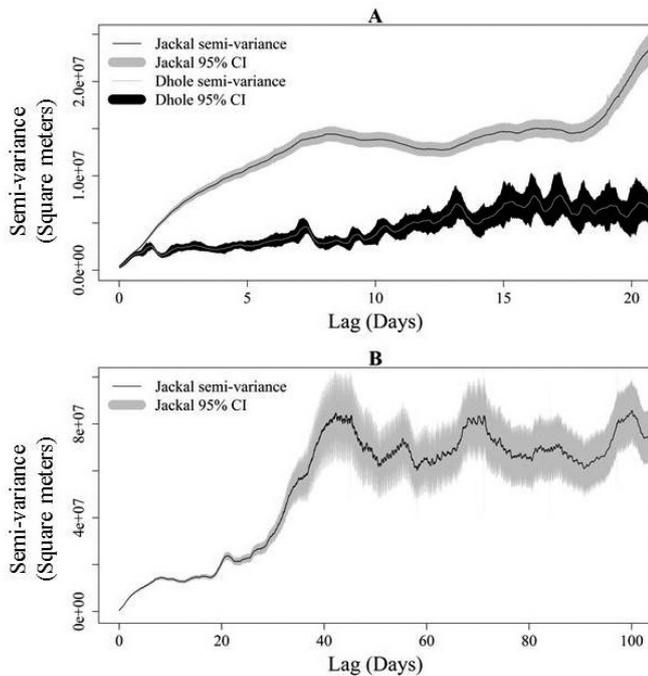


Fig. 6. A, Semi-variance comparison of dhole and jackal positions. Since the dhole was monitored for a shorter time than the jackal (due to collar malfunctions), we present comparative data for this shorter time period. B, The complete jackal semi-variogram. Both semi-variograms are limited in scope to the first two thirds of the data, since estimates in the last third of the semi-variogram has very large confidence intervals. Semi-variance and 95% confidence intervals (CI) estimated from the standard error of the mean semi-variance, were smoothed using a moving average over 20 lags.

thrive in a wide range of resource landscapes, from natural habitats and agricultural systems to garbage dumps and villages (Macdonald, 1979; Admasu et al., 2004; Jaeger et al., 2007; Rotem et al., 2011). In cases where resources are highly concentrated in patches, such as garbage piles, jackal groups can approach 10–20 individuals (Macdonald, 1979). While in studies of agricultural areas, where rodent prey is abundant, but daytime shelter is limited and patchy, jackals live solitarily or in mated pairs (Jaeger et al., 2007). Agricultural mosaics provide resources in the form of small prey, such as rodents (Jaeger et al., 2007) and domestic fowl. Utilisation of this agricultural landscape probably represents a trade-off for the jackal, between access to areas rich in resources and increased risk of mortality from human persecution. In this scenario, the nocturnal behavior of the jackal in our study, demonstrated through analysis of step lengths, might allow it to minimise risk associated with human encounters (Jaeger et al., 2007; Rotem et al., 2011). In contrast, in areas of Africa where human disturbance is negligible, jackals are seen moving during daylight hours (Skinner & Chimimba, 2006).

Our K-means cluster analysis identified distinct encamped and exploratory movements for both canids. In contrast to a larger proportion of encamped movements for the dhole, the jackal displayed more exploratory movements. This jackal appeared to be more mobile, interspersing periods of residency, with long distance movement to new sites within

the agricultural landscape. She was captured centrally within the sanctuary, but immediately travelled south, crossed outside of the sanctuary boundary, and spent the remaining time in agricultural areas. This could indicate that we captured a transient animal that was not established in the sanctuary. Or, if the jackal was pregnant, she may have been searching for a suitable area to give birth. We tracked the jackal to a clump of trees within an agricultural matrix and attempted visual observations, but we were not able to locate a specific resting or potential birthing site.

IMPLICATIONS FOR CONSERVATION

Although this analysis provides very preliminary results, we hope that by publishing these results along with the associated code we can encourage others to implement our analysis in order to more rigorously evaluate some of the hypotheses that we have put forward. We found that the dhole pack completely avoided areas with high human densities and restricted their movements to a home range within the boundaries of the protected area. This could mean dholes have low adaptability to areas with high human use and are at a greater disadvantage than other species in dealing with habitat fragmentation. In some range countries, dholes are persecuted for preying on livestock (Morris, 1927; Wang & Macdonald, 2006; Lyngdoh et al., 2014). Our limited data show that some dholes may avoid livestock. In dhole-human conflict areas, it could be beneficial to show movement data of dhole packs to villagers to offer proof if the dholes stay in the forest core and are less likely to prey on livestock. These results also suggest that direct contact between dholes and village domestic dogs may be limited. Therefore, studies focused on disease dynamics should also focus on species with intermediate tolerance of humans, such as jackals, that use both protected forest and agricultural lands.

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