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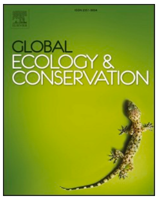

Original Research Article

Daily activity patterns and response to lunar cycle of *Chinchilla chinchilla* and *Lycalopex culpaeus* in an extreme Andean environment: Insights into the predator-prey relationship

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ABSTRACT

Circadian rhythms, which reflect 24-hour activity cycles, are critical for survival, helping species optimize foraging and predator avoidance. In principle, prey species are expected to adjust their activity patterns to minimize the overlap of their foraging activities with that of predators, while predators may align their activity patterns with that of their prey. In this study, the daily activity and response to the lunar cycle of two native Chilean mammals, the endangered short-tailed chinchilla (*Chinchilla chinchilla*) and one of its predators, the culpeo fox (*Lycalopex culpaeus*), were studied in a 4500 m-elevation area in northern Chile during three consecutive years using trap cameras. While chinchillas presented a predominantly nocturnal activity pattern, foxes were more active during the day, resulting in a low temporal overlap in their activity patterns. Regarding the response to the lunar cycle, the short-tailed chinchilla rhythm remained relatively constant across lunar phases, and the culpeo fox showed increased activity during the first and third lunar quarters at intermediate luminosity. The activity pattern shown by the two species differed from the expected under a predator-prey relationship. We suggest that the availability of alternative diurnal prey may provide greater benefits to *L. culpaeus* than to the endangered *C. chinchilla*, potentially shaping their daily activity rhythms and responses to the lunar cycle.

1. Introduction

The circadian rhythm of a species refers to the daily pattern of activity repeated in 24-hour cycles, in which a species exploits the resources available in the environment. In predator-prey relationships, the activity patterns of the species involved is of major importance as predation events can only occur when prey and predator populations coexist in the same place and simultaneously, implying that the activity pattern of a species is critical for its persistence. On the one hand, it is proposed that prey populations' activity patterns evolved towards minimizing mortality risks while maximizing foraging time (Kronfeld-Schor and Dayan, 2003). On the other hand, the activity pattern of predator populations would have evolved towards a high overlap with the activity rhythm of their prey (Kronfeld-Schor and Dayan, 2003; Herrera et al., 2018). However, the activity of a species does not depend only on interspecific interactions. Variation of photoperiod (i.e., day length) along the year is known to influence the daily activity of a species

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in a similar way as physiological and behavioral traits are affected, such as moulting, fat storage, food storing, and reproduction (Halle, 2000). In consequence, daily activity patterns are currently considered a characteristic of a species that results largely from physiology (Halle, 2000; Roll et al., 2006) and molded by various environmental factors, such as seasonality (Caravaggi et al., 2018), food availability (Pereira, 2010), predation risk (Monterroso et al., 2013; Caravaggi et al., 2018), competition (Monterroso et al., 2014; Bhatt et al., 2021) and anthropogenic disturbances (Zaman et al., 2022).

In addition to daily activity patterns, some species show a response to the lunar cycle, that is, by the 29.5-day cycle in which the moon orbits around the Earth (Kronfeld-Schor et al., 2013). For instance, the three-order magnitude variation in luminosity throughout the lunar cycle has been suggested to represent mammal species' most relevant cycling variable (Kyba et al., 2017). Prugh and Golden (2014) raised three hypotheses for the effect of moonlight in the activity of nocturnal mammals. First, the 'predation-risk hypothesis' where the activity of prey species is expected to decrease during the brightest phases of the cycle, presenting a 'lunar-phobic' pattern of activity, as greater luminosity would represent a signal informing high predation risk. Second, the 'visual-acuity hypothesis' proposes that species with high visual capacity would increase their activity during the brightest phases of the lunar cycle, showing a 'lunar-philic' pattern because the high luminosity would allow efficient foraging and acute predator detection. And lastly, the 'habitat-mediated predation risk hypothesis' proposes that if moonlight increases predation risk, with higher habitat cover the activity of prey should increase. Several studies have documented patterns consistent with these predictions, reporting both lunar-phobic and lunar-philic responses across different species (e.g., Michalski and Norris, 2011; Pratas-Santiago et al., 2017; Dias et al., 2018; Bhatt et al., 2021; Zaman et al., 2022). However, as with the daily activity, the response to the lunar cycle seems to be contingent on the local environmental conditions, as revealed by study performed on the ocelot (*Leopardus pardalis*), which was characterized as lunar-phobic in the southern United States (Leonard et al., 2020), and insensitive to lunar cycle in northeastern Brazil (Dias et al., 2018).

Many studies of animal behavior in natural populations are currently performed by using camera traps or radio collars (e.g., Theuerkauf et al., 2003; Huck et al., 2017; Caravaggi et al., 2018; Zaman et al., 2022). Remote sensors provide important advantages in comparison to direct observation methods, such as the reduction of the inherent interference associated with the presence of observers and the feasibility of performing long-term studies in places that cannot be accessed with desirable periodicity due to logistic or economic limitations (O'Connell et al., 2011). In recent years, numerous statistical techniques have been developed to study activity patterns using camera traps, including studies of competition between species, temporal and spatial niche partitioning, and evaluation of the effect of anthropogenic disturbance, among others (Frey et al., 2017). This study seeks to characterize, using camera traps, the daily activity pattern and response to the lunar cycle of the short-tailed chinchilla (*Chinchilla chinchilla*) and the culpeo fox (*Lycalopex culpaeus*) in an extreme environment located ~4500 m.a.s.l. in the Andes Mountain Range of northern Chile, where both species coexist in sympatry.

Chinchilla chinchilla (previously *Chinchilla brevicaudata*), commonly known as the short-tailed chinchilla, is a rodent species native to northern Chile. It has been described in Argentina, Bolivia, and Peru. It measures between 30 and 38 cm, weighing between 500 and 850 g. It has nocturnal habits, living in crevices and rocky formations between 3500 and 5000 m above sea level (Iriarte, 2008). Its diet consists mainly of Gramminae such as *Stipa chrysophylla* (Valladares et al., 2014) or *Pappostipa frigida* (Minera GoldFields Salares Norte SpA, 2018a). Three predator species have been described for the short-tailed chinchilla: the lesser grison (*Galictis cuja*), the puma (*Puma concolor*), and the culpeo fox (*Lycalopex culpaeus*) (Walker et al., 2007; Valladares et al., 2014). Because its distribution range covers less than 500 km^2, the species is currently classified as Endangered ("EN") by the IUCN (Roach and Kennerley, 2016). The primary reason for the limited distribution of this species seems to be the indiscriminate hunting during the late 19th and early 20th centuries (Jiménez, 1996). *Lycalopex culpaeus*, commonly known as the culpeo fox, is the largest canid in Chile, weighing between 7 and 9 kg. It is a widely distributed canid that ranges from Colombia to Tierra del Fuego, inhabiting up to 4800 m above sea level (Iriarte, 2008; Guntiñas et al., 2021). *L. culpaeus* has been trophically characterized as generalist/opportunist, including diverse items in its diet depending on the environmental food availability (Guntiñas et al., 2021). In general, culpeo foxes are currently classified as of Least Concern ("LC") by the IUCN (Lucherini, 2016), albeit it has been classified as Vulnerable ("VU") in Ecuador and Colombia due to an alleged reduction in population abundance (Guntiñas et al., 2021). Camera trap records indicate that this species has a predominantly nocturnal activity pattern (Lucherini et al., 2009; Monteverde and Piudo, 2011; Gantchoff and Belant, 2016) with a lack of response to variation in lunar cycle luminosity (Lucherini et al., 2009).

As *C. chinchilla* has been reported as potential prey for *L. culpaeus* (Walker et al., 2007), the two species represent an appropriate system to examine the predator-prey relationship's activity pattern. In this regard, the response of species to the lunar cycle and the synchronicity of activity patterns at the daily and seasonal time variation are relevant measurements to inquire into predator-prey activity dynamics. For instance, previous studies reveal that short-tailed chinchillas show a nocturnal activity pattern (Roll et al., 2006; Iriarte, 2008), similar to that of the culpeo fox (*L. culpaeus*) (Lucherini et al., 2009; Monteverde and Piudo, 2011; Gantchoff and Belant, 2016). On this basis, a high temporal overlap between the two species is anticipated. In terms of seasonality, an increase in diurnal activity is expected in the summer season according to changes in the photoperiod (e.g., Halle, 2000). Regarding the response to the lunar cycle, according to the predation risk hypothesis chinchillas are expected to reduce their activity during the brightest phases of the lunar cycle (Prugh and Golden, 2014). Likewise, as species of the order Carnivora generally have strong visual acuity (Botts et al., 2020), culpeo foxes are anticipated to exhibit a lunar-philic rhythm, in line with the visual-acuity hypothesis (Prugh and Golden, 2014).

2. Methods

2.1. Study site

This study was carried out between 2017 and 2019 in the Atacama Region at 4500 m above sea level (26°0′33" S, 68°51'40" W) covering an area of about 316 km^2. The study site is dominated by rock formations and the presence of herbaceous vegetation, with *Pappostipa frigida*, *Adesmia erinacea* and *Adesmia echinus* as the most representative species. During 2017–2019, the mean monthly temperature (± SD) was close to 0°C (± 3.74 °C), with minimum values from May to August (-4.32 °C ± 1.48 °C) and maximum values from December to February (4.46 °C ± 1.17 °C). The mean annual accumulated precipitation in the three years was 29 mm (± 26.72 mm). The site is snowed from April to September. All conditions were measured on-site using three meteorological stations. Additional information on the location and equipment used is detailed in the supplementary material (Appendix I). We considered summer and winter seasons for seasonal comparisons based on climatic conditions. This criterion seemed appropriate as the presence of snow tends to block the burrow entrances of short-tailed chinchillas. Winter seasons included the presence of snow during May - August 2017, May - September 2018, and April - September 2019.

Using data from Minera GoldFields Salares Norte SpA, (2018a), the population density of the short-tailed chinchilla is estimated to be between 1.0 and 1.5 individuals/ha. The density of culpeo foxes varies substantially across locations depending of habitat characteristics (Guntiñas et al., 2021). It inhabits the edges of streams and dense scrubs (Iriarte, 2008), and have a generalist diet largely dependent on prey availability (Guntiñas et al., 2021; Lagos et al., 2023). In northern Chile, rodents are the main prey category for culpeo foxes (74.3% of prey), with *P. xanthopygus* being the main species consumed (Lagos et al., 2023). In addition to chinchillas, other potential prey species for culpeo foxes in the site include the Andean field mouse (*Abrothrix andinus*), the austral leaf-eared mouse (*Phyllotis xanthopygus*), and *Liolaemus rosenmannii* (Minera GoldFields Salares Norte SpA 2018b).

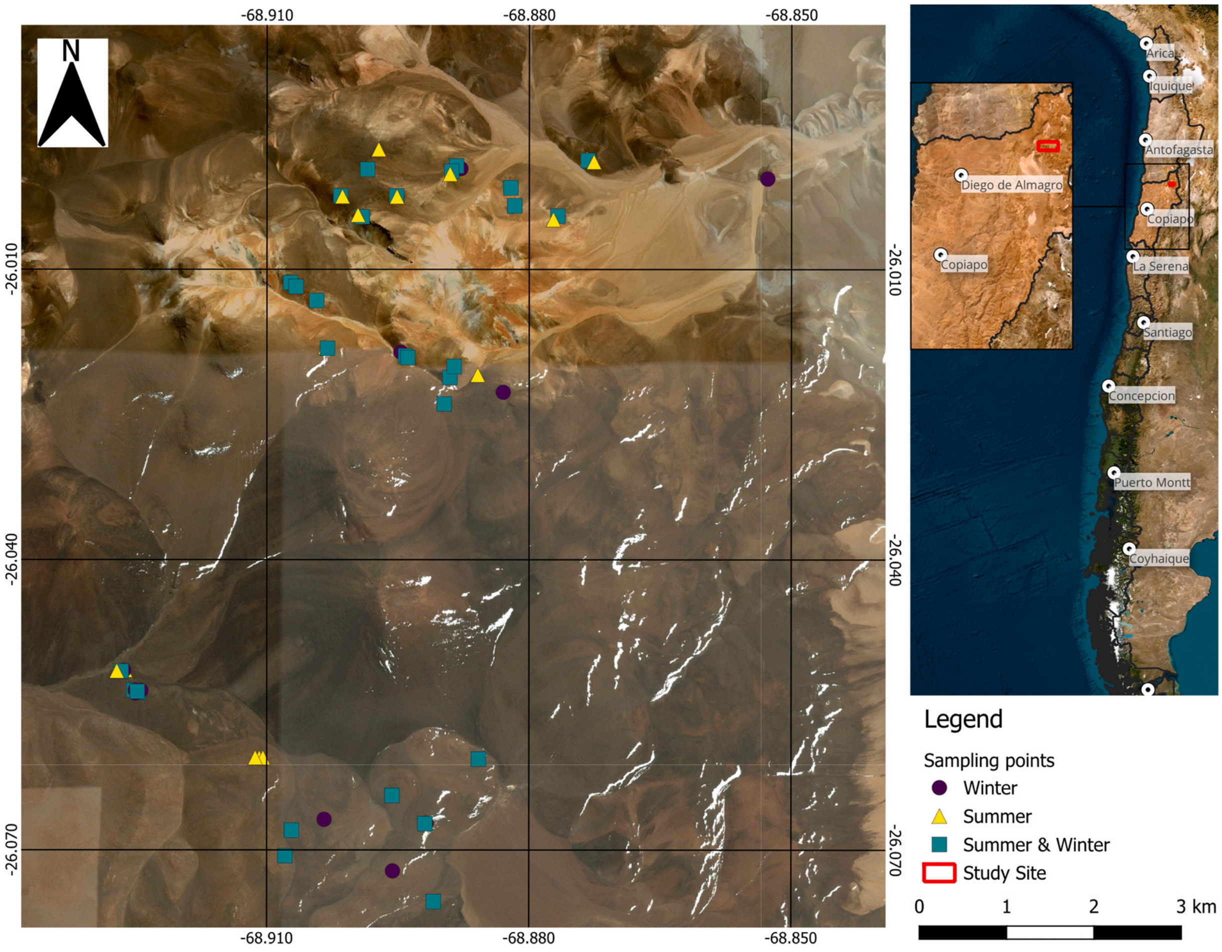

Fig. 1. Geographical location of the camera traps used in this study on a per season sampling.

2.2. Sampling design

The study was conducted over 10 field campaigns between February 2017 and May 2019, using Bushnell camera traps, model 119774 C, configured in photo mode to capture bursts of three photographs, with no inactivity period between bursts. A total of 42 camera traps were deployed across 57 sampling points (Fig. 1), with cameras being partially rotated at each point during subsequent field campaigns. No bait was used in this study. Each sampling point was monitored for an average (± SD) of 238.9 trap-nights (± 254.4). Throughout the study, a total of 13 618 trap-nights were active across all field campaigns.

During the summer season, 45 out of 57 sampling points were monitored. Summer sampling points were monitored for 157.1 trap-nights (±166.5) on average (±SD), resulting in a total sampling effort of 8956 trap-nights. In the winter season, 41 out of 57 sampling points were monitored, with 81.8 trap-nights (± 101.8) on average (±SD). The total sampling effort in the winter season was 4662 trap-nights. The number of points sampled per season varied depending on the feasibility of accessing traps. Because of this limitation, the detection frequency was standardized to the number of records relative to the total sampling effort by season. The location of sampling points in the landscape was chosen to maximize the chance of detecting short-tailed chinchillas. To identify potential chinchilla burrows, satellite imagery, and LIDAR data were used to locate rock formations, after which field transects were conducted in search of feces indicative of recent chinchilla activity to place camera traps. In addition, the presence of culpeo foxes in the site was initially confirmed by observations of fox scats within the altitudinal and latitudinal range described by Minera GoldFields Salares Norte SpA (2018b) and Iriarte (2008). The sampling design and overall strategy formed part of an environmental impact assessment for a mining project (Minera GoldFields Salares Norte SpA, 2018c).

2.3. Patterns of activity

Estimates of daily activity patterns are based upon the assumption that camera trap recordings capture random samples from an essentially continuous distribution of animal activity (Ridout and Linkie, 2009). The activity of each species was estimated using kernel density functions following the procedure of Ridout and Linkie (2009). In this way, the estimated density functions were treated as the estimated activity pattern for species, assuming that camera traps capture active and moving individuals (Ridout and Linkie, 2009). Under this assumption, it is unnecessary to apply correction filters used in abundance estimates to ensure data independence, as the use of filters may introduce substantial bias in activity patterns estimates, especially for herbivorous species and to a lesser extent for carnivorous species (Peral et al., 2022). In this way, only duplicate records resulting from the burst of photographs were removed by considering a one-minute interval between successive recordings. When more than one individual was simultaneously recorded, only one event was considered per individual.

To account for the seasonal variation in the sun's position and the resulting changes in day length, each event's time was converted to "*sun time*" . This was achieved by mapping each day's sunrise to $\frac{\pi}{2}$ and sunset to $\frac{3\pi}{2}$, and adjusting each event time accordingly, following the procedure described by Ridout and Linkie (2009). To gain insight on the predator-prey relationship between species, we used the coefficient Δ_4 proposed by Ridout and Linkie (2009). This coefficient quantifies the overlap between two kernel density functions, ranging from 0 (no overlap) to 1 (complete overlap). The confidence interval for Δ_4 was estimated in 1000 bootstrap replications implemented with the R package "overlap" (Ridout and Linkie, 2009). To be consistent with previous published studies, overlap levels were classified as low ($\Delta_4 \leq 0.5$), moderate ($0.5 < \Delta_4 \leq 0.75$), and high ($0.75 < \Delta_4$) (Monterroso et al., 2014; Caravaggi et al., 2018). As Δ_4 is a descriptive coefficient only precluding hypothesis testing, we used the Watson-Wheeler test to examine whether circular distributions between species and between seasons differ statistically (Jammalamadaka and SenGupta, 2001). To this end we used the "circular" package implemented in R (Agostinelli and Lund, 2023).

To classify the activity patterns along the time of day, the following time periods were defined: the diurnal period was defined as the time encompassing one hour after sunrise until one hour before sunset; the night period as the time encompassing one hour after sunset until one hour before sunrise; and the crepuscular periods as the time encompassing one hour before and after sunrise and one hour before and after sunset (Ross et al., 2013; Monterroso et al., 2014). Based on these definitions, the species were classified in the following mutually exclusive categories: nocturnal (90% - 100% of observations recorded at night), mostly nocturnal (71% - 89% of observations recorded at night), diurnal (0% - 10% of observations recorded at night), and mostly diurnal (11% - 29% of observations recorded at night). When around 50% of observations occurred at the crepuscular period the species was classified as crepuscular. Finally, when the species was not crepuscular and had 30% - 70% of observations recorded at night, the species was classified as cathemeral (Cox and Gaston, 2024). A similar methodology was used to estimate the response to the lunar cycle. Kernel density functions were estimated from nighttime records, in this instance considering the lunar cycle instead of the time of day as a circular variable. As before, the information regarding the lunar cycle was obtained using the R package "suncalc" (Thieurmel and Elmarhraoui, 2022), which expresses the lunar cycle as values ranging from 0 to 1, with 0 and 1 indicating a new moon and 0.5 indicating a full moon. A significant response to the lunar cycle was estimated by Rao's spacing test, which indicates whether records are homogeneously distributed (Jammalamadaka and SenGupta, 2001). As before, the package "circular" implemented in R was used to perform this test (Agostinelli and Lund, 2023). All statistical analyses were performed in R 4.4.0 (R Core Team, 2023), using an alpha-level = 0.05.

3. Results

Overall, *C. chinchilla* was observed 3747 times during the entire sampling period, with a detection rate of 0.275 records per trap-night. The detection rate in the summer season was slightly lower than in winter, with 0.239 and 0.345 records per trap-night, respectively. The short-tailed chinchilla was detected mainly at night, with 94.1% of records occurring during this time period. The percentage of nocturnal activity of this species remained broadly similar in the two seasons, with 92.3% of summer records occurring at night and 96.3% in the winter season (Fig. 2). Therefore, as $>$ 90% of chinchilla records occur at night in both seasons, this species can confidently be classified as nocturnal.

Lycalopex culpaeus was observed a total of 984 times during the entire sampling period, with an annual detection rate of 0.072 records per trap-night. Figures were broadly similar during the summer and winter seasons, with 0.066 and 0.083 records per trap-night, respectively. When analyzed on an annual basis, foxes exhibited the highest level of activity during the daytime. Sixty-one percent of the records occurred during this period, while 28.5% occurred at night. The remaining records occurred at the crepuscular period. In the summer, 67.1% of records were obtained during the day and 21.9% at night; however, daytime activity decreased to 52.5% in winter, accompanied by an increase in nighttime activity to 38.6% (Fig. 2). Considering the distribution of records, culpeo foxes can be classified as mostly diurnal at the annual scale. Seasonally, they can be classified as mostly diurnal in summer and cathemeral in winter.

The assessment of activity patterns on an annual basis revealed a low Δ_4- overlap coefficient (CI) = 0.343 (0.315–0.370) between species, indicating that chinchillas and foxes presented different patterns of daily activity (Watson-Wheeler test, W = 1121.9, $p < 0.001$, Fig. 3). Likewise, the two species presented a low Δ_4 - value in their activity patterns during the summer season (Δ_4 - overlap coefficient (CI) = 0.299 (0.264–0.3315); W = 702.4, $p < 0.001$, Fig. 4A). In the winter, the Δ_4 - overlap coefficient was still low and significant (Δ_4 (IC) = 0.365 (0.325–0.408); W = 43489, $p < 0.001$, Fig. 4B). Regarding within-species comparison between seasons (see Supplementary Information, Appendix II), the activity pattern of the short-tailed chinchilla differed between seasons (W = 29.5, $p < 0.001$), showing a flattened pattern of activity in the winter as compared to the summer season (Fig. A, Appendix II). Like chinchillas, the activity pattern of the culpeo fox differed between summer and winter seasons (W = 82.2, $p < 0.001$) (Fig. B, Appendix II).

Both chinchillas and culpeo foxes respond significantly to the lunar cycle (*C. chinchilla*: Rao = 324.5, $p < 0.01$; *L. culpaeus*: Rao = 303.1, $p < 0.01$, Fig. 5). Qualitatively, culpeo foxes exhibit higher activity during the intermediate phases of the cycle, specifically during the first and third quarters. Similarly, chinchillas exhibit two minor activity peaks during the first and third quarters, though they are less pronounced than those of culpeo foxes (Fig. 5). Culpeo foxes exhibit activity density peaks of 0.148 versus a mean activity density of 0.0416, while short-tailed chinchillas exhibit peaks of 0.0583 versus a mean activity density of 0.0417.

4. Discussion

In this study, we document for the first time the activity pattern and response to the lunar cycle of the short-tailed chinchilla (*Chinchilla chinchilla*). In general, the activity pattern of *C. chinchilla* follows the general pattern of nocturnal activity reported for the order Rodentia by Roll et al. (2006). However, it is important to note that the family Chinchillidae was not included in said study. The observation that *C. chinchilla* is currently endangered suggests that information on activity rhythms or other aspects of its natural history may be pivotal for future management initiatives on this species. For example, the activity pattern described in this study may be used as background knowledge for the effectiveness of management actions upon chinchilla populations (e.g., relocation plans) and also as a baseline to evaluate the putative response of the species to anthropogenic disturbance (Caravaggi et al., 2017).

Regarding *L. culpaeus*, the results indicate that the studied population in the years 2017–2019 behaved as a cathemeral species and

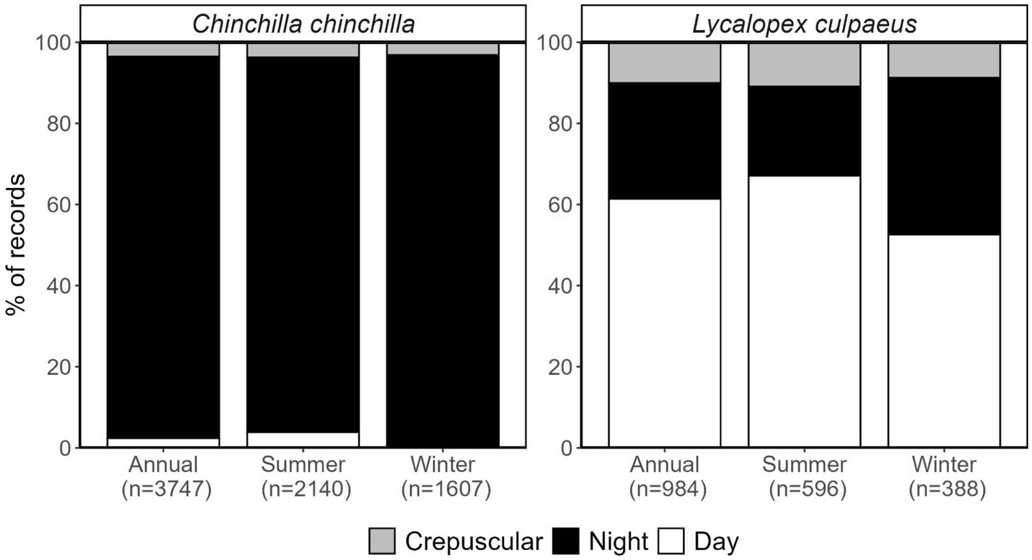

Fig. 2. Distribution of records of *Chinchilla chinchilla* and *Lycalopex culpaeus* along day on an annual and seasonal scale.

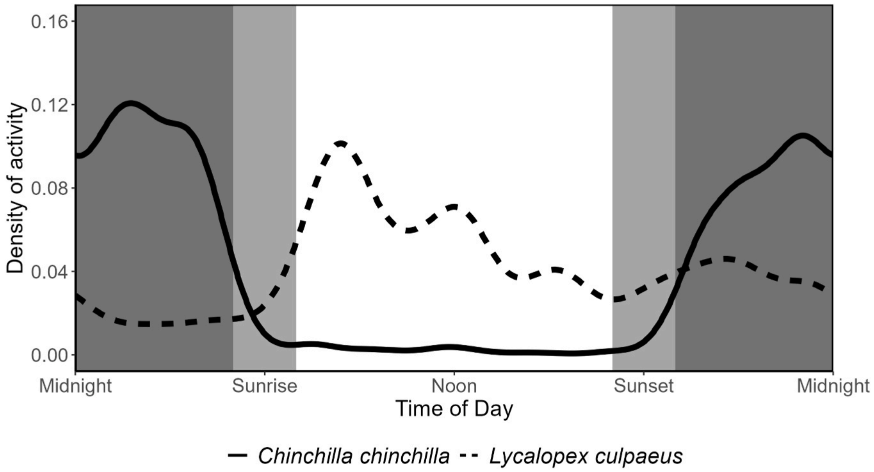

Fig. 3. Daily activity patterns of *Chinchilla chinchilla* (solid line) and *Lycalopex culpaeus* (dashed line). Dark gray, light gray, and white areas indicate night, crepuscular, and daytime periods, respectively. Overlap coefficient Δ_4 (IC) $= 0.342$ (0.315–0.370), Watson-Wheeler test, W $= 1120.9$, $p < 0.001$.

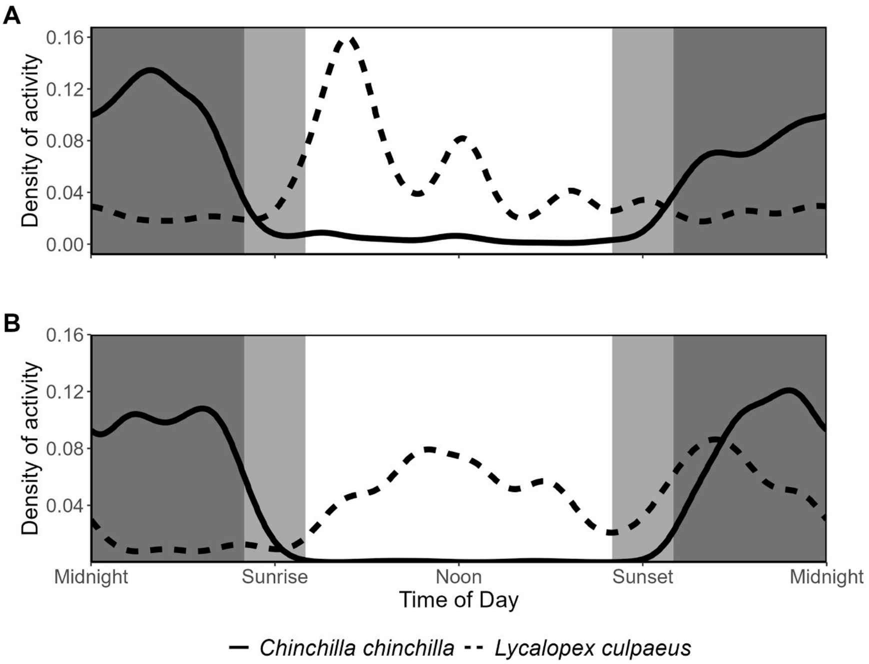

Fig. 4. Seasonal variation of the daily activity patterns of *Chinchilla chinchilla* (solid lines) and *Lycalopex culpaeus* (dashed lines). Dark gray, light gray, and white areas indicate night, crepuscular, and daytime periods, respectively. A: Summer season: overlap Δ_4 - coefficient (CI) $= 0.299$ (0.263–0.335), W $= 702.4$, $p < 0.001$. B: Winter season: overlap Δ_4 - coefficient (IC) $= 0.365$ (0.324–0.408), W $= 433.8$, $p < 0.001$.

more diurnal than nocturnal. This result contrasts with other studies that report the culpeo fox as a predominantly nocturnal species (e. g., Lucherini et al., 2009; Monteverde and Piudo, 2011; Gantchoff and Belant, 2016). For instance, Gantchoff and Belant (2016) suggested that the nocturnal activity of the culpeo fox was mainly attributable to the high temporal synchrony with its main prey in the area, the nocturnal European hare (*Lepus europeaus*) (temporal overlap $\Delta_1 = 0.79$). Therefore, they invoked prey availability as the most important factor to account for the activity pattern of the culpeo fox. A similar result was reached by Monteverde and Piudo (2011), as culpeo foxes were nocturnal, like their potential prey. At first glance, this discrepancy with our results could be due to climatic factors. However, the studies by Gantchoff and Belant (2016) and Monteverde and Piudo (2011) were conducted in Argentinian Patagonia, an area with different climatic conditions than our study site. Specifically, sites in Patagonia occur at lower elevations and have higher average annual rainfall and temperatures than our study site. Gantchoff and Belant (2016) reported altitudes between 700 and 1700 m with annual precipitation ranging from 600 to 1200 millimeters. Monteverde and Piudo (2011) recorded

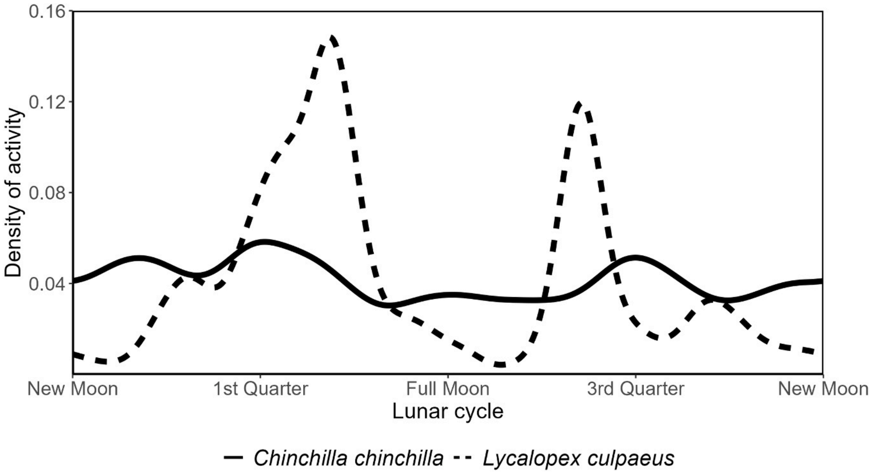

Fig. 5. Response to the lunar cycle of *Chinchilla chinchilla* (solid line) and *Lycalopex culpaeus* (dashed line). Watson-Wheeler test, W = 338, $p < 0.001$.

temperatures ranging from 4.1°C in winter to 21.1°C in summer with average annual precipitation reaching 2500 millimeters. Notwithstanding, the study by Lucherini et al. (2009), carried out in the geographic intersection of northern Chile, Argentina, and southern Bolivia, which have broadly similar climate conditions to our study, showed results consistent with those of Gantchoff and Belant (2016) and Monteverde and Piudo (2011). These findings suggest that climatic factors do not explain the differences observed. Consequently, it seems unlikely that the activity pattern of the culpeo fox is determined by climatic conditions. One possibility is that the cathemeral and mostly diurnal activity pattern shown by foxes in this study represents a behavioural response aimed at increasing the chance of finding potential prey rather than a response to local climatic conditions. If so, why do foxes have such a low activity time overlap with chinchillas? *C. chinchilla* is likely a suboptimal prey species for *L. culpaeus*, in part because of their low density in the study site. Additional data collected in this research (Minera GoldFields Salares Norte SpA, 2018a) indicate that chinchilla densities are in the range of 1.0–1.5 individuals/ha, which suggests that other diurnal species, such as the rodent *A. andinus*, may play an important role in the diet of culpeo foxes. It is reasonable that a generalist-opportunistic predator like *L. culpaeus* does not depend uniquely on chinchillas as staple prey but includes further items in its diet according to their availability in the environment (e.g., Walker et al., 2007; Lagos et al., 2023). Overall, these results suggest that the activity pattern of *L. culpaeus* is flexible and potentially shaped by prey availability rather than by climatic constraints alone. Therefore, based on these results, *L. culpaeus* can be classified as a facultative cathemeral species.

Regarding seasonality, *L. culpaeus* had a lower activity in the winter months, as revealed by the lower proportion of diurnal records than in the summer season (52.5% and 67.1% of the records, respectively). It is likely that the shorter daylight in winter as compared to the summer season accounts for this pattern, with individuals extending their activities into nighttime to meet their energetic demands, as depicted in Fig. 4B. Overall, these findings provide support to the hypothesis that photoperiod plays a significant role in the seasonal regulation of species' circadian rhythms (Halle, 2000). Regarding the response to the lunar cycle, short-tailed chinchillas and culpeo foxes did not follow the patterns expected under Prugh and Golden (2014)'s hypotheses. On the one hand, the predation risk hypothesis predicts that prey species are expected to avoid the brightest phase of the lunar cycle as they would face higher predation risks. Chinchillas, however, were active at all lunar phases, showing only a slight, but not significant, decrease in activity at the full moon phase. On the other hand, the visual acuity hypothesis predicts that predator species are expected to concentrate their activity on full moon phases. However, culpeo foxes avoided full moon nights, being mostly active at nights of intermediate luminosity. Although each species responded significantly to the lunar cycle, luminosity appears to be an uninformative variable in the predator-prey relationship between the two species. It does not signal predation risk to short-tailed chinchillas nor provide information about predation benefits to culpeo foxes.

Even though the activity patterns and response to the lunar cycle of chinchillas and foxes described in this study seem to be clear, some methodological caveats need to be considered. First, because the sampling methodology was designed with the short-tailed chinchilla as the focal species, information on the activity of culpeo foxes is restricted to those that circulate around areas inhabited by chinchillas, implying that activity may vary to some extent when using truly spatial random sampling. However, as culpeo foxes often have low population densities (< 1 individual/km^2) with broad ranges of mobility, reaching up to 1000 km^2 in northern Chile (Lagos et al., 2023), deviations from spatially random sampling are unlikely to change substantially the results obtained in this study. Second, studies estimating response to the lunar cycle present inherent limitations that are not present when studying daily activity patterns. For example, the response to the lunar cycle may depend not solely on vision but on other senses, such as hearing or smell (Botts et al., 2020). As there is no objective way to evaluate the overall sensorial capacity of species in the field, studies relying mostly on vision run the risk of oversimplification, as the factors determining the activity of species during lunar phases are probably by far more complex than often assumed.

5. Conclusion

In this study we show that the threatened short-tailed chinchilla (*C. chinchilla*) presents a predominantly nocturnal activity pattern that is asynchronous with the mostly activity rhythm of the culpeo fox (*L. culpaeus*). This result contrasts with previous studies that characterize this species as predominantly nocturnal. Both species responded to the lunar cycle; however, their responses did not align with expectations from previous studies. For example, chinchillas did not avoid the brightest phase of the lunar cycle, as predicted by the predation risk hypothesis, and foxes were not predominantly active during the brightest full moon periods, as expected from the visual acuity hypothesis, being mostly active at nights of intermediate luminosity. These discrepancies can be tentatively explained by: (i) the generalist feeding behaviour of *C. culpaeus*, (ii) the suboptimal prey status of *C. chinchilla* in the environment, and (iii) the occurrence of alternative prey that confer higher energetic benefits for *C. culpaeus*.

Author contribution

M.S-S, C.B-M and R.M. conceived the idea, M.S-S analyzed the data and wrote the first version of the manuscript; R.M. and C.B-M supervised the work and contributed to writing and editions; FN, AS, and IS curated the original data and contributed critically to preliminary drafts. All authors gave their final approval to the manuscript for publication.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2026.e04249.

Data availability

Data will be made available on request.

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