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SHORT COMMUNICATION

Interannual activity pattern of the European hare (*Lepus europaeus*) in the coastal foothills of southern Chile

Patrón de actividad interanual de la liebre europea (*Lepus europaeus*) en la Cordillera de la Costa del sur de Chile

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ABSTRACT

The European hare *Lepus europaeus* is an exotic mammal with a wide distribution potential, suggesting the presence of highly flexible anti-predation mechanisms. Through the use of camera traps, the activity pattern of this species was studied for two years at a site of the coastal foothills in southern Chile. During the second year it was observed that the hare maintained a non-random pattern of activity in relation to the light periods of the day. This fact suggests the adoption of anti-predator strategies, considering the variation in the presence of their predators between both years. The effect of predation on the observed temporal patterns is discussed, as well as its population fluctuations in the long term, to describe the role of this lagomorph in this type of ecosystem.

Keywords: anthropized landscape, camera-traps, invasive species, population fluctuations, predation.

RESUMEN

La liebre europea *Lepus europaeus* es un mamífero exótico con un amplio potencial de distribución, lo que sugiere la presencia de mecanismos anti-depredación de gran flexibilidad. Mediante el uso de trampas-cámara, se estudió durante dos años el patrón de actividad de esta especie en un sitio precordillerano del sur de Chile. Durante el segundo año se observó que la liebre mantuvo un patrón no aleatorio de actividad en relación a los periodos de luz del día. Este hecho sugiere la adopción de estrategias anti-depredador, considerando la variación en la presencia de sus depredadores entre ambos años. Se discute acerca del efecto de la depredación sobre los patrones temporales observados, así como de sus fluctuaciones poblaciones en el largo plazo, para describir el rol de este lagomorfo en este tipo de ecosistemas.

Palabras clave: depredación, especie invasora, fluctuación poblacional, paisaje antropizado, trampas-cámara.

The European hare (*Lepus europaeus*) is a lagomorph of Eurasian origin (Chapman & Flux 1990). With herbivorous habits, it feeds mainly on grasses and herbs, while it uses open environments, with scattered shrubs (Chapman & Flux 1990). Due to its origin and ecological flexibility, it is considered an invasive species, since it has had a wide expansion to various regions, including South America (Jaksic 2023). This species has had a progressive irruption into different ecosystems in Chile (Jaksic 2023), affecting the structure of the local communities. It has become a

frequent prey for Chilean predators in agricultural and peri-urban environments (Zúñiga *et al.* 2021; Zúñiga *et al.* 2022), which suggests behavioral changes in the predator's prey preferences (Novaro *et al.* 2000). Despite its great adaptive capacity to different ecosystems, there is little information related to changes in anti-predation behaviors, which is especially important given its status as an exotic invading species (Wu *et al.* 2018). The activity pattern is an issue of special relevance in predator-prey dynamics, due to the continuous pressure between these groups mediated by natural selection (Wu *et al.* 2018), thus leading their temporary decoupling of the prey from their predators.

In Chile, although the activity pattern of hares has been addressed in disturbed environments (Zúñiga & Sandoval 2020), there are gaps regarding this lagomorph in other ecological contexts, which may be an indicator of the degree of interaction both with local predators, and other species in their own herbivorous guild (Akababa & Ayaş 2012). The aim of this study is to document the pattern of activity and the detection rate of the European hare in a foothills landscape of southern Chile, over two years. Our hypothesis about the adaptive variations in the pattern of activity between these periods is tested.

The present study was carried out in the Hueyusca area (40°55'44'' S - 73°31'51'' W), a pre-mountainous locality of the Coastal Ranges of southern Chile. It has an elevation of 127 masl, and the climate is temperate rainy, characterized by moderate temperatures, varying from a mean of 7.5°C in the coldest season to a mean of 22°C in the warmest season (Koeppen *et al.* 2011). The forest formation is of the Magellanic forest type of *Nothofagus obliqua* (Mosyakin *et al.* 2019), in combination with Chilean laurel (*Laurelia sempervirens*), Dombey's beech (*Nothofagus dombeyi*) and ulmo (*Eucryphia cordifolia*). The landscape is made up of mosaics of *Pinus* sp. and Eucal*yptus* sp. plantations, as well as anthropogenically generated shrublands, which are used for livestock fodder.

For the detection of individuals and as part of a study on a larger spatial scale (García-Solís *et al.* 2022), camera trap equipment was used, which consisted of photographic devices that were activated by the movement of animals as they move in front of their sensors (Kays & Slauson 2008), thus allowing their unequivocal identification. During 2016 and 2017, we operated nine Bushnell Trophy Cam traps in the study area, for which secondary trails were used, following a random spatial pattern. The equipment was installed on tree trunks, at an approximate height of 70 cm from the ground, and at a distance of 3 km from each other (García-Solís *et al.* 2022). These devices were reviewed monthly, to check batteries and change memory cards. For analytical purposes, a time horizon of one hour was considered for independent photographic events (Lucherini *et al.* 2009).

The analysis of the activity pattern of *L. europaeus* was carried out through the accumulation of independent photographic records obtained every 1 hour, to establish the frequency distribution in the 24-hour cycle that includes an entire day (Zúñiga *et al.* 2017). Probability density functions were generated for each year (2016 and 2017). Subsequently, the overlap coefficient (Δ) was calculated, which is obtained by evaluating the area under the curve formed by determining the minimum between the two density functions. To carry out this process, the overlapEst function from the 'overlap' package in R was used (Ridout & Linkie 2009; Meredith & Ridout 2021). The Δ1 estimator was chosen because it is suitable for smaller data sets (Ridout & Linkie 2009). In order to estimate the 95% confidence interval of Δ, 5000 bootstrap samples were generated from the data distributions for each year. To evaluate the significance of the differences between the curves, Watson's U2 statistic was applied, using the watson.two function of the 'CircStats' R package (Agostinelli & Lund 2018). This test analyzes the probability that two circular data sets come from the same population, allowing us to determine whether they are homogeneous or not (Jammalamadaka *et al.* 2021). In parallel, the periods of the day used by the hare were compared based on light exposure, which were delimited as follows: dawn (6:00-7:59), day (8:00-17:59), dusk (18:00-19:59), and night (20:00-5:59; Fedriani 1997). For this purpose, goodness-of-fit tests (Sokal & Rohlf 1995) were used, where the expected frequency was the duration of each period. To estimate the detection rate of hare, the number of independent records obtained per 100 days of camera trapping was calculated, which has been previously used as a proxy for abundance (Zúñiga & Jiménez 2018). Statistical significance of this parameter was calculated by means of Mann-Whitney paired tests (Sokal & Rohlf 1995), using the abundance of records of the species/15 days of trapping.

A total of 80 records was obtained (48 in 2016 and 32 in 2017), with a sampling effort of 5,823 camera-nights (2,637 in the first year and 3,186 in the second year), which meant a detection rate of 20.16 records/ traps/100 days the first year, and 11.22 records/traps/100 days the second year (1.82 and 1.00, respectively, based on sampling effort). No significant differences were found in the records obtained in these periods (Mann-Whitney test, U=182.5, p=0.84).

The hare showed two peaks of activity throughout the day in the first year of the study centered at 7:00 and 19:00 h (Fig. 1), while in the second year it displayed lower counts but during these same periods. However, no statistical differences were observed when compared to each other

(Watson's Two-Sample Test of Homogeneity U2 = 0.0963; p= 0.187).

Regarding the use of time linked to availability of light, in the first year a random pattern of hare activity was obtained (Fig. 2; $\chi^2 = 5.54$, p = 0.1353, d.f. = 3). This situation changed in the second year, where significant differences were observed, due to a greater concentration of hare during the night period ($\chi^2 = 14.5$, p = 0.023, d.f. = 3).

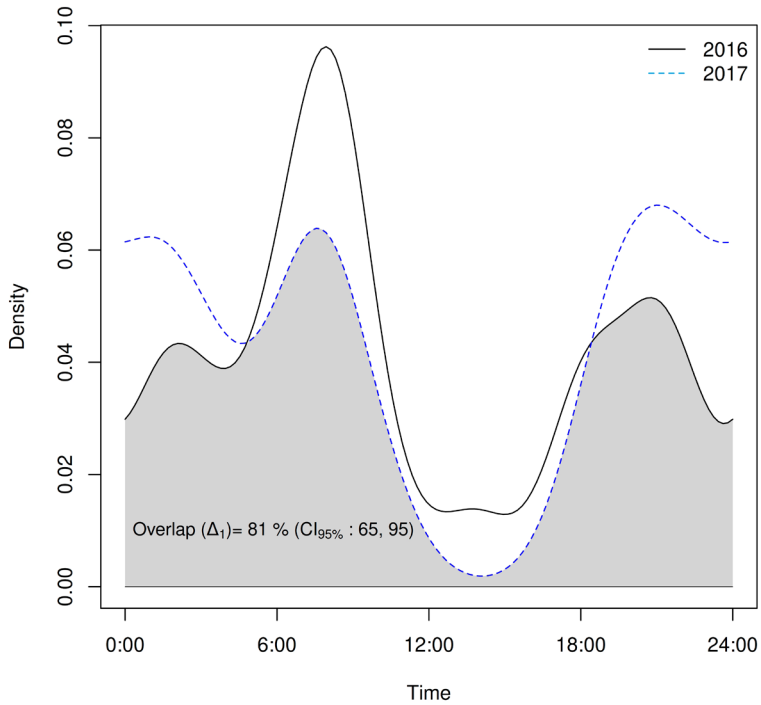

Figure 1. Activity time of European hare (*Lepus europaeus*) for the two years of study (2016 and 2017) in southern Chile. / Tiempo de actividad de la liebre europea (*Lepus europaeus*) para los dos años de estudio (2016 y 2017) en el sur de Chile.

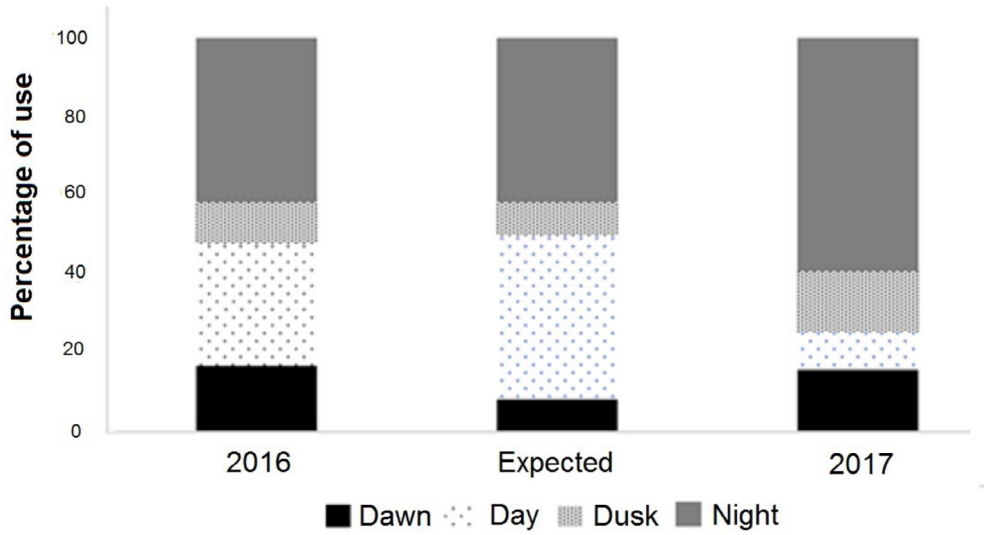

Figure 2. Proportion of observed and expected activity of European hare (*Lepus europaeus*) in the two years of study (2016 and 2017), according to light periods in a 24-hour cycle in southern Chile. / Proporción de actividad observada y esperada de la liebre europea (*Lepus europaeus*) en los dos años de estudio (2016 y 2017), según periodos de luz en un ciclo de 24 horas en el sur de Chile.

The detection rate of *L. europaeus* was lower than that reported in burned forests of central-southern Chile (Zúñiga & Sandoval 2020), which suggests that the absence of large-scale disturbances (such as fires) in the study area may have kept hare abundance at low values. This situation could be explained by predator control, which seems persistent in the study area due to the constant recordings of such species (García-Solís *et al.* unpublished data). This is different to findings in burned ecosystems, where a low abundance of prey results in greater efforts by predators (Zúñiga *et al.* 2020; Zúñiga *et al.* 2021), with low detection rates. On the other hand, the absence of statistical significance of the records between years must be considered with caution, because hare display interannual fluctuations in abundance due to interactions of endogenous factors and predation (Wasilewski 1991; Panek 2013), which regulate their population size. Despite this, it should be important in future monitoring to combine camera trap records with other signs of activity, such as feces, which have been previously used as indicators of abundance between counting periods (Langbein *et al.* 1999).

The activity pattern of hare observed in both years differs from that reported in the foothills of central-southern Chile (Zúñiga & Sandoval 2020), suggesting that predation pressure may have affected their evasion behaviors, based on different contexts of associated species. Here, it is important to highlight the variation in abundances between the two studies regarding the presence of native predators, such as chilla foxes (*Lycalopex griseus*) and puma (*Puma concolor*), and the one exotic predator, the domestic dog (*Canis lupus familiaris*) (García-Solís, unpublished data). The first two are predators of *L. europaeus* (Zúñiga & Muñoz-Pedreros 2014; Zúñiga *et al.* 2021), while the latter may be less important. In the first year, the abundances of both native predators were lower in comparison to dogs. This suggests a type of indirect interaction (Morin 2011), which could be explained by the ability of domestic dogs to displace chilla foxes (Gálvez *et al.* 2021), thus affecting their capture rate of hares. In the second year, this pattern was reversed, with chilla foxes and pumas presenting greater abundance than dogs (García-Solís, unpublished data), which could relax the interference of the latter and therefore generate greater predation pressure on hares by native predators. To this we must add that given the nocturnal activity of the chilla fox (Gálvez *et al.* 2021), there should be greater pressure from this native canid. Despite the above, it is necessary to quantify the predation rate by local carnivores, to establish the relationship between their presence and eventual anti-predation mechanisms by hares.

In conclusion, *L. europaeus* presented a more diurnal activity pattern when predation pressure was lower, which was largely modulated by the presence of domestic dogs, which exerted strong interference on native predators.

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