

Activity patterns of mammals in commercial plantations of South-central Chile

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Abstract

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Commercial plantations have been recognized worldwide as “green deserts” due to their low biological diversity. This fact is explained by the low availability of resources, which would result in a change in the interactions between species. While changes in occupancy among species in plantations have been documented, little is known about their species’ temporal ecology, as competitors, predators or prey. We studied the activity patterns of the mammals of *Pinus radiata* plantations. We used photo-trapping to explore their temporal patterns and the overlap among species. Five native and three exotic mammal species were detected, as well as humans. The broader temporal niche breadth was shown by pudu deer (a dwarf deer but still the largest native prey) and the domestic dog. While the temporal overlap was high among similar-sized species, they differed in their use of space. Among prey, birds were the most abundant, and their activity patterns were essentially diurnal. Ecological aspects of the species are discussed, both in relation to the temporal flexibility of the species and the structural complexity of the study area.

Keywords

avoidance, camera traps, native and exotic mammals, overlap, prey, temporal flexibility

Introduction

Loss of natural habitats is one of the main threats to biodiversity globally (HANSKI, 2011), due to the multiple mechanisms that are disrupted for the persistence of different taxa. This pattern of loss is mainly related to the change in land use for productive purposes (XIE et al., 2022), whose increase in surface area have increased progressively over time (MATTHEWS et al., 2004), aimed at the production of raw plantations for human use (CARLE et al., 2002). Moreover, in regard to biodiversity, forest plantations have been recognized as “green deserts” due to the homogeni-

zation of their vegetational structure and low biodiversity (HORÁK et al., 2019), which limits their use by native species. This forces animal species to use new habitats in a limited extent, requiring them to adapt to a novel environments that differ dramatically compared to their native habitats (CHRISTIAN et al., 1998; CROOKS, 2002). The result might be an impoverished biota due to a limited biological suitability.

The Chilean native forest is characterized by its isolation from the rest of the Neotropics, resulting in low species richness but a high percentage of endemism (MELLA et al., 2002), which affects the ecological relation-

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spaced 350 m apart on average. This distance was based on the species' home range (CARBONE and GITTLEMAN, 2002; IRIARTE and JAKSIC, 2012), which allowed for spatial independence of the records. For the purposes of temporal independence, records whose time difference with the following image was greater than or equal to 60 min were considered (LUCHERINI et al., 2009).

To estimate the activity pattern of the species present, the accumulation of independent records obtained for each of these was carried out, thus generating a frequency distribution based around the 24-hour cycle comprising a day (ZÚÑIGA et al., 2017). The temporal extent of the species was calculated using the niche diversity index (LEVINS, 1968), whose value fluctuates between 1 and 24, which is the number of hours comprising the day. The standard deviation of this temporal niche breadth was calculated using the Jackknife procedure (JAKSIC and MEDEL, 1987). Temporal overlap among species (Δ) was estimated through the curve formed by the minimum value between each pair of density functions, which was carried out using the statistical package `overlapEst` from the 'overlap' package in R (RIDOUT and LINKIE, 2009; MEREDITH and RIDOUT, 2021). The $\Delta 1$ estimator was used because it is best suited for small data sets (RIDOUT and LINKIE, 2009). 95% confidence intervals were generated for the distribution of data for each species. To obtain the significance of the difference between curves coming from each species, Watson's U^2 statistics were used, using the `watson.two` function of the R package 'CircStats' (AGOSTINELLI and LUND, 2018). This test analyzes the probability that two circular type data do or do not belong to the same population (JAMMALAMADAKA et al., 2021). To establish the temporal relationship of species with their potential prey, the overlap between pairs of species was compared using the same procedure mentioned above (ZÚÑIGA et al., 2025). In this case, to avoid the occurrence of type I errors as a consequence of multiple comparisons, the Bonferroni correction was

used to determine the statistical significance of each pair of species analyzed (HOLM, 1979).

The proportion of the period of the day in which the species are active was calculated, which are defined in categories based on the availability of light. For this purpose, four intervals were used: dawn (06:00–07:59); day (08:00–17:59); dusk (18:00–19:59); and night (20:00–05:59; FEDRIANI, 1997). The statistical significance of these comparisons was obtained by goodness-of-fit tests (SOKAL and ROHLF, 1995), where the expected frequency was established according to the duration of each period. To establish the relationship of species in a spatial framework, a nonparametric multidimensional analysis of the records obtained in each chamber was performed (CLARKE et al., 2014), and their interaction was assessed using a permutational analysis of variance (QUINN and KEOUGH, 2002).

Results

With a sampling effort of 3,655 traps night⁻¹, five native species were recorded: cougar (*Puma concolor*; n = 15 recordings), culpeo fox (*Lycalopex culpaeus*; n = 38), kodkod (*Leopardus guigna*; n = 26), hog-nosed skunk (*Conepatus chinga*; n = 8), and pudu deer (*Pudu puda*; n = 35). In addition, domestic dog (*Canis lupus familiaris*; n = 72) and the brown hare (*Lepus europaeus*; n = 7) were found. In the case of hog-nosed skunk and hares, due to their low numbers, they were not included in the analyses. Humans were recorded circulating in a very restricted area, which corresponds to the entrance of the study area (n = 87). On the other hand, specimens of the black rat *Rattus rattus* and indeterminate cricetids were detected, which were classified as "rodents" (n = 21). Likewise, the species Chilean pigeon *Patagioenas araucana*, Austral thrush *Turdus falcklandii*, Black-throated huet-huet *Pterotochos tarnii* and Chucao tapaculo *Scelorchilus rubecula* were recorded and

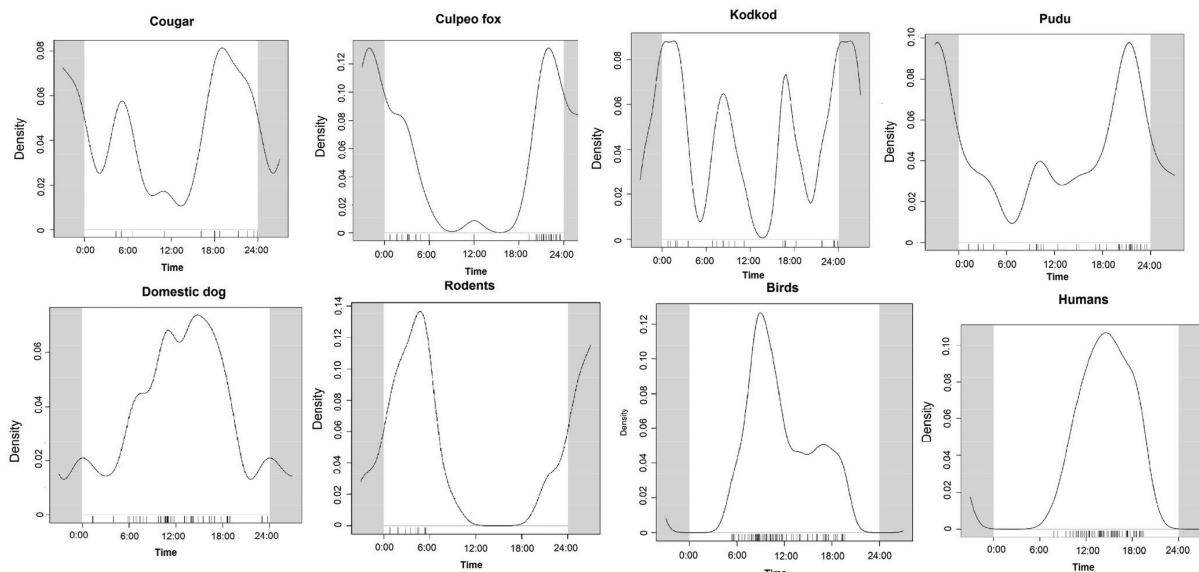


Fig. 2. Activity patterns of the species recorded in the study area.

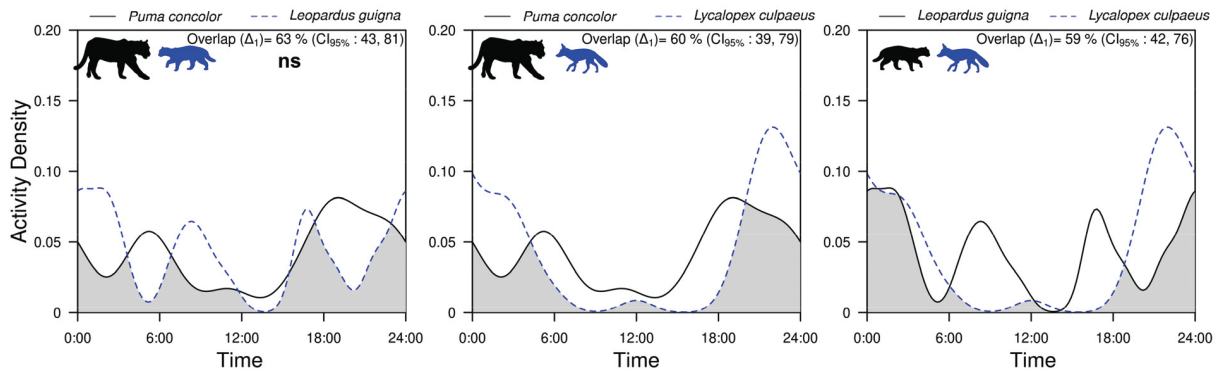


Fig. 3. Overlap in the temporal pattern for the native carnivores recorded (ns = not significant).

classified as “birds” ($n = 79$). Both groups were considered as potential prey (ZÚÑIGA et al., 2025).

The activity pattern varied among the species, with kodkod having 4 peaks throughout the day, and cougar 3 peaks (Fig. 2), while the culpeo fox, pudu and rodents had only two. Regarding the temporal extent of the species, it was observed that pudu and domestic dog presented the greatest temporal niche breadth ($\beta = 14.08 \pm 1.29$; $\beta = 14.20 \pm 0.070$, respectively), followed by birds ($\beta = 11.61 \pm 0.086$). Intermediate values were obtained by kodkod ($\beta = 10.96 \pm 0.97$), culpeo fox and cougar ($\beta = 9.70 \pm 2.17$; $\beta = 9 \pm 1.10$, respectively). Rodents and humans showed the lowest values ($\beta = 7.00 \pm 0.14$; $\beta = 5.23 \pm 0.18$, respectively).

Regarding to the temporal overlap among species, it was found that cougar presented varied values with the rest of the carnivores, highlighting its interaction with culpeo fox ($U^2 = 0.25$; $p = 0.014$; Fig. 3), with an interaction of intermediate magnitude with birds and humans ($U^2 = 0.55$, $p = 0.001$ in both cases, Fig. 4). For culpeo fox, an intermediate overlap was obtained with kodkod ($U^2 = 0.22$; $p = 0.024$; Fig. 3), and low interaction for dogs, humans, and birds ($U^2 = 1.34$, $U^2 = 2.06$, $U^2 = 1.89$, respectively; $p = 0.001$ in all cases, Fig. 4). In the case of kodkod, an intermediate overlap with birds was observed ($U^2 = 0.53$, $p = 0.001$; Fig. 4), and low overlap with humans ($U^2 = 0.88$; $p = 0.001$). It is also important to note the high temporal overlap that the dogs had with pudu ($\Delta = 0.60$; confidence intervals_{95%}: 0.44–0.75; $U^2 = 0.46$; $p = 0.001$).

When the activity of the species was analyzed according to the proportion of the day used, it was found that in the case of cougars, culpeo foxes and rodents, the pattern was predominantly nocturnal ($\chi^2 = 9.97$, $p < 0.0001$; $\chi^2 = 33.19$, $p < 0.0001$, $\chi^2 = 25.32$, $p < 0.0001$, respectively; Fig. 5). Kodkod and pudu showed a random pattern ($\chi^2 = 0.44$, $p = 0.93$; $\chi^2 = 5.39$, $p = 0.14$, respectively), while birds, dogs and humans presented a diurnal type pattern ($\chi^2 = 46.09$, $p < 0.0001$; $\chi^2 = 16.36$, $p = 0.001$; $\chi^2 = 82.45$, $p < 0.0001$, respectively). Degrees of freedom in all cases: 3). In relation to the use of space, it was found that the species differed in their distribution throughout the study area (Permanova test, Pseudo-F = 5.84, $p = 0.002$). This situation was evident in the ordination analysis, where the species were placed in groups relatively differentiated

from each other (Fig. 6).

Discussion

The mammal detection rate was lower than reported for continuous forest (ZÚÑIGA et al., 2017; GÁLVEZ et al., 2021), highlighting the structural limitation of plantations to support mammal populations. This fact is supported mainly by the low rate of occurrence of prey, mainly rodents, which are found in lower diversity in relation to the native forest (ZÚÑIGA et al., 2021a). Currently, it has been proposed that plantations could facilitate the occurrence of wildlife, to the extent that they add structural complexity to the dominant plant species, mainly in the form of understory (RAMÍREZ and SIMONETTI, 2012). This structural complexity allows the appearance of multiple spatial niches available in a three-dimensional environment, for use by species of different taxa (AUGUST, 1983). This situation could be applicable to the case of the study area, where the age of the plantation promotes the development of this microhabitat cover. Moreover, this scenario has only been evidenced for birds, which is consistent with what has been obtained in plantations near protected areas (BARCELÓ et al., 2021; ZÚÑIGA et al., 2021b), a fact that should be evaluated to consider possible migrations between patches.

The activity pattern of cougar observed in the study area showed a similarity in relation to anthropized forest landscapes (GARCÍA-SOLÍS et al., 2025; ZÚÑIGA et al., 2020). This scenario can be explained in a first instance by the weak temporal coupling with prey, which suggests a lack of selectivity for any specific group, with the consequent adoption of opportunistic behavior in their diet (JAKSIC, 1989). This should adjust to energy needs, prioritizing capture of medium to large-sized prey (IRIARTE et al., 1990). In the case of birds, despite their intermediate temporal overlap, they are not prey for cougar (RAU and JIMÉNEZ, 2002), with a consequent absence of predatory selectivity. By other hand, the human presence in the study area could affect the daily activity of cougar as part of an avoidance behaviour (PAVIOLO et al., 2009), increasing their proportion of nocturnal recordings and affecting their movements across the landscape (ALLDREDGE et al.,

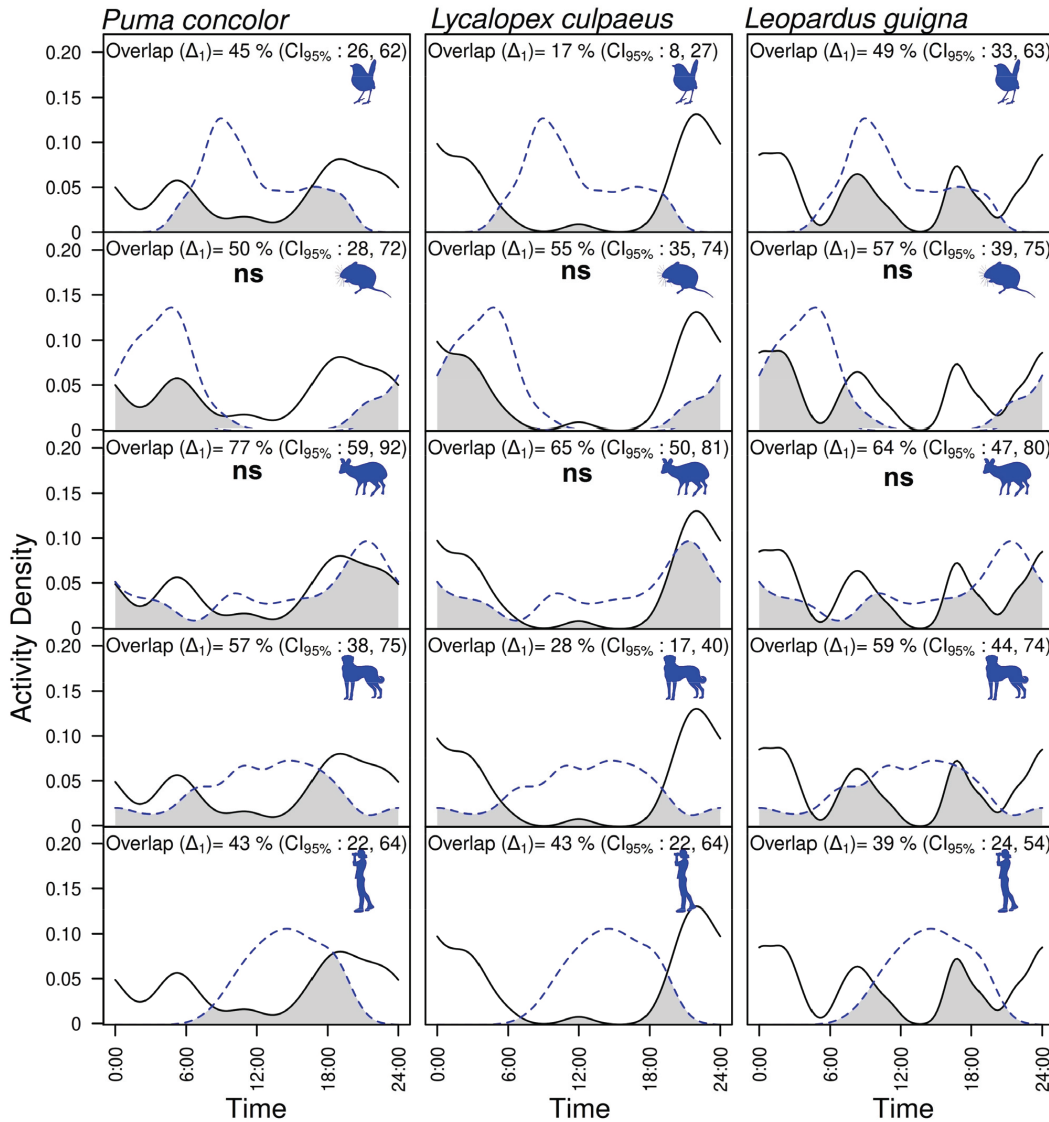


Fig. 4. Overlap between native predators and their potential prey (dashed lines), humans and dogs (ns = not significant).

2019).

The activity pattern of the culpeo fox is similar to that reported in native forest (ZÚÑIGA et al., 2017), where it predominantly uses the nocturnal period. Likewise, its high overlap with cougar (0.60) suggests the need for compensation through spatial avoiding to enable their co-existence. This has been documented in the same type of habitat previously mentioned (ZÚÑIGA et al., 2017), and reflected in the present study through the ordination graph. Their low temporal overlap with dog (0.28) is similar to that recorded for the congeneric chilla fox *Lycalopex griseus* in anthropized environments (SILVA-RODRÍGUEZ et al., 2010a; GARCÍA-SOLÍS et al., 2025), highlighting the strong interference effect exerted by this exotic canid. This situation would partially explain their low overlap with birds, whose activity pattern is essentially diurnal. Moreover, the interference caused by dogs would affect the foxes' hunting pattern towards rodents, despite their recognized consumption (IRIARTE and JAKSIC 2012), which is reflected in the absence of statistical significance. On the other hand, although their lack of statistical significance

with pudu, the overlap with the pudu suggests a capture potential, which is consistent with reports of predation on larger artiodactyls (NOVARO et al., 2009).

The kodkod exhibited a pattern of activity partially different from that reported in continuous and anthropized forests (ZÚÑIGA et al., 2017; GÁLVEZ et al., 2021), where a low representation of diurnal records was obtained. In the study area, this felid showed fluctuations in its activity throughout the day and night, which could be explained by their type of prey consumed. In the case of birds, it has been documented that this felid can optionally change its activity pattern to diurnal hours to facilitate predation on this group (ZÚÑIGA et al., 2025). In the case of rodents, despite not showing statistical significance, it is a group widely used as prey, with which it temporally overlaps (PEKCHAM et al., 2023; ZÚÑIGA et al., 2025), which would allow for eventual hunting expeditions. On the other hand, although their temporal overlap with culpeo fox suggests a potential for competitive interaction, this could be partially compensated by the differentiation in the use of space, both at the horizontal level and in the vertical axis from

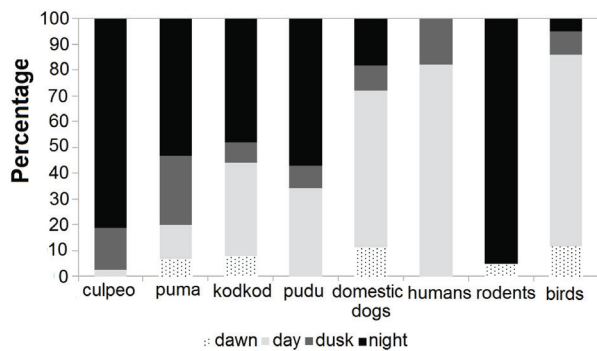


Fig. 5. Percent of activity periods of species recorded in the study area according to light availability.

the ground (HUNTER and CARO, 2008). However, it is particularly important to evaluate this behavior throughout the productive cycle of this type of plantations, in order to determine whether the evolution of structural complexity affects their presence.

Pudu deer presented a temporal amplitude greater than that reported in continuous forest (ZÚÑIGA and JIMÉNEZ, 2018), which will constitute a part of a broad anti-predation strategy. This pattern is explained by the need to limit the temporal overlap with its natural predator, the cougar, which exhibits a heterogeneous activity pattern (ZÚÑIGA et al., 2017; GARCÍA-SOLÍS et al., 2025). On the other hand, it is necessary to avoid dogs in plantations, which have been detected in a large extension of the study area. Dogs have been recognized as important predators of pudu in anthropized environments (SILVA-RODRÍGUEZ et al., 2010b). In this context pudu is forced to complement both temporal and spatial avoidance. This fact is evident in the ordination graph, where the occurrence of this deer was differentiated from both carnivores, restricting the probability of capture. It is important to note that dogs in the study area presented

lower values than in anthropized forests (GARCÍA-SOLÍS et al., 2025), which could be partially explained by their association with humans. Although dogs linked to humans have restricted ranges (GRISS et al., 2021), there is a group outside this group that exerts significant predation pressure for different types of prey, competitively affecting the rest of the assemblage.

The activity pattern of humans in the present study was lower than that recorded in anthropized environments (GARCÍA-SOLÍS et al., 2025), which would be partially explained by characteristics of the individuals recorded. These were mainly occasional visitors, with no connection to the study area, suggesting that their presence is limited to a 24-hour period because it is private property. However, the rate of records obtained implies a persistent impact over time, affecting the occurrence of wildlife through a continuous interaction (LEWIS et al., 2019), which urges the need to study the extent of the effects at the community level.

In conclusion, it was observed that carnivore species maintain a moderate temporal overlap, where differentiation in the use of space would facilitate their coexistence. Regarding prey, a low temporal overlap with each predator was observed, which suggests a hunting behavior that maximizes the capture of diverse species. It is necessary to integrate systematic monitoring in plantations throughout their productive cycle (and a landscape scale involving a larger number of that patches), to determine how interactions between species evolve, as well as temporal couplings with their respective prey.

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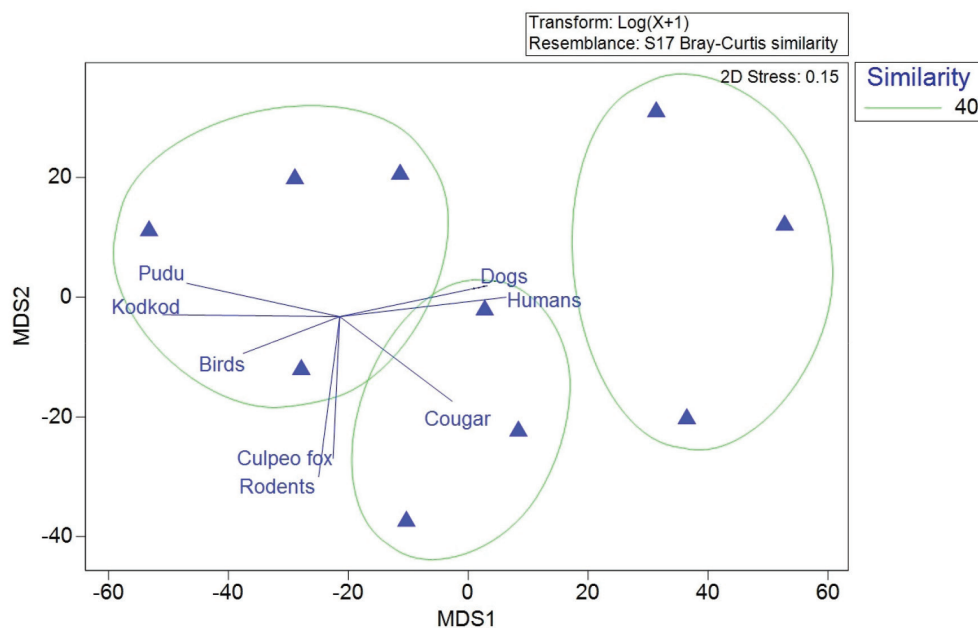


Fig. 6. Non-metric dimensional scaling based on the abundance of records of the species through the cameras arranged in the study area

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