*THERYA, 2026, Vol. 17:XXX-XXX*

DOI: 10.12933/therya.2026.6278 ISSN 2007-3364

# Camera traps reveal four feline species coexisting, facilitated by temporal segregation in Parque Nacional Tingo María, Perú

Deyvis Cano[1*], Frank Cámara[1], Niler Chahua-García[1], Jhendy Inga[1] and, Homer Sandoval[2]

[1]Programa Académico de Ingeniería Ambiental, Universidad de Huánuco, Huánuco, Perú. E-mail: frank.camara@udh.edu.pe (FC), niler.chahua@udh.edu.pe (NC-G), jhendy.inga@udh.edu.pe (JI)

[2]Parque Nacional Tingo María – Servicio Nacional de Áreas Naturales Protegidas por el Estado (SERNANP), Tingo María, Perú. E-mail: hsandoval@sernanp.gob.pe (HS)

[*]Corresponding author: deyvis.cano@udh.edu.pe

The transformation of natural ecosystems by human activities has significantly reduced the availability of functional habitats for wild felids. In this context, Parque Nacional Tingo María (PNTM), a conservation area of limited extent within a heavily transformed landscape, has confirmed the coexistence of *Herpailurus yagouaroundi*, *Leopardus tigrinus*, *Panthera onca*, and *Puma concolor*. This study determines the locations and frequencies of these species' records and analyzes their hourly activity patterns. For this purpose, 19 camera traps were installed at PNTM from January to December 2024, yielding 52 independent records (with a total of 5,861 camera-days of sampling effort) for felids. *H. yagouaroundi* was the most frequently recorded species (17 records), followed by *L. tigrinus* (12), *P. onca* (12), and *P. concolor* (11). In addition, clear temporal segregation is evident: *H. yagouaroundi* was predominantly diurnal, *L. tigrinus* mainly nocturnal, and *P. onca* and *P. concolor* showed cathemeral activity throughout day and night. These results suggest that the coexistence of the four species in a limited space is facilitated by differences in their activity patterns and support the role of PNTM as a key refuge for territorial felids in an environment undergoing urbanization and landscape fragmentation.

**Keywords:** Biodiversity, conservation, Felidae, habitats, monitoring, protected natural areas, wildlife.

La transformación de los ecosistemas naturales por las actividades humanas ha reducido significativamente la disponibilidad de hábitats funcionales para los felinos silvestres. En este contexto, el Parque Nacional Tingo María (PNTM), un área de conservación de extensión limitada dentro de un paisaje fuertemente transformado, ha confirmado la coexistencia de *Herpailurus yagouaroundi, Leopardus tigrinus, Panthera onca* y *Puma concolor*. Este estudio determina las ubicaciones y las frecuencias de los registros de estas especies y analiza sus patrones de actividad horaria. Para ello, se instalaron 19 cámaras trampa en el PNTM entre enero y diciembre de 2024, obteniéndose 52 registros independientes de felinos (con 5,861 días-cámara de esfuerzo total de muestreo). *H. yagouaroundi* fue la especie registrada con mayor frecuencia (17 registros), seguida de *L. tigrinus* (12), *P. onca* (12) y *P. concolor* (11). Además, se evidencia una clara segregación temporal: *H. yagouaroundi* fue predominantemente diurno, mientras que *L. tigrinus* fue principalmente nocturno, mientras que *P. onca* y *P. concolor* mostraron actividad catemeral a lo largo del día y de la noche. Estos resultados sugieren que la coexistencia de las cuatro especies en un espacio reducido se ve facilitada por la diferenciación de sus patrones de actividad y respaldan el papel del PNTM como refugio clave para felinos territoriales en un entorno sometido a procesos de urbanización y de fragmentación del paisaje.

**Palabras clave:** Áreas naturales protegidas, biodiversidad, conservación, Felidae, fauna silvestre, hábitats, monitoreo.



The transformation of natural ecosystems caused by human activities has considerably reduced the extent of functional habitats for large carnivores worldwide. Deforestation in tropical regions fragments the landscape and forces felids to adapt to smaller territories, thereby altering their spatial use patterns (Anderson *et al.* 2024). From an ecological perspective, wild felids, as they occupy upper trophic levels, require extensive, continuous areas to maintain their regulatory role in the ecosystem, making them sensitive indicators of habitat degradation (Sunquist *et al.* 2014). Moreover, although some species may exhibit similar body sizes, they do not necessarily share the same trophic niche. Coexistence in the same space and time is only possible when resources are diverse and abundant, or when niche partitioning occurs, whether in terms of diet, space, or time, which reduces competition (Ruiz-Gutiérrez *et al.* 2023). Even in protected areas, human presence continues to exert pressure on the spatial occupation of these predators, affecting their distribution and behavior (Poulain *et al.* 2023).

In this context, camera traps emerge as a fundamental tool for studying and monitoring cryptic predators, such as wild felids. These cameras are particularly valuable alternatives in contexts where direct observation is difficult, either because animals are elusive or because understory vegetation is dense (Burton *et al.* 2015). They also make it possible to record, without direct interference, presence, behavior, individual traits, and demographic variation, including patterns of hourly activity, key aspects for understanding the response and adaptation of mammals to anthropogenic change (Jiménez *et al.* 2010; Allen and Allan 2024).

In the Cordillera Escalera Regional Conservation Area San Martín, Perú, for example, nocturnal records have been obtained of *Panthera onca* (Linnaeus 1758), the largest felid in the Americas and the main apex predator of the Neotropics (Saucedo-Bazalar *et al.* 2023). Similarly, Castagnino Vera (2017) used camera traps in the Peruvian Amazon to study the ecology of the *Leopardus tigrinus* (Schreber 1775), demonstrating their effectiveness for identifying individuals, estimating population density, and analyzing habitat use in tropical environments. Likewise, Mena *et al.* (2020) used spatial capture–recapture models with camera traps to estimate densities of *P. onca* and other vertebrates in fragmented Amazonian landscapes, confirming the value of this methodology for generating robust data to support conservation strategies.

In Perú, Parque Nacional Tingo María (PNTM) stands out as an area of high biological value in the Huánuco region, recognized for its remarkable biodiversity and for the increasing fragmentation of its natural habitats in the surrounding matrix (Puerta and Iannacone 2023; Zuloaga-Obregón and Gabriel-Campos 2023). This area harbors a diverse community of mammals, both prey and predators, that persists in a relatively pristine core despite the anthropogenic pressures recorded in its immediate surroundings (Cossios and Zevallos 2019; Briceño *et al.* 2025). According to Clavijo and Ramírez (2009), the ecological complexity of PNTM and its environmental variability favor the presence of different species along altitudinal gradients. However, systematic studies on felids in this area have been scarce and punctual. Although the presence of several felid species has been confirmed across different sectors of the park, there is still no integrated evidence to explain their ecological interactions, distribution patterns, or spatial use. In this context, Ruiz-Gutiérrez *et al.* (2023) highlight the need to strengthen the scientific basis for decision-making in the conservation and sustainable management of wildlife, especially for felids, which, as apex predators, serve as key indicators of ecosystem health.

Therefore, the present study aims to report the coexistence of four wild felid species, *Herpailurus yagouaroundi* (É. Geoffroy Saint-Hilaire, 1803), *L. tigrinus*, *P. onca*, and *Puma concolor* (Linnaeus 1771), in a habitat of reduced extent, such as PNTM, using camera-trap records. Specifically, it proposes to (i) determine the location and frequency of felid records in the park and (ii) analyze the hourly activity patterns of the recorded species. The results provide ecological information that enables the interpretation of coexistence mechanisms, particularly temporal segregation and spatial use. Likewise, this study seeks to contribute to the design of management and conservation strategies grounded in scientific evidence, strengthening the protection of felids and their habitats, and providing technical inputs for the sustainable management of PNTM and the conservation of biodiversity in Andean–Amazonian ecosystems.

## Materials and Methods

*Study area.* The study was carried out in PNTM, located approximately between 9°19'48" S and 9°09'36" S latitude, and 76°03'36" W and 75°58'12" W longitude (equivalent to the UTM coordinates 382000–392000 m E and 8952000–8970000 m N, zone 18S), the administration of the Servicio Nacional de *Áreas* Naturales Protegidas por el Estado (SERNANP 2022), in the province of Leoncio Prado, Huánuco region, Perú (Figure 1). The park covers approximately 4,777 hectares and is part of the Premontane Humid Forest of the Peruvian Yungas. It is not formally declared as part of a biological corridor, but it is not completely isolated either, which constitutes partial functional connectivity for large species from an ecological perspective. The area lies between 750 and 1,748 m a.s.l. and has a warm and humid climate, with average temperatures between 22 °C and 29 °C and annual precipitation greater than 3,000 mm, conditions typical of the humid montane forests of the central sector of the Peruvian Amazon, where the dense vegetation cover favors the presence of carnivorous mammals with cryptic habits such as felids.

*Felid data source within PNTM.* Wildlife monitoring was conducted using 19 Browning camera traps (Recon Force Edge model, BTC-7E) strategically installed across the PNTM from January to December 2024. With the support of park ranger staff, accessible sectors showing evidence of wildlife movement were identified, and monitoring points were selected in accordance with the recommendations of the Peruvian Ministry of the Environment (MINAM 2015). The cameras were distributed along transects, separated by a minimum distance of 250 m to ensure spatial independence among sampling stations and reduce the probability of recording the same individuals at nearby cameras. Their placement prioritized trails, water sources, and areas frequently used by wildlife. During installation, the geographic coordinates of each station were recorded using high-precision GPS receivers. The devices, equipped with passive infrared (PIR) motion sensors, an integrated digital thermometer, a color screen for field configuration, and an invisible infrared flash system, can capture images of up to 20 megapixels and record high-definition videos (1080p) with sound, while also storing metadata such as date, time, and approximate temperature at the moment of capture (Browning 2018).

Each camera was installed at an average height of 60 cm above ground and oriented toward trails or common crossing areas used by felids, a configuration considered one of the most effective methods for estimating species presence. Each unit was programmed to capture a burst of three photographs followed by a 20-second video, with a 30-minute interval before reactivation to avoid the overrepresentation of the same individuals. The system operated continuously throughout the study period, and

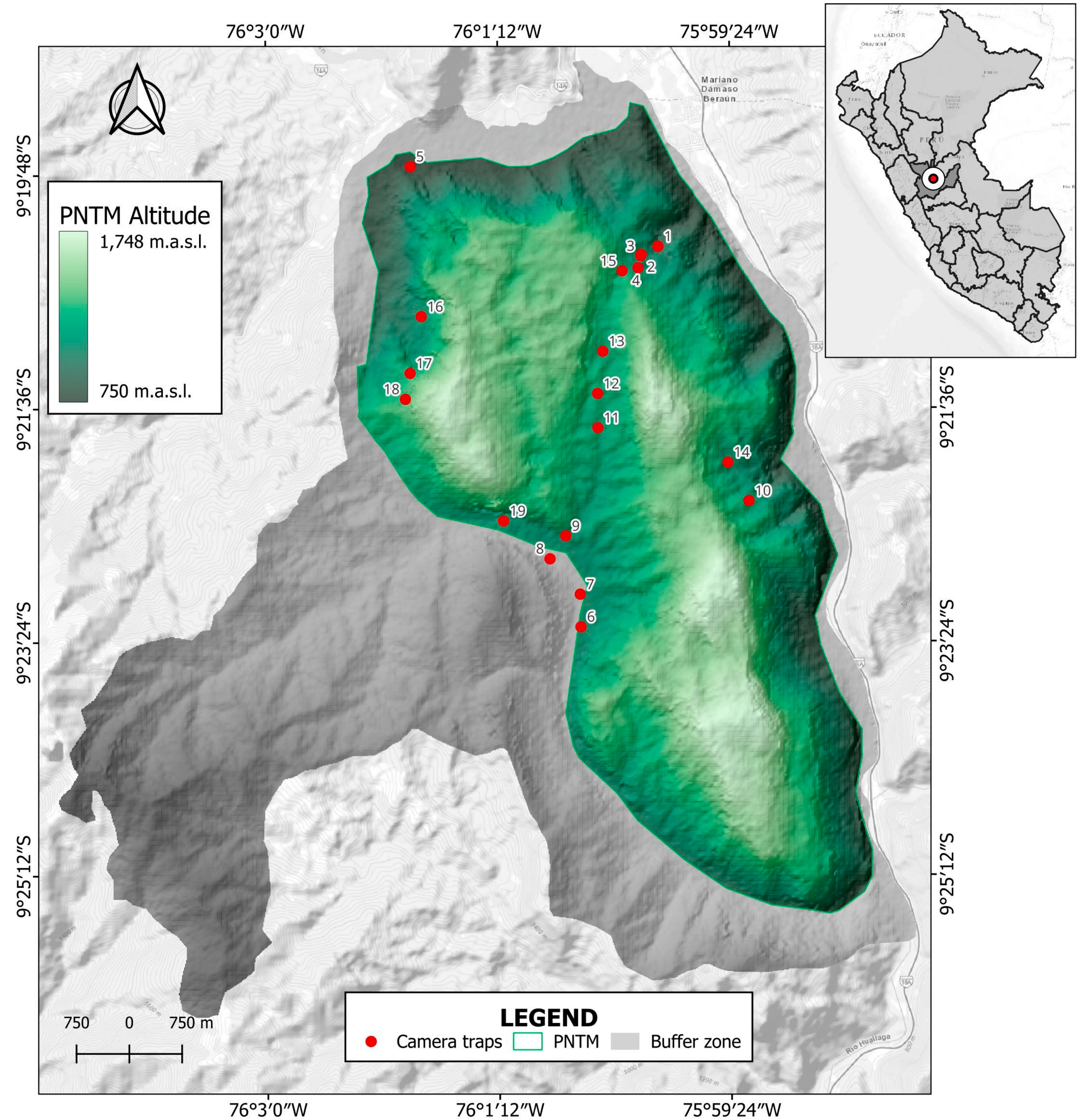


**Figure 1.** Location map of Parque Nacional Tingo María (PNTM) in Perú. The entire study area is shown in green. In the upper right corner, the legend shows the altitudinal distribution of the PNTM (m a.s.l.), with a gradient from dark green to light green. The red points indicate the locations of the 19 camera traps. The gray outline indicates the boundary of the PNTM buffer zone.

periodic inspections (approximately every two months) were conducted to check battery status and memory cards, ensuring uninterrupted operation of the equipment.

*Data processing.* The information obtained from photographs and videos recorded by the camera traps was carefully reviewed, organized, and filtered to ensure its quality and consistency before analysis. All records not directly attributable to the presence of felids were excluded. Likewise, indirect evidence, such as the presence of prey or other indicators of their occurrence, was not considered; only images and videos in which individuals of the target felid species were clearly observed were included. Before conducting any analysis, it was ensured that the field-collected information was reliable and accurate for the evaluated area. Photographic and video records were interpreted, recorded, and classified in Microsoft Excel (version 2602, Microsoft 365) by species. Each record was associated with the date, time, and geographic location


**Figure 2.** Photographic records of felid species obtained using camera traps in the study area: (A) *Herpailurus yagouaroundi* recorded by camera 3 (X = 390020, Y = 8967352); (B) *Leopardus tigrinus* captured by camera 6 (X = 389172, Y = 8962080); (C) *Panthera onca* recorded by camera 1 (X = 388732, Y = 8963046); and (D) *Puma concolor* recorded by camera 13 (X = 389482, Y = 8965996). Coordinates are expressed in UTM, Zone 18S.

recorded by each camera. Events were considered independent when a different individual appeared in front of the camera or when they were separated by intervals of more than 30 minutes, as determined by the camera's technical configuration, for both photographs and videos. (Karanth and Nichols 1998; Zhao *et al.* 2020). For spatial representation, QGIS v.3.34.9 was used; for the generated information, the geographic coordinate system with the WGS 84 datum in UTM zone 18 was used.

*Data analysis*. Since the study is exploratory and descriptive, simple analyses were employed. Once the database was consolidated, field sightings were quantified by species to determine frequency of occurrence and abundance in the study area. The time intervals analyzed record frequencies in months and by schedule, allowing classification of species according to their activity habits (diurnal, nocturnal, or hourly and monthly). The organization of the data also enabled observation of the frequency of sightings at the spatial level (map) based on recorded coordinates.

To evaluate whether the sampling effort was sufficient to characterize felid richness, a rarefaction analysis of species richness was conducted using camera-trap records. An abundance matrix was constructed with the total number of independent records per felid species, considering camera-days as the unit of effort. Using this matrix, the sample-size–based rarefaction curve was estimated with iNEXT Online version 3.0.2, which implements diversity and sample-coverage estimators for abundance data (Chao *et al.* 2014; 2016). The curve was generated for the diversity order q = 0 (species richness). It included 95% confidence intervals, and the sampling effort was considered to reach the asymptote when the expected richness approached a constant value and the confidence intervals no longer overlapped with lower richness values, that is, when the addition of new camera-days did not produce appreciable increases in the expected number of felid species in the study area. In addition, a sample coverage index greater than 0.95 was considered sufficient to justify and complement the sampling effort.

## Results

The 19 cameras installed in the PNTM recorded 2,681 images and videos of various mammals, totaling 5,861 camera-days total sampling effort, for a capture rate of 45.7 records per 100 camera-days. Of these, 14 out of the 19 cameras detected four felid species, with 17 records of *H. yagouaroundi*, 12 of *L. tigrinus*, 12 of *P. onca*, and 11 of *P. concolor*, for a total of 52 independent records; examples of some captures of the four felid species are shown in Figure 2. For more details, see Table 1, which presents all records of felid consolidations, detailing for each event the corresponding camera, date, number of individuals observed, and the UTM coordinates of the detection point, information that serves as the basis for the ecological and comparative analyses developed in this study.

A rapid increase in the number of felid species detected is observed as the number of camera-days increases (Figure

**Table 1.** Geographic records of the four felid species in PNTM, Perú.

| Scientific name | UTM coordinates – Zone 18S | | No. / Camera | Date | Recording time (24h format) |
|---|---|---|---|---|---|
| | X | Y | | | |
| *Herpailurus yagouaroundi* | 386677 | 8965312 | Camera 18 | 15/5/2024 | 13:30 |
| | 386677 | 8965312 | Camera 18 | 22/5/2024 | 12:50 |
| | 386745 | 8968617 | Camera 5 | 24/10/2024 | 16:30 |
| | 386745 | 8968617 | Camera 5 | 8/11/2024 | 07:32 |
| | 386902 | 8966488 | Camera 16 | 11/8/2024 | 14:47 |
| | 386902 | 8966488 | Camera 16 | 1/9/2024 | 16:30 |
| | 386902 | 8966488 | Camera 16 | 23/10/2024 | 11:07 |
| | 386902 | 8966488 | Camera 16 | 19/12/2024 | 07:40 |
| | 388732 | 8963046 | Camera 8 | 20/5/2024 | 11:30 |
| | 388732 | 8963046 | Camera 8 | 11/7/2024 | 15:48 |
| | 388956 | 8963374 | Camera 9 | 28/3/2024 | 16:39 |
| | 389408 | 8965396 | Camera 12 | 25/2/2024 | 18:35 |
| | 389482 | 8965996 | Camera 13 | 8/11/2024 | 10:02 |
| | 389482 | 8965996 | Camera 13 | 12/11/2024 | 16:26 |
| | 389507 | 8966190 | Camera 14 | 2/2/2024 | 16:05 |
| | 389507 | 8966190 | Camera 14 | 9/2/2024 | 15:34 |
| | 390020 | 8967352 | Camera 3 | 22/4/2024 | 16:18 |
| *Leopardus tigrinus* | 386745 | 8968617 | Camera 5 | 23/8/2024 | 22:23 |
| | 386902 | 8966488 | Camera 16 | 10/6/2024 | 18:02 |
| | 386902 | 8966488 | Camera 16 | 27/9/2024 | 23:39 |
| | 388073 | 8963584 | Camera 19 | 21/3/2024 | 22:40 |
| | 388732 | 8963046 | Camera 1 | 10/1/2024 | 02:01 |
| | 388732 | 8963046 | Camera 1 | 19/2/2024 | 03:31 |
| | 388732 | 8963046 | Camera 8 | 31/5/2024 | 20:04 |
| | 389172 | 8962080 | Camera 6 | 24/2/2024 | 00:33 |
| | 389172 | 8962080 | Camera 6 | 25/2/2024 | 00:21 |
| | 389172 | 8962080 | Camera 6 | 16/4/2024 | 00:54 |
| | 389172 | 8962080 | Camera 6 | 23/4/2024 | 22:13 |
| | 390020 | 8967352 | Camera 3 | 14/4/2024 | 23:25 |
| *Panthera onca* | 386745 | 8968617 | Camera 5 | 23/8/2024 | 22:23 |
| | 386745 | 8968617 | Camera 5 | 4/10/2024 | 04:07 |
| | 386745 | 8968617 | Camera 5 | 12/10/2024 | 06:16 |
| | 386745 | 8968617 | Camera 5 | 6/11/2024 | 07:26 |
| | 386745 | 8968617 | Camera 5 | 24/11/2024 | 12:24 |
| | 388732 | 8963046 | Camera 1 | 29/8/2024 | 12:32 |
| | 388732 | 8963046 | Camera 8 | 7/5/2024 | 18:20 |
| | 388956 | 8963374 | Camera 9 | 1/9/2024 | 00:32 |
| | 388956 | 8963374 | Camera 9 | 1/9/2024 | 05:25 |
| | 388956 | 8963374 | Camera 9 | 1/9/2024 | 07:07 |
| | 388956 | 8963374 | Camera 9 | 2/9/2024 | 15:25 |
| | 389162 | 8962544 | Camera 7 | 30/1/2024 | 09:05 |
| *Puma concolor* | 386902 | 8966488 | Camera 16 | 22/12/202 | 22:02 |
| | 388956 | 8963374 | Camera 9 | 22/8/2024 | 19:49 |
| | 388956 | 8963374 | Camera 9 | 22/11/2024 | 12:12 |
| | 389162 | 8962544 | Camera 7 | 29/1/2024 | 06:45 |
| | 389162 | 8962544 | Camera 7 | 29/1/2024 | 18:45 |
| | 389408 | 8965396 | Camera 12 | 17/1/2024 | 07:21 |
| | 389482 | 8965996 | Camera 13 | 17/1/2024 | 06:53 |
| | 389482 | 8965996 | Camera 13 | 30/3/2024 | 04:00 |
| | 389482 | 8965996 | Camera 13 | 22/9/2024 | 01:28 |
| | 390020 | 8967352 | Camera 3 | 29/5/2024 | 03:16 |
| | 390027 | 8967372 | Camera 2 | 6/6/2024 | 19:50 |

3), with a pronounced rise from 1 to approximately 4 species in the first 12 camera-days (sample coverage index = 0.97). From that threshold onward, the curve approaches an asymptote near 4 species. It remains practically stable up to the maximum sampling effort (52 camera-days), while the 95% confidence band (gray-shaded area) narrows progressively, indicating a decrease in uncertainty in the richness estimate. This stabilization of the curve suggests that the sampling effort employed was sufficient to record most, or possibly all, of the felid species present in the study area and that a further increase in effort would have a very low probability of adding new felid species to the inventory.

Figure 4 shows the spatial distribution of records of *H. yagouaroundi*, *L. tigrinus*, *P. onca,* and *P. concolor* in PNTM, where the size of the circles indicates the number of sightings per sampling station. In *H. yagouaroundi* and *L. tigrinus,* a higher concentration of records is observed in the northern and central sectors of the park, with several points showing multiple sightings, suggesting areas of preferential use and a broader spatial distribution. Despite this broad distribution, both species overlap at a few stations (at four common points), suggesting a degree of fine-scale spatial segregation.

By contrast, the records of *P. onca* and *P. concolor* are fewer and appear more dispersed, a pattern that may be related to more solitary habits, lower population densities, or a wider use of space within the study area. Nevertheless, both species show a core of records in the central part of the park and, in the case of *P. onca*, an additional sighting was documented in the northern sector, near the Cueva de las Lechuzas, where visitor presence and human activity are significant.

*Activity pattern*. In *H. yagouaroundi* (Figure 5A–B), the records were concentrated mainly in February, May, and November, with peaks of up to three events in cameras 14, 12, 18, 8, 13, and 5. Activity was markedly diurnal, with the highest number of sightings between 10:00 and 16:00 h, where two to six events were recorded, indicating a clear preference for daylight hours. In *L. tigrinus* (Figure 5C–D), maximum records were observed in February and April, with up to three events in cameras 1, 6, and 3. Its activity was predominantly nocturnal, with a higher frequency of sightings between 22:00 and 02:00 h, indicating a strong preference for hours of darkness. For *P. onca* (Figure 5E–F), records were concentrated in September (four events) and in August, October, and November (two records in each month), mainly in cameras 1, 9, and 5. Activity was distributed both at night and during the day, with peaks

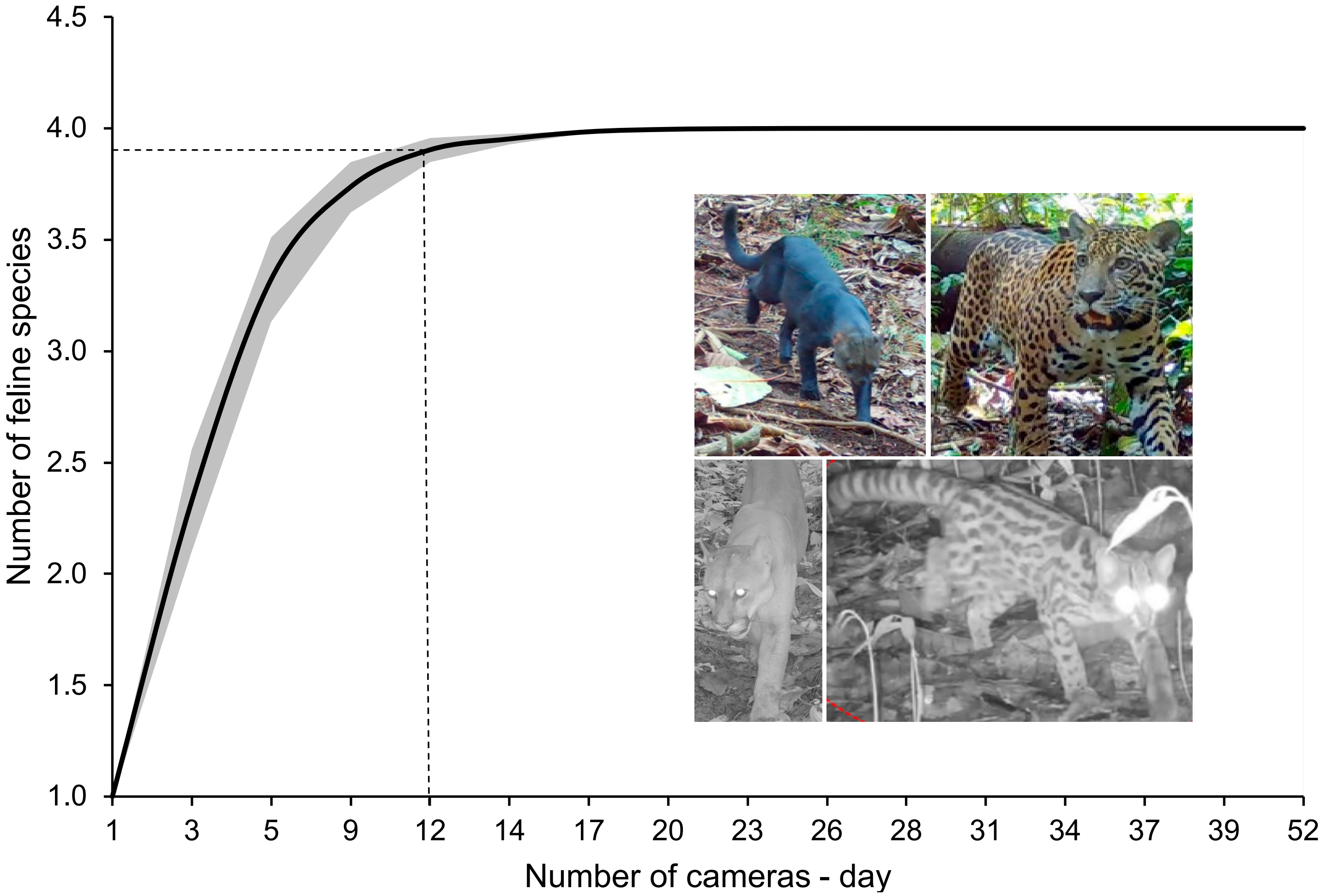


**Figure 3.** Rarefaction curve analysis showing the number of wild felid species detected as a function of cumulative camera-days. The gray shaded area represents the 95% bootstrap confidence interval for species richness. Dashed black lines indicate the inflection point and horizontal asymptote (sample coverage = 0.97), confirming sampling sufficiency for felid inventory in PNTM.

between 04:00 and 09:00 h (one to two records) and between 18:00 and 00:00 h (one record), without showing a clearly defined hourly pattern in the context of this study. In *P. concolor* (Figure 5G–H), the highest number of records occurred in January, with four events in cameras 7, 13, and 12. Its activity was spread throughout the day and night, with one peak between 01:00 and 06:00 h (two records) and another between 18:00 and 19:00 h (one and two records, respectively), reflecting a mixed activity pattern that could be related to variation in environmental conditions and prey availability.

## Discussion

Our results partially agree with those reported by Cossios and Zeballos (2019) for the same park, who, with a sampling effort of 2,940 camera-days over four years of monitoring, recorded 26 events of *P. concolor*, 7 of *H. yagouaroundi*, and 1 of *L. tigrinus*. Taken together, both studies indicate low detectability of felids, consistent with their cryptic behavior and low population densities. Nevertheless, our study, which focused on documenting the coexistence of these species, provides important contributions. We recorded the presence of *P. onca*, a species previously unreported, expanding current knowledge of the felid community in PNTM. In addition, our work involved a more intensive sampling effort over a shorter period: we conducted simultaneous monitoring for one year by deploying 19 active camera traps, accumulating a large number of camera-days compared with the previous study, which was conducted over four years. Similarly, Cossios *et al.* (2022) reported only four *Leopardus pardalis* events in the Allpahuayo Mishana National Reserve, reaffirming the low detectability of felids and their generally low population densities in Amazonian ecosystems. This low recording rate has also been documented by Ruiz-Gutiérrez *et al.* (2023) in the Sierra Madre del Sur, Mexico, where 362 detections of three felids are interpreted as evidence of coexistence mediated by spatial and temporal overlap rather than high abundance. Likewise, Behnke (2015) showed in the lowland Peruvian Amazon that an effort of 2,614 camera-days generated 108,558 photographs of mammals but with very few captures of large felids, suggesting that prolonged efforts are required to detect apex predators and that the low numbers of records reflect reduced densities and extensive home ranges rather than actual absence.

Our results concerning monthly and hourly activity patterns agree with Cossios and Zevallos (2019) in PNTM, where *H. yagouaroundi* was exclusively diurnal, and *L.*

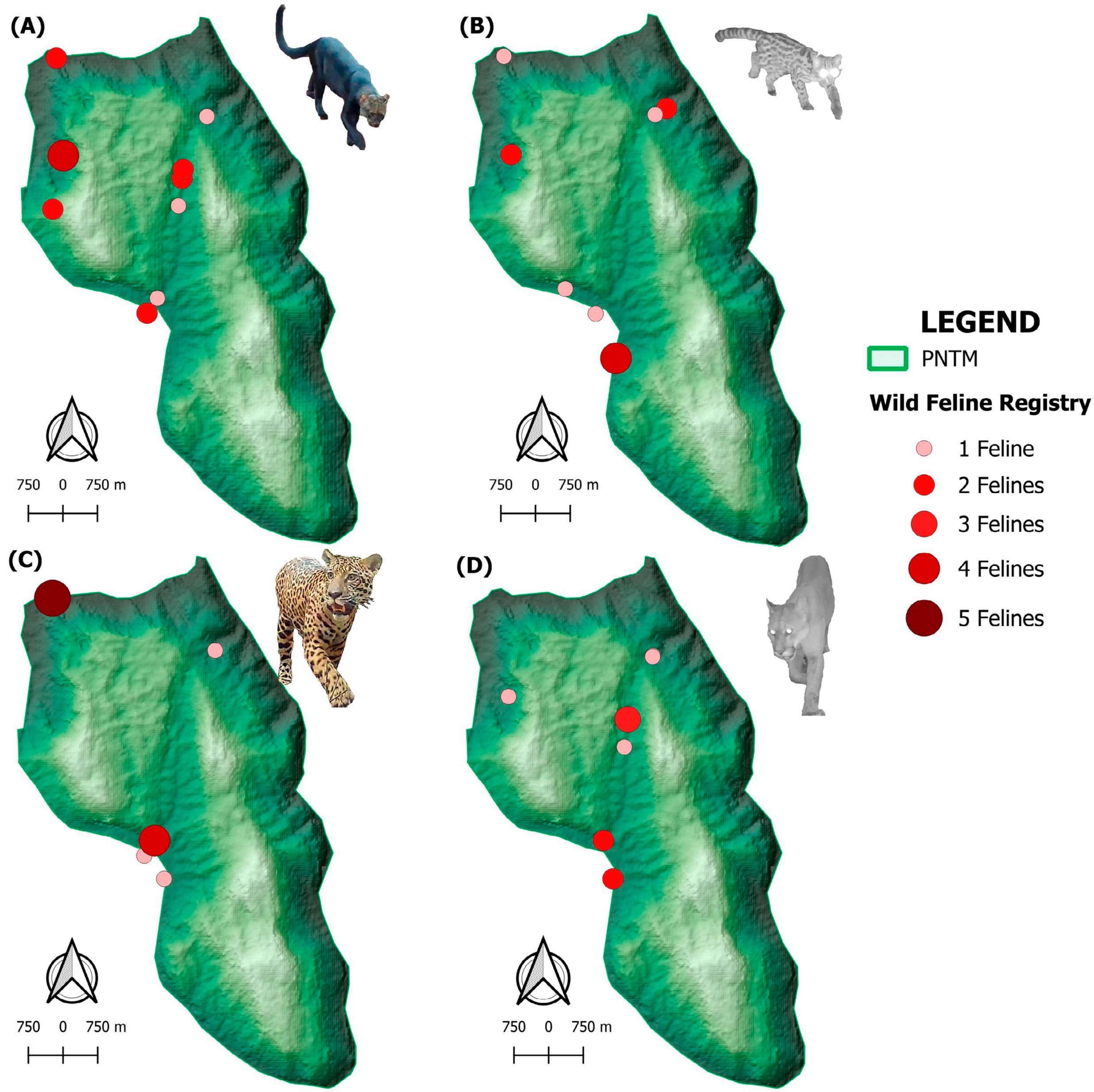


**Figure 4.** Spatial distribution of records of (A) *Herpailurus yagouaroundi*, (B) *Leopardus tigrinus*, (C) *Panthera onca*, and (D) *Puma concolor* in PNTM, Perú, according to the number of sightings per monitoring station with camera traps.

*tigrinus* was completely nocturnal, which supports the predominant diurnality and nocturnality observed in this study, as well as *P. concolor,* which showed 30.77% of diurnal records and 53.85% nocturnal. Contrary to what Mosquera-Guerra *et al.* (2018) reported, *L. tigrinus* in the forests of the Bita River (Colombia) exhibits a cathemeral pattern, suggesting some flexibility in its activity. In general, variations among diurnal, nocturnal, and cathemeral habits are usually associated with temperature, humidity, prey availability, and the need to avoid predators or competitors. In the Allpahuayo Mishana Reserve, Cossios *et al.* (2022) pointed out that hunting and tourism can reduce diurnal activity and shift it toward nighttime hours with lower human presence, so the nocturnality of *L. tigrinus* and the mixed patterns of *P. concolor* and *P. onca* in PNTM could be interpreted as behavioral adjustments to coincide with their prey and minimize contact with people.

The spatial distribution of records of *H. yagouaroundi* and *L. tigrinus* is concentrated mainly in the northern and central sectors of PNTM, although with relatively

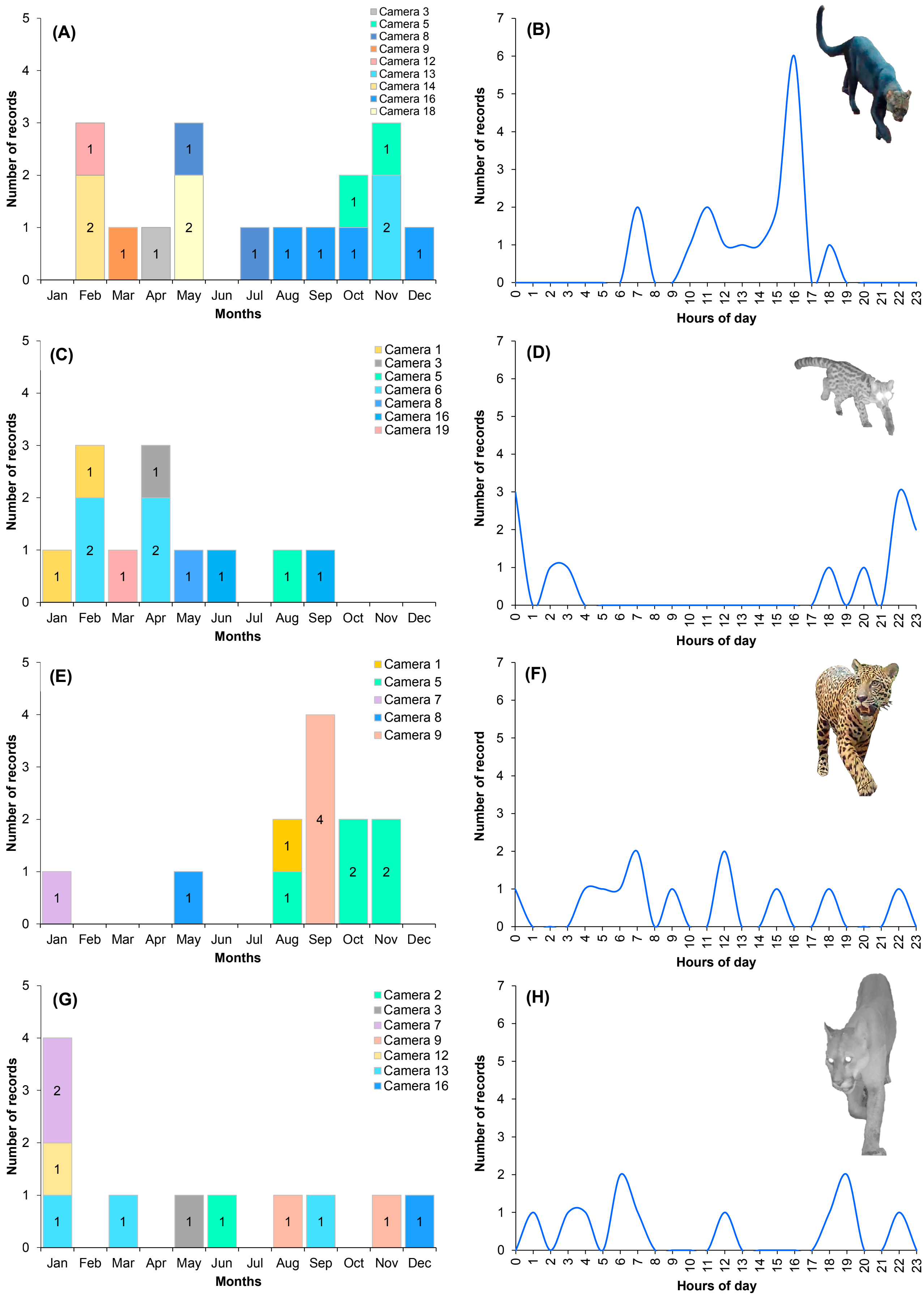


**Figure 5**. Monthly records and hourly activity of the felids: (A–B) *Herpailurus yagouaroundi*, (C–D) *Leopardus tigrinus*, (E–F) *Panthera onca*, and (G–H) *Puma concolor* in PNTM, Perú. In the first column, the different colors of the bars represent the months in which presence records were captured. In the second column, the blue lines indicate the 24-hour daily activity patterns of the felid species recorded by the camera traps.

wide dispersion among sampling stations. In contrast, records of *P. onca* and *P. concolor* are less frequent and occur in more restricted areas, suggesting lower-density populations or a more limited use of space. This distribution may be related to food availability. In the northern and western sectors of the park, the presence of this felid species appears to be associated with greater prey availability, both domestic (such as chickens) and wild, which constitute its food base. This situation is particularly relevant in areas occupied by users within the Buffer Zone and the Special Use Zone of the protected area (Anderson *et al.* 2024; Briceño *et al.* 2025).

The simultaneous presence of these four species in a relatively small, protected area can be explained by the fact that PNTM acts as one of the few remaining minimally disturbed habitats within a matrix heavily transformed by agriculture, deforestation, urbanization, and hunting, processes documented for the area (Guillén and Reátegui 2014; Puerta and Iannacone 2023). These anthropogenic pressures reduce and fragment the available range, "cornering" felid populations and limiting the availability of safe sites to obtain food, water, and shelter. This scenario has direct implications for both the conservation of apex predators and for wildlife that finds the park one of the few remaining refuges in the landscape (Massara *et al.* 2015).

In addition, the presence of *P. concolor* in the PNTM, a species widely distributed from the Andes to the Amazon, suggests functional ecological connectivity between surrounding montane forests and adjacent forested landscapes. A similar interpretation may apply to *P. onca*, whose occasional records suggest that the park may be part of a broader movement network rather than a fully isolated habitat. Given the extensive spatial requirements of both large felids, it is likely that individuals move through the park while maintaining connections with surrounding forest remnants and buffer zones (Arias-Alzate *et al.* 2022). However, the present study was not designed to estimate population densities or to identify specific corridors, so the degree of connectivity and the size of the populations using the area remain subjects for future research.

The results of this study are relevant to the conservation and management of felids in PNTM because they provide important information on species presence and the sites with the highest activity levels. These data can be incorporated directly into the design of monitoring programs, allowing prioritization of camera placement at stations with concentrated records and focusing effort on areas with a higher probability of detection. In this regard, what was stated by Mosquera-Guerra *et al.* (2018) is relevant, as the information generated through camera traps on activity patterns and spatial distribution of medium- and large-sized mammals constitutes a fundamental input for management planning.

The 52 independent records obtained from 14 monitoring stations confirm the active use of the area by the four species evaluated. A limitation of the study is that no specific individual-identification design was implemented, nor were photographic capture–recapture models applied, which prevents robust estimation of population size or the minimum number of individuals. However, the confirmed evidence of presence, together with information on spatial distribution and observed temporal segregation, provides a strategic baseline to guide zoning processes, threat control, and long-term monitoring programs in the PNTM and in other protected natural areas with similar characteristics.

Nevertheless, the work has limitations that must be considered when interpreting the results: the number of records is relatively low (52 events across 14 cameras), which limits more detailed analyses of diversity, such as overlap in activity or differential habitat use among species. In addition, prey availability and the intensity of human activities at each station were not specifically quantified, so their influence on distribution and activity schedules can only be inferred in general terms. Finally, as in any study based on camera traps, the records reflect the use of the sampled points and not the entire movement range of the felids; therefore, the described patterns should be interpreted with caution and considered an initial approximation of the coexistence of these species in the PNTM. In this regard, future studies could strengthen these results by designing surveys specifically to estimate occupancy, incorporating standardized temporal replicates, increasing station density, and using hierarchical models that allow estimation of detection probability and actual site use. This approach would enable more robust inferences about spatial dynamics and population persistence within the protected area.

## Conclusions

This study documents the coexistence of four felid species (*H. yagouaroundi, L. tigrinus, P. onca,* and *P. concolor*) within the relatively small area of PNTM, supported by 52 independent camera-trap records obtained over 5,861 camera-days. The stabilization of the rarefaction curve and the high sample coverage index (0.97) further indicate that the sampling was sufficient to characterize the local felid community. Clear temporal segregation was observed among species: *H. yagouaroundi* was predominantly diurnal, *L. tigrinus* mainly nocturnal, and *P. onca* and *P. concolor* exhibited cathemeral activity. This pattern suggests that temporal niche partitioning is a key mechanism facilitating their coexistence. Considering the wide movement ranges of large felids, particularly *P. onca* and *P. concolor*, PNTM likely functions not only as a local refuge but also as part of a network of connected habitats that supports movement between buffer zones and surrounding fragmented landscapes. In this context, the park may serve as a resident habitat for smaller felids while acting as a functional corridor or use area for larger carnivores within Andean–Amazonian landscapes.

From a management perspective, the results provide strategic information on the sectors of the PNTM where greater felid activity was recorded and on the periods of the day in which each species shows a higher probability of detection. It is recommended to prioritize installing camera traps in microhabitats, along movement routes, and in sectors of the park where the probability of recording is higher, and to adjust inspection, maintenance, and repositioning of the equipment to the periods of greater species activity. Likewise, it is recommended to expand the sampling effort by increasing the number of stations and extending the temporal series, and to incorporate complementary variables such as prey abundance, human pressure, and microclimate. The integration of these factors, along with the use of occupancy and density models, would allow more precise estimates of space use and a better understanding of how these populations respond to processes such as agricultural expansion, hunting, and other threats in the surrounding landscape.

## Acknowledgments

The authors express their gratitude to the Vice-Rectorate for Research of the Universidad de Huánuco for logistical support for the project "Efecto del cambio de uso del suelo en la distribución potencial de especies de mamíferos en el Área de Conservación Regional (ACR) Bosque Montano de Carpish". We also express our gratitude to the staff of the Servicio Nacional de Áreas Naturales Protegidas por el Estado (SERNANP), especially park ranger Alex Ricra, for their support and for the facilities provided for access and fieldwork in PNTM.

## Declaration of artificial intelligence use

During the preparation of this manuscript, the authors used Perplexity AI (Grok 4.1) and GPT-5.3 solely to improve the grammar, style, the logical cohesion and translation of the text. These tools were not employed for data generation, statistical analysis, the creation of figures or tables, or the scientific interpretation of the results. The authors critically reviewed and edited the AI-assisted content and hold full responsibility for the integrity, originality, and conclusions presented in this work.

## Author contributions

Deyvis Cano: Conceptualization, methodology, research supervision, data analysis and interpretation, visualization, and writing - original draft, review and editing. Frank Cámara: Data collection (fieldwork), data analysis and interpretation, and writing - review and editing. Niler Chahua-García: Data analysis and interpretation, visualization, and writing-review and editing. Jhendy Inga: Visualization and writing -review and editing. Homer Sandoval: Methodology, data collection (fieldwork), visualization, and writing - review and editing.

## Literature cited

Allen ML, and Allan ATL. 2024. Detection rates and diel activity patterns of four understudied felids from Borneo. *Ecology and Evolution* 14:e70301. https://doi.org/10.1002/ece3.70301

Anderson C, Zuckerwise A, Wallace RB, Ayala G, Viscarra M, and Schmitz OJ. 2024. Small felids coexist in mixed-use landscape in the Bolivian Amazon. *Animals* 14:697. https://doi.org/10.3390/ani14050697

Arias-Alzate A, Arroyave FJ, Romero Goyeneche OY, Hurtado Heredia RG, González-Maya JF, Arroyo-Cabrales J, *et al.* 2022. Functional niche constraints on carnivore assemblages (Mammalia: Carnivora) in the Americas: what facilitates coexistence through space and time? *Journal of Biogeography* 49:497–510. https://doi.org/10.1111/jbi.14319

Behnke R. 2015. *A camera-trap based inventory to assess species composition of large- and medium-sized terrestrial mammals in a lowland Amazonian rainforest in Loreto, Peru: a comparison of wet and dry season.* [Master's thesis]. [Vienna (AUT)]: University of Natural Resources and Life Sciences.

Briceño N, Cano D, Cámara F, Campos B, Sandoval H, Ricra A, *et al.* 2025. Potential distribution of the oncilla *Leopardus tigrinus* (Carnivora: Felidae) based on high-resolution spatial data and camera traps in a national park in Peru. *Journal of Animal Behaviour and Biometeorology* 13:8269. https://10.31893/jabb.2025006

Browning. 2018. Instruction Manual. Browning Trail Cameras. Birmingham, Alabama (AL, EE.UU.): Prometheus Group; December, 2025. [Accessed December 14th, 2025]. https://www.bhphotovideo.com/lit_files/605737.pdf

Burton AC, Neilson E, Moreira D, Ladle A, Steenweg R, Fisher JT, *et al.* 2015. Wildlife camera trapping: a review and recommendations for linking surveys to ecological processes. *Journal of Applied Ecology* 52:675–685. https://doi.org/10.1111/1365-2664.12432

Castagnino Vera R. 2017. Estudio ecológico del ocelote (*Leopardus pardalis*) utilizando el método de cámaras trampa en el distrito de Las Piedras, Madre de Dios, Perú. *Espacio y Desarrollo* 29:153–178. https://doi.org/10.18800/espacioydesarrollo.201701.007

Chao A, Gotelli NJ, Hsieh TC, Sander EL, Ma KH, Colwell RK, *et al.* 2014. Rarefaction and extrapolation with Hill numbers: A framework for sampling and estimation in species diversity studies. *Ecological Monographs* 84:45–67. https://doi.org/10.1890/13-0133.1

Chao A, Ma KH, and Hsieh TC. 2016. iNEXT Online: Software for Interpolation and Extrapolation of Species Diversity. Program and User's Guide. [Accessed December 13th, 2025] http://chao.stat.nthu.edu.tw/wordpress/software_download/inextonline/

Clavijo A, and Ramírez GF. 2009. Taxonomía, distribución y estado de conservación de los felinos suramericanos: revisión monográfica. Boletín Científico. *Centro de Museos. Museo de Historia Natural* 13:43–60.

Cossios ED, Díaz E, and Pizango F. 2022. Mamíferos registrados con cámaras trampa en la zona de uso turístico de la Reserva Nacional Allpahuayo-Mishana, Loreto, Perú. *Folia Amazónica* 31:31–45. https://doi.org/10.24841/fa.v31i1.564

Cossios ED, and Zevallos AR. 2019. Diversidad y actividad horaria de mamíferos medianos y grandes registrados con cámaras trampa en el Parque Nacional Tingo María, Huánuco, Perú. *Revista Peruana de Biología* 26:325–332. https://doi.org/10.15381/rpb.v26i3.16776

Guillén FNG, and Reátegui GL. 2014. Cacería de mamíferos en la zona de uso especial y de amortiguamiento del Parque Nacional Tingo María, Huánuco, Perú. *Revista Peruana de Biología* 21:283–286. https://doi.org/10.15381/rpb.v21i3.10904

Jiménez CF, Quintana H, Pacheco V, Melton D, Torrealva J, and Tello G. 2010. Camera trap survey of medium and large mammals in a montane rainforest of northern Peru. *Revista Peruana de Biología* 17:191–196. https://doi.org/10.15381/rpb.v17i2.27

Karanth KU, and Nichols JD. 1998. Estimation of tiger densities in India using photographic captures and recaptures. *Ecology* 79:2852–2862. https://doi.org/10.1890/0012-9658(1998)079[2852:EOTDII]2.0.CO;2

Massara RL, Paschoal AM de O, Bailey LL, Doherty PF Jr, Hirsch A, and Chiarello AG. 2015. Ocelot population status in protected Brazilian Atlantic Forest. *PLOS One* 10:e0141333. https://doi.org/10.1371/journal.pone.0141333

Mena JL, Yagui H, Tejeda V, Cabrera J, Pacheco-Esquivel J, Rivero J, *et al*. 2020. Abundance of jaguars and occupancy of medium- and large-sized vertebrates in a transboundary conservation landscape in the northwestern Amazon. *Global Ecology and Conservation* 23:e01079. https://doi.org/10.1016/j.gecco.2020.e01079

MINAM. 2015. Guía de inventario de la fauna silvestre [Guía]. Lima (PER): Ministerio del Ambiente, Dirección General de Evaluación, Valoración y Financiamiento del Patrimonio Natural. [Accessed January 20th, 2026]. https://www.gob.pe/institucion/minam/informes-publicaciones/2676-guia-de-inventario-de-la-fauna-silvestre

Mosquera-Guerra F, Trujillo F, Diaz-Pulido AP, and Mantilla-Meluk H. 2018. Diversidad, abundancia relativa y patrones de actividad de los mamíferos medianos y grandes, asociados a los bosques riparios del río Bita, Vichada, Colombia. *Biota Colombiana* 19:202–218. https://doi.org/10.21068/c2018v19n01a13

Poulain F, Breuer T, Fonteyn D, Lhoest S, Lushimba A, Ahanda YA, and Vermeulen C. 2023. A camera trap survey in the community zone of Lobéké National Park (Cameroon) reveals a nearly intact mammalian community. *African Journal of Ecology* 61:523–529. https://doi.org/10.1111/aje.13109

Puerta R, and Iannacone J. 2023. Análisis de la cobertura boscosa del Parque Nacional Tingo María (Perú) utilizando el algoritmo random forest. *Scientia Agropecuaria* 14:291–300. https://doi.org/10.17268/sci.agropecu.2023.025

Ruiz-Gutiérrez F, Ávila-Nájera DM, Chávez C, and Sánchez-Rojas G. 2023. Spatial and temporal coexistence of medium-sized felines and their potential preys in Sierra Madre del Sur of Guerrero, México. *Therya* 14:319–328. https://doi.org/10.12933/therya-23-1220

Saucedo-Bazalar MJ, Carlos-Gómez GM, Krose C, Barco J, and Benavides R. 2023. *Panthera onca* en el Área de Conservación Regional Cordillera Escalera: un nuevo registro de jaguar melánico en la selva tropical del Perú. *Folia Amazónica* 32:e32662. https://doi.org/10.24841/fa.v32i2.662

SERNANP. 2022. Plan de sitio del Parque Nacional Tingo María 2022–2027 [Plan]. Lima (PER): Servicio Nacional de Áreas Naturales Protegidas por el Estado. [Accessed January 20th, 2026]. https://sis.sernanp.gob.pe/biblioteca/?publicacion=2635

Sunquist F, Sunquist M, and Whittaker T. 2014. The wild cat book. Chicago (EEUU): University of Chicago Press. https://doi.org/10.7208/chicago/9780226145761.001.0001

Zhao G, Yang H, Xie B, Gong Y, Ge J, and Feng L. 2020. Spatio-temporal coexistence of sympatric mesocarnivores with a single apex carnivore in a fine-scale landscape. *Global Ecology and Conservation* 21:e00897. https://doi.org/10.1016/j.gecco.2019.e00897

Zuloaga-Obregón JL and Gabriel-Campos EN. 2023. Cambio de uso de tierra y su impacto en la cobertura vegetal del Parque Nacional Tingo María entre los años 2006–2021. *Revista Kawsaypacha: Sociedad y Medio Ambiente* 12:1–22. https://doi.org/10.18800/kawsaypacha.202302.a009

*Associated editor: Miguel Ángel León Tapia*
*Submitted: January 20, 2026; Reviewed: February 17, 2026*
*Accepted: March 11, 2026; Published online: March 23, 2026*