

Article

Changes in the Spatiotemporal Activity of a Wolf Family in an Anthropized Natural Reserve of Central Italy: Insight from Camera Trapping over Two Consecutive Pup-Rearing Periods

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Simple Summary

A wolf family inhabiting a natural reserve in central Italy was monitored using camera traps from May to October over two consecutive years. The results revealed that while adult activity remained relatively stable, pup activity showed marked spatial and temporal variations, along with a decline in detections over time. These variations suggest dynamic territorial use and possible shifts in pack structure, potentially linked to increasing climatic and anthropogenic pressures. Overall, this exploratory study highlights the species' behavioral plasticity in response to environmental and human-related changes. However, increasing human disturbance and climate change pose significant conservation challenges, particularly in areas characterized by a high human–wildlife interface.

Abstract

The activity of an Apennine wolf (*Canis lupus italicus*) family inhabiting the natural reserve Calanchi di Atri in central Italy was monitored during the post-reproductive period (May–October) of two consecutive years (2023–2024), using ten camera trap sites. Detections were classified into adults and pups. Although records cover a limited period and focus on a single pack, they allowed the detection of variations in the spatiotemporal activity of the wolf family. In the first year, wolf activity peaked in summer, with adults frequently supervising pups at rendezvous sites. In the second year, activity by both adults and pups declined significantly and was accompanied by an evident shift in territory use. In addition to potential intrinsic factors, such as individual variability and litter dynamics, these variations may also reflect increased environmental stressors and anthropogenic disturbance. These findings provide insights into how wolves adapt their behavior in human-modified landscapes and highlight the importance of integrating human–wildlife dynamics into conservation and management strategies.

Keywords: *Canis lupus italicus*; wildlife monitoring; camera trapping; anthropogenic disturbance; environmental stress



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1. Introduction

In Italy, the Apennine wolf (*Canis lupus italicus*) has successfully regained much of its original range over the years, thanks to specific protection efforts [1]. Its presence has generated both conservation interest and challenges, especially in areas where human activities such as farming are predominant [2]. Although the Apennine wolf is essentially a carnivorous predator, it follows an opportunistic diet according to the local availability of various food categories. The main preys are usually ungulates but, depending on the location or season, it can also feed on smaller mammals [3] and, to a lesser extent, on birds, fish, insects, fruits, vegetables and human waste [4]. Predation on livestock represents a major issue when wolf habitat and farming activities overlap, often leading to economic losses for farmers and potential conflicts that can hinder wolf conservation efforts [5–7].

As part of the Italian PAN project (Nature-Farmers Project, from Italian: Progetto Allevatori-Natura) aimed to protect local livestock farmers from wild predators [8,9], we conducted a study on the spatio-temporal activity and behavioral dynamics of the Apennine wolf living in the WWF protected Regional Reserve “Calanchi di Atri-Teramo”, Italy. The reserve is a relatively restricted zone where wild predators and livestock are often found in proximity. It therefore offers a unique opportunity to study animal behavior within an anthropogenic environment.

To explore the impact of human activities on wild apex predators, a wolf family that established a den in the reserve was monitored during the pup-rearing period (from May to October) over two consecutive years (2023–2024). The reported observations reveal that wolf activity significantly peaked during periods of increased pup mobility and development. Even though these observations are related to a single pack in a specific ecological context, they suggest that, in addition to differences in the composition of the observed individuals and social dynamics, anthropogenic and environmental factors may have strongly influenced the territorial use by wolves, prompting individuals to avoid disturbed areas while still exploiting resources within human-modified landscape. However, this behavioral flexibility may entail elevated energetic costs and impose constraints on reproductive success.

Understanding wolves' habits during the pup-rearing period, when the nutritional demands of the family unit significantly increase, may have important implications for ecosystem management, in supporting the development of strategies to promote coexistence between humans and this wild predator.

2. Materials and Methods

2.1. Study Area

The Reserve ‘Calanchi di Atri, established in 1995 and designated as a WWF conservation area in 1999, is located in the Northern part of Abruzzo region, Italy, between the Gran Sasso National Park and the Adriatic coast, in the province of Teramo (Figure 1). The reserve's boundaries extend for a total of approximately 600 hectares, a 220-hectare buffer zone included, from an elevation of 106 m to 468 m above sea level (website: <https://riservacalanchidiatri.it/la-riserva/> accessed on 1 February 2026).

The reserve is renowned for its significant concentration of badlands, locally referred to as “Devil's scratches” due to their striking geological formations. These badlands are the result of specific geomorphological conditions, including clayey soils with a particular sand content, a climate marked by alternating storms and dry seasons, and a lack of vegetation. The conspicuous geological formations of the reserve create a mosaic of habitats, including dry grasslands, rocky outcrops, and sparse woodlands. This topographic variety, coupled with the Mediterranean climate, produces a range of microhabitats that support different species.

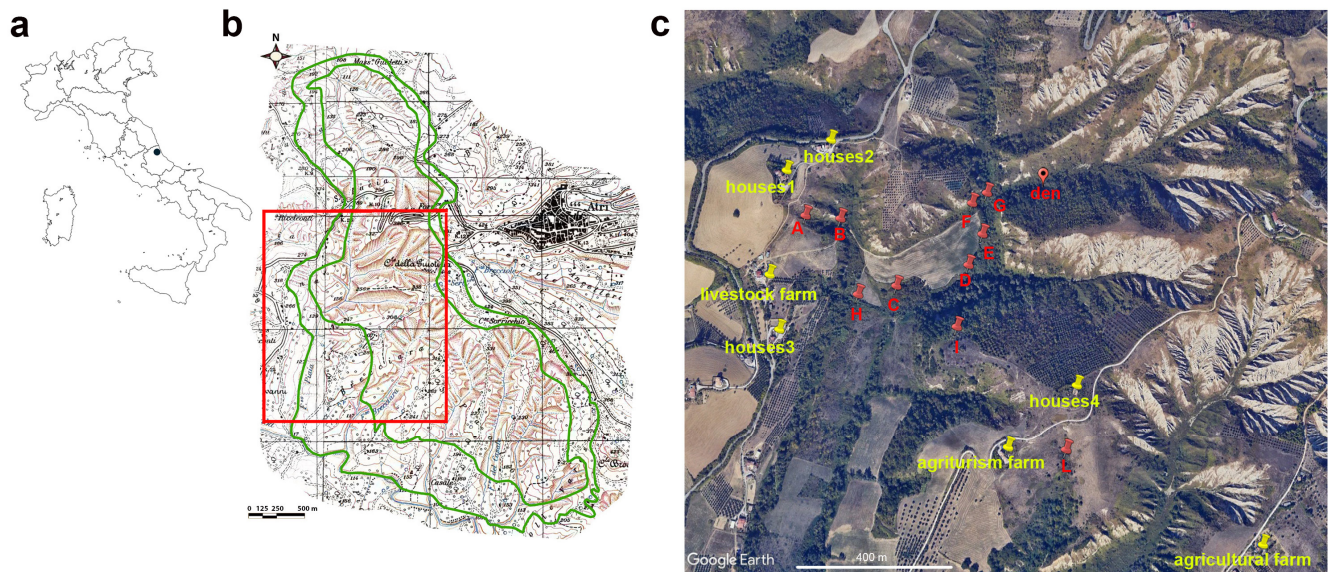


Figure 1. Maps of the study area. (a) In the map of Italy, the location of the Regional Reserve Calanchi di Atri is indicated by a black dot. (b) In the geographic map, the border of the Reserve is indicated by a green line; the area where camera traps are located is boxed in red. (c) Detailed view of the study area, showing the locations of camera traps A–L (red markers), main anthropogenic activities (yellow markers), and area potentially containing the den (red pointer). Map was generated using Google Earth Pro 7.3.

Despite the seemingly hostile conditions, the reserve hosts numerous plant species specialized in living in extreme environments. The high concentration of sodium in the substrate, steep walls, sun-exposed slopes, scarcity of organic matter in the soil, and frequent landslides are all factors that influence the floristic composition of the area. Among the ungulates present, the wild boar (*Sus scrofa*) and the roe deer (*Capreolus capreolus*) are the main prey of the Apennine wolf. Other medium and large mammals present in the reserve include the beech marten (*Martes foina*), the European brown hare (*Lepus europaeus*), the European badger (*Meles meles*), the red fox (*Vulpes vulpes*), and the crested porcupine (*Hystrix cristata*).

2.2. Camera Trap Location

Ten Stealth trail camera traps (Model: CW-200W01, 2MP CMOS) were used to collect data. The appropriate sites to locate camera traps were identified after experimenting several locations and paths near farms within the reserve and close to grazing areas (Figure 1), according to the Italian “Farmers-Nature Project” aimed at reducing conflicts between wild predators and livestock farmers. In addition, camera traps’ sites were chosen based on both direct and indirect signs of animal activity, including the observation of footprints, natural trails, and the presence of feces [8,9]. The cameras, marked from A to L, were installed at key access points to pastures and livestock shelters, such as trails and bushes adjacent to the meadows used for grazing (Table 1).

Table 1. Linear distances (in meters) between selected camera trap sites and anthropogenic structures within the study area, calculated as the crow flies using Google Earth Pro’s measurement tool.

Starting Point	Point of Interest	Distance (m)
Camera Trap A	Houses 1	132
Camera Trap A	Houses 2	211
Camera Trap A	Livestock Farm 1	182
Camera Trap H	Houses 3	222

Table 1. Cont.

Starting Point	Point of Interest	Distance (m)
Camera Trap H	Livestock Farm	243
Camera Trap I	Houses 4	352
Camera Trap I	Agritourism Farm	338
Camera Trap L	Houses 4	164
Camera Trap L	Agritourism Farm	154
Camera Trap L	Agricultural Farm	560
Camera Trap F	Den	156

2.3. Data Collection, Analysis and Elaboration

The planned wolf monitoring program focused on the post-reproductive period, spanning from the emergence of pups from the den in May, to the attainment of sufficient independence, at the end of October. Camera traps were programmed to operate from 6:00 PM to 8:00 AM CEST, coinciding with the crepuscular and nocturnal activity peaks typical of wolves, and to avoid false triggers and data overload from high daytime human and domestic animal activity within the reserve. Videos were collected regularly every 10 days. For each video, the collected data included: camera location and coordinates, date and time of the recording, observed species, number of individuals per species, sex (if visible), age category divided into adults (including young wolves) and pups, type of activity (e.g., feeding, predation, interaction, marking, crossing, resting, vocalization), and any additional notes. All the collected data were entered into an Excel file and statistically analyzed using R (R Core Team) [10], with significance set at $\alpha = 0.05$.

Spatial analyses were also performed in R. Camera trap locations were summarized by calculating mean coordinates for each station, based on a projected coordinate system (Gauss–Boaga). A Euclidean distance matrix among camera traps was then computed to quantify spatial relationships among sampling sites. Spatial structure was assessed using Moran’s I, calculated through a k-nearest neighbors approach ($k = 3$) to define spatial weights, implemented in the spdep package. This analysis was applied to both the number of contacts and behavioral diversity recorded at each camera station. Finally, a spatial analytical map, showing camera trap locations in a Cartesian coordinate system, was produced using the ggplot2 package.

3. Results

3.1. Comparison of the Temporal Activity of Wolf Adults and Pups

In the two-year period of observations, camera traps collected over 8000 videos, of which 710 related to the Apennine wolf, for a total of 986 wolf detections. In contrast to other mammals (except the roe deer), whose detection rates generally remained stable or slightly increased between 2023 and 2024, wolf detections showed a marked decline (Table 2).

Table 2. Total number of the Apennine wolf and other mammals detected in the study area in 2023 and 2024.

Year	<i>Canis lupus italicus</i>	<i>Hystrix cristata</i>	<i>Martens foina</i>	<i>Capreolus capreolus</i>	<i>Meles meles</i>	<i>Vulpes vulpes</i>	<i>Sus scrofa</i>
2023	603	434	106	21	176	641	7563
2024	383	503	124	4	143	571	8701

Monthly variations in wolf detections differed between years, with particularly high values recorded in September 2023 and a clear reduction in September 2024 (Figure 2).

Age structure also varied significantly between sampling years. The proportion of pup detections was substantially higher in 2023 (405 of 603 detections, 67%) than in 2024 (170 of 383 detections, 44%), indicating a shift in population age composition or in the use of the area. In 2023, pup detections increased from July and peaked in August–September, reaching a maximum in September. In contrast, in 2024 pups were absent until August and declined sharply thereafter. Overall, these results suggest strong interannual variation in reproductive output or pup detectability.

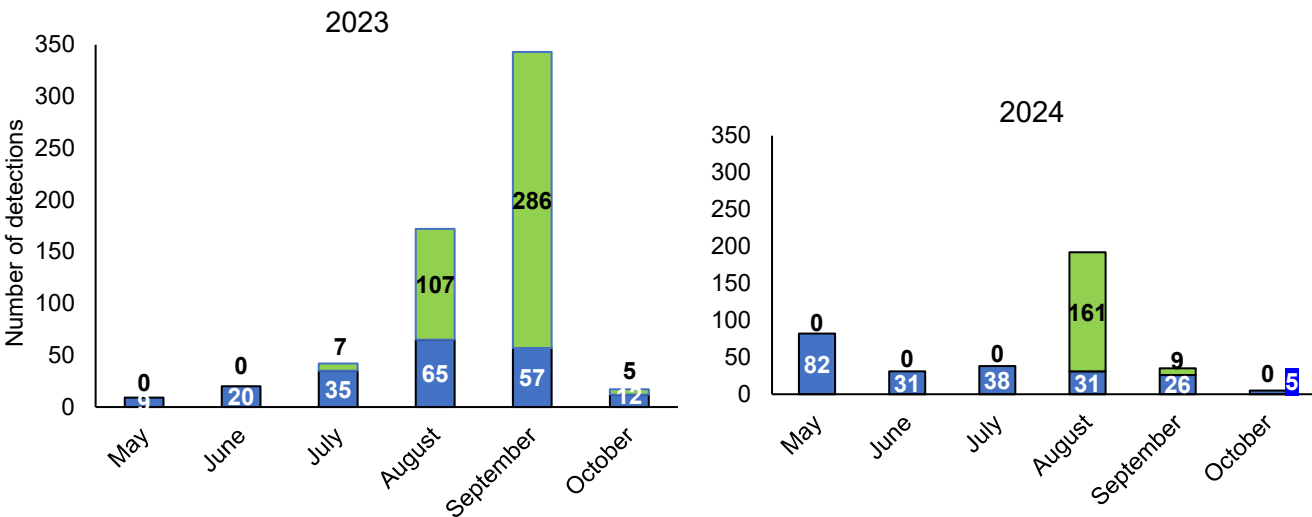


Figure 2. Total detections of adult wolves (blue bars) and pups (green bars) from May to October in the two consecutive years. The number of detections is indicated in white (adults) and black (pups). Zero indicates no detection.

Both adults and pups were active during the night, with high numbers of pup detections in particular (Figure 3). Adult activity was similar in 2023 and 2024, whereas pup detections declined significantly in 2024. Moderate positive correlations were observed between adult and pup numbers in both years (2023: $r = 0.43$; 2024: $r = 0.36$), suggesting that the higher numbers of adult detections were associated with higher numbers of pup detections.

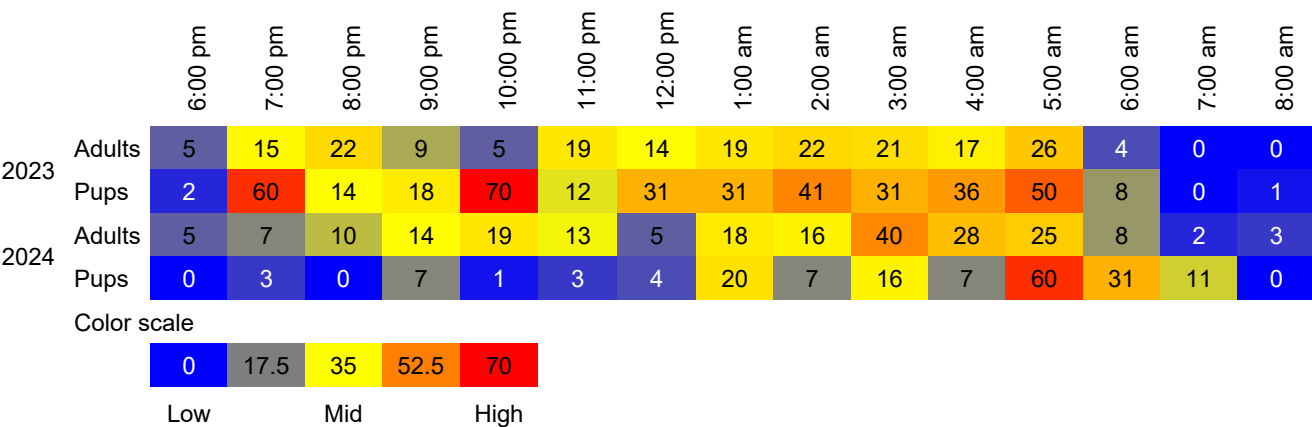


Figure 3. Heatmap of hourly detections of wolf adults and pups in 2023 and 2024. Rows represent groups, and columns represent observation times from 6:00 PM to 8:00 AM. Color intensity indicates the number of individuals observed, from low (blue) to high (red).

Adults were active throughout the night, peaking between 2:00 and 5:00 AM. Pup activity in 2023 showed pronounced evening peaks (7:00 and 10:00 PM) and an early

morning peak (5:00 AM), whereas in 2024, pup counts were generally lower, with activity concentrated around 5:00–6:00 AM. This pattern reflects the reduction in pup abundance between the two years.

3.2. Comparison of the Spatial Activity of Wolf Adults and Pups

Comparison of wolf spatial activity between 2023 and 2024, monitored across the ten camera trap sites (A–L) and distinguished between adults and pups, shows notable trends in spatial use and population distribution, suggesting dynamic territorial use and changes in pack structure over time. In 2023, camera traps B (73 adults) and G (58 adults) recorded the highest adult wolf activity, while traps F (55 pups), G (94 pups), and especially E (149 pups) showed significant pup activity (Figure 4). Several sites, including A, H, and L, recorded relatively low activity for both adults and pups. These patterns suggest that wolves concentrated their activity in specific areas, potentially corresponding to core territory zones near the den. Due to the frequent observations of pups engaged in social interactions, areas surrounding traps E, F, and G were identified as key sites for aggregation and potential rendezvous points, as pups recurrently gathered in groups at these sites remaining near the camera traps. The rendezvous site close to location E remained the preferred one, where play activities were most frequently observed.

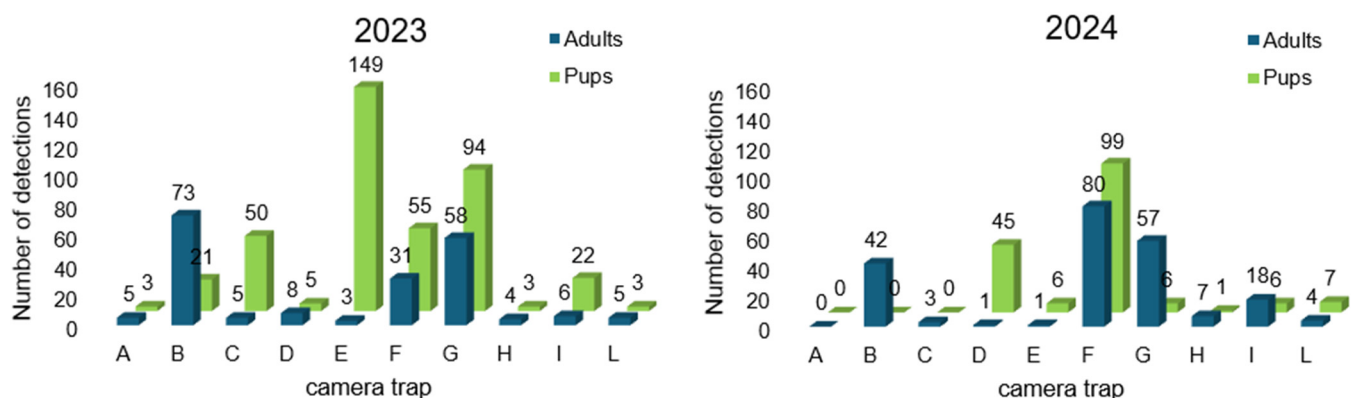


Figure 4. Spatial activity of wolves registered by the different camera traps (A–L) in 2023 and 2024. For each camera trap, the number of adult and pup detections is indicated.

The use of the area near camera trap C—near the zootechnical facility and overlooking part of the reserve—suggests a growing familiarity of pups with the surroundings, as indicated also by an increase in visible markings during the peak period of pup activity (Figure S1). In the same year, data collected by camera traps B, F and G, along with numerous sightings of wolves crossing that area while transporting prey, allowed the identification of a preferred food transport route. Food transport along this route was consistently carried out by adult wolves; in contrast, food transport observed at meeting points C and E was primarily carried out by pups.

In 2024, notable shifts occurred in both adult and pup distribution. Camera traps F and G consistently recorded high numbers of both adults and pups, supporting the role of these areas for the pack in proximity of the den. The activity of adult wolves increased at F (31 → 80 adults) and I (6 → 18 adults), indicating a movement into these areas or a shift in hunting patterns. In 2024, a clear reduction in pup presence was observed at B (21 → 0) and C (50 → 0), as evidenced also by the absence of fecal markings at the rendezvous points near these locations (Figure S1). Trap A, the closest to farms and pastures, went from moderate activity in 2023 to no detections in 2024, suggesting potential abandonment or temporary avoidance of the area. Conversely, trap D (5 → 45) recorded increased pup presence in 2024, implying movement of pack into these areas.

3.3. Behavioral Analysis

A combined analysis of wolf behavioral activity from 2023 and 2024 revealed that movement and resting were the most frequently recorded behaviors across all camera traps (568 and 66 records, respectively). Both activities typically involved one or two individuals per event, with limited to moderate variability in group size. Food carrying was consistently observed as individual behavior, suggesting that feeding-related activities are predominantly solitary when detected (34 records). In contrast, social behaviors such as interactions, play, and vocalizations were comparatively rare but generally involved multiple individuals. Although the number of recorded events was generally low, play was more frequent (36 records) and characterized by small-to-medium group sizes (average number of individuals 2.5). Vocalizations were infrequent and involved more than one individual, though the limited number of observations (3 records) restricts interpretation.

Movement was the predominant behavior in both age classes, accounting for 91% of events in adults and 68% in pups. Marked differences emerged in the distribution of other behaviors between adults and pups ($\chi^2 = 114.87$, $df = 5$, $p < 0.0001$), providing strong evidence that age plays a key role in shaping activity patterns. Adults were almost exclusively engaged in movement, with only limited occurrences of feeding (7.4%) and resting (1.6%), and no observations of play or social interaction. Pups exhibited a broader behavioral repertoire: in addition to movement, they frequently engaged in social and recreational activities, with play accounting for 10.5% of events and resting for 17.5%. Interaction and vocalization were rare but present (0.9% each).

Spatial analysis across camera traps revealed a heterogeneous distribution both in terms of total frequency and behavioral diversity (Figure 5). The highest number of records containing behavioral events was registered at camera trap F (175 records), followed by G (145 records), B, and E, indicating areas of higher animal activity. In contrast, camera traps A, H, and L recorded the lowest number of behavioral events. Interestingly, the relationship between observation frequency and behavioral diversity was not consistent across locations. The highest diversity values, measured using the Shannon diversity index (SDI), were observed at E, C, and D (SDI 0.938, 0.844 and 0.811, respectively), suggesting that, despite a lower total number of records containing behavior activities compared to F or G, behaviors are more evenly distributed across categories, thereby increasing overall diversity. Conversely, B, H, and L showed the lowest diversity values (SDI 0.263, 0.271, and 0.271, respectively), reflecting a combination of few events and limited behavioral diversity.

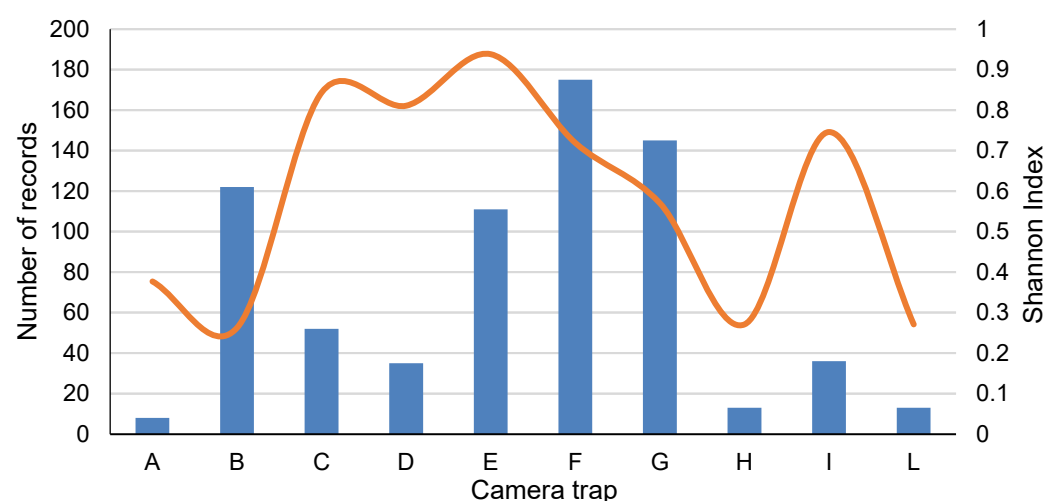


Figure 5. Frequency of behavioral observations (blue bars) and behavioral diversity (Shannon index; orange line) recorded at each camera trap location. Behavioral activity and diversity varied among sites, suggesting spatial differences in habitat use and behavioral functions.

When considering the geographic distribution of camera traps, behavioral diversity showed a clear spatial structure across camera trap locations (Figure 6). The Mantel test revealed a positive correlation between geographic distance and behavioral difference among sites ($r = 0.406$, $p = 0.005$), indicating that more distant sites tended to exhibit more distinct behavioral patterns. Consistently, Moran's I indicated strong positive spatial autocorrelation in behavioral diversity ($I = 0.530$, $p = 0.0003$), suggesting that nearby camera traps tended to record similar levels of behavioral diversity. Notably, variation in behavioral diversity was not consistently associated with the number of records (Moran's $I = 0.169$, $p = 0.064$), reinforcing the lack of a direct relationship between activity and behavioral complexity.

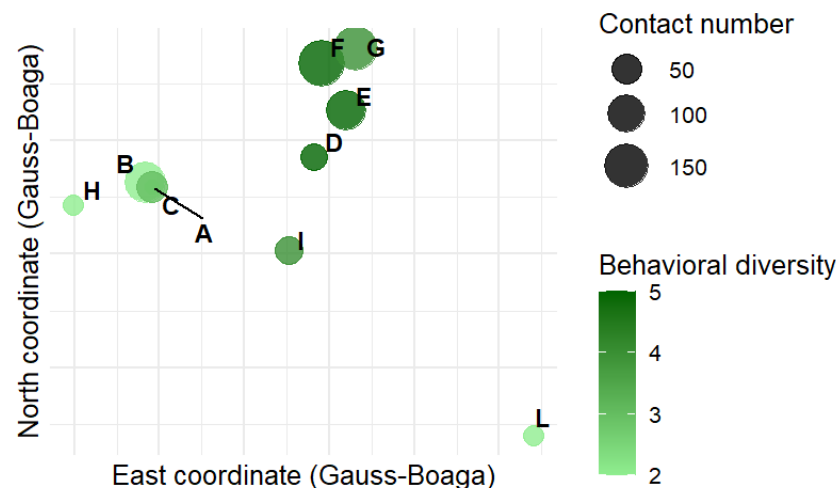


Figure 6. Spatial distribution of camera traps in the study area. Each point represents a sampling station, positioned according to Gauss–Boaga coordinates. Point size is proportional to the number of recorded contacts, while color intensity (green gradient) indicates behavioral diversity, expressed as the number of distinct activities observed at each camera.

4. Discussion

Although limited to a two-year period a single wolf pack, this study provides a preliminary description of spatial and temporal patterns of wolf activity within the relatively small Natural Reserve Calanchi di Atri. Adult activity remained largely stable across years, whereas pup activity varied markedly in both magnitude and timing. This interannual variability may influence the stability of the family unit, although longer-term monitoring is required to assess its demographic consequences. Spatially, adult activity showed site-specific fluctuations, while pup distribution changed more substantially, with some areas abandoned and others newly occupied.

The observed differences in spatiotemporal activity between years may reflect intrinsic individual variability and litter-specific social dynamics, particularly given that pups represent different individuals each year. However, climatic conditions may also have contributed to the observed patterns. A prolonged drought, combined with elevated temperatures, occurred from late June to mid-August 2024 (Figure S2). Water scarcity likely led shepherds to abandon higher-altitude pastures and shift grazing activities to lower-altitude areas—where wolf presence was more consistent—as indicated by the movement of sheep into areas that had been used solely for hay production in previous years (2020–2023) (Gallizia and Pennacchioni, personal communication). Consequently, the increased livestock presence around camera traps A, B, and C, along with the daily flock movements at dawn and dusk and the presence of protection dogs and agricultural machinery, may have played a role in the progressive avoidance of this area by the wolf family. The absence of wolf detections by camera trap A, located near the livestock farm, is

consistent with previous studies indicating that wolves tend to avoid areas with intensified human activity [11–16]. Conversely, wolf activity increased significantly at camera trap F, suggesting a spatial redistribution rather than an overall decline. The regular use of this area indicates that it functioned as a primary access route to the den, further supported by direct observations of food transport concentrated at this location. Therefore, the wolf family rapidly adjusted movement patterns while maintaining proximity to the den. Such adjustments likely represent adaptive strategies aimed at minimizing disturbance while maintaining access to essential resources [17–19].

Environmental stressors may also have influenced reproductive outcomes. Altered movement patterns and potential constraints on foraging efficiency could have affected energy allocation and parental investment, possibly contributing to the lower number of pup detections recorded in 2024 compared to 2023.

Behavioral observations were strongly dominated by a few key activities; however, age-related differences revealed clear patterns linked to developmental stage and social roles within the group. The mismatch between activity levels and behavioral diversity indicates that frequently used sites are not necessarily those supporting the most complex behavioral repertoires. This finding highlights the importance of integrating behavioral diversity metrics with traditional measures of activity when interpreting space use from camera trap data.

The observed spatial clustering of high behavioral diversity suggests the presence of behavioral hotspots, where wolves engage in a wider range of activities. In the study area, these hotspots were located near the den and may correspond to key ecological sites such as feeding zones, resting areas, or locations of social interaction. Conversely, sites characterized by lower behavioral diversity may function primarily as movement corridors, where animals are frequently detected but exhibit a limited range of behaviors.

Overall, the patterns observed in this study suggest that wolves may exhibit flexible spatial responses under varying environmental and anthropogenic conditions. However, given the exploratory nature of the study, further research including multiple packs and longer time series is needed to test these hypotheses and provide stronger inferential support.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/wild3020020/s1>, Figure S1: Spatial distribution of wolf markings recorded in 2023 and 2024; Figure S2: Daily precipitation and air temperature recorded in July and August of 2023 and 2024.

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