World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

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Social structure and ecology of *Panthera pardus* Linnaeus, 1758 in Taï National Park, Côte d'Ivoire

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World Journal of Advanced Research and Reviews, 2024, 24(03), 420–432

Publication history: Received on 26 October 2024; revised on 02 December 2024; accepted on 04 December 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.24.3.3696

Abstract

Knowledge of the periods of activity and the social structure of large carnivores constitute a challenge in African forest habitats due to their cryptic behaviour and the difficulty of observing them with traditional inventory methods such as counting along line transects and recce surveys. The present study was carried out to provide reliable information on the periods of activity and the social structure of the leopard (*Panthera pardus*) in a protected humid forest, the Taï National Park (TNP), in Côte d'Ivoire. Over 12 months, we installed 200 camera traps in the five sectors of the TNP. The processing of trapping data made it possible to obtain one hundred video recordings of leopard. Our observations indicate that in the TNP, the leopard has cathemeral activity, 37% of which occurs at night, 47% during the day and 16% at dusk. However, we had 31 solitary adult individuals which correspond to 60% of the overall encounter rate and twenty-one (21) individuals in groups including nine (09) groups of two individuals and a group of three individuals corresponding to 34% and 6% of the encounter rate, respectively. We conclude that the leopard leads a mainly solitary life in the TNP.

Keywords: Leopard; Taï National Park; Period of activity; Social structure

1. Introduction

Tropical forests constitute one of the largest reservoirs of biodiversity on planet earth [1]. Unfortunately, the alteration of ecosystems by devastating human actions is a major threat to biodiversity loss [1,2,3,4,5] . Given this situation, the conservation of animal populations in their natural habitats is becoming a global concern.

In Côte d'Ivoire, despite efforts to conserve plant cover, the Ivorian forest block continues to regress under the pressure of anthropogenic activities [6] such as, timber exploitation, deforestation, extensive cultivation, bush fires and poaching. Taï National Park is the largest forest massif in West Africa [7,8,9]. Thanks to its rich biodiversity, the TNP remains one of the last refuges for wildlife in general and large mammals in particular, including the leopard (*Panthera pardus*, Leaennus, 1758).

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The loss of natural habitats means that animals are increasingly confined to protected forest fragments[7,10,11]. In these protected areas, wildlife in general, and leopards in particular, play important roles in maintaining the balance of ecosystems[7,12,13,14,15,16], such as in the Taï National Park (TNP). The leopard (*Panthera pardus*), as an apex predator, plays a very important ecological role in the functioning of ecosystems, considerably influencing the structure and function of these ecosystems [17, 18, 15]. Indeed, the leopard plays the role of ecological engineer, being a regulator for excellence of prey populations in habitats where it remains the largest carnivore in the food web[19, 16].

However, despite its role in the food web, few studies have been carried out on the leopard. In TNP, the only studies carried out on the leopard are those by Jenny [20] and Züberbuhler & Jenny [21], conducted by radio tracking the spectrum of their prey at the ecology research station. Consequently, no study has been carried out on the Leopard at the TNP scale, and the one available deserves to be updated. With a view to overcoming this information deficit, a study to determine the social structure and ecology of the leopard has been initiated in the TNP.

2. Material and methods

2.1. Study site

Taï National Park, located between latitudes 7°17' and 6°48'N and longitudes 5°18' and 6°14'W, is situated in south-west Côte d'Ivoire (Figure 1). It is the largest strictly protected rainforest park in West Africa. Together with the N'Zo Partial Wildlife Reserve, it covers an area of 536,016 hectares [22]. It is characterized by the presence of dense humid vegetation of the evergreen or ombrophilous type. In view of its inestimable value in terms of its floristic and faunal diversity and the ecosystem services it provides, the TNP was classified as a "biosphere reserve" in 1978. It has also been on UNESCO's list of World Heritage Sites since 1982 [6]. The average annual rainfall is 1,800 mm and the average annual temperature is 24°C [23, 24]. The TNP is characterized by exceptional species diversity and a high level of endemism, making it one of the world's biodiversity hotspots [25].

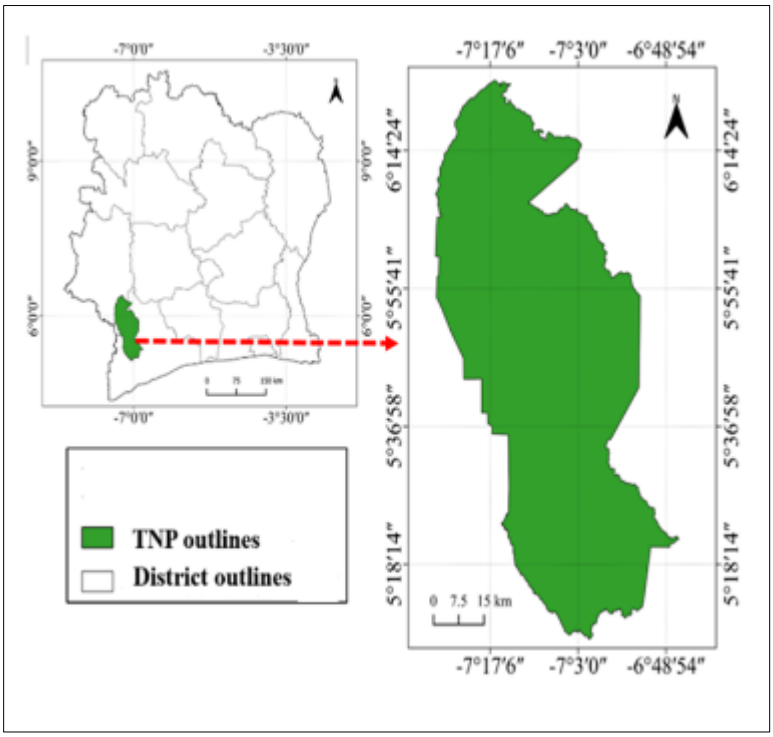

Figure 1 Study site localization

The TNP is home to around 145 mammal species, corresponding to 93% of the mammal species in the West African forest zone. Twelve species are endemic to the region (from Sierra Leone to Taï), including the Jentink's duiker (*Cephalophus jentinki*), the zebra duiker (*Cephalophus zebra*) and the diana cercopithecus (*Cercopithecus diana diana*). The pygmy hippopotamus (*Choeropsis liberiensis*) now lives only in eastern Liberia and the Taï region. More than a thousand vertebrates (mammals and rainforest birds) are present in the park [26, 27]. The primate order is represented in TNP by 12 species belonging to the Pongidae, Cercopithecidae, Loridae and Galagonidae families [28, 29, 30, 31, 32,

33]. The bovid family is also well represented, with 11 species[34, 7, 1]. The forest elephant (*Loxodonta africana cyclotis*), part of TNP's rich heritage, is one of the park's conservation target species [35, 36].

The equipment used for the study consisted of Bushnell Trophy Cam HD Agressor camera traps (CT) for leopard data collection, a GARMIN 64s GPS (Global Positioning System) for geo-referencing camera trap sites, a compass for forest orientation, and a decameter for measuring the height at which the CT were installed on the "tutor tree".

2.2. Data collection

The data collection phase for this study covers a period from March 2019 to February 2020, i.e. 12 months. The point transect method adapted to photographic traps was used to collect data over the entire extent of the TNP, which is subdivided into five sectors (ADK/V6, Djapadji, Djouroutou, Soubré and Taï). This methodology is in line with that described by Howe *et al*. [37]. It consisted in establishing a systematic sampling system based on a 4×4 km grid. This grid was superimposed on the park map, using Qgis software version 2.18.7. The four vertices of a mesh were chosen as the camera trap (CT)points.

CT were located 4 km from each other throughout the park. The final layout comprised 291 CT installation points, distributed in proportion to the area of the different sectors: 66 points in Taï (130127 ha); 56 points in Djouroutou (97896 ha); 58 points in Soubré (104352 ha); 55 points in ADK/V6 (101917 ha) and 56 points in the Djapadji Sector (102030 ha) (Figure 1). However, given the limited number of CT (200), their deployment was rotated on a fortnightly basis. Thus, after a period of installation of two consecutive months at a given point, the CT is removed and redeployed at another site in order to cover all five sectors of the park.

Access to the installation point was by land navigation using GPS and compass [38, 39]. In the forest, for each of the points to be sampled, the CT was oriented at either 0° or 180° in a north-south direction to avoid sunlight in the field of view of the camera traps [38, 39]. Sometimes a deviation of ± 20° was made to deflect obstacles such as windfalls, streams and dense undergrowth. In addition, CT were sometimes installed within 30 m of the planned theoretical point [38, 39] when more interesting signs of presence were observed there. Finally, the CT was mounted on a "tree-tutor" at a height of around 0.5 m from the ground. The CT were calibrated in video mode with 60 seconds recording sequences, where the trigger interval between two successive detections was programmed at 2 seconds to optimize the chances of capturing the target species[38, 39].

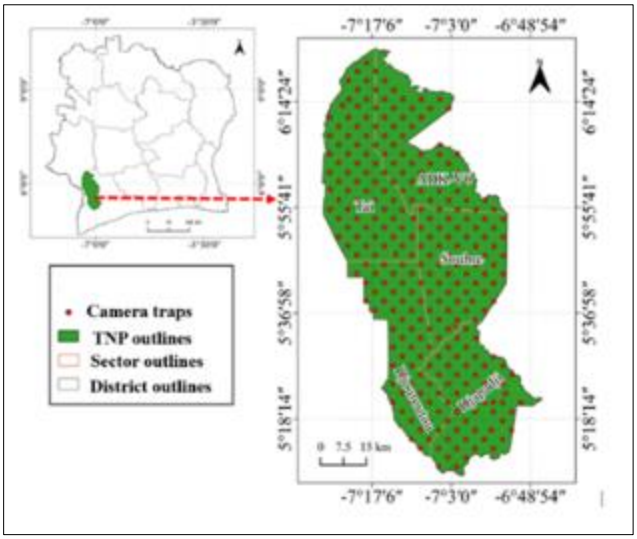

Figure 2 Camera trapping system for Taï National Park

2.3. Data analysis

2.3.1 Determining periods of activity

In this study, the notion of activity periods refers to the period when the leopard is active, when it is moving, and therefore detectable by CT[37]. The start time of the first video of each event was considered the event time [40, 41, 42, 38, 39,]. An event is the set of videos taken at the same trapping point during a period of duration ≤ 30 minutes [43, 38, 39,]. The capture times of the various events were used to determine leopard activity periods following the classification

of Gómez *et al*., [44] (Table 1). For this purpose, the 24 hours day was divided into three periods[44, 45]: daytime from 6:30 a.m. to 5:30 p.m., nighttime from 6:30 p.m. to 5:30 a.m. and twilight between 5:30 a.m. - 6:30 a.m. and 5:30 p.m. - 6:30 p.m..

Table 1 Activity periods according to the Gómez *et al*. [44] classification

Periods of activity	**Definition**
Diurnal species	Less than 10% of sightings at night
More diurnal than nocturnal species	10 to 30% of sightings at night
Cathemeral species	30 to 70% of sightings at night
More nocturnal than diurnal species	70-90% of sightings at night
Nocturnal species	Over 90% of sightings at night
Crepuscular species	50% of observations at dusk

2.3.2 Determining the social structure

In order to analyze the leopard's type of association (solitary or association). We analysed the leopard's activity on the basis of video sequences. After grouping the detections into events, we counted the number of distinct individuals for each event. This number is considered the size of the group observed[46, 38, 39]. The age class of individuals is determined on the basis of morphological traits such as size, height and rosette shapes where appropriate [14].

2.3.3 Determining aspects of leopard behaviour

For each video of the species viewed, the type of behaviour observed, the location and the period of observation were indicated in the database. For the four aspects of behaviour (spotting, moving, foraging and resting) researched, we summed up the number of times it was observed in independent videos. The description of these behaviours made in accordance with Green-Barber & Old [47], is presented in Table 2.

Table 2 Behavior categories and descriptions

Behaviour category	**Description**
Spotting	Any tracking, sniffing and/or manipulation of the camera attached to the tree stake Stands silently, motionless, stopped or turning its head to scan the environment, or with only its ears moving.
Foraging	Any active catch or pursuit of prey
Resting	Lying on the ground or standing still for a while on the ground or on a tree, or stopping in front of the camera
Moving	Any consecutive quadruped movement

3. Results

3.1. Social structure of the TNP leopard

According to the analysis of our CT capture events, group size varies from one (01) individual (solitary) to three (03) individuals (association). Solitary individuals, mostly adults, were observed on 31 occasions, equivalent to 60% of capture events. Groups of 2 and 3 individuals were observed on nine (09) occasions (34%) and one (01) occasion (6%) respectively (Table 3). These results allow us to deduce that the TNP leopard is preferentially solitary, as it is mostly observed alone (60%). In addition, we recorded 31 solitary individuals (adults), corresponding to 60% of the overall rate and 21 individuals in association, made up of juveniles and adults. In this category, we counted nine (09) groups of two (02) individuals corresponding to 34% of the overall rate and one (01) group of three (03) individuals corresponding to 6% of the overall rate. Figure 5 shows photographs of forest leopards at PNT captured by CT.

Table 3 Group composition and frequency of leopard sightings at TNP

		Capture event		Total number of individuals	Group structure		
		Number	%		Adult		Juvenile
					♂	♀	
Solitary individual		31	60	31	6	14	11
Group	2 individuals	9	34	18	5	10	3
	3 individuals	1	6	3	NA	NA	3
Total		41	100	52	11	24	17

3.2 Some behavioural aspects of leopards in TNP

A total of four (04) behaviours were considered in this study: moving, spotting, foraging and resting (Table 2). However, the processing of these behavioural data gave us 81.25% movement, 8.33% foraging or feeding, 6.25% spotting and 4.16% resting throughout the Park. As the rates indicate, movement is the dominant behaviour, so the leopard spends its time on the move (Figure 4). Foraging is the second most frequently observed behaviour, followed by tracking. Resting is the least observed (see distribution map: figure 3a to figure 3d). The figure 6 illustrates the behavioural aspects of the forest leopard at the TNP captured by the CT.

This distribution over the entire park territory enables us to deduce rates by sector: 80% displacement, 10% foraging, 5% spotting, 5% resting in the Taï sector; 67 % displacement, 16.5% spotting, 16.5% resting in ADK-V6 sector; 89% moving, 11% foraging in Soubré sector; 70% moving, 10% foraging, 10% spotting, 10% resting in Djouroutou sector; 100% moving in Djapadji sector (Table 4).

The leopard's movement behaviour was observed in all sectors (ADK-V6, Djapadji, Djouroutou, Soubré, Taï), with a high observation rate (Figure 4) in ADK-V6, where the leopard spends a great deal of time on the move (Figure 3a). Resting behaviour was least observed in the Taï sector (Figure 3d), with a low observation rate (Figure 4). Leopards spend less time resting. Foraging was the second most frequently observed behaviour (Figure 3b), followed by camera-trap spotting, which can be seen as a form of vigilance (Figure 3c).

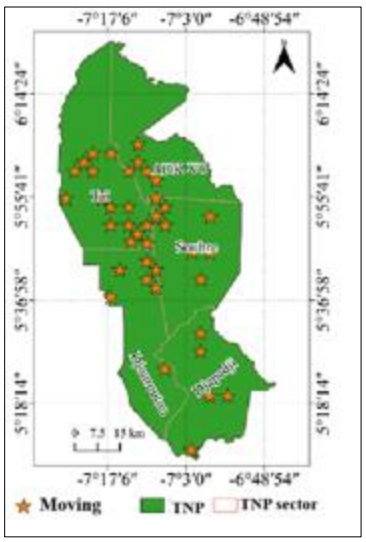

Figure 3 a Move distribution map

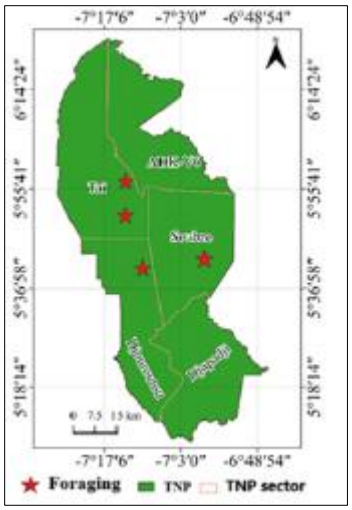

Figure 3b Forage distribution map

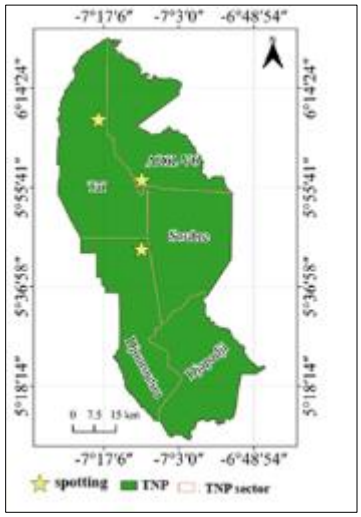

Figure 3C Spotting distribution map

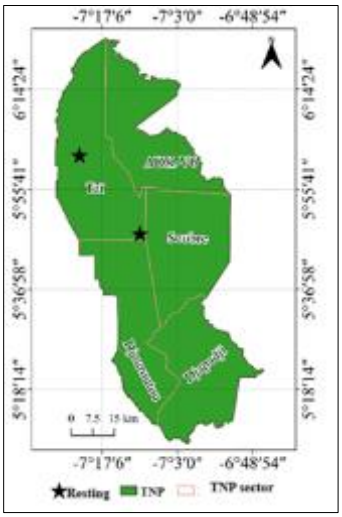

Figure 3d Resting distribution map

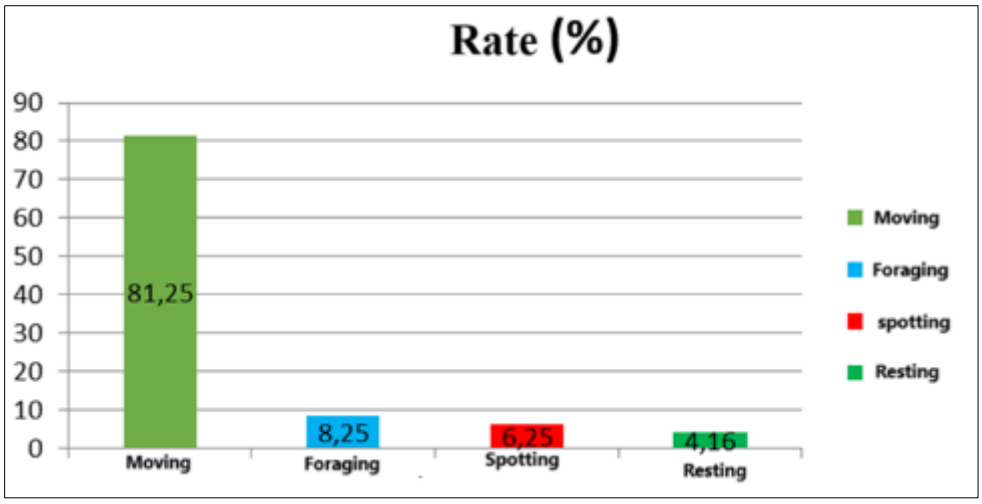

Figure 4 Frequency of observation of behavioural aspects in Taï National Park

Figure 5 Some images of forest leopard captured by CT in Taï National Park (5.a solitary; 5.b two individuals, 5.c three individuals)

Figure 6 Some illustrations 6.a: Feeding / 6.b: Resting / 6.c: Moving a female / 6.d: Camera tracking / 6.e and 6.f: Moving a male

Table 4 Observation rate of leopard behaviour by sector

Common name	Scientific name	Behavioral aspects	ADK-V6	Djapadji	Djouroutou	Soubré	Taï
		Moving	67%	100 %	70 %	89 %	80 %
		Spotting	16.5	0 %	10 %	0 %	5 %
Leopard	*Panthera pardus*	Foraging	0 %	0 %	10 %	11%	10 %
		resting	16.5	0 %	10 %	0%	5 %
Total			100 %	100 %	100 %	100 %	100 %

3.3 PNT leopard activity periods

When we relate these different behaviours to the periods during which they were recorded, we identify different periods of activity. In this study, the leopard was cathemerally active, with 37% at night, 47% during the day and 16% at dusk (figure 3a). This means that the species is active both day and night, as well as at dusk. This species has two major peaks, the first occurring just after the start of the day (07:00) and the second just after the start of the night (18:00). Movement peaks at the beginning of the day, with a peak of 12% at 07:00. On the other hand, leopard activity remains continuous both day and night, with several small peaks (Figure 3b). However, during the night, the dominant behavior is moving (70%), scouting (20%), foraging (10%), which is recorded very infrequently, and no resting behaviour was observed during the night. Moving (65%), foraging (30%) and spotting (5%) were recorded, and very little resting behaviour was observed during the day.

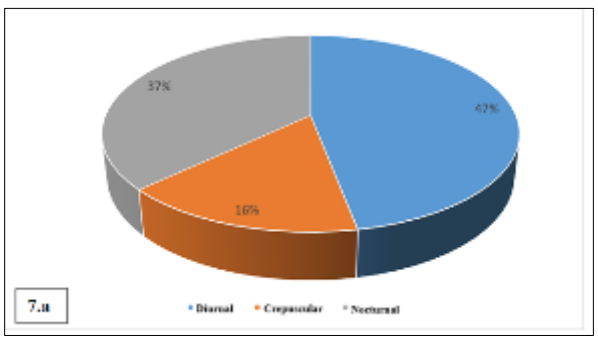

Figure 7.a *Panthera pardus* nocturnal activity frequency at PNT

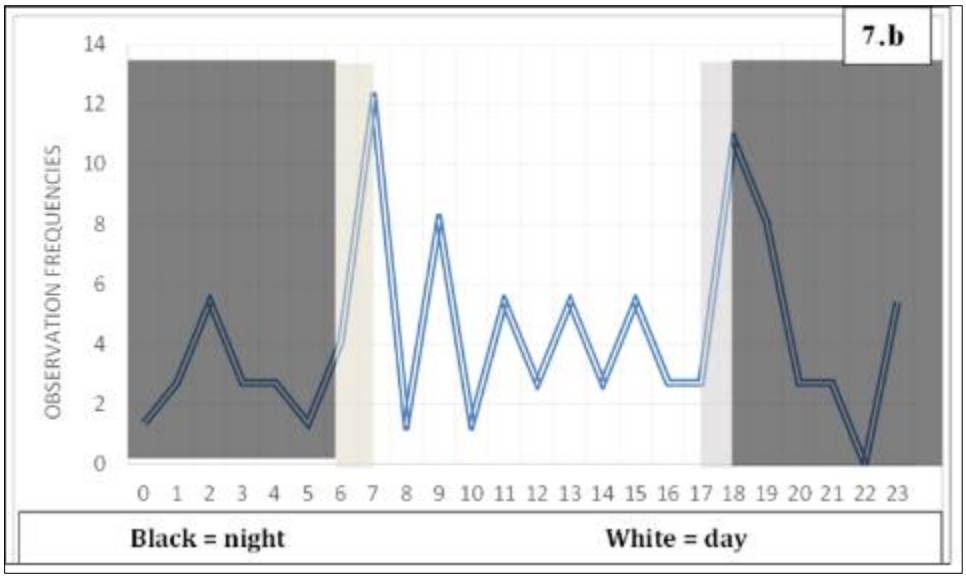

Figure 7.b Frequency of *Panthera pardus* sightings at TNP

4. Discussion

This work shows that the leopard has cathemeral activity. This study corroborates that of Özgün *et al*. [48], who found that the leopard exhibited cathemeral activity. This could be explained by the fact that prey species are available during the indicated periods. Indeed, forest leopards seem to follow the activity rhythms of their main prey [13, 49]. However, our study differs from that of Jenny [20], which involved the radio tracking of two leopard species at TNP. In this study, it was shown that leopards are more active during the day than the night. This could be explained by a difference in methodology. Jenny's study [20] was carried out using radio tracking, whereas ours was carried out using photographic trapping. Secondly, the limited duration of the study (54 hours for the male, 223 hours for the female) compared with ours, which was conducted over a full year (12 months). Indeed, according to Akpatou *et al* [50], the time spent on a wildlife survey can have a significant influence on the long-term results.

Our results also differ from those of N'goran *et al*., [51]. In their photo-trapping study of mammals in the TNP ecology research zone, these authors found that leopard activity was more diurnal than nocturnal. This could explain why the leopard's activity matches that of its main prey in the predominantly diurnal zone [20, 21]. This could explain the leopard's activity peaks at 7 a.m. and 6 p.m., as these times would represent the activity times of potential prey such as duikers [39].

The present study has highlighted the leopard's solitary structure. Indeed, this work corroborates those of several authors such as de Henschel [13], Boast., [52], Stein & Hayssen, [53], who highlight the solitary structure of the leopard in East and Central Africa. This solitary lifestyle enables them to be cryptic and efficient, while avoiding competition with other predators for prey or conflicts of interest [53, 54]. On the other hand, other authors believe that the solitary lifestyle is linked to the polygamous diet of male leopards [54], as they conquer their territories and like to be the territory leaders. However, associations have been observed at low frequency. However, these associations have been observed between females and their cubs. Not only would this explain the fact that females are in the process of initiating their young into hunting and various forest survival techniques [53, 13]. But also, by the fact that adults rarely meet except during mating periods when females are in heat and may attract surrounding suitors [55, 56].

The high rate of movement and tracking means that the leopard is constantly on the move in search of prey. The fact that this solitary species spends much of its time on the move while remaining vigilant is an indicator of predation. This implies that it spends more time on the move while remaining vigilant in order to surprise its prey. The work of Hunter and Barret [55], Strampelli P *et al.,* [57] confirms this. The low rate of observation of resting behaviour could be explained by the fact that leopards rest less because they are constantly on the move to ensure their survival and that of their offspring. This confirms the work of Hoppe-Dominik, [58]. We deduce that the preys are aware of the danger posed by this predator in the forest, and that the predator has developed attitudes that enable it to capture its prey.

5. Conclusion

This photographic trapping study made it possible to simultaneously determine the periods of activity, social structure and some behavioural aspects of the forest leopard. The leopard is cathemeral, with 37% activity at night, 47% during the day and 16% at dusk, and has a solitary lifestyle. The leopard's near-constant movement, scouting and foraging behaviours, combined with its low resting rate, suggest that the prey of the leopard is a solitary creature. We deduce that preys are aware of the danger posed by this predator in the forest, and that the predator has developed attitudes that enable it to capture its prey.

Compliance with ethical standards

Disclosure of conflict of interest

All authors of this manuscript Jarvis Brumel KOPOIN, Kouakou Djakaria DRAMANE, Djaha André KOFFI, Yao Célestin KOUAKOU, Malé Roger KELY, Claude-Victorien KOUAKOU, Kouamé Antoine N'GUESSAN, Kramoko BAMBA, Ange Edgard Habib MONKET, and Jean-Claude Koffi BENE confirm that they have no conflicts of interest or competing interests related to its publication.

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