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Preliminary survey of the threatened carnivores in the Daraina Loky-Manambato Protected Area, Madagascar

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ABSTRACT

Madagascar's protected areas safeguard numerous threatened endemic plant and animal species, including Euplerid carnivores, considered to be the most threatened yet understudied group of carnivores globally. The Loky-Manambato Protected Area (PA) in northern Madagascar encompasses a unique transitional forest ecosystem that is under pressure from forest loss and fragmentation. We provide the first photographic survey of Madagascar's carnivore community occupying this region with the aim of documenting carnivore species richness, relative activity (Trap Success), and spatial distribution (Naïve occupancy) across the landscape. To do this, we used 60 motion-activated cameras to survey along established trails in three forest patches across the Loky-Manambato PA: Antsahabe, Bekaraoka, and Antsaharaingy. We surveyed each forest for two weeks in September and October 2018. We collected 498 independent captures of fauna across the landscape, including five of the six endemic carnivores known to occupy eastern Madagascar: *Galidia elegans*, *Galidictis fasciata*, *Eupleres goudotii*, *Fossa fossana*, and *Cryptoprocta ferox*. We found *F. fossana* and *G. elegans* to be the most active and widely distributed carnivores, while *C. ferox*, *G. fasciata* and *E. goudotii* were the least. Additionally, we documented the presence of two invasive carnivores: *Canis familiaris* and *Felis catus*. These findings extended the northern-most known range of *Galidictis fasciata* (Antsahabe) and *Fossa fossana* (Bekaraoka) into the Loky-Manambato PA. Forest size was not a good predictor of activity or occurrence as the largest forest patch in Bekaraoka had the fewest captures of all carnivores. Our findings highlight some of the biodiversity within the Loky-Manambato PA and the need for effective management across this unique transitional forest ecosystem.

RÉSUMÉ

Les aires protégées de Madagascar protègent de nombreuses espèces végétales et animales endémiques menacées, y compris les carnivores eupléridés. Les carnivores eupléridés sont considérés comme l'un des groupes de carnivores les plus menacés mais les moins étudiés au monde. L'aire protégée (PA) de Loky-Manambato dans le nord de Madagascar englobe un écosystème forestier de transition unique qui subit la pression de la perte et de la fragmentation des forêts. Nous fournissons la première étude photographique de la communauté de carnivores de Madagascar occupant cette région dans le but de documenter la richesse en espèces de carnivores, l'activité relative (Trap Success) et la distribution spatiale (Naïve occupancy) à travers le paysage. Pour ce faire, nous avons utilisé 60 caméras activées par le mouvement pour surveiller le long des sentiers établis dans trois parcelles forestières à travers l'AP Loky-Manambato : Antsahabe, Bekaraoka et Antsaharaingy. Nous avons étudié chaque forêt pendant deux semaines en septembre et octobre 2018. Nous avons procédé à 498 captures indépendantes de la faune à travers le paysage, incluant cinq des six carnivores endémiques connus pour habiter l'Est de Madagascar : *Galidia elegans*, *Galidictis fasciata*, *Eupleres goudotii*, *Fossa fossana* et *Cryptoprocta ferox*. Nous avons constaté que *F. fossana* et *G. elegans* étaient les carnivores les plus actifs et les plus largement distribués, tandis que *C. ferox*, *G. fasciata* et *E. goudotii* étaient les moins nombreux. De plus, nous avons documenté la présence de deux carnivores envahissants : *Canis familiaris et Felis catus*. Ces découvertes ont étendu l'aire de répartition la plus septentrionale connue de *Galidictis fasciata* (Antsahabe) et de *Fossa fossana* (Bekaraoka) dans l'AP Loky-Manambato. La taille de la forêt n'était pas un bon prédicteur de l'activité ou de l'occurrence car la plus grande parcelle forestière de Bekaraoka avait la moindre présence de tous les carnivores. Nos résultats mettent en évidence une partie de la biodiversité au sein de Loky-Manambato PA et la nécessité d'une gestion efficace dans cet écosystème forestier de transition unique.

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INTRODUCTION

Madagascar is recognized for its rich biodiversity and endemism; 84% of all vascular plants and 100% of native mammal species on the island nation are endemic (Goodman and Benstead 2005, Callmander et al. 2011). Most of these organisms are found across the eastern humid, western deciduous, and southern spiny forest regions (Lourenço and Goodman 2013). Unfortunately, Madagascar's forests have experienced widespread deforestation (Harper et al. 2007, Vieilledent et al. 2018), and are projected to lose their remaining forest cover within the coming decades if current climate and forest loss trends continue (Morelli et al. 2020). Importantly, forest conversion has contributed to increased forest fragmentation and ecosystem degradation, threatening endemic species with extirpation or extinction (Vielledent et al. 2018). As Madagascar's forests dwindle, research on its threatened biodiversity has intensified, often with a focus on lemurs and seldom the island's carnivores (Gardner 2009). This is troublesome, as the endemic carnivores of Madagascar are already among the world's most threatened carnivores (Brooke et al. 2014, IUCN 2022). Habitat selection and preference for each native carnivoran varies across the eastern rainforest region. For a summary of habitat use see Wampole et al. (2021). Over the past decade, most of Madagascar's national parks have been surveyed and the carnivore populations within them estimated (Gerber et al. 2010, Murphy et al. 2018). Lower tier protected areas, however, still lack initial surveys such as Loky-Manambato PA in north-eastern Madagascar. Here, missing information on carnivore populations is paired with increasing anthropogenic destruction of the ecosystems they inhabit (Ingram and Dawson, 2005). Though results have been contrasted, genetic studies and aerial imagery suggest that while forest cover remained relatively stable from 1950-2000, forest fragmentation began around the arrival of humans to the area ca. 4,000 years ago (Quéméré et al. 2012; Salmona et al. 2017). Between 1996 and 2016, 9.2% of humid forests and 1.1% of dry deciduous forests in the Loky-Manambato PA were destroyed (Goodman and Wilme 2006, Goodman et al. 2018). Deforestation and forest degradation leads to decreased carnivore populations in Madagascar (Wampole et al. 2021).

Madagascar's carnivores, like other small carnivores, are difficult to study due to their elusive behavior, large home ranges, and low population densities (Hawkins and Racey 2005, Brooke et al. 2014). To survey and estimate Madagascar's carnivores, studies have employed motion activated camera traps to photographically capture fauna that cross the camera's line of sight (Wampole et al. 2021). These authors reviewed carnivore research in Madagascar and found the primary threats to carnivores include forest loss and fragmentation, invasive predators, disease transmission, and poaching. These threats from invasive species, namely free-ranging dogs (*Canis familiaris*) and cats (*Felis catus*), as well as the small Indian civet (*Viverricula indica*) have increased competition, influenced the spatial distribution (Farris et al. 2015, Beaudrot et al. 2018), temporal activity (Gerber et al. 2012, Farris et al. 2015, Merson et al. 2019), disease transmission (Rasambainarivo et al. 2017, 2018, Apanaskevich and Goodman 2020), and even long-term occurrence (Farris et al. 2017) of native carnivores across multiple protected areas. In addition, these invasive carnivores have negatively influenced native birds, small mammals, and lemur species across Madagascar's forests that many of Madagascar's native carnivores predate (Brockman et al. 2008, Farris 2014, Murphy et al. 2018). The widespread, invasive nature of *C. familiaris* and *F. catus* present a serious threat to Madagascar's threatened wildlife and to similar wildlife globally (Doherty et al. 2016). These negative effects on native carnivores and co-occurring wildlife are exacerbated as forest habitat shrinks and becomes increasingly fragmented.

Carnivores previously known to exist within the Loky-Manambato PA from opportunistic observations include: *Eupleres goudotii*, observed in the Binara forest, *Galidia elegans*, observed at the Antsahasolika fragment and forests adjacent to Lac Isahaka, and *Cryptoprocta ferox*, observed in the Binara forest and in forests adjacent to Lac Isahaka (Safford 2000). The invasive carnivore *Viverricula indica* has been confirmed to inhabit the Binara forest, Antsahasolika forest, and forests near Lac Isahaka. The goal of our project was to provide the first standardized survey of the carnivore community across the Antsahabe, Bekaraoka, and Antsaharaingy forest patches of the Loky-Manambato PA with the aim of: 1) documenting the presence of native and invasive carnivores, 2) estimating trap success and naïve occupancy, 3) describe temporal activity patterns for all carnivores, and 4) examine if native carnivore trap success or naïve occupancy vary between distinctive forest patch sites. Naive occupancy is a measure of the spatial distribution of a given species and is referred to as "naïve" due to the lack of accounting for imperfect detection (MacKenzie et al. 2006), which results in a lower estimate of spatial occurrence compared to models that use detection to estimate true occupancy (MacKenzie and Bailey 2004).

MATERIALS AND METHODS

STUDY AREA. Among the numerous protected areas of Madagascar, the Loky-Manambato PA (Figure 1) is unique for its organismal composition and variety of habitat types (Goodman et al. 2018). The Loky-Manambato PA legally became an IUCN category V protected area in April 2015, and is the only protected area to overlap the range of many threatened endemic species, such as the critically endangered golden-crowned sifaka *Propithecus tattersalli* (Vargas et al. 2002, Ranirison et al. 2007). The Loky-Manambato PA is located approximately 74 km to the southeast of Antsiranana of northeastern Madagascar. It consists of ten forest patches and a marine sanctuary. The Loky-Manambato PA encompasses 250,000 ha total, but its forests are patchy and only cover 44,000 ha of the area (2018). All of the Loky-Manambato PA forests are separated from one another by barren hills and grazing maintained grasslands. Forest types range from moderate-elevation (ca. 1,000 m asl) humid forest to low-elevation (10 m asl) deciduous forest. Despite being legally protected, the region is threatened by slash-and-burn subsistence farming, as well as logging and charcoal creation (Goodman et al. 2018). We surveyed three forests across the Loky-Manambato PA: Antsahabe, Bekaraoka, and Antsaharaingy. These forests were chosen to represent the wide range of forest types found within the Loky-Manambato PA. We intentionally selected remote sites to minimize the risk of camera theft.

FOREST DESCRIPTION. Antsahabe is a deciduous mid-elevation humid forest that during 2021 covered 4370 ha (Semel 2021). It has the highest average elevational range, 790m asl, and is the wettest of the three sites we examined in the Loky-Manambato PA. Antsahabe is characterized by steep, ridged mountains

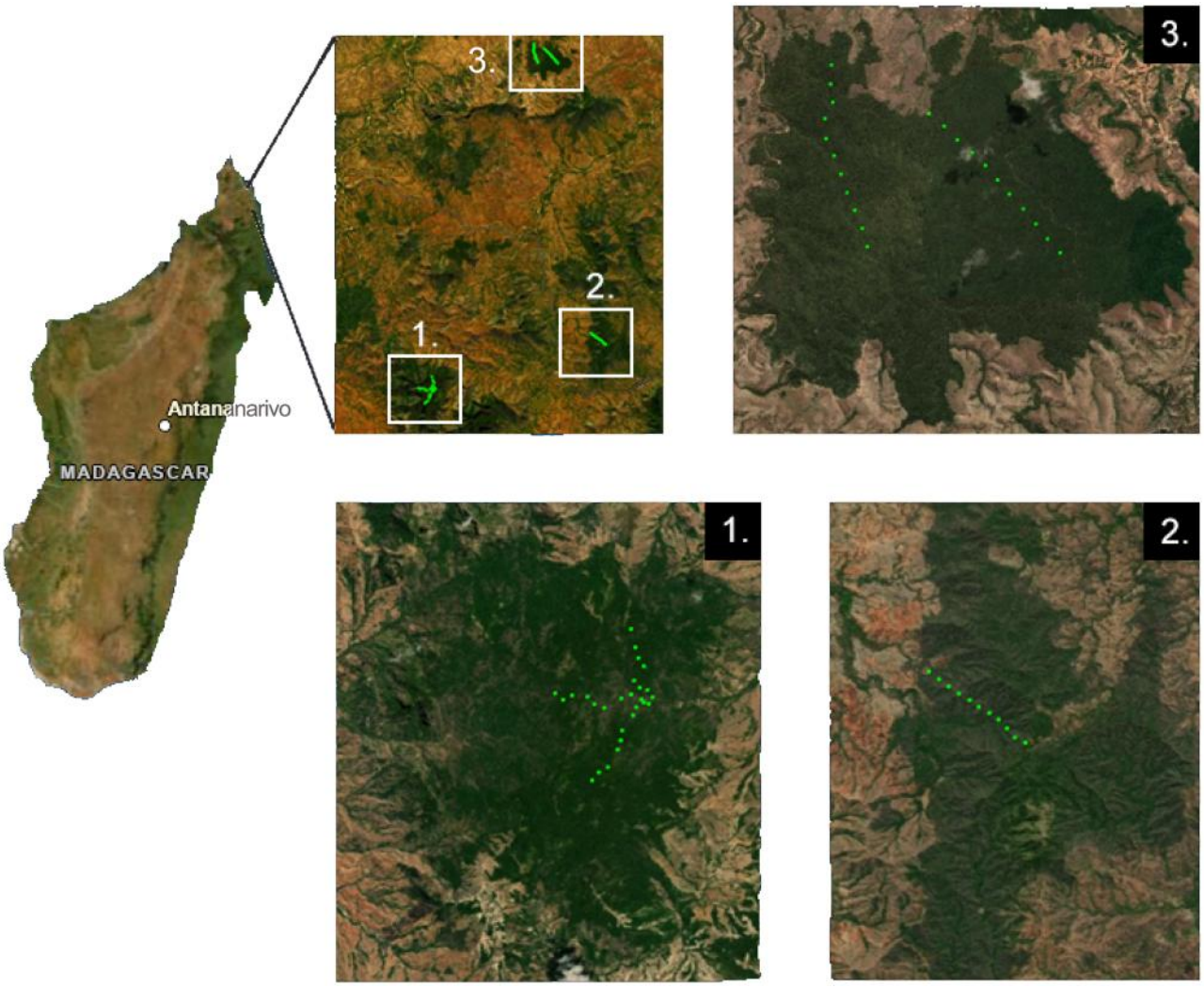

Figure 1. Map of Madagascar (left) with the location of the three Loky-Manambato PA forests surveyed. (1 = Antsahabe (bottom left), 2 = Bekaraoka (bottom right), 3 = Antsaharaingy (top right); we surveyed the three forests from September to October 2018; green dots represent camera trap locations)

with a tall, closed overhead canopy (8–12m in height in steep, exposed areas; 20–25m in height on more gentle slopes (Goodman et al. 2018).

Bekaraoka is the largest forest patch in Loky-Manambato PA, covering 69.1 km2 and stretching from north to south along a massif (Semel 2021). Its average elevation is 198m asl, and its forests are dry and deciduous. Thick shrub layers are dominated by an 8–12m high canopy. A large gold mining site exists around the town of Andranotsimaty, which is characterized by a heavily disturbed understory and dry riverbeds during the dry season (May–November), and deep pits (Goodman et al. 2018).

Antsaharaingy exists upon sandy substrates at the northern end of the Loky-Manambato PA and was the smallest forest surveyed, at 11.6 km2 (Semel 2021). Its average elevation is 71m asl. This dry, hilly lowland is covered by dense, sclerophyllous forest 6–7m in height (Semel 2021, Goodman et al. 2018).

PHOTOGRAPHIC SAMPLING. We used motion-activated camera traps to sample terrestrial wildlife. For Antsahabe, we placed 27 cameras that were operational from 7 September 2018 to 19 September 2018. For Bekaraoka, we placed 11 cameras that were operational from 21 September 2018 to 30 September 2018. For Antsaharaingy, we placed 22 cameras that were operational from 5 October 2018 to 15 October 2018. Each of the surveyed areas consisted of existing transects, 2-2.5 km in length, totaling 11 km across the three surveyed forests. Camera models included Moultrie M888, M880, D55, A35 (Moultrie Feeders, Birmingham, AL 35201), WGI Terra Extreme (WildGame Innovations Grand Prairie, TX), Bushnell Trophy Cam HD (Bushnell Overland Park, KS), HCO-SG565 (HCO ScoutGuard Duluth, GA) and Stealth Cam ZX3 (Stealth Cam Grand Prairie, TX). Detection differences were negligible in our study. Cameras were placed an average of 181m ± 34m (SD) apart. This distance is smaller than the estimated home range for five of Madagascar's endemic rainforest carnivores (Goodman 2012) but was used due to the small size of each forest patch. This spacing did not ensure spatial independence throughout the photographic captures, meaning the same individual carnivore could have triggered a camera at more than one location/station. Across all three forests, camera sites included degraded, edge forest nearest to villages (< 500m from edge; n = 12) and non-degraded forest (> 500m from edge; n = 48). All cameras were set to high sensitivity and programmed to record three consecutive photographs per independent trigger. We mounted cameras 25–45 cm above the ground and used no baits or lures. We recorded the location of each camera (UTM) and elevation using handheld Garmin Etrex GPS units. We verified the functionality of all cameras within three days of deployment. To ensure proper functioning of cameras (e.g., battery percent, angle of camera, and normal functioning), we checked on all cameras every two days and retrieved all cameras 10 days after their initial deployment.

DATA ANALYSIS

To conduct species identifications and to produce a capture history for statistical analyses, we manually sorted and identified the photos using the tagging software DigiKam (www.digikam.org) and the package "CamtrapR" (Niedballa et al. 2016) in program R (RStudio 2020 edition, R Core Team 2017). We defined a capture event as a photograph of an animal at a camera station within a 30-minute period (Di Bitetti et al. 2006). This half-hour time period allows the captured species temporal independence among other captures.

We defined a trap night as a 24-hour period during which the cameras ran with no malfunctions. We calculated trap success to represent a measure of relative activity for all fauna to compare their activity and presence across the three surveyed forests and previously surveyed protected areas of Madagascar. Trap success is calculated by dividing the total number of captures by the total trap nights, and then multiplied by 100. We did this for each carnivore species, within each forest. We calculated naïve occupancy to understand the spatial distribution of each species across each forest and to compare with other protected areas. Naïve occupancy is calculated by dividing the total number of camera stations where a species was captured by the total number of camera stations. We analyzed temporal activity patterns by constructing temporal activity charts from "time of capture" metadata embedded within each photo. We used Google Earth Pro (Google, 7.3. 2020) and ArcMaps (ESRI, 10.8.1 2019) to generate maps of each forest and the camera trap locations within them.

RESULTS

We sampled from September 2018 to October 2018, across a total of 60 camera stations for 494 trap nights total. Across the three surveyed forests we collected 27 unique capture events including 6 captures of invasive terrestrial carnivores (Table 1). We observed five endemic carnivore species: *Galidia elegans*, *Galidictis fasciata*, *Eupleres goudotii*, *Fossa fossana*, and *Cryptoprocta ferox* and two invasive carnivores *Canis familiaris* and *Felis catus*. *Galidictis fasciata* and *Fossa fossana* were range extensions. We did not observe the endemic *Salanoia concolor* or the invasive *Viverricula indica*.

CARNIVORE TRAP SUCCESS AND NAÏVE OCCUPANCY ACROSS THE LMPA. Across the LMPA landscape, the native carnivores with the highest trap success estimates were *G. elegans* and *F. fossana* (Table 1). The remaining native carnivores had considerably lower relative activity and spatial distributions (Table 1). Conversely, for invasive carnivores we found free-ranging *F. catus* to be almost as active and widely distributed as *F. fossana* and *G. elegans* while *C. familiaris* was similar to the sparser native carnivores (Table 1).

Table 1. Comparison of trap success estimates from the Loky-Manambato Protected Area to the larger, intact protected areas of Anjanaharibe Sud Special Reserve (ASSR) and Makira Natural Park (Makira) found south of the Loky-Manambato PA. (Species in bold represent invasive carnivores; 1 Ross et al. 2020, 2 Farris et al. 2015a)

Species	Loky-Manambato	Anjanaharibe-Sud	Makira
Cryptoprocta ferox	0.25	0.53	2.18
Fossa fossana	2.13	4.7	3.17
Eupleres goudotii	0.25	0.05	1.04
Galidia elegans	1.03	0.47	1.09
Galidictis fasciata	0.1	0.86	0.8
Canis familiaris	**0.13**	**2.2**	**9.64**
Felis catus	**0.63**	**NA**	**0.79**

TEMPORAL ACTIVITY PATTERNS. Using the limited number of captures for each native and invasive carnivore, the only two species to demonstrate diurnal activity were the native *G. elegans* and invasive *C. familiaris*. The native *C. ferox* and *G. fasciata* showed strictly nocturnal activity, though this resulted from only a single capture each. The remaining carnivores, including native *F. fossana* and *E. goudotii*, as well as the invasive *F. catus*, demonstrated nocturnal activity, with captures bordering crepuscular periods (Figure 2).

FOREST SPECIFIC TRAP SUCCESS AND NAÏVE OCCUPANCY. Since the forests of the Loky-Manambato PA are all separated from one another and vary in altitude as well as floral and faunal composition, we report the findings of each independently. In Antsahabe , we sampled 204 trap nights and captured three native carnivore species, *G. elegans*, *F. fossana*, and *G. fasciata*. *Galidia elegans* were the most captured native carnivore TS= 1.03 Naïve occupancy was 0.11 for *G. elegans* compared to *F. fossana*, and *G. fasciata*, (Table 1, 2). In Bekaraoka, we sampled 99 trap nights and captured only a single native carnivore, *F. fossana*. Naïve occupancy was 0.36 (Figure 3, 4). In Antsaharaingy , we sampled 191 trap nights and captured two native carnivores (*C. ferox*, *E. goudotti*) and two invasive carnivores (*C. familiaris*, *F. catus*). Naïve occupancy for *C. ferox* was 0.08, *E. goudotii* was 0.04, *C. familiaris* was 0.04, and *F. catus* was 0.20 (Figure 3, 4).

DISCUSSION

We provide a preliminary survey of the native and invasive carnivores of the Loky-Manambato PA, evaluating relative activity and spatial occurrence across multiple forest patches. Due to the low number of forests surveyed (n=3) and overall capture events (n=27) the results should be considered cautiously, as trends may be the result of low sampling effort rather than interpretable patterns. Our results suggest that there are fewer captures and lower relative activity for native carnivores in the Loky-Manambato PA when compared to larger protected areas across the north-eastern region of Madagascar, including Anjanaharibe Sud Special Reserve (Ross et al. 2020), Makira Natural Park (Farris et al. 2015a) and Betampona Strict Nature Reserve (Rasambainarivo et al. 2018). Across the three Loky-Manambato PA forests, we found high species diversity with five out of Madagascar's six eastern rainforest carnivores captured, with the exception of *Salanoia concolor*. These findings point to the need for more in-depth surveys that measure multiple landscape and micro-habitat variables to effectively explore and understand carnivore habitat use and selection across species. Additional variables for evaluation should include local bushmeat hunting as studies across northern Madagascar have revealed that bushmeat hunting is common and widespread (Golden 2009, Borgerson et al. 2019, Borgerson et al 2021,).

For spatial occurrence, we used estimates of naïve occupancy. Compared to true occupancy, it provides potentially biased estimates as it fails to account for imperfect detection (MacKenzie

Table 2. Summary of study site forest patches across the Loky-Manambato Protected Area, including type of forest, elevation, area, and total area surveyed by camera traps. (This survey was conducted from September to October 2018)

Species	Antsahabe	Bekaraoka	Antsaharaingy	Total	IUCN Status
Galidia elegans	0.11	N/A	N/A	10	LC
Galidictis fasciata	0.037	N/A	N/A	1	VU
Cryptoprocta ferox	N/A	N/A	0.08	2	VU
Eupleres goudotii	N/A	N/A	0.04	2	VU
Fossa fossana	0.11	0.363	N/A	12	VU
Canis familiaris	N/A	N/A	0.04	1	N/A
Felis catus	N/A	N/A	0.2	5	N/A

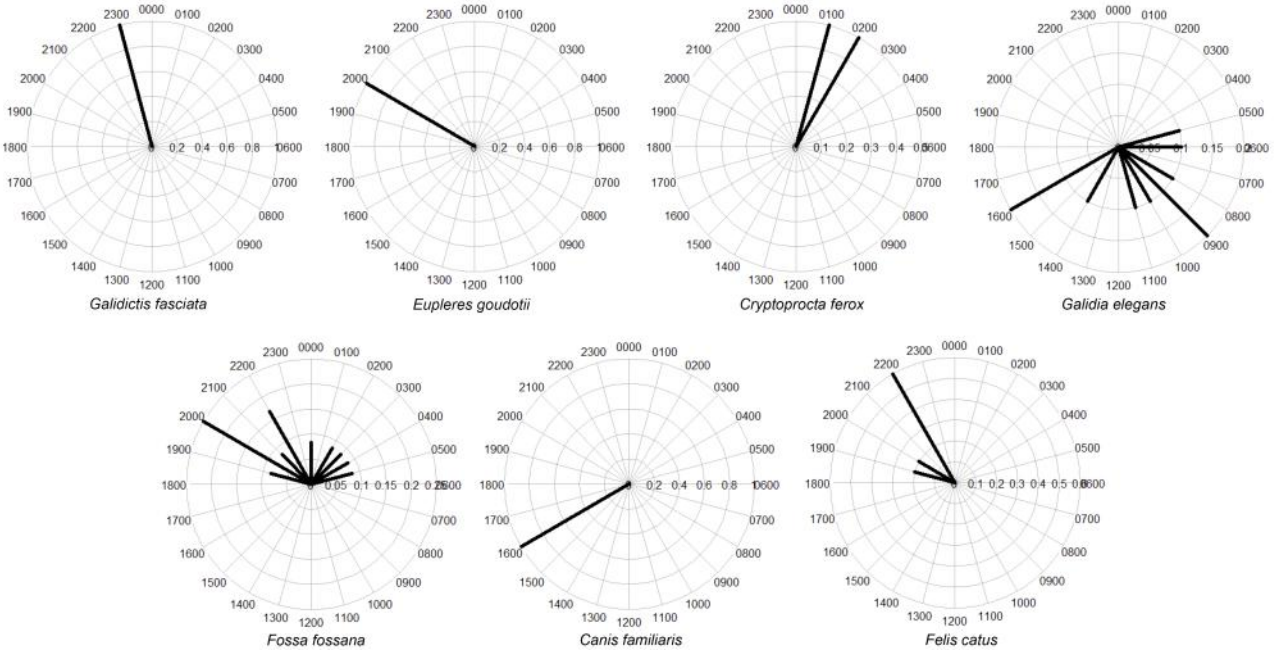

Figure 2. Temporal activity estimates/patterns for all carnivores captured within our survey. (Each temporal graph includes all captures across the three surveyed forests for both native (*Galidictis fasciata*, *Eupleres goudotii*, *Cryptoprocta ferox*, *Galidia elegans*, and *Fossa fossana*) and invasive (*Canis familiaris* and *Felis catus*) carnivores; length of the bar is equal to the percentage of captures at the indicated time)

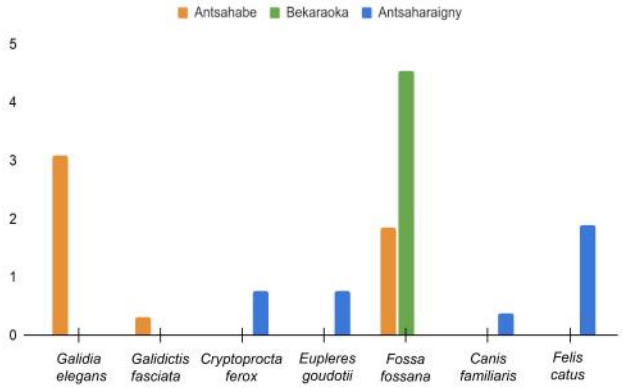

Figure 3. Trap success calculated for all native and invasive carnivores across the three surveyed forests, Antsahabe (orange), Bekaraoka (green), and Antsaharaingy (blue) from the Loky-Manambato Protected Area. (Trap success is the number of captures divided by the number of total trap nights and multiplied by 100. Surveys were conducted from September to October 2018)

and Bailey 2004). Therefore, we did not compare our estimates to other published studies from nearby regions. Our findings on temporal activity are in line with previously published findings of native and invasive carnivore diel activity (Farris et al. 2015b, Gerber et al. 2012, Merson et al. 2019): However, for this study most activity patterns were determined by very few capture events.

Canis familiaris and *F. catus* were only found within the Antsaharaingy forest, *C. familiaris* and *F. catus* are known to represent a serious threat to Madagascar's native fauna. The Antsaharaingy forest was the only site where Madagascar's top predator, *C. ferox*, was observed. *C. ferox* is one of the most widespread, flexible and resilient euplerid species (Wampole et al. 2021). The overlap with two invasive carnivore species with *C. ferox* warrants additional surveys to determine if this leads to local extinction for smaller endemic carnivores across the Loky-Manambato PA forests. We suspect that our lack of *S. concolor* and *V. indica* detection are explained by habitat preference for *S. concolor*, which has been shown to prefer low-mid altitude rainforest (Wampole et al. 2021) and our survey's low sampling effort for *V. indica*. Long-term and large-scale surveys are needed particularly across un-surveyed forest patches in the Loky-Manambato PA. These studies are needed to explore carnivore temporal activity and spatial distributions, including which factors or variables influence these parameters and contribute to reductions in richness and abundance.

The Loky-Manambato PA safeguards a unique transitional forest landscape that many carnivore species rely upon. The loss of habitat and resulting fragmentation presents a large threat to the native carnivores we surveyed and the threatened wildlife with which they co-occur and depend upon. Surveys in other highly degraded, fragmented patches across the north of Madagascar have revealed a considerable decrease in carnivore richness (Mann et al. 2015) and the on-going trends across the Loky-Manambato PA could result in similar patterns if these pressures are not addressed. Efforts that include and incorporate local desires, needs and livelihoods are needed to slow or stop these losses and protect the native carnivores occupying this protected area landscape.

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SUPPLEMENTARY MATERIAL

Camera traps photos of the 27 unique capture events of native Madagascar carnivores in the Loky-Manambato Protected Area