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Critical Corridor: Survey of predator occurrence and habitat use in a threatened rainforest protected area: COMATSA-Sud and Marojejy National Park, Madagascar

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Thesis cover letter***

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Critical Corridor: a Survey of predator occurrence and habitat use in a threatened rainforest protected area: COMATSA-Sud and Marojejy National Park, Madagascar

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN BIOLOGY

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MASTER OF SCIENCE THESIS

OF

PATRICK H ROSS

Thesis Committee:

Advisor Professor: Dr. Patricia Parker

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Preface: This thesis is prepared according to manuscript format, consisting of one manuscript. The manuscript: “ Critical Corridor: a Survey of predator occurrence and use of a threatened rainforest corridor protected area: COMATSA, Madagascar” is currently in preparation for submission to *Biotropica*. The manuscript is presented as submitted to the journals and may be subsequently amended for publication. Additional authors for manuscripts are listed at the beginning of the manuscript. Appendices are presented at the end of the thesis and contain data in support of this thesis that were not included in the text.

Cover letter end *****

Masters Thesis

Critical Corridor: Survey of predator occurrence and habitat use in a threatened rainforest protected area: COMATSA-Sud and Marojejy National Park, Madagascar

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Abstract:

Madagascar is a nation praised for its floral and faunal endemism and biodiversity. Among the island nation's most emblematic fauna are its native mammalian carnivores; they are members of the threatened and endemic Eupleridae family. The Corridor of Marojejy – Anjanaharibe Sud – Tsaratanana (COMATSA) is a system of forest protected areas in which three large protected areas are connected in northern Madagascar: Tsaratanana Reserve, Anjanaharibe Sud Special Reserve and Marojejy National Park which is also a UNESCO World Heritage site. COMATSA is a newly protected and currently threatened corridor system that lacks detailed surveys and assessments of its native carnivore community. To identify which terrestrial carnivores and associated fauna occupy the rainforest corridor structure in the boundaries of COMATSA-Sud (southernmost section of COMATSA) and Marojejy National Park, and to identify the effects of forest loss and fragmentation upon their movement and occupancy, we deployed 28 camera stations, 12 single camera stations and 16 double camera stations to document organisms that cross the motion activated camera sensors. From October 20th 2021 to February 10th 2022 (113 days) we collected 1048 unique capture events (all species) and confirmed the presence of four native species in Eupleridae: *Cryptoprocta ferox*, *Fossa fossana*, *Galidia elegans*, and *Galidictis fasciata*. We also captured one non-native carnivore species: *Canis familiaris*. These results officially extend the known range of *F. fossana* and *G. fasciata.* In our survey, *C. ferox* and *G. elegans* were the most common and widespread native carnivores, while *F. fossana* was the least common. We discuss the negative impacts of forest fragmentation and degradation on native carnivores and highlight the threats posed by the free-ranging non-native carnivore *Canis familiaris*. This study provides the first detailed survey and occupancy estimates of the carnivore community in the COMATSA-Sud and Marojejy corridor protected area, allowing for comparison with other protected areas in Madagascar. Our findings show that anthropogenic changes to the forest corridor are likely correlated with a biased distribution of carnivore occurrence within the corridor area, as some native carnivores are underrepresented in more disturbed areas. Following our presentation of the data, we provide important management recommendations for protection of the forest corridor and its endemic carnivore community. Primarily we suggest that deforestation and habitat degradation within and around the corridor be halted and that the corridor area be reforested to remedy the forest loss that has already happened. We also suggest that invasive, non-native carnivores be managed or culled to reduce their impact on wildlife, human and ecosystem health.

Keywords: Rainforest, Wildlife, Corridor, Landscape Conservation, Carnivores

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1. Introduction:

Forests globally are intensely threatened. Between 2000 and 2012, 2.3 million square kilometers of forest were destroyed, 32% of which were tropical forest areas (Hansen et al. 2013). While forest loss happens internationally, it has particularly damaging impacts on biodiversity hotspots, many of which are tropical (Mittermeier et al. 2008, Brown 2014). The forests of Madagascar have faced numerous decimations (Primack &

Morrison 2013), among the largest of which started during French colonization (Sodikoff 2005). The few forests that remain in Madagascar are bastions for biodiversity that harbor endemism rivaled in very few places on earth, as 90% of the organisms on the island nation of Madagascar are endemic (Hobbes & Dolan 2008). Those organisms are threatened by continued forest fragmentation and degradation, which are known to lead to biodiversity loss (Zuidema et al. 1996). Between 1953 and 2014 Madagascar lost 44% of its forest cover (Vieilledent et al. 2018). One method of conserving fragmented forest areas that has been backed by scientific consensus is through the promotion, preservation and or construction of habitat corridors that bridge larger protected areas together, thus forming a web within which biodiversity can live and move through (Bond 2003). These wildlife corridors are critical for preserving the connectivity that remains of a once interconnected web of similar habitat (Noss 1987).

The Corridor of Marojejy – Anjanaharibe Sud – Tsaratanana (hereafter COMATSA) is in North Eastern Madagascar, which is one of the most biodiverse regions in the nation (Goodman and Wilme 2003, Goodman et al. 2018). The protected areas that COMATSA connects are the Tsaratanana Massif in the north, the Anjanaharibe Sud Special Reserve in the West and Marojejy National Park in the East. All of these protected forest areas are experiencing an increase in forest edge and are threatened by anthropogenic destruction (Vielledent et al. 2018, Goodman et al. 2018). Populations of organisms that are sensitive to forest fragmentation or those that exist in small densities such as tropical carnivorans can be connected and preserved by forest corridors (Beier and Noss 1998).

Among the native wildlife in Madagascar most sensitive to forest edge encroachment and fragmentation are the endemic Eupleridae family of carnivores (Farris & Kelly 2011). Tropical carnivorans like those of the Eupleridae family (sometimes called Euplerids) have been shown to be cornerstones in the health of the habitats that they inhabit (del Rio et al. 2001). Further since many of the carnivores within the Eupleridae family rely on the contiguous and interconnected sections of forest (Gerber et al. 2012), they are umbrella species, in that approaches to conserve these threatened carnivores result in protection for numerous other fauna and flora species within their home ranges.

In the last 20 years there has been a significant effort to understand the 8 extant Euplerid species of carnivores in Madagascar (Wampole et al. 2021). Most studies have utilized motion activated camera traps to non-invasively capture photographs of the animals that walk infront of them (Wampole et al. 2021). These studies have demonstrated how deforestation and forest fragmentation have negatively influenced Eupleridae carnivore occupancy and density across Madagascar (Gerber et al. 2012, Farris et al. 2017, Rasambainarivo et al. 2017, Ross et al. 2020). Studies have also shown that non-native carnivore species including *Canis familiaris, Felis catus*, and *Viverricula indica* compete with Eupleridae and transmit diseases to them (Evans et al. 2013, Weston and Stankowich 2013, Farris et al. 2015, Rasambainarivo et al. 2017).

While multiple protected areas have been host to these surveys, many of the forested areas that remain in Madagascar lack in depth carnivore surveys and thus have unknown amounts of biodiversity. This diminishes the ability of managers to conduct biodiversity conservation effectively. To fill gaps in the knowledge surrounding these threatened carnivores and a critical forest corridor in Madagascar, we conducted a non-invasive survey using camera traps across the rainforest corridor structure within the boundaries of COMATSA-Sud and Marojejy National Park. We predicted that carnivore occupancy and trap success across all species would be less in the corridor structure than in the nearby and recently surveyed Anjanaharibe Sud Special Reserve protected area. We also predicted that anthropogenic disturbance level of the forest would have negative impacts on the occupancy of Eupleridae carnivores within the corridor. Our objectives were to (1) Identify the native and non-native carnivores that exist within the corridor structure; (2) calculate site-level trap success (relative activity) of each carnivore species; (3) estimate the probability of species occupancy and detection for each species; (4) assess habitat degradation in the corridor and (5) examine the impact that this degradation might have on their occurrence.

2. Materials and Methods

2.1 Study Site:

Our study site and camera trap grid is within an area formerly known as the Betaolana corridor. The grid of camera trap stations covers 900 hectares of montane tropical forest on the border of the southernmost section of COMATSA-Sud, and the Westernmost portion of Marojejy National Park (Figure 1). COMATSA-Sud recently achieved its IUCN category five protected area status in 2015 and is managed by the World Wildlife Fund. The COMATSA-Sud area is decreed to cover 80,204 ha, and has a widely variable elevational range of 250m ASL to 2000m ASL (WWF 2016, Goodman et al. 2018). While the COMATSA-Sud protected area has a variety of habitat types the immediate study site we surveyed consists only of montane tropical forest. COMATSA-Sud's wet environment (2300 mm of rainfall annually), unique microclimates, and variable elevations result in high levels of biodiversity (Garreau & Manantsara 2003, Goodman & Wilme 2003). COMATSA-Sud, however, lacks detailed surveys and assessments of its carnivore communities. Prior to this survey the only carnivores that had been reported in COMATSA-Sud were the native *Cryptoprocta ferox* and *Galidia elegans* as well as the invasive *Viverricula indica* (Goodman et al. 2018). COMATSA-Sud also protects numerous other biota, including 89 bird species and 42 species of amphibians, 62 species of reptiles and 9 species of lemurs, such as the critically endangered Silky sifaka (*Propithecus candidus*) and Aye Aye (*Daubentonia madagascariensis*) (Goodman et al. 2018).

Some of our camera trap stations were also within the border of Marojejy National Park. Marojejy NP is an IUCN category 2 protected area (more strictly protected than COMATSA-Sud), managed by Madagascar National Parks. It has been formally protected since 1952 and was assigned national park status in 1998. Marojejy NP covers 55,885 ha (Goodman et al. 2018). While smaller than COMATSA-Sud, Marojejy NP has been host to more intensive research and is known to be inhabited by a more diverse set of fauna and flora. The elevational range of Marojejy is 75m ASL to 2133m ASL. Prior to this survey Marojejy National Park has been reported to contain the native carnivores *Cryptoprocta ferox, Eupleres goudotii, Fossa fossana, Galidictis fasciata, Galidia elegans*, as well as the invasive carnivores *Viverricula indica*, recorded through personal communication and opportunistic sightings (Goodman et al. 2018). Marojejy NP is home to 119 species of birds (Langrand 1990, Goodman et al. 2018), 74 species of amphibian, 84 species of reptile and 11 species of lemur (Goodman et al. 2018). In addition to the biodiversity that can be found within the protected borders of the corridor area, the forest is integral to connecting a protected area complex (which includes Marojejy National Park, COMATSA-Sud and Anjanaharibe Sud Special Reserve) that when taken together is among the largest and most biodiverse landscapes in Madagascar (Goodman & Wilme 2003, Goodman et al. 2018).

2.2 Camera Trap Placement and Use:

The camera trap grid was situated inside a corridor of montane rainforest that connects Anjanaharibe Sud Special Reserve (hereafter ASSR) in the East to Marojejy National Park in the West. The center of our research area was (14°28'2.48"S 49°32'56.39"E) (Figure 1). We chose this unsurveyed study site for its corridor structure and proximity to the previously surveyed ASSR rainforest. The study site also presented an ideal system to monitor carnivore presence and possible movement throughout a forest corridor in Madagascar. The forest within the corridor is fragmented and habitat degradation is visible in satellite imagery (Figure 2). We placed 44 motion activated camera traps across 28 camera stations, 12 single camera stations and 16 double camera stations. No lure or bait was used at any station and all camera traps were placed 15cm above the forest floor (ideal height for our targeted taxa). All camera stations were within the boundary of COMATSA-Sud or the boundary of Marojejy National Park (Figure 1). Stations were set in degraded or healthy forest which we evaluated in surveys measuring disturbance per hectare. We used double camera stations in an attempt to both sides of an individual so that we could use marking or unique traits to identify individuals that the stations photographically captured. This was done so that the movement of individual carnivorans across the landscape could be examined. The camera trap model used was the Stealth Cam PXP3NG. All camera stations were spaced on average (±SD) 483m ± 70m apart, thus allowing for spatial independence as shown to be equal to or greater than average home range for the majority of Eupleridae carnivores (Farris et al. 2014a). The cameras were placed on October 20th 2021 and were all taken down by February 10th 2022 (113 days). The camera traps operated during the project period without any gaps in capturing and none suffered memory related faults. Our sampling grid totaled 2893 trap nights. We chose the center of the camera grid location based on the narrowing of the forest corridor, with the goal of capturing individual carnivore movement through the narrowed corridor structure (Figure 1, Figure 2). We set up camera trap stations across four transects each 4km long. All cameras were set to high sensitivity and 3 shot bursts for each independent trigger. We recorded the location and elevation of each station (UTM) using handheld Garmin GPS units. After the initial setup and check of all camera stations, we checked the cameras after the first 14 days, and then every 30 days for the remainder of the study period.

2.4 Habitat Degradation:

The management areas differ in their IUCN protected area category. The IUCN international protected area category system ranks the safeguarding of protected areas into six possible categories where “1” represents the most protected and “6” represents the least protected (IUCN 2022). COMATSA-Sud, managed by WWF is an IUCN category 5, and Marojejy National Park, managed by Madagascar National Parks is category 2. COMATSA-Sud has a higher allowance of resource extraction. In 2019 WWF Madagascar estimated that approximately 1273 people utilize forest products from COMATSA-Sud (S. Volanoro,WWF, personal communication, 2019). To evaluate the difference in the impact of anthropogenic disturbances in both systems we calculated anthropogenic disturbances per hectare (hereafter DPH) in the two management areas within our sampling area. To do this the survey team walked throughout each management area, on and off the transects of which the camera trap stations were installed. The location of each anthropogenic degradation site was recorded with photos and GPS points. The GPS points were factored into the DPH calculation by dividing the disturbance encounters by the hectares surveyed 350ha for COMATSA-Sud and 550 for Marojejy NP with a landscape total of 900 ha. We used these ratios to calculate if one management area was more degraded than the other. To correlate the impact that these degradations had on carnivoran detections we calculated unique capture events per hectare across the total surveyed area and within each management zone (Table 1).

2.3 Data Analysis

We categorically sorted and labeled every image using the open source program Digikam (www.digikam.org). Once the images were sorted we created a capture history file using the package ”CamtrapR” within the program RStudio (R version 3.6). We defined a unique capture event in our analysis as a photograph of an organism at a camera station within a 30 minute period. We used this time period to ensure temporal independence among capture events (Di Bitetti et al. 2006). Using these unique capture events across all of our camera stations, we assembled a new capture history using these unique capture events for each carnivore species where 0 indicates non-detection and 1 indicates detection for each 24 h period. We defined a trap night as a 24 h period in which one camera station was functioning properly with no malfunctions. For each carnivore we calculated trap success (TS) as the total number of captures divided by total trap nights multiplied by 100. The ratio of TS is used as a measure of relative activity for all detected carnivores to compare their activity and presence across the entire surveyed landscape (Kelly et al. 2008). To evaluate species occurrence while also accounting for imperfect detection, we used single-season, single species occupancy modeling implemented in the ‘Unmarked’ package in R v.3.6 (MacKenzie et al. 2002, Fiske & Chandler 2011, R Core Team 2014). Given the limited spatial scale of the camera trap grid (900ha), our 4 month collection period, and the limited habitat sampling degradation based on habitat disturbance per hectare, we chose to not include covariate model estimates in our occupancy estimates as to not overstate our findings. However we encourage the multi-season sampling period that would be sufficient to model these covariates. We calculated species occupancy (ψ) and detection probability (p) for all native and non-native carnivores. We assumed that occupancy did not change during the survey period and that detection of each species at each location was independent (Anderson & Burnham 2002). We calculated our GLMER (generalized linear effects model) statistical analysis with the lme4 package in “R” version 3.6. The GLMER model fits a poisson distribution and features “Distance to Forest edge” as a fixed effect and “Species” as a random effect while the number of carnivore occurrences is the response variable.

3. Results:

From October 20th 2021 to February 10th 2022, we sampled across 2893 trap nights and collected 1028 unique photographic capture events (capture event with temporal independence), including 132 unique captures of native terrestrial carnivores and 8 unique captures of non-native terrestrial carnivores (Table 2). We observed four endemic carnivore species (*Galidia elegans, Galidictis fasciata, Fossa fossana, and Cryptoprocta ferox*) and only one non-native carnivore (*Canis familiaris*). We did not detect the native carnivores *Salanoia concolor* or *Eupleres goudotii.* We did not detect the non-native carnivores *Felis catus* or *Viverricula indica*, though *V.indica* was noted to exist within the region (Goodman et al. 2018). Our survey extends the documented range of *Galidictis fasciata* and *Fossa fossana*. Occupancy modeling showed that the native carnivore *G. elegans* had the most widespread distribution, with an average occupancy estimated at $\psi = 0.73$. We calculate and compare carnivore TS and occupancy with other surveyed protected areas in Madagascar (Table 3, Figure 3) The most common native carnivore in our survey was *G. elegans* with 70 captures across 19 sites and a TS estimate (±SE) of 2.42 ± 0.86, followed by *C. ferox* with 37 captures across 12 sites and a TS estimate (±SE) of 1.28 ± 0.42 (Table 3, Figure 3). *Fossa fossana* had 16 captures across 9 sites and a TS estimate (±SE) of 0.55 ± 0.18. The least common native carnivore was *G. fasciata* with 8 captures across 6 sites, (TS = 0.28 ± 0.13). The non-native *C. familiaris* had 8 captures at 6 sites (TS = 0.28 ± 0.10; Table 3, Figure 3). In addition, we also calculate occupancy estimates of detected carnivores and compare them with other surveyed protected areas in Madagascar: *C.*

ferox (0.48 ± 0.11), *F. fossana* (0.44 ± 0.14 *Galidia elegans* (0.73 ± 0.10), *G. fasciata* (0.42 ± 0.25), *C.familiaris* (0.41 ± 0.37) (Table 3, Figure 3).

3.2 Carnivore Habitat use and Movement within the corridor:

We found the highest diversity and presence of native carnivores away from forest edges and human settlements (Figures 4,5,6,7). We found that when native carnivore species is a random variable the distance to the edge of the forest is a significant or causative factor in the number of occurrences (Figure 8). This correlation of habitat preference supports previous research that shows that *G. fasciata* and *F. fossana* prefer forest habitat that is 1km or greater from forest edge (Ross et al. 2020). We found non-native carnivore detections to be most located around human settlements (Figure 9). We highlight the level of anthropogenic disturbances through the calculation of disturbance per hectare (Table 1), which negatively corresponds to areas with higher detection of native carnivores. The detections of some native carnivores (Figures 4,5,7) contrast the detections of potential prey species such as, rodents, tenrec and lemurs (Figures 10,11,12). These known prey species were widely distributed across the sampling grid. Yet native carnivore detections were seemingly more prevalent on the Eastern side of the sampling grid. Through regression analysis we show that the Eastwardness of the camera trap station in our survey was not a statistically significant determiner of carnivore occurrences (Figure 13). We identify sensitivity to edge as a major concern to the corridor in between Marojejy NP and ASSR as there is a section of the corridor area that is thinner than 3km (Figure 2). The layout of our camera trap grid was designed to photographically capture individual carnivores so that their movement through the corridor structure could be recorded. After we tagged, sorted and assembled all photographic captures of carnivores we were unable to provide any evidence of an individual carnivoran crossing from one side of the protected area to the other. While there are native carnivoran detections on both sides of the protected area structure, the identification of individual carnivorans was limited by the amount and quality of photographic captures. We were only able to see that an individual *Cryptoprocta ferox* had appeared across two camera stations on the Marojejy side of the sampling grids MNP. Absence of evidence does not mean there is an absence of movement of these carnivores within the study area. A lack of evidence of carnivore movement across this sampling grid does not confirm that the carnivores are not moving across the habitat, but that our results are not conclusive enough to show that there is movement across the corridor structure. This lack of evidence however supports our other findings that suggest that degradation in this forest corridor negatively impacts carnivore presence across the habitat. Further investigation and genetic testing or GPS collaring of fauna on either side of the corridor would be required to thoroughly understand the functionality of this corridor system.

3.3 Habitat Disturbance

Surveying the two protected areas in the corridor structure revealed differences in the types of habitat disturbance across the two management areas (Table 1). In our surveyed area COMATSA-Sud had a larger number of disturbances n=133 and more types of disturbances n=7 (Selective logging, Banana plantation, Informal mining, Tavy, Vanilla plantation, Pineapple plantation, Tenrec trap) when compared to the Marojejy

NP section of our surveyed area which had n=30 total disturbances and only n=2 types of disturbances (Selective logging and Informal mining). COMATSA-Sud comprised only 350 ha of the surveyed area and Marojejy NP comprised 550 ha of the surveyed area.

4. Discussion:

In our sampling and analysis of the carnivore community within the COMATSA-Sud and Marojejy NP corridor structure we describe the presence, relative activity and occupancy of *Cryptoprocta ferox*, *Fossa fossana*, *Galidia elegans*, and *Galidictis fasciata*. We also capture one non-native carnivore species, *Canis familiaris*. These results officially extend the documented range of *F. fossana* and *G. fasciata* into the COMATSA-Sud area. Our findings of *G. elegans* disregarding the edge of the forest also reinforce past research which shows that not all species that fill a particular niche have the same sensitivities to forest edge, or requirements for a forest corridor to be useful (Laurance & Laurance 1999). We suggest that multi-season surveys of the corridor need to be completed to more closely examine the patterns of Euplerid movement in COMATSA-Sud and Marojejy NP. We argue that Euplerids are an ideal organismal family for targeted conservation and forest management in Madagascar due to their comparatively large home range and needs for contiguous undegraded forest (Gerber et al. 2012).

4.1 Species Overview:

Prior to this study, systematic surveys for carnivorans had not been carried out in COMATSA-Sud or Marojejy NP. In our study we found *Cryptoprocta ferox* which is classified as Vulnerable and is the largest native carnivore in Madagascar (IUCN 2022).

Our occupancy and trap success findings reveal that *C. ferox* occupancy = (0.48 ± .11 and was the second most active in our survey TS= (1.28 ± 0.42). The occupancy and TS of *C. ferox* (shown in Table 3) in this survey was higher than in the more pristine and neighboring protected area of ASSR (Ross et al. 2020). The higher occupancy and activity level of *C. ferox* in this degraded habitat may be related to factors such as the lower occupancy of native carnivores such as *F. fossana and G. fasciata. Cryptoprocta ferox* is known to exist within near-edge environments (Rasambainarivo et al. 2017), and unlike other endemic carnivorans in Madagascar *C. ferox* can be found outside of forested areas, and is thought to be more resilient in degraded habitats (Hawkins & Racey 2005). We believe that this might result in a reduced level of competition and thus a higher recorded occupancy and trap success.

In contrast we also found *Fossa fossana,* classified as Vulnerable (IUCN 2022). *F. fossana* was less common in the corridor landscape than in the neighboring ASSR, and was among the least active TS= (0.55 ± 0.18) and least prevalent carnivore on the corridor landscape occupancy = (.44 ± .14). *Fossa fossana* is known to be sensitive to the effects of forest edge (Gerber 2010, Goodman 2012, Ross et al. 2020). We suggest that the lower occupancy of *F. fossana* within our study area is likely due to the high prevalence of degraded and near edge habitat as well as the presence of non-native carnivores in the surveyed area. These factors may also result in lower numbers of potential prey species (birds and small mammals) across the corridor forest, thus contributing to fewer *F. fossana* individuals.

We found *Galidia elegans* which is classified as Least Concern with population decreasing (IUCN 2022). *G. elegans* had the highest relative activity and was the most widespread native carnivore in our survey TS of (2.42 ± 0.86), occupancy = (0.73 ± .10). The distribution and activity of *G. elegans* in our survey was higher than what was recorded in the adjacent and less disturbed protected area of ASSR (Ross et al. 2020) The higher distribution and activity of *G. elegans* in the corridor when compared to the more pristine ASSR may possibly be explained by the more degraded state of the corridor forest when compared to ASSR. The ASSR survey showed that *F. fossana* and *G. fasciata* are edge sensitive species (Ross et al. 2020) and may be limited in the amount of suitable habitat within the corridor survey area, which in turn would allow for a more widespread distribution of *G. elegans* which is described as generalist, with plastic behavior (Goodman 2012). Our findings support this prior knowledge as we show that proximity to forest edge did not affect *G.elegan*s occurrences (Figure 14). *G. elegans* has also been shown present within degraded forests (Farris et al. 2015, Ross et al. 2022). These traits likely help explain the wide-spread distribution of *G. elegans* across the corridor habitat.

Similar to *F. fossana* we found *Galidictis fasciata* which is classified as Vulnerable (IUCN 2022) *G. fasciata* which has been shown to be among the least common native carnivores in Madagascar (Farris et al. 2014b), had a smaller distribution and lower activity level occupancy = (0.42 ± 0.25) TS= (0.28 ± 0.13) in COMATSA-Sud / Western Marojejy NP than what was recorded In ASSR occupancy = (0.52 ± 0.13) (TS= 0.86 ± 0.33) (Ross et al. 2020). This may be explained by previous work which has shown *G. fasciata* to be more sensitive to edge than other co-occurring carnivores (Farris et al. 2014b, Ross et al. 2020) The corridor landscape in which our survey was conducted is nearly surrounded by edge and is generally composed of less contiguous more fragmented forest (Goodman 2018).

Canis familiaris classified as Least Concern (IUCN 2022). We recorded lower TS estimates TS= 0.28 ± 0.10 and occupancy estimates, occupancy = 0.41 ± 0.37 of the invasive *C. familiaris* in the corridor forest connecting ASSR to Marojejy when compared to those of ASSR or Betampona (Table 3). *C. familiaris* distribution inside of COMATSA may be best explained by a lower prevalence of pet ownership in villages near the corridor areas.

4.2 Deforestation:

The distance to forest edge varied at each camera trap station within the corridor structure that we examined. The camera trap stations in our sampling grid within Western Marojejy NP were at greater distance from the edge of the forest when compared to those within the COMATSA-Sud section of our sampling grid. They also detected slightly more native carnivores Figure 13). Early inventories of the Andapa basin landscape noted a high prevalence of degradation inside of COMATSA-Sud (Goodman and Wilme 2003), and since then the degradation has gotten worse; between 2005 and 2010 8,859ha were deforested in COMATSA (Grinand et al. 2013). The COMATSA protected area and Marojejy National Park both face deforestation from multiple sides (Goodman et al. 2018). The already endangered and endemic organisms that live within are further put at risk by this deforestation and fragmentation which is caused primarily by unpermitted agriculture inside of the corridor (Patel pers., comm., 2022) and tavy form slash and burn agriculture for the creation of temporary rice paddies and charcoal production on the edges of the corridor (Vieilledent et al. 2018).

4.3 Impact of Protected Area Status on carnivore diversity:

Marojejy is formally classified as a Category #2 Protected Area and COMATSA-Sud is classified as a Category #5 Protected Area (Goodman et al. 2018). The category of forest protection specifies the degradation that is deemed acceptable for these forest systems.The lower category number the lower the amount of degradation that is permitted. Higher protected area category numbers allow for greater resource extraction and are often associated with higher habitat disturbance (Gardner 2011). In 2019 WWF estimated that approximately 1273 people utilize COMATSA-Sud (pers. comm ., Suzy Maeva Volanoro at WWF Madagascar). Some of our degradation sampling was steered by initial satellite imagery which shows notable fragmentation in the core of the forest corridor. (Figure 2). Table 4 and Table 1 describe carnivore occurrence levels and habitat disturbance levels. Our findings show that protected area category level correlates to forest health and thus the supported biodiversity and endemism.

4.4 Protection and management of COMATSA:

The findings of this study highlight the threats posed to Madagascar’s endemic carnivores by forest loss and invasive species within the COMATSA-Sud. In particular, we believe that the negative effects of edge and severely fragmented forest on native carnivores requires a targeted management program that addresses further forest loss on the north and south boundaries of COMATSA-Sud. Specifically, we highlight through our GLMER statisical analysis where “Species” is a random effect and the number of unique carnivore occurrences is the response variable to the fixed effect of “Distance to Forest edge” that the native carnivores we recorded tend to avoid forest edge (Figure 8: Pr Value = 0.0033. Std. Error = 0.0015).

We believe that the intense deforestation in and around the corridor limits carnivore presence. Further, we argue that the presence and distribution of free-ranging *C. familiaris* warrant efforts to reduce this threat to the native fauna and flora of the corridor and the protected areas it connects. Since the protection of these carnivores is based on large interconnected contiguous sections of healthy forest (Gerber et al. 2012). Effective management of the corridor structure will not only result in the protection of these native carnivores but will also safeguard the connectivity of the SAVA region rainforests and the numerous, diverse wildlife that occupy the protected area complex. If this habitat is to function as a corridor or hallway in which genetic information can transfer between these larger protected areas its width must not be further compromised by tavy, logging and fragmentation both inside or out.

List of Tables:

COMATSA-SUD		
Hectares surveyed	350	
Manager	WWF	
Disturbance Type	**Disturbance Encounters**	
Selective Logging	133	
Banana Plantation	10	
Informal Mining	7	
Slash-Burn Rice Farming	4	
Vanilla Plantation	2	
Pineapple Plantation	2	
Tenrec Poaching	1	**Disturbance Per Hectare**
Overall Disturbance	159	0.454
Marojejy National Park		
Hectares surveyed	550	
Manager	MNP	
Disturbance Type	**Disturbance Encounters**	
Selective Logging	20	
Informal Mining	10	**Disturbance per Hectare**
Overall Disturbance	30	0.055

Table 1

Table of Disturbances Per Hectare for COMATSA-Sud, and Marojejy National Park. Habitat disturbance sampling showed that COMATSA-Sud was more than 7x as degraded per hectare than Marojejy National Park

Species	IUCN Status	Activity	Body Size	Trap Success (SE)	AIC	ψ (SE)	p (SE)
Cryptoprocta ferox	VU	Crepuscular	7kg	1.28 (0.42)	212.7	.48 (.11)	.152 (.028)
Fossa fossana	VU	Nocturnal	1.7kg	0.55 (0.18)	128	.44 (.14)	.082 (.029)
Galidia elegans	LC	Diurnal	<1kg	2.42 (0.86)	304	.73 (.10)	.167 (.023)
Galidictis fasciata	VU	Nocturnal	<1kg	0.28 (0.13)	81.6	.42 (.25)	.045 (.029)
Canis familiaris	**N/A**	**Crepuscular**	**30kg**	**0.28 (0.10)**	**57.5**	**.41 (.37)**	**.028 (.027)**

Table 2.

Recorded carnivore species, IUCN status, Activity, Body Size, Trap Success, AIC, Occupancy

Occupancy (**ψ**) and Detection (**p**) estimates for *Cryptoprocta ferox*, *Fossa fossana*, *Galidia elegans*, *Galidictis fasciata*, and *Canis familiaris*, including Akaike's information criterion (AIC) value,for four native carnivores and 1 non-native carnivorans resulting from static (singleseason, single-species) occupancy estimation determined through photographic surveys of rainforest in COMATSA-Sud. Bold represents non-native species.

Trap success comparison	This study	Ross et al. 2020	Rasambainarivo et al. 2017
Protected Area	COMATSA-Sud / Marojejy	ASSR	Betampona
Cryptoprocta ferox	1.28 ± 0.42	0.53 ± 0.18	5
Eupleres goudotii	NA	0.05 ± 0.04	0.15
Fossa fossana	0.55 ± 0.18	4.7 ± 1.2	NA
Galidia elegans	2.42 ± 0.86	0.47 ± 0.17	2.89
Galidictis fasciata	0.28 ± 0.13	0.86 ±0.33	1.69
Salanoia concolor	NA	NA	1.66
Canis familiaris	**0.28 ± 0.10**	2.20 ± 0.55	**9.24**
Felis catus	**NA**	**NA**	**0.77**
Viverricula indica	**NA**	**NA**	**0.04**
Occupancy comparison	This study	Ross 2020	Rasambainarivo 2017
Protected Area	COMATSA-Sud / Marojejy	ASSR	Betampona
Cryptoprocta ferox	.48 ± .11	0.65 ± 0.23	0.95 ± (.08)
Eupleres goudotii	NA	NA	.03†
Fossa fossana	.44 ± .14	0.80 ± 0.09	NA
Galidia elegans	.73 ± .10	0.8 ± 0.35	0.62 ± (.12)
Galidictis fasciata	.42 ± .25	0.52 ± 0.13	0.8 ± (.09)
Salanoia concolor	NA	NA	0.68 ± (.13)

Canis familiaris	**.41 ± .37**	**0.7 ± .13**	**0.91 ± (.07)**
Felis catus	**NA**	**NA**	**.13†**
Viverricula indica	**NA**	**NA**	**0.03†**

Table 3.

Trap Success and occupancy comparison table. Comparing recently surveyed protected areas COMATSA (this study) Anjanaharibe Sud Special Reserve (Ross et al. 2020), and Betampona Nature Reserve (Rasambainarivo et al. 2017). Standard error (if calculated) is noted after (±). Naive occupancy estimates (marked by (†)) is the proportion of sites that recorded at least one photograph of the target species. Naive occupancy estimates are used in lieu of sufficient data to account for imperfect detection.

	COMATSA	Marojejy
	WWF	MNP
Occurrences	35	104
Hectares	350	550
Occurrence per ha	0.10	0.19
Landscape Avg Occ per ha	0.15	

Table 4

Carnivore occurrences per hectare

Calculations of unique carnivore occurrences (a photographic capture event that is separated for temporal independence). The calculations show that the Marojejy NP produced significantly more unique carnivore occurrences than the COMATSA-Sud area. The landscape average was found by dividing the total carnivore occurrences by the total area (ha) surveyed.

List of Figures:

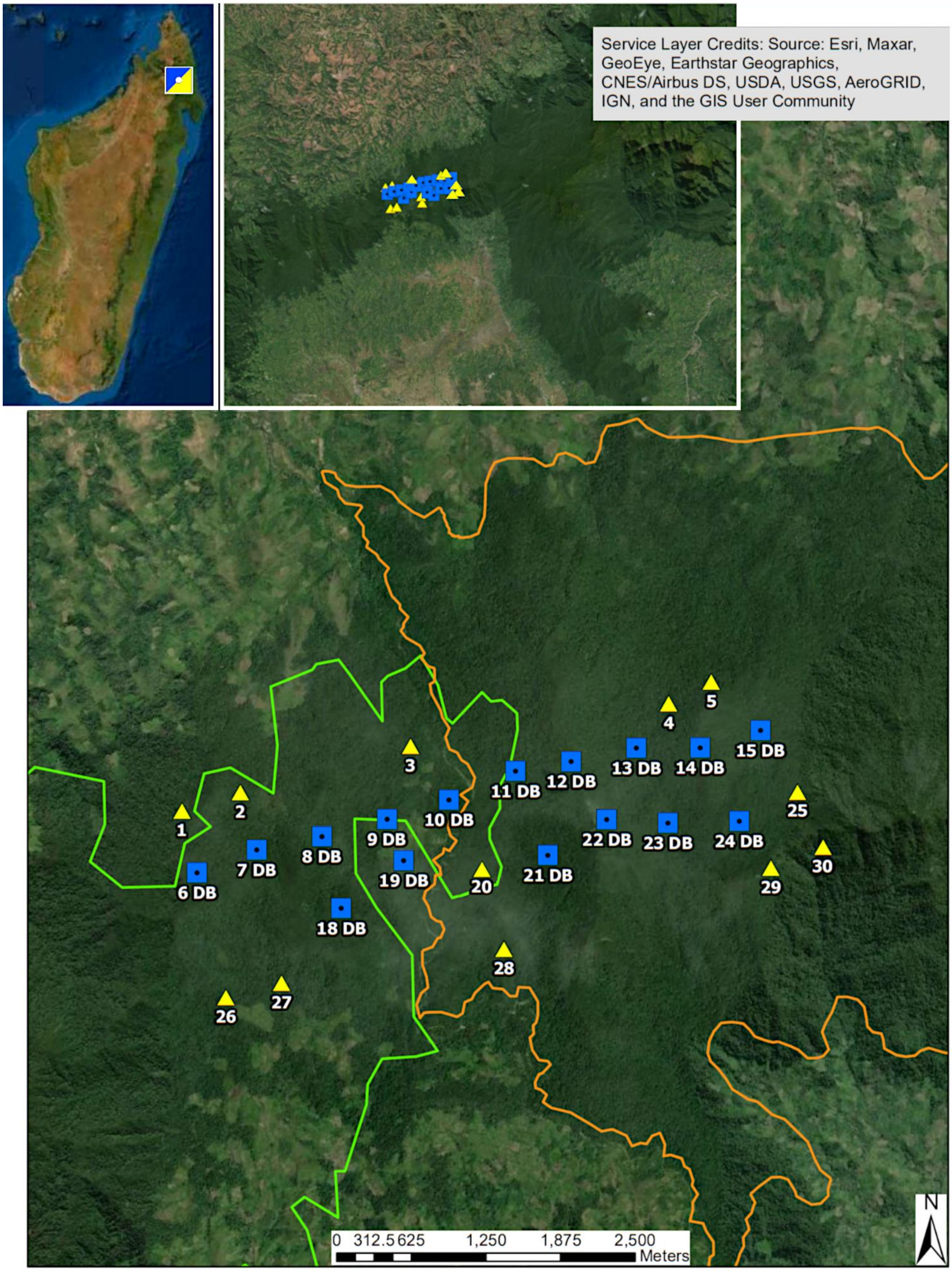
Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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Figure 1. COMATSA / Marojejy NP Camera Traps Map

Map of the study site within COMATSA-Sud and Western Marojejy National Park / UNESCO World Heritage Site. Made using ArcGis and Arc Maps. by: Patrick Ross. *COMATSA / Marojejy NP Camera Traps*. [ESRI ArcMaps] 10.8. 1. License from the University of Missouri St Louis, 3.21.2022. Yellow triangles represent single camera trap stations, blue squares represent double camera trap stations. Average spacing of stations is (±SD) of 484m ± 71m. Green line delineates the boundary for COMATSA. Orange line delineates the boundary for Marojejy National Park and UNESCO World Heritage Site.

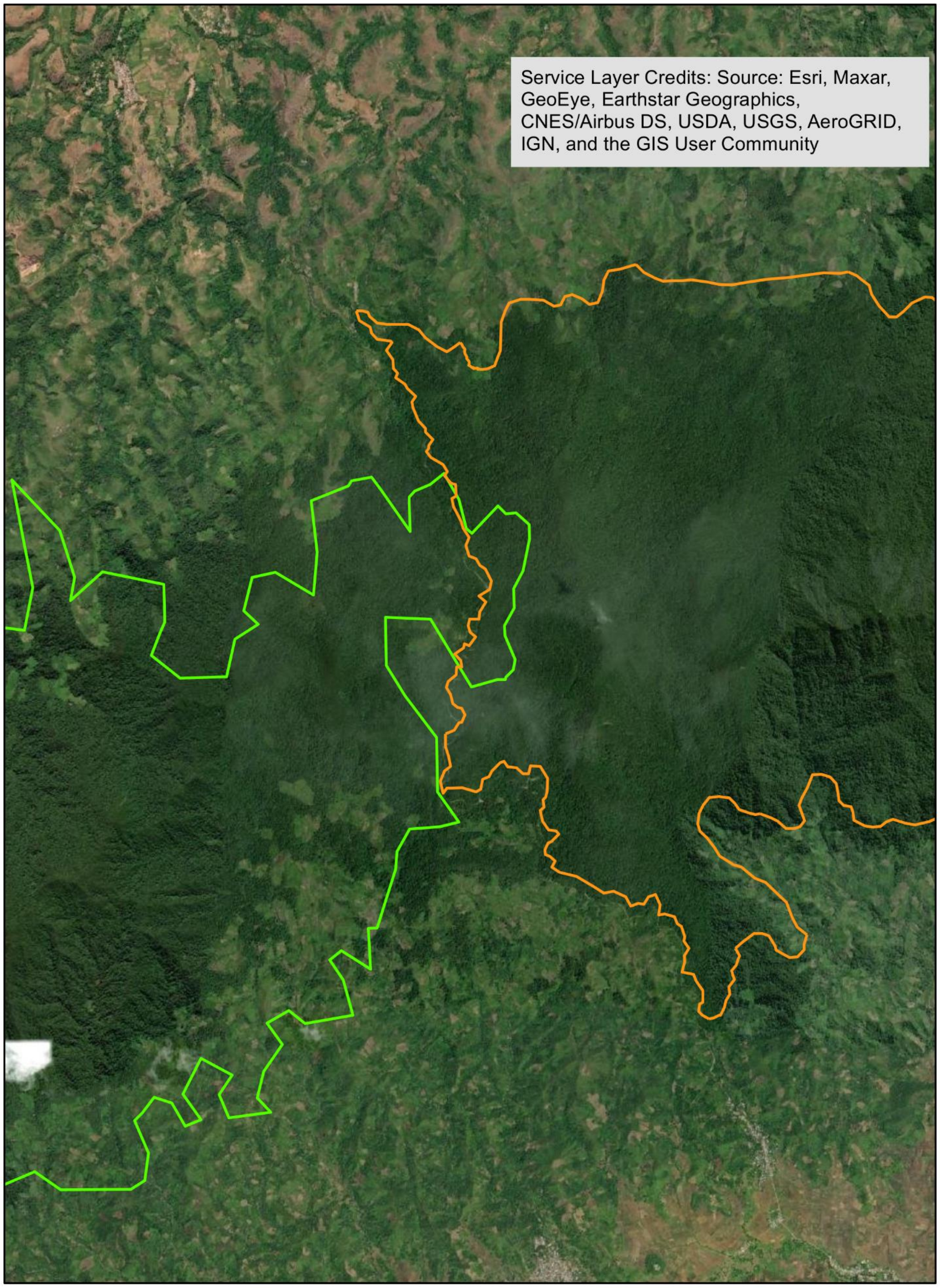


Figure 2.

Map of the study site without camera trap locations. Degraded lighter patches are visible in the center of the corridor. There is a 350m by 500m deforested hole in the center of the corridor. Located at (14°28’06. 80”S 49°32’41.31”E).

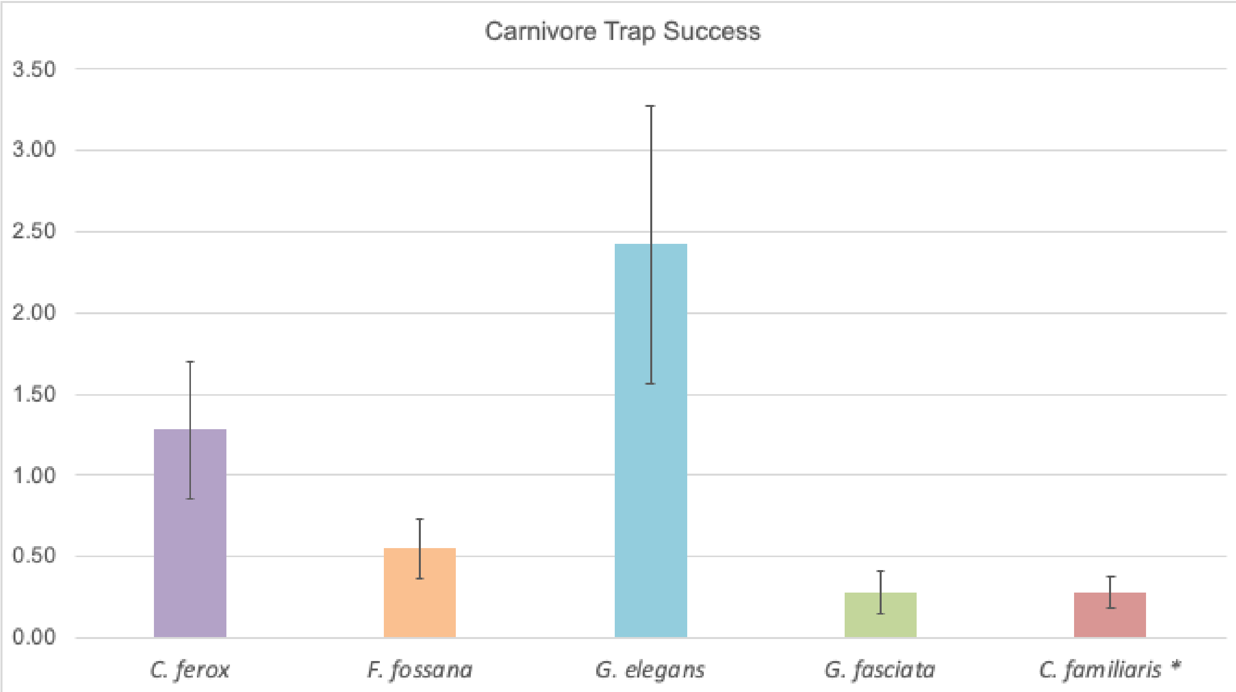


Figure 3.

Carnivore trap success (±SE) within COMATSA and Western Marojejy.

Trap success is the number of independent photographic capture events of a species divided by the number of trap nights, multiplied by 100. Species shown are *Fossa fossana, Galidictis fasciata, Cryptoprocta ferox, Galidia elegans,* and *Canis familiaris*. * represents non-native species.

Circle size indicating faunal detection is not consistent across maps

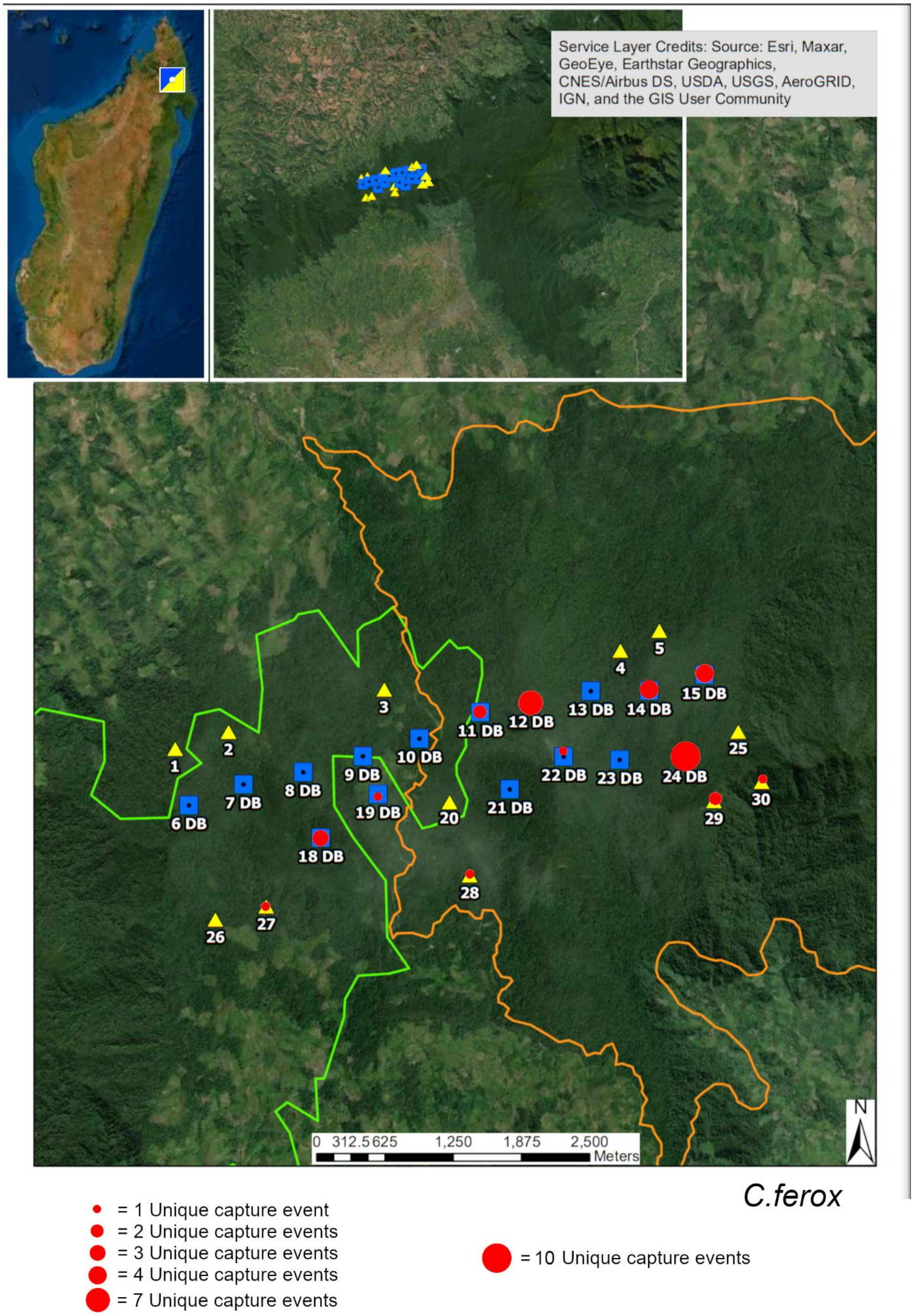


Figure 4.

Map of *Cryptoprocta ferox* unique capture events with a scale that notes red circle size with capture amount.

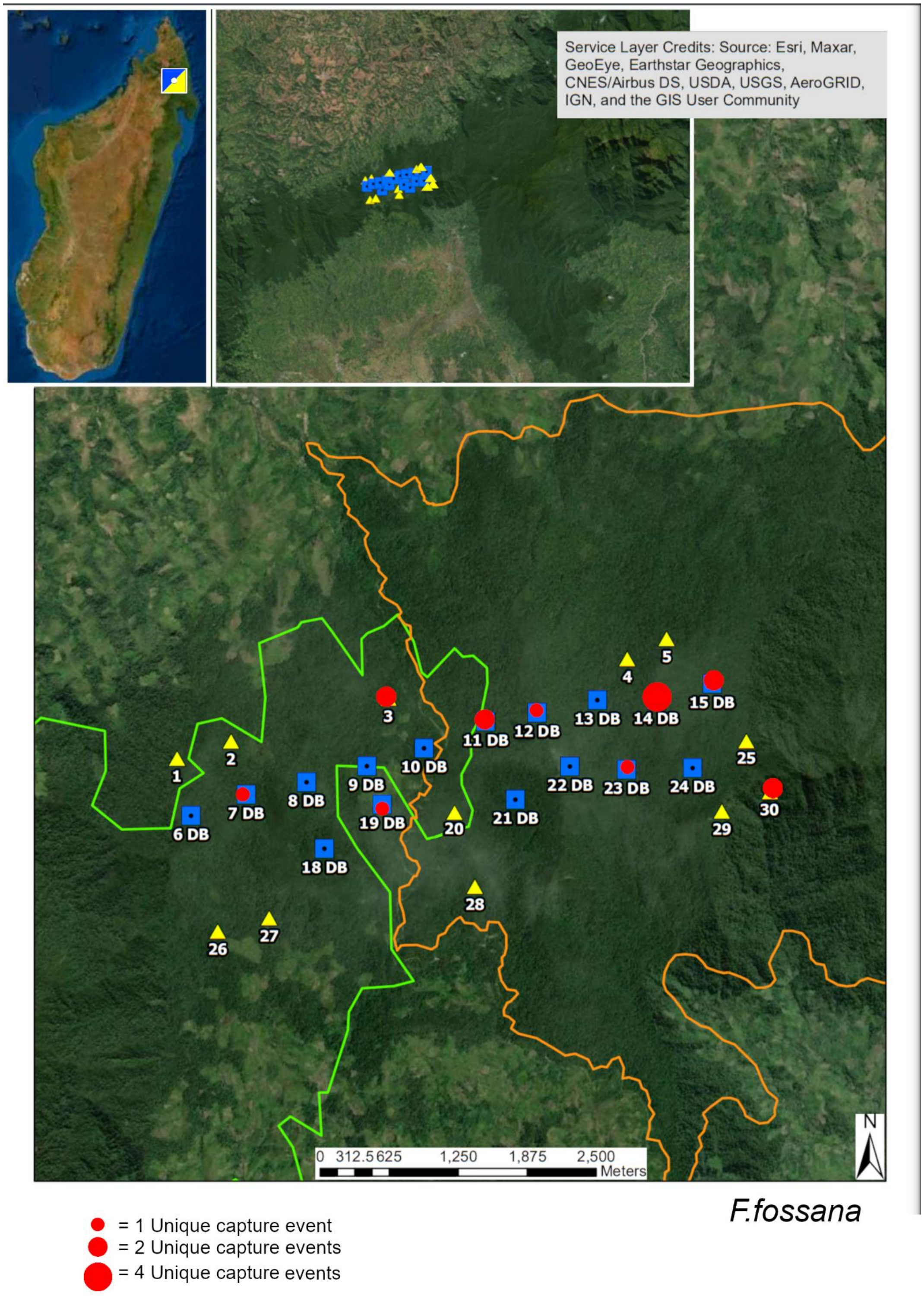


Figure 5.

Map of *Fossa fossana* unique capture events with a scale that notes red circle size with capture amount.

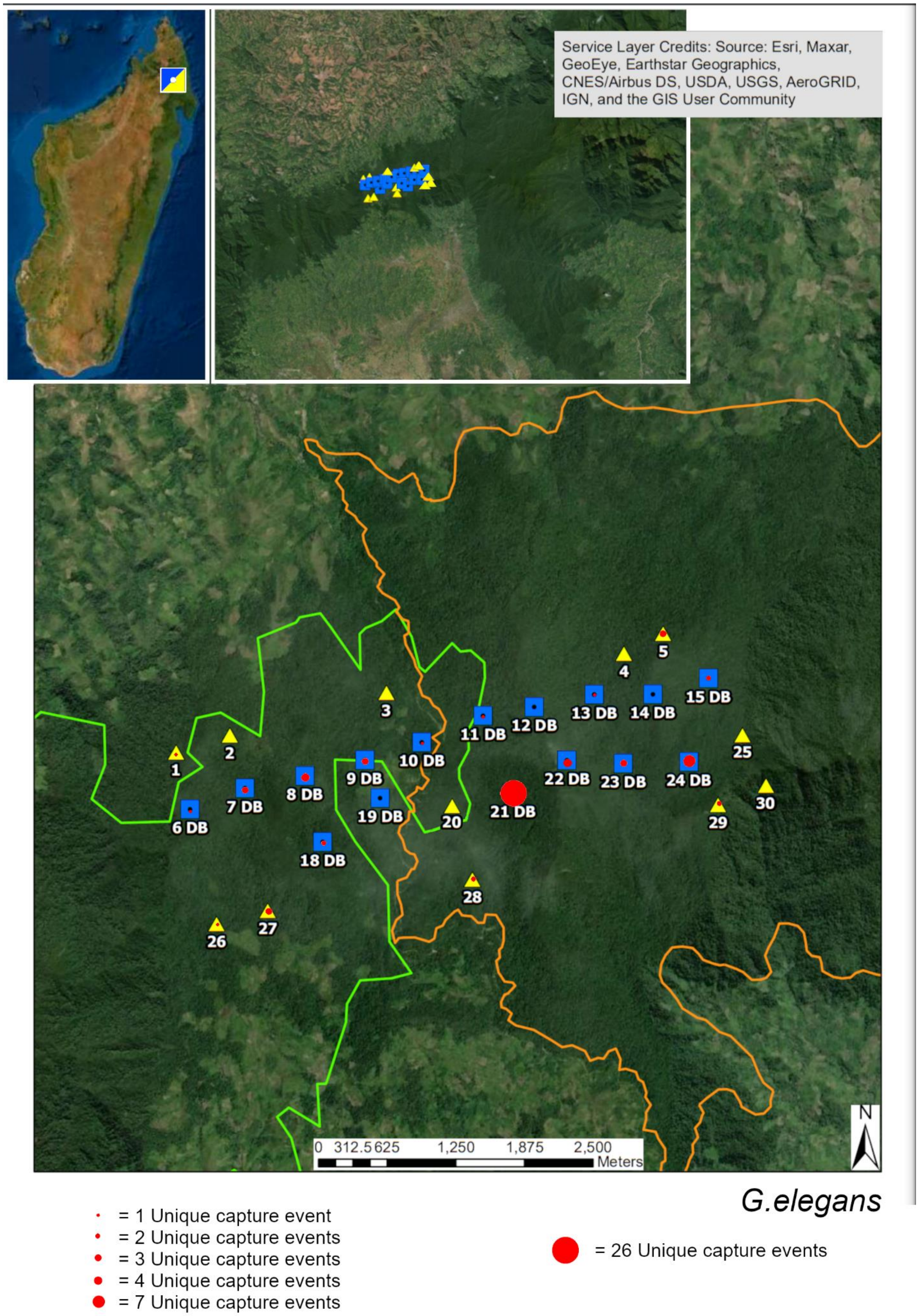


Figure 6.

Map of *Galidia elegans* unique capture events with a scale that notes red circle size with capture amount.

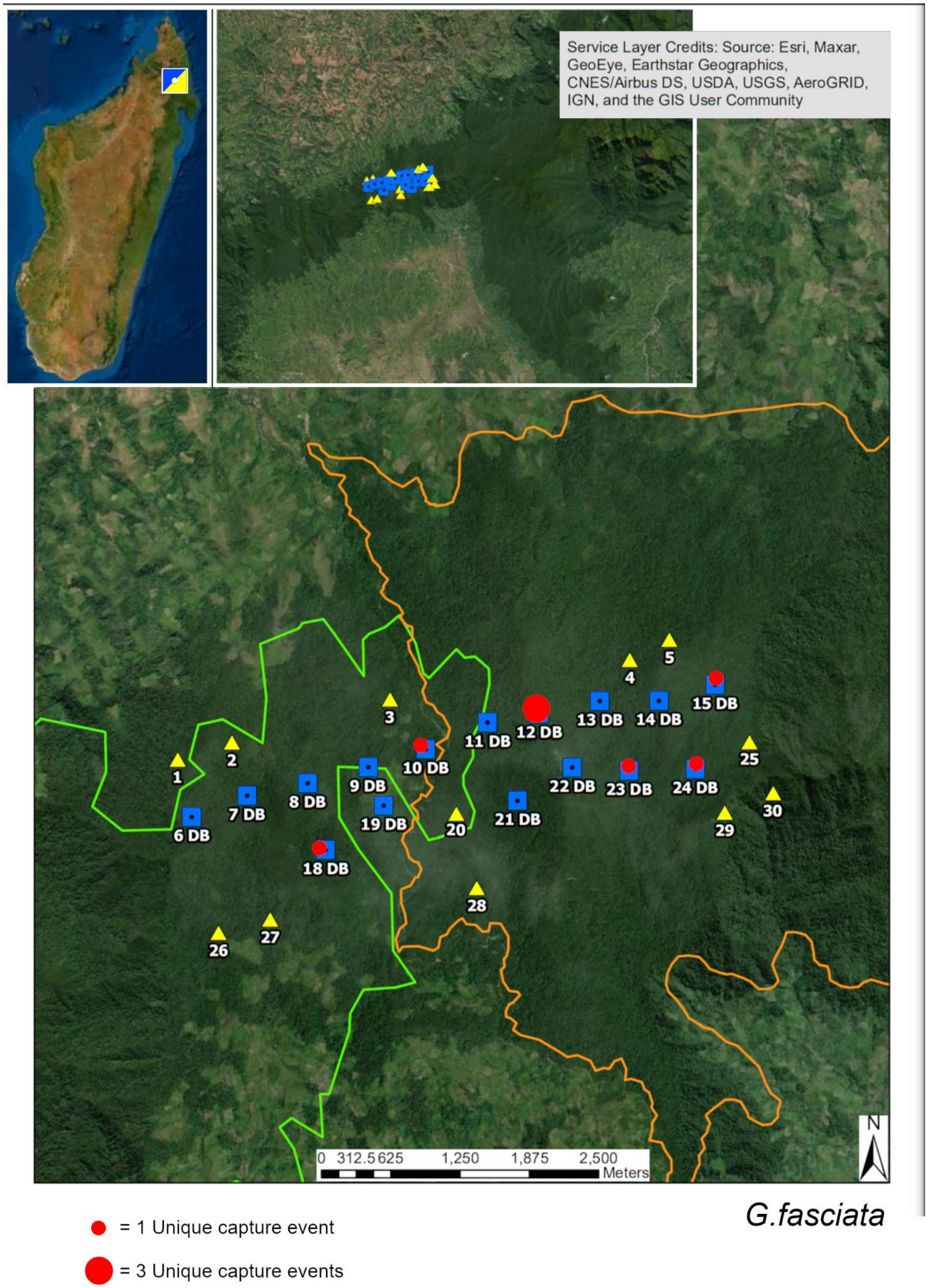


Figure 7.

Map of *Galidictis fasciata* unique capture events with a scale that notes red circle size with capture amount.

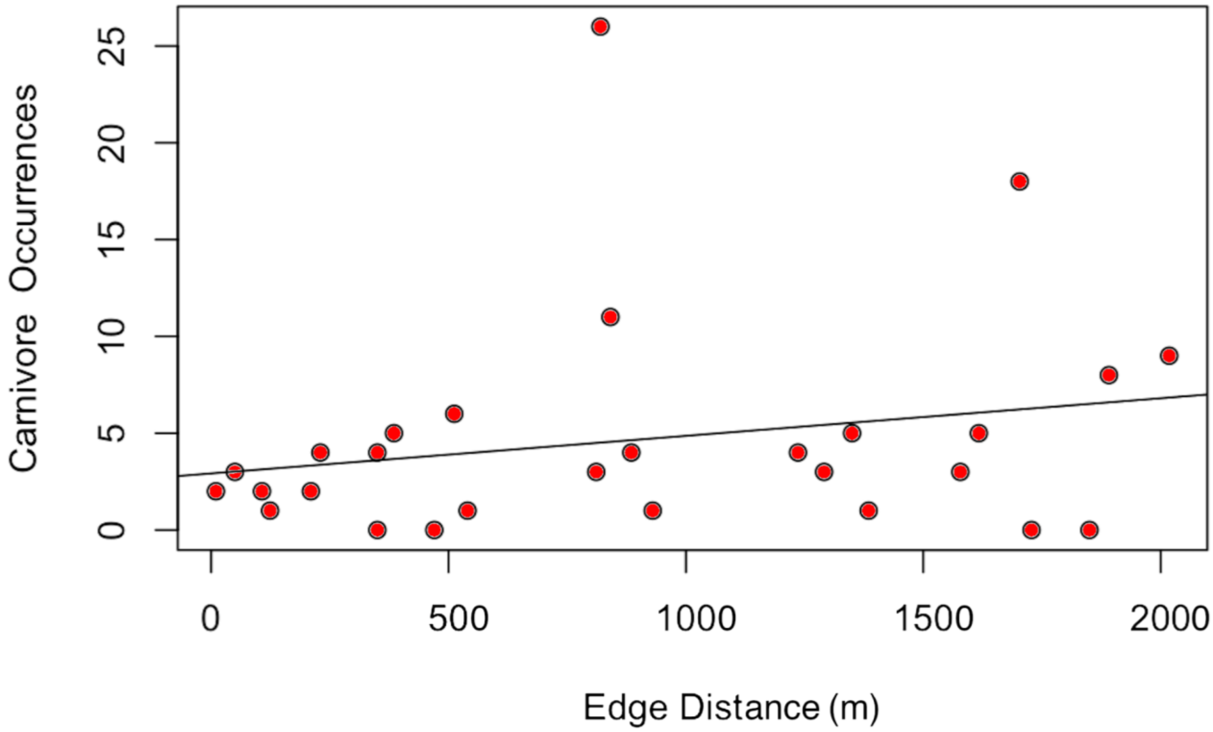
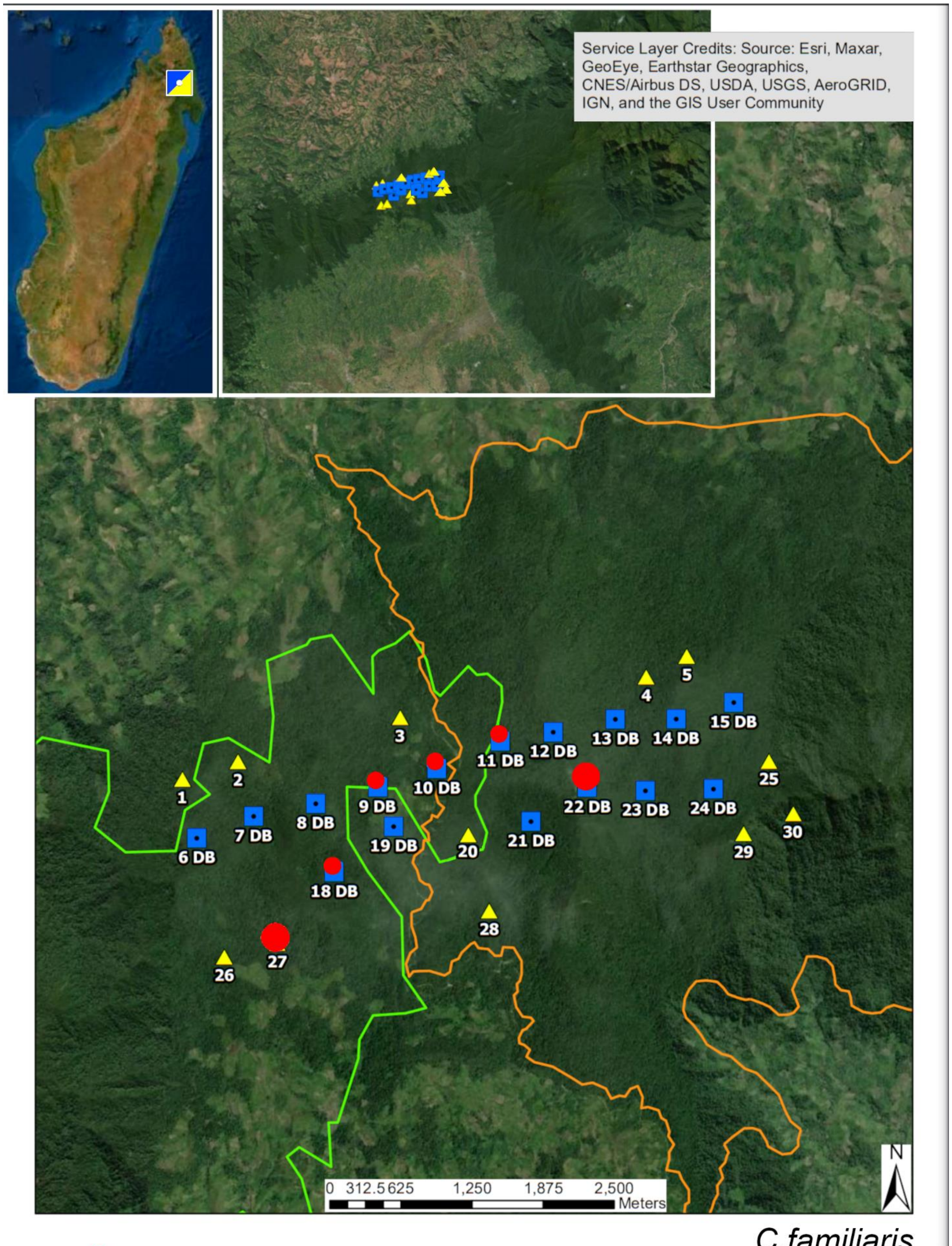


Figure 8.

Unique native carnivore occurrences graphed by their relation of the capturing camera trap station to forest edge within the COMATSA-Sud and Marojejy National Park corridor landscape. Distance to forest edge is a fixed effect, Species is a random effect and number of carnivore occurrences is the response variable. (Pr Value = 0.0033) (Std. Error = 0.0015)



= 1 Unique capture event

= 2 Unique capture events

Figure 9.

Map of *Canis familiaris* unique capture events with a scale that notes red circle size with capture amount.

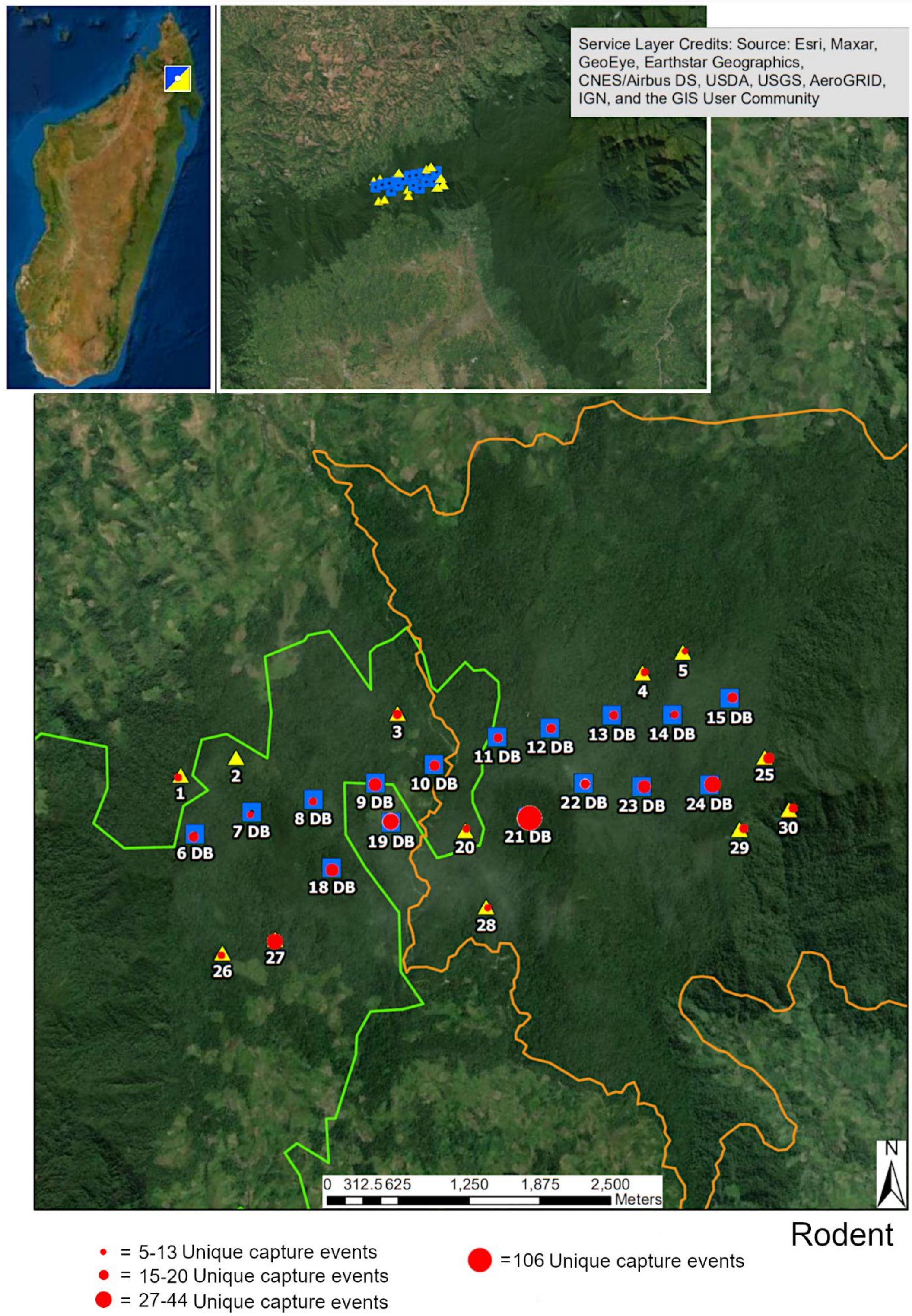


Figure 10.

Map of Rodent (all species) unique capture events with a scale that notes red circle size with capture amount.

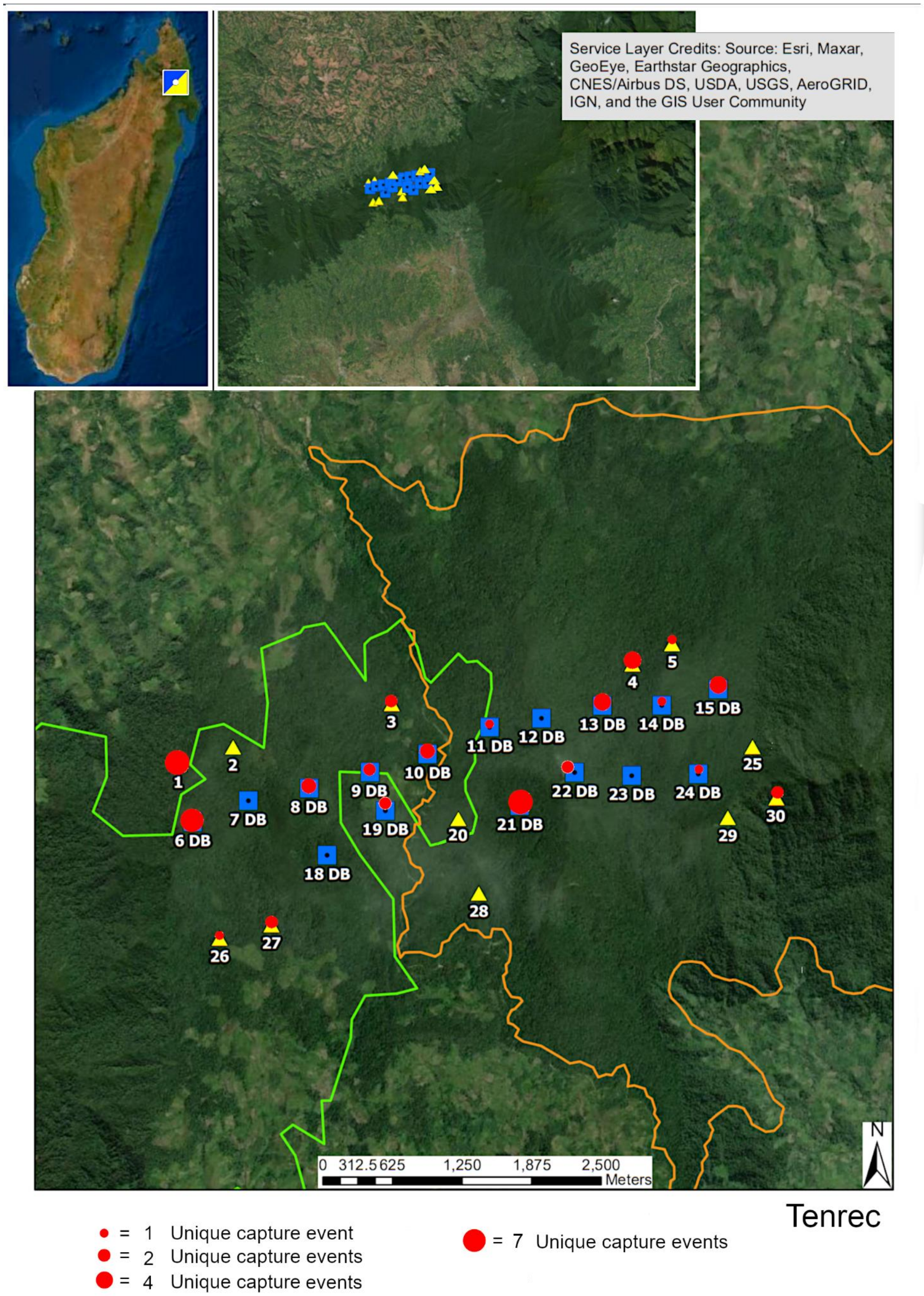


Figure 11.

Map of Tenrec (all species) unique capture events with a scale that notes red circle size with capture amount.

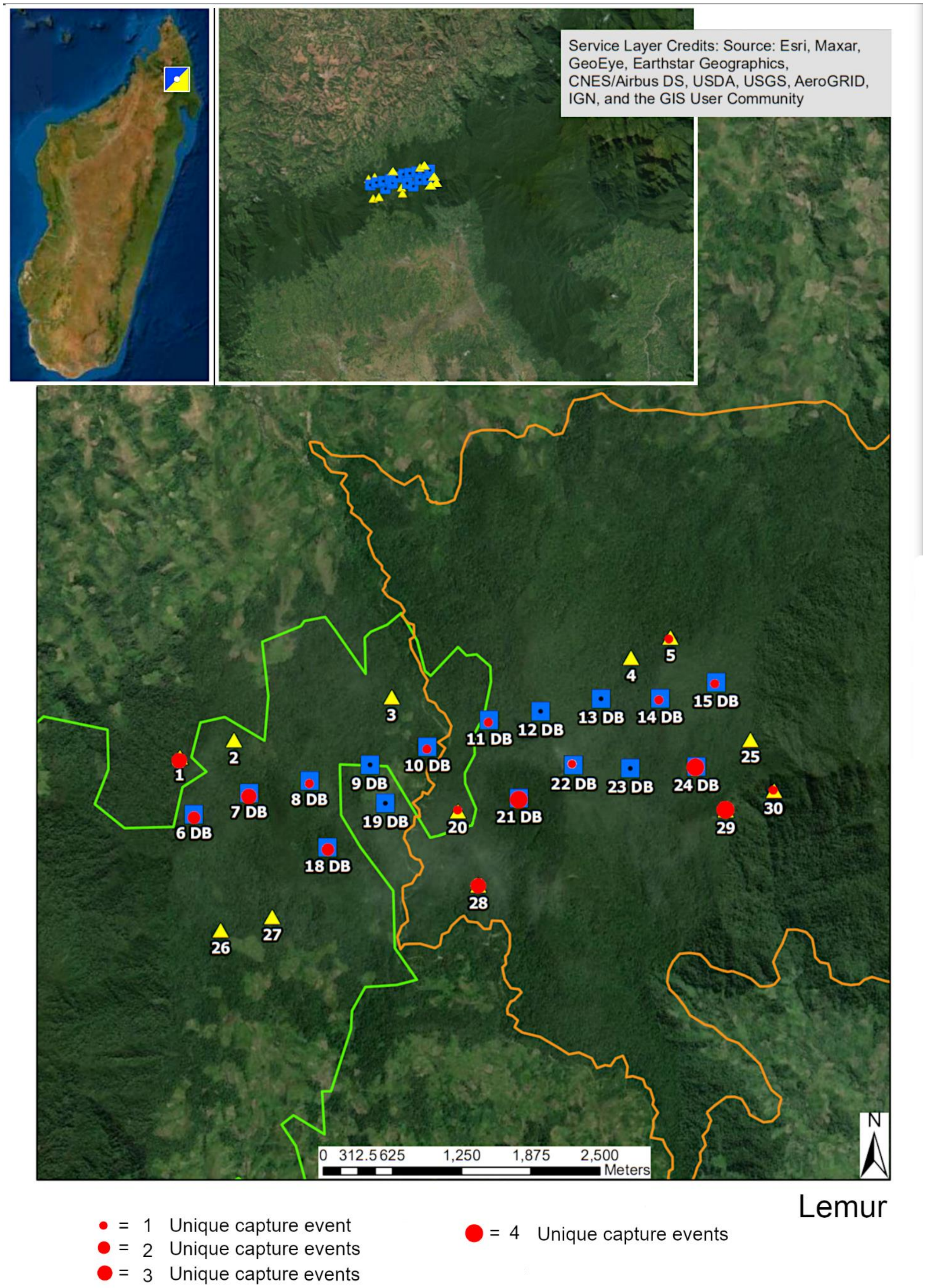


Figure 12.

Map of Lemur (all species) unique capture events with a scale that notes red circle size with capture amount.

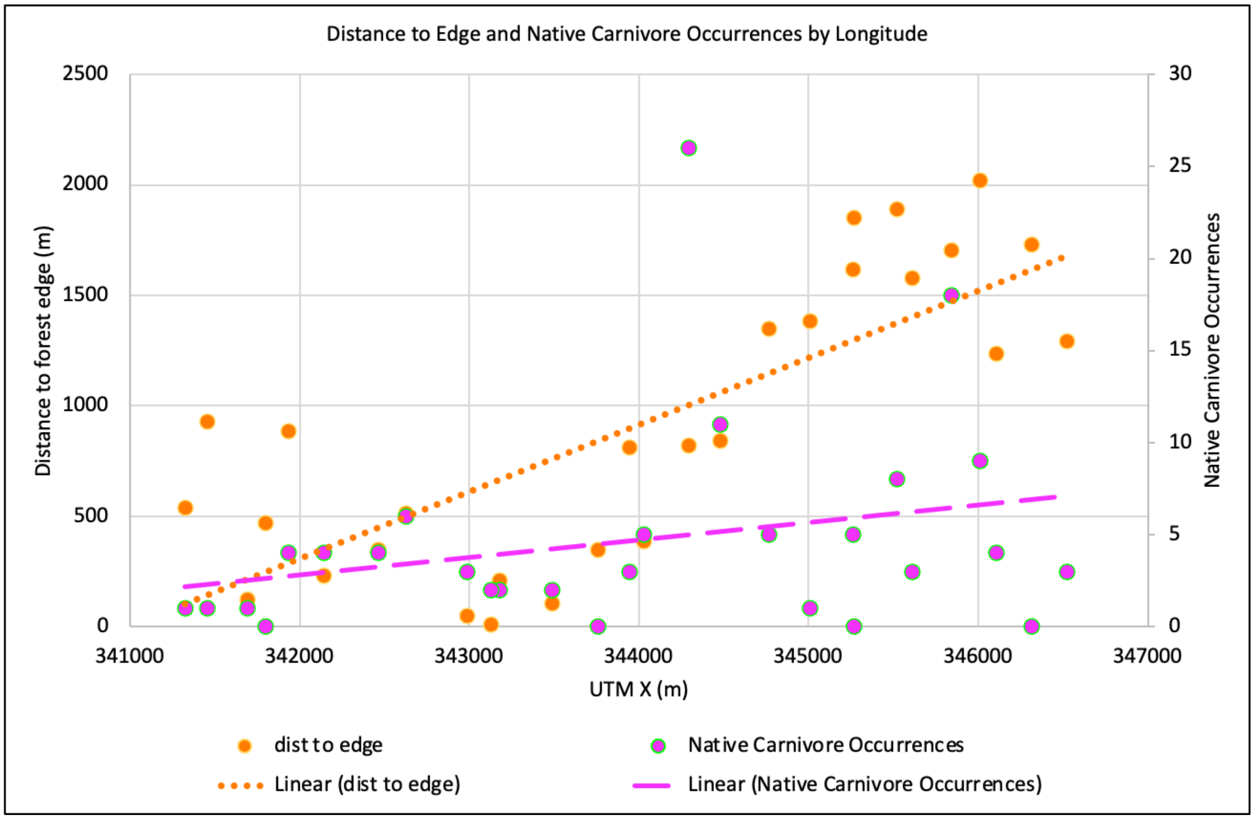


Figure 13.

Distance to forest edge and native carnivore occurrences graphed by their relation to longitude (East to West) within the COMATSA-Sud and Marojejy National Park forest corridor landscape. WGS 84 / UTM zone 39S. (Significance F = 0.16) (P Value= 0.17) for Native Carnivore occurrences by Eastwardness of camera trap station in our sampling grid.

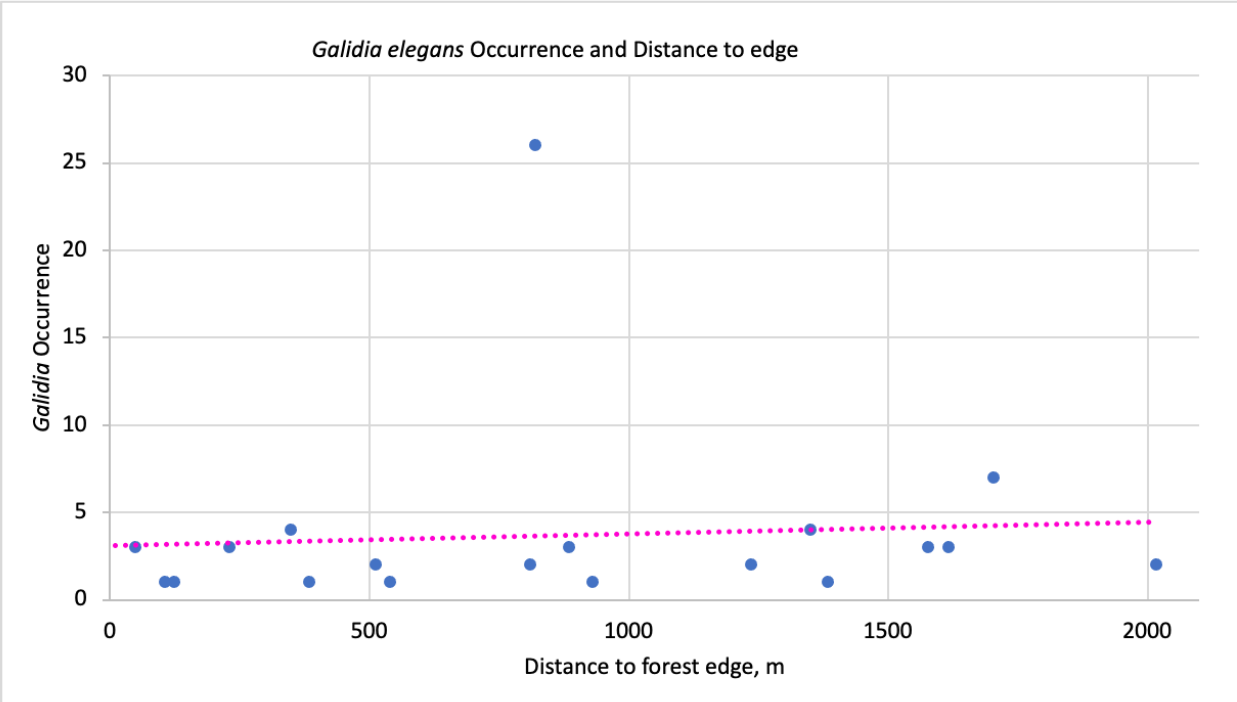


Figure 14.

Unique occurrences of *Galidia elegans* graphed by distance to forest edge of the capturing camera trap station within the COMATSA-Sud and Marojejy National Park forest corridor landscape. *Galidia elegans* displays no sensitivity to edge. Regression test (Significance F = 0.87) (P Value= 0.17).

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Author Contributions:

Patrick Ross was involved in conceptualization, funding acquisition, investigation, methodology, supervision, data curation, formal analysis, visualization, and writing (original draft) review & editing.

Dr. Erik Patel was involved in conceptualization, funding acquisition, methodology, supervision, review and editing.

Rojo Nandrianina Ravelijaona was involved in investigation and methodology

Guy Irenel Raoloniana was involved in investigation and methodology

Dr. Luke Dollar was involved in funding acquisition, review & editing

Dr. Patricia G. Parker was involved in conceptualization, funding acquisition, review & editing

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