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## New distribution records and population density of the Critically Endangered Tarzan Chameleon (*Calumma tarzan*), eastern Madagascar

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### ABSTRACT

The distribution and population density of the Critically Endangered Tarzan Chameleon (*Calumma tarzan*) in eastern humid forests of Madagascar was studied using line transect-distance sampling. Based on the results from species distribution models, eight sites were visited over a four-month period from February 2020 to March 2021. In total, 46 transects of 1 km were investigated in 23 different forest fragments to understand the distribution of *C. tarzan*. Another 28 transects of 200 m in length were surveyed to estimate population density. Among the 23 investigated forest fragments, *C. tarzan* was confirmed from 14 fragments belonging to five sites. All 14 records are completely new and represent a significant range extension for the species. *Calumma tarzan* is distributed within an elevation range of 604–1048 m above sea level. An analysis of the population of the species across sites show that density varies broadly and ranges from 25 to 78 individuals per hectare. This study fills important knowledge gap on a Critically Endangered and endemic chameleon species and is vital to the development of urgently needed conservation strategy for the Tarzan Chameleon.

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## Introduction

Almost half of the world's chameleons are found in Madagascar (Glaw and Vences 2007), a key chameleon biodiversity hotspot with more than 97 endemic species (Prötzel et al. 2017a, 2017b, 2020; Glaw et al. 2021). Madagascar's chameleons comprise four genera (Glaw et al. 2013), with species varying widely in size and appearance. *Brookesia* and *Palleon* are amongst the smallest species and include the smallest known chameleons

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in the world (Glaw et al. 2013). In contrast, *Furcifer* and *Calumma* species are among the largest, reaching over 50 cm in length (Glaw and Vences 2007).

More than 50% of Malagasy chameleons on the IUCN Red List of Threatened Species are threatened with extinction (IUCN Red List 2023), driven largely by habitat loss and over-collection for the pet trade (Jenkins et al. 2014). Habitat destruction and fragmentation, primarily caused by land transformation for agricultural purposes and logging, are the most significant threats (Jenkins et al. 2014). As forests are cleared, chameleons lose their habitat, therefore populations struggle to survive. Chameleon conservation in Madagascar is a complex and ongoing effort that requires collaboration between government agencies, conservation organisations, local communities, and other stakeholders. Unfortunately, while some species have been relatively well studied, there is paucity of data for most. These knowledge gaps hinder efforts to design and implement conservation strategies for many species.

The Tarzan Chameleon (*Calumma tarzan*) is a medium-sized green chameleon (snout-vent length 61–72 mm, total length 119–150 mm) with a characteristic rostral profile, consisting of the rostral crests which are fused anteriorly to form a spade-like ridge that slightly projects beyond the snout tip (less than 1 mm), and a distinct colour pattern, consisting of a green to bright yellow ground colouration (with dark transversal bands when stressed) and a brown to blackish casque and neck in males (Gehring et al. 2010; Figure S1).

*Calumma tarzan* was initially recorded from three small humid forest fragments within the Alaotra-Mangoro Region, eastern Madagascar (Gehring et al. 2010; Randrianantoandro 2012). It is listed as Critically Endangered on the IUCN Red List based on the continuing decline of its forest habitat and a severely fragmented population (Jenkins et al. 2011), though this assessment is now in need of updating (i.e., > 10 years old). *Calumma tarzan* has since been reported within the Atsinanana Region, eastern Madagascar (Andriantsimanarilafy et al. 2020). There is the possibility that the species may occur in other unsurveyed areas particularly in forests below 910 m elevation (Gehring et al. 2010). Little is known about the ecology and biology of this threatened chameleon, and its distributional range is still uncertain. Thus, more surveys are needed to determine the distribution of *C. tarzan* (Jenkins et al. 2011) as many other potential sites may be overlooked which could inform its conservation status.

This study, undertaken by national NGO Madagasikara Voakajy and the Zoology and Biodiversity of Animals Department of the University of Antananarivo, aimed to identify new sites for *C. tarzan* whilst concurrently assessing the chances of its long-term survival at Tsiazombazaha, Ranomafana, Beanana, Ambalavato, Ambavala, Fanantsarana, Madiofasina, and Manandriana sites through robust density estimation using distance sampling.

## Materials and Methods

### *Species distribution models*

*Calumma tarzan* occurrence data were gathered from previous surveys (Gehring et al. 2010; Randrianantoandro 2012) alongside more recent survey data from Tarzanville, Ambatofotsy and Ankorabe (Andriantsimanarilafy et al. 2020; Figure S1). A maximum

entropy approach using Maxent v. 3.3.3 (Phillips et al. 2006; Phillips and Dudik 2008) was utilised to identify the potential areas of occurrence (please see **Site selection and description** below for details). A primary model was run using 89 unique species occurrence records with 19 bioclimatic predictor variables at 30-sec resolution, available from WorldClim v. 2.0 (Fick and Hijmans 2017). The parameters used in the primary model remained as default, with the regularisation multiplier set at 10.

Upon completing the field surveys, we re-ran our distribution models and evaluated the updated model performance using ENMeval v. 2.0.4 (Kass et al. 2021) applying the maxent algorithm (Phillips et al. 2017) from the maxent R package. This was done in order to construct models with different parameter settings and perform model evaluation to identify the most optimum model to better inform suitable areas for *C. tarzan* (Muscarella et al. 2014; Kass et al. 2021). We included an additional 81 unique records obtained through field surveys informed by our primary model. To reduce spatial autocorrelation, records were spatially rarefied to a distance of 200 m using the package *spThin* (Aiello-Lammens et al. 2015) run in R v. 4.1.0 (R core Team, 2022). This resulted in a total of 50 unique data points. Models were built with different combinations of the linear (L), quadratic (Q), hinge (H), product (P) and threshold (T) feature classes (LQHPT; LQHP; LQH; L; LQ; H) and varying the regularisation multiplier (0 to 4.5 with 0.5 increments). Data were partitioned into testing and training bins using the 'jack-knife' method since this is the recommended method with sample sizes smaller than 25 (Muscarella et al. 2014). To account for spatial sampling bias, 10 000 background points were randomly selected across the study area (Phillips et al. 2006).

Optimal model parameters were selected using a variety of criteria. The Akaike Information Criterion (AIC) corrected for small sample sizes was first considered. The model with the lowest AIC value indicates a balance between the best goodness of fit and complexity (Warren and Seifert 2011). The area under the curve (AUC), difference between training and validation AUC (AUCdiff), minimum training presence omission rate (ORmtp) and the training omission rate (OR10) were also inspected to ensure that the models were not overfitting (Anderson and Gonzalez 2011). Variable contributions in the optimum model were inspected, and the most important variables were noted as per the permutation importance (Phillips et al. 2006). Variable contributions to optimum model predictions were based on variable permutation importance, with all variables with an importance value < 1 being removed. The remaining variables were BIO4 – temperature seasonality; BIO5 – max temperature of the warmest month; BIO6 – min temperature of the coldest month; BIO7 – temperature annual range; BIO8 – mean temperature of the wettest quarter; BIO10 – mean temperature of the warmest quarter; BIO13 – precipitation of the wettest month; BIO14 – precipitation of the driest month; and BIO19 – precipitation of coldest quarter.

### **Site selection and description**

Based on the results from species distribution models (SDMs), we selected and checked the localities with a probability of occurrence from 70–100% (represented by green squares in Figure S1) to confirm the presence of *C. tarzan*. These localities coincided with six municipalities: Ampandroatraka, Antanandehibe, Antanambao-Manampotsy,

Lakato, Mahela and Tratramarina within the Alaotra-Mangoro and Atsinanana Regions in eastern Madagascar (Figure S1).

Among the six municipalities selected from the SDMs (Figure S1), a preliminary analysis in Google Earth was conducted to identify the remaining forest. We selected forests with an area greater than 5 ha for field surveys. In total, 23 forest fragments dispersed in eight sites were visited: Tsiazombazaha, Ranomafana, Beanana, Ambalavato, Ambavala, Fanantsarana, Madiofasina, Manandriana (see Table S1). The forests in the study sites are highly fragmented and form several blocks (Table S1). All fragments displayed indications of disturbance including evidence of previous bush fires and logging activities. The level of disturbance in each fragment was determined by the magnitude of the disruption, and was classified as: 'less disturbed', 'disturbed', or 'highly disturbed' (Table S1).

The vegetation was characterised as low altitude (0–800 m) and mid altitude (800–1 800 m) evergreen humid forest (Du Puy and Moat 1996). The annual rainfall in these fragments varied from 2 000 to 4 000 mm/year with no dry months (Koechlin et al. 1974). The temperature is typically above 15 °C with high relative humidity (Koechlin et al. 1974). The soil in the study area is dominated in particular by ferralitic soils (Koechlin et al. 1974).

## ***Sampling design***

### ***Data collection***

Fieldwork was conducted during the rainy season, to coincide with maximum chameleon activity (Raxworthy 1998). We conducted a series of surveys: from March to April 2020 at Tsiazombazaha and Ranomafana sites; November to December 2020 at Beanana, Ambalavato, Ambavala and Fanantsarana sites, and February to March 2021 at Madiofasina and Manandriana sites. The GPS location of each transect and detected chameleon were recorded using a handheld GPS receiver (Garmin etrex 10) with 5 m precision.

### ***Species distribution***

To investigate the presence of the species, pre-defined transects (pre-existing trails inside the forest) of 1 km in length were used. Two transects were established within each of the 23 forest fragments (see Table S1). Each transect was visited over three consecutive nights (visit spaced by 48 hours) to keep each visit independent. Chameleon surveys were conducted at night from 19:00 to 23:00 using head torches to spot individuals. Teams consisted of two individuals experienced in chameleon detection and survey protocols, walking slowly along the transect, carefully looking for individuals on the right or left from the lower strata to the canopy level.

### ***Population density assessment***

To estimate the population density of the species, a distance sampling approach was used; a common method for chameleon surveys (Jenkins et al. 1999; Brady and Griffiths 1999; Jenkins et al. 2003; Randrianantoandro et al. 2010). The four main assumptions of distance sampling are: (i) transect lines or points are placed at random in relation to the objects' distribution; (ii) all objects at zero distance from the transect line or point are detected; (iii) objects are detected at their initial location, before any movement occurs as a result of disturbance from the observer; and (iv) perpendicular distance from the animal original position to the transect line is measured accurately (Buckland

et al. 1993). Transects were placed randomly in the forest. Each transect was 200 m in length which comprises four parallel lines of 50 m separated from each other by 20 m to avoid double counting. To limit the effects of disturbance on the distribution of chameleons within the transect area, all lines were set up at least 24 hours before being surveyed in accordance with recommendations by Jenkins et al. (1999). The number of transects per site varied according to the size of the forest fragment. Each transect was visited once. For each individual detected, the following parameters were recorded: age class (adult, juvenile), sex, and the perpendicular distance from the roost location to the line. Perpendicular distance was measured accurately with a tape measure to the nearest centimetre. Density estimates were carried out in Tsiatzombazaha, Ranomafana, Beanana and Ambalavato.

To document the occurrence of the species, individuals were photographed in situ. Species identification was based on the key description (Gehring et al. 2010).

## Data analysis

### Density estimate

Density was computed using Distance software 7.3. Because low numbers of individuals were encountered in some fragments, we performed a global analysis of density for each site (see Table S1 for site details). We ran analyses in Conventional Distance Sampling (CDS) using stratum by post-stratify. We used four model combinations which have performed best in many studies (Thomas et al. 2010) including uniform key with cosine adjustments, half-normal key with cosine adjustments, half-normal key with Hermite polynomial adjustments, hazard-rate key with simple polynomial adjustments. The best model fitting the data was selected under the Akaike Information Criterion (Buckland et al. 2001).

### Area of occupancy and extent of occurrence of *Calumma tarzan*

We have combined the data on species occurrences from previous surveys and the current study to estimate the area of occupancy (AOO) and extent of occurrence (EOO) of the species. The data occurrences were uploaded (as CSV files) into GeoCAT website, an online tool to estimate AOO and EOO (<http://geocat.kew.org/>), where we used the default IUCN parameter of cell widths of 2 km.

## Results

### Species distribution models

Our initial model predictions were able to inform field surveys resulting in novel records for *C. tarzan*. Initial maxent models attained high levels of performance with an AUC score of 0.997 (Table S2). However, this is largely due to the limited number of occurrence points included in the initial model. Furthermore, precipitation seasonality (BIO15) contributed the most to the model prediction (permutation importance: 57.85), which suggests ecologically relevant variables may be under-represented as the model prediction is likely under-fitting due to the limited input data. When we re-ran the distribution model with the new occurrence records using ENMeval, model

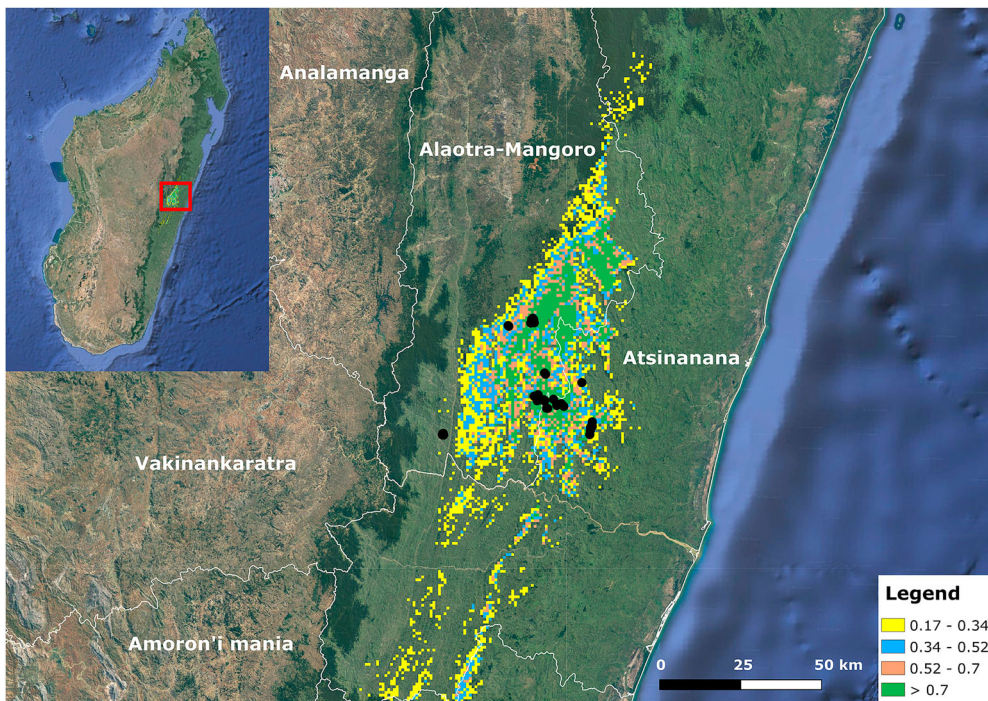
**Table 1.** Evaluation metrics of the optimum Maxent models for *Calumma tarzan* from the ENMeval outputs. Metrics shown are feature class (L: linear, Q: quadratic, H: hinge), regularisation parameter, Akaike Information Criterion (AIC), threshold-independent metric (AUC<sub>Train</sub>), difference between training and validation AUC (AUC<sub>Diff</sub>), minimum training presence omission rate (OR<sub>mtp</sub>), and training omission rate (OR<sub>10</sub>).

Feature Class	Regularisation Parameter	$\Delta$ AIC Value	AIC <sub>weight</sub>	AUC <sub>Train</sub>	AUC <sub>Diff</sub>	OR <sub>mtp</sub>	OR <sub>10</sub>
LQH	1.5	0	0.89	0.99	> 0.01	0.03	0.10

performance was good considering evaluation metrics meeting expected thresholds for our optimum model (i.e.,  $\Delta$ AIC was zero with low values of OR<sub>mtp</sub> and OR<sub>10</sub>, Table 1). We show that while our primary model produced adequate evidence to inform field surveys (Figure S1), with the additional records we were able to generate models with greater confidence for potential sites of occurrence (Figure 1). We also note areas suitable for additional surveys given that our models expand both northerly and further south.

### Distribution of *Calumma tarzan*

In total, 46 transects were investigated across 23 forest fragments. Among the 23 forest fragments visited, *C. tarzan* was confirmed from 14 fragments: four fragments in Tsiazombazaha, two in Ranomafana, six in Beanana, and one in both Ambalavato and Ambavala (Table 2, Figure 2). The species elevation range varied across the sites,



**Figure 1.** Predicted distribution of *Calumma tarzan* from our Maxent species distribution models evaluated with ENMeval.

**Table 2.** Presence and absence of *Calumma tarzan* across the eight sites and corresponding forest fragments investigated (-: species not found).

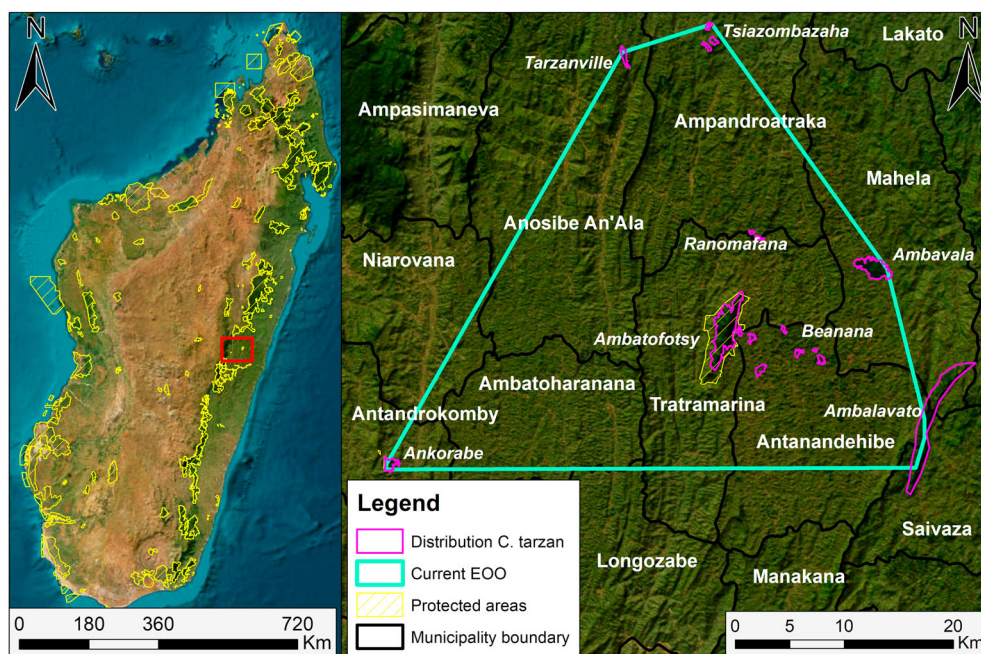
Site	Fragments visited	Number of transect (km)	Fragment yield <i>C. tarzan</i>	Species elevation range (m)
Tsiazombazaha	4	8	4	898–1 048
Ranomafana	7	14	2	717–725
Beanana	7	14	6	737–915
Ambalavato	1	2	1	720–780
Ambavala	1	2	1	604–670
Fanantsarana	1	2	–	NA
Madiofasina	1	2	–	NA
Manandriana	1	2	–	NA

specifically from 604 m to 1048 m a.s.l. (Table 2). Surveys in Fanantsarana, Madiofasina and Manandriana did not reveal the presence of *C. tarzan*.

### Population density

In total, 10 transects of 200 m length were surveyed in Tsiazombazaha, two transects in Ranomafana, six in Beanana, and ten transects in Ambalavato. One transect was only 150 m in Ranomafana due to small fragment size.

The population density of *C. tarzan* varied across the study sites, and 100 individuals were recorded across these four sites: 46 individuals along 2000m of transects in Tsiazombazaha, 12 individuals along 350 m in Ranomafana, 20 individuals along 1200 m in Beanana and 22 individuals along 2000m in Ambalavato (Table 3). The

**Figure 2.** Distribution of *Calumma tarzan* across the study sites.

**Table 3.** Density of *Calumma tarzan* across the four study sites. (Ind: individual, CV: coefficient of variation, CI: confidence interval).

Site	Effort (m)	Number of observations	Density (ind/ha)	CV	95% CI
Tsiazombazaha	2 000	46	52,81	38.20	23.38–119.28
Ranomafana	350	12	78,72	11.35	62.87–98.57
Beanana	1 200	20	38.26	27.63	20.18–72.54
Ambalavato	2 000	22	25.25	45.70	9.59–66.51

highest density was estimated in Tsiazombazaha with 78 individuals per hectare whilst the lowest was in Ambalavato with 25 individuals per hectare.

### **Area of occupancy and Extent of occurrence of *Calumma tarzan***

We combined the occurrence data from this study with that from all previous surveys to estimate a new AOO and EOO for the species. The updated AOO of *C. tarzan* is estimated to be 80 km<sup>2</sup> and its extent of occurrence (EOO) is estimated to be of 1 112 km<sup>2</sup>.

### **Discussion**

*Calumma tarzan* was previously confirmed from three forest fragments at elevations between 800 m to 910 m a.s.l.: Tarzanville, Ambatofotsy (Gehring et al. 2010), and Ankorabe (Randrianantoandro 2012), in Anosibe An'Ala district, Alaotra-Mangoro Region, eastern Madagascar. While our initial SDM was informed using limited published occurrence records, we were able to reliably inform field surveys from which we obtained novel occurrence records for this species. We recorded a new locality of *C. tarzan* in the Alaotra-Mangoro Region and a range extension into the Atsinanana Region, in eastern Madagascar. We recorded the species within 14 new forest fragments belonging to five sites from 604 m to 1 048 m a.s.l.: Tsiazombazaha, Ranomafana, Beanana, Ambalavato and Ambavala, mostly situated around 10–37 km to the east and north-east of Anosibe An'Ala district. We note that our optimum model, developed with our novel records included, provided potentially new areas of suitability and with greater confidence. As there are areas of high suitability that we did not survey, we expect *C. tarzan* to be present in sites not explored in this study. We should note, however, that while we were able to obtain novel records for this species, these areas in which *C. tarzan* occurred were restricted to forested areas. Furthermore, we acknowledge that while our models predict a wide area of suitability across the region, we would recommend conservation estimates for the distribution of *C. tarzan*, particularly limited to forest patches. To date, no complete assessment for the species' entire distribution has been published. Therefore, additional surveys are warranted to better understand the geographic distribution of *C. tarzan*, with potential further validation of our predictions here.

Although we inform novel occurrence records for *C. tarzan*, in 2020 Randrianantoandro (unpublished report) reported the presence of *C. tarzan* in Sahamahitsy, a littoral forest patch belonging to Manombo forest (Ankarana Mirahina municipality, Farafangana District, Atsimo-Atsinanana Region) with an elevation range of 21 m to 79 m a.s.l. Thus, though we have surveyed new sites and provided updated data on the distribution of *C. tarzan*, the true distributional limits of the species still need to be established.

### **Population density and conservation status of *Calumma tarzan***

The density of *C. tarzan* varied between forest fragments. The populations in Ranomafana and Tsiazombazaha occurred at higher densities than Ambalavato and Beanana. This variation is likely due to the level of disturbance occurring in the forests, with less disturbed fragments having higher densities. Here, we provide the first density estimates for the four sites which serves as a baseline to begin population monitoring and assess the effects of habitat disturbance and degradation. We therefore recommend future monitoring programmes to survey *C. tarzan* populations in the forests where the species occurs. Also, any formal protection of the remaining forests would help protect an important population of this species. Andriantsimanarilafy et al. (2020) concluded that *C. tarzan* is forest dependent and prefers less disturbed habitats. They reported the following densities: 110 individuals per hectare in the Ankorabe protected area, 98 individuals per hectare in Tarzanville and 34 individuals per hectare in Ambatofotsy protected area. Although we provide density estimates for the four sites, we acknowledge the high coefficient of variation in population density for some sites which is probably linked to our low number of sightings and smaller sample sizes.

According to our surveys, *C. tarzan* has severely fragmented populations across its range. Slash-and-burn agriculture and logging were recorded at all sites, with continuing decline of the forest habitat across its range. Some parts of the two forest fragments in Tsiazombazaha and four others in Beanana were destroyed by fires during our investigation period. We recorded active illegal artisanal gold mining taking place inside Beanana and Tsiazombazaha forests as well as along the edge. All new forest fragments confirmed to contain *C. tarzan* have no formal protection status. *Calumma tarzan* was present in some fragments and absent in others at Ranomafana suggesting the species may have already been lost from some fragments following extensive destruction and disturbance. Our findings indicate *C. tarzan* may therefore be vulnerable to habitat degradation and disturbance.

Based on the IUCN Red List assessment in 2011, the area of occupancy (AOO) of *C. tarzan* was less than 10 km<sup>2</sup> and an extent of occurrence (EOO) not much greater (Jenkins et al. 2011). Here, we provide an updated AOO of 80 km<sup>2</sup> and an EOO of 1 112 km<sup>2</sup> for the species. According to the updated AOO and EOO and evidence of declining habitat extent and quality, we propose the status of *C. tarzan* as Endangered under criterion B of the IUCN Red List (AOO < 500 km<sup>2</sup>, EOO < 5 000 km<sup>2</sup> with severely fragmented locations undergoing continued decline).

*Calumma tarzan* was reported present at Manombo forest, a classified forest in the south-east of Madagascar (Randrianantoandro, unpublished report). Records at this forest could be also used to update the AOO and EOO for this species. However, due to the fairly large distances between *C. tarzan* populations in eastern and south-eastern Madagascar, there is an urgent need to assess the genetic distinctness between populations.

### **Conclusion**

In this study, we present recent information on the range and population densities of the Tarzan Chameleon (*Calumma tarzan*). Our findings confirm the previously unreported

occurrence of this species in 14 forest fragments located across five municipalities (Ampandroatraka, Tratramarina, Antanandehibe Saivaza, and Mahela) in the Alaotra-Mangoro and Atsinanana regions of eastern Madagascar. It is of concern that these newly discovered forest fragments are currently unprotected and face imminent threats such as logging and illegal gold mining activities. Further studies are needed to understand population dynamics and genetics, and better understand the natural history of *C. tarzan*.

For the conservation of *C. tarzan* and other endemic species living within vulnerable forest fragments, it is crucial that formal and effective management measures are implemented by the Malagasy government and NGOs. Therefore, we strongly recommend the inclusion of Ambalavato and Ambavala, two rainforest fragments measuring 521 ha and 324 ha respectively, in Madagascar's protected area network. The urgency of the situation demands that conservation initiatives for these forests be undertaken immediately.

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## Disclosure statement

No potential conflict of interest was reported by the author(s).

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