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Assessing carnivore distribution from local knowledge across a human-dominated landscape in central-southeastern Madagascar

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Abstract

Carnivores are often sensitive to habitat loss and fragmentation, both of which are widespread in Madagascar. Clearing of forests has led to a dramatic increase in highly disturbed, open vegetation communities dominated by humans. In Madagascar's increasingly disturbed landscape, long-term persistence of native carnivores may be tied to their ability to occupy or traverse these disturbed areas. However, how Malagasy carnivores are distributed in this landscape and how they interact with humans are unknown, as past research has concentrated on populations within continuous and fragmented forests. We investigated local ecological knowledge of carnivores using semi-structured interviews in communities 0 to 20 km from the western edge of continuous rainforest in central-southeastern Madagascar. Responses from 182 interviews in 17 different communities indicated distinct distribution patterns for two native and two exotic carnivore species, suggesting a range of tolerances to the human-dominated landscape. The largest extant native carnivore, the fossa *Cryptoprocta ferox*, does not persist in much of this landscape; they were only observed in communities < 5 km from the continuous forest within the last five years. In contrast, the ring-tailed mongoose *Galidia elegans* was observed by most communities (82%), but was observed by a higher proportion of interviewees from communities in close proximity to continuous forest. The exotic small Indian civet *Viverricula indica* was ubiquitous, while the exotic/feral cat (*Felis sp.*) was observed by a higher proportion of interviewees in communities farther from continuous forest. Over 20% of interviewees had experienced loss of poultry to wild carnivores in the last year and negative perceptions of carnivores were common. We found the human-dominated landscape to provide little conservation value to native carnivores, emphasizing the need for adequate protected areas and increased engagement of local communities to sustain Madagascar's carnivore species. This information is critical to multitaxon conservation planning in Madagascar.

Introduction

Many mammalian carnivores are vulnerable to habitat loss and fragmentation. This is due to intrinsic biological traits (e.g. large body size and slow population growth) as well as extrinsic factors, such as conflict with humans, that lead to displacement or mortality (Woodroffe & Ginsberg, 1998; Crooks, 2002; Cardillo *et al.*, 2004). As only a small percentage of connected, high-quality carnivore habitat is protected globally (Crooks *et al.*, 2011), these areas are of extreme importance to the long-term viability of carnivore species. Some carnivores, however, are able to sustain populations in highly disturbed, human-dominated landscapes (Gehrt, Riley & Cypher, 2010; Athreya *et al.*, 2013). These areas may hold greater carnivore conservation value than previously thought, but the capacity for human-dominated landscapes to sustain carnivore populations is likely highly variable and dependent on the types of interactions between carnivores and people. Sustaining carnivore populations is important because of their considerable influence on ecosystems (Letnic *et al.*, 2009; Terborgh & Estes, 2010), making them an integral part of conservation planning. As such, understanding carnivore distribution in disturbed habitats is important.

Madagascar carnivore distribution and the effects of anthropogenic changes on the landscape are poorly understood. However, Madagascar's landscape is radically changing; deforestation has reduced primary forest cover to < 16% of the island and > 80% of the remaining forest exists within 1 km of non-forest edge (Harper *et al.*, 2007). Cleared forest areas are dominated by a mixture of agriculture, bushlands, shrublands and grasslands with flora dominated by exotic species (Irwin *et al.*, 2010). Native Madagascar carnivores are strictly endemic, belonging to the family Eupleridae (Yoder *et al.*, 2003). Studies of these unique species have primarily occurred in highly connected and protected forests (Dunham, 1998; Hawkins & Racey, 2005; Dollar, Ganzhorn & Goodman, 2007; Gerber *et al.*, 2010). Recent studies provide evidence of decreasing carnivore richness and density of native carnivores with forest degradation and fragmentation (Gerber, Karpanty & Randrianantenaina, 2012). The larger native carnivores (fossa *Cryptoprocta ferox*, small-toothed civet *Eupleres goudotii*, Malagasy civet *Fossa fossana*) appear most sensitive to these habitat changes. The decline in native carnivores may be exacerbated by bushmeat hunting (Golden, 2009) and human–carnivore conflict, which has been found in other areas to be the top source of mortality for adult carnivores living in, but ranging beyond, protected areas (Woodroffe & Ginsberg, 1998). Carnivore distribution and carnivore–human interactions in the human-dominated landscape of Madagascar are unknown.

To understand how forest loss impacts carnivores, we need to know the distribution patterns of carnivores in the human-dominated landscape and how humans and carnivores interact. This information is important for (1) planning the restoration of forest corridors (Irwin *et al.*, 2010); (2) understanding behavioral and ecological interactions between carnivores and their endangered lemur prey (Irwin, Raharison & Wright, 2009; Kotschwar, 2010); (3) assessing options for mitigating human–carnivore conflict (Treves, Wallace & White, 2009). Increasingly, local ecological knowledge is recognized as an important complement to other types of information about distribution, population trends, response to habitat changes and harvest of wildlife species (Gilchrist, Mallory & Merkel, 2005; Brook & McLachlan, 2008; Jones *et al.*, 2008*b*; Anadón *et al.*, 2009; Brinkman *et al.*, 2009). Especially because carnivores are often difficult to study, the input of local people with years of experience in living and working in the landscape can significantly contribute to a basic understanding of the species' ecology (López-Arévalo *et al.*, 2011). Furthermore, the inclusion of local ecological knowledge in conservation-related research can increase the involvement of local stakeholders in conservation activities (Steinmetz, Chutipong & Seuaturien, 2006).

In this study, we investigated local knowledge of carnivore distribution and carnivore–human conflict at varying distances from continuous rainforest within a human-dominated landscape in central-southeastern Madagascar.

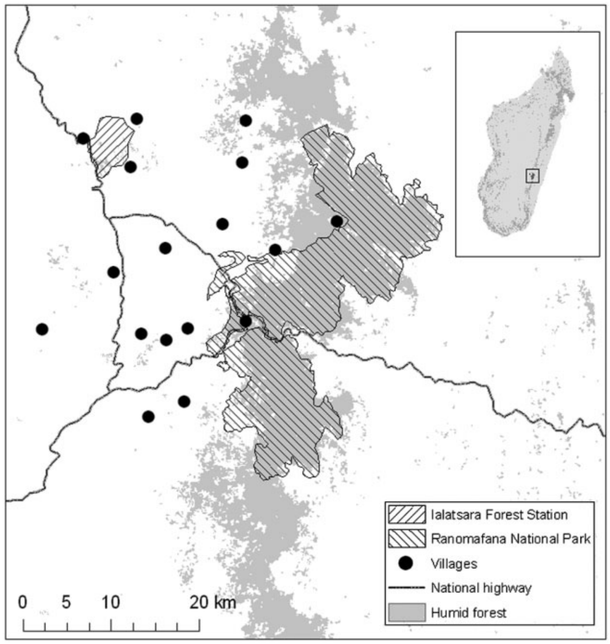

Figure 1 Locations of 17 communities in central-southeastern Madagascar (see inset for general region) in which we investigated human observations and perceptions of carnivores in October–December 2009. Rainforest cover is based on primary forest cover estimated from 2005 satellite imagery (Center for Applied Biodiversity Science, 2010) and vegetation classification of Moat & Smith (2007).

Our objectives were to (1) investigate landscape- and community-level factors that may influence the distribution patterns of native and exotic carnivore species in a human-dominated landscape; (2) evaluate the level of human–carnivore conflict across the landscape.

Materials and methods

Study area

We conducted surveys in Madagascar between two protected areas, Ranomafana National Park (RNP) and Ialatsara Forest Station (IFS, Fig. 1). RNP was located at 47° 18' to 47° 37' east, 21° 02' to 21° 25' south and is part of the continuous forest tract along the eastern escarpment of Madagascar; the park is 41 300 ha of submontane rainforest. RNP protects five species of native carnivore, *C. ferox, F. fossana, E. goudotii*, ring-tailed mongoose *Galidia elegans* and the broad-striped mongoose *Galidictis fasciata* (Gerber *et al.*, 2010; Gerber *et al.*, 2012). IFS was located 19 km west of the northern extent of RNP at 47° 12' to 47° 15' east, 21° 02' to 21° 06' south and is a private ecotourism reserve. The reserve consists of exotic pine (*Pinus sp.*), exotic eucalyptus (*Eucalyptus sp.*) and approximately 500 ha of native rainforest distributed in 10 fragments of varying size (2–240 ha; Gerber *et al.*, 2012). Deforestation for subsistence-level agriculture has isolated the rainforest fragments from the continuous forest for at least 30 years (D. Rajaona, pers.

comm.). Only two endemic carnivores, *G. elegans* and *G. fasciata* have been observed at IFS (Gerber *et al*., 2012). The human-dominated landscape between IFS and RNP is a mixture of grassland and shrubby savannah with patches of secondary-growth trees, agricultural cultivation and interspersed native forest fragments (Moat & Smith, 2007).

Community sampling

We selected local communities by generating random points between RNP and IFS at a minimum of 3 km from each other using ArcMap 9.2 (ESRI Inc., Redlands, CA, USA). We identified the community nearest each point using Google Earth 5.0 (Google, Inc., Mountainview, CA, USA) satellite imagery and known community locations from the Madagascar National Parks Association. The selected communities included both Tanala and Betsileo communities, representing the two major ethnic groups in the region.

Interview structure

From October to December 2009, we interviewed adult male heads of households from communities at varying distances from the western border of RNP (0–20.2 km from continuous rainforest; Fig. 1). Participants were at least 20 years of age and had lived in the focal community for a minimum of 5 years. To efficiently locate long-time residents that were willing to participate in our interviews, we identified an initial group of interviewees with the aid of community elders and located additional interviewees through chain referral (Huntington, 2000). We conducted semi-structured interviews, consisting of primarily open-ended questions that guided the interview, but allowed respondents to discuss information they considered pertinent. A researcher native to the study area conducted the interview in Malagasy, while a second Malagasy researcher and MKL (proficient in conversational Malagasy) took written notes and asked for clarification as needed. We recorded interviews when interviewees consented.

We first asked participants to identify carnivore species using color photographs and information about size and basic ecology. We provided multiple photographs of the five native species and two exotic species (cat *Felis sp.,* small Indian civet *Viverricula indica*) known to occur in the region. Shortly after each interview, we categorized the interviewee's identification of each species on the following six-point scale: (1) interviewee quickly recognized and named the species in the photo; (2) interviewee named and accurately described the species after viewing all photos; (3) interviewee recognized and accurately described the species, but did not know its name or used an improbable name; (4) interviewee inaccurately described the species and used an improbable name; (5) interviewee guessed a name, but stated he had never seen the species; (6) interviewee stated he did not know the species. We considered levels 1 to 3 to be positive identifications, and excluded reported observations from further analysis when the interviewee seemed uncertain of the species' identity (levels 4–6).

Following species identification, interview questions were focused on three main topics: (1) the interviewee's experience with wild (non-domestic) carnivore species; (2) livestock and poultry husbandry and predation; (3) the interviewee's residency and activities within the region. Directed questions pertained to interviewee's experience with each carnivore species, particularly the frequency, locations and timing of observations. Interviewees were also asked to describe their perceptions (i.e. beneficial, harmful or neutral) of each species and whether or not they were hunted. Interviewees were also asked questions about livestock and predation; specifically, the number of domestic livestock they raised, for how many years and how/where animals were kept throughout the day. We focused predation questions on when, where and how often it occurred, by which predators and how the predator was identified. Lastly, we inquired about methods used to prevent predation of livestock and their effectiveness.

Data analyses

We tabulated species observations across interviews. To quantify the spatial context of observations of carnivore species, we estimated locations based on reported distances and directions from known locations. We described the limits of a community as the mean of the maximum distance each interviewee traveled to a field or forest location at least once per week; only observations within the community limits were included in analyses. We modeled the proportion of interviewees within a community ($n = 17$) reporting a carnivore species occurrence in the last five years, examining landscape- and community-level variables using logistic regression (PROC Logistic, SAS 9.2, Cary, NC, USA). We quantified three landscape characteristics using ArcMap 9.2 (ESRI Inc.). We calculated distance to continuous forest (*DistForest*) as the Euclidian distance from the community center to the nearest patch of humid forest cover visibly connected to the contiguous forest of the eastern escarpment, based on classification of 2005 satellite imagery (Center for Applied Biodiversity Science, 2010). We also measured distance from each community to the nearest national highway (*DistRoad*) and quantified community spread (*Spread*) as the area of the minimum convex polygon containing community households, scaled by the largest community. We also quantified four community characteristics; (1) number of households (*#Houses*); (2) the proportion of interviewees owning dogs *Canis familiaris* (*Dogs*) and (3) cats (*Cats*); a (4) poultry index (*Poultry*). The poultry index was calculated as the product of the proportion of interviewees owning poultry and the mean flock size reported.

For each species, we developed a set of biologically plausible models containing the aforementioned variables. Due to sample size constraints, models were strictly additive (no interactions) and maximally included three parameters. We approximated model parsimony, given our data and model set by species, using Akaike's information criterion for small samples (AIC_c) and weighted the support of each model using AIC_c weights (Burnham & Anderson, 2002).

Table 1 Percentage of interviewees ($n = 182$) and communities ($n = 17$) reporting carnivore observations within their communities in central-southeastern Madagascar within the previous five years (2004–2009)

Species	% Interviewees[a]	% Communities[b]	Distance (km)[c]
Fossa *Cryptoprocta ferox*	8.2	35.3	4.9
Small-toothed civet *Eupleres goudotii*	2.2	17.6	6.3
Malagasy civet *Fossa fossana*	3.8	17.6	9.5
Ring-tailed mongoose *Galidia elegans*	31.9	76.5	16.7
Broad-striped mongoose *Galidictis fasciata*	1.1	11.8	0.2
Wild cat *Felis sp.*	56.6	100.0	20.2
Small Indian civet *Viverricula indica*	18.1	88.2	20.2

[a]The percentage of interviewees that reported observing a species within 2500 m of their community center within the five years prior to the survey.

[b]The percentage of communities in which at least one interviewee reported observing a species within 2500 m of their community center within the five years prior to the survey.

[c]Distance between the edge of continuous forest and the center of the community farthest from the forest where a species was observed.

Parameters were model-averaged to incorporate model selection uncertainty and we report significantly positive or negative effects when 95% confidence intervals of parameter estimates do not contain zero. We also report the relative importance of model variables ($RI_{variable}$) by summing the Akaike model weights of all candidate models containing the variable; model sets were equally balanced with each variable present an equal number of times per model set.

We explored patterns of livestock predation using logistic regression by modeling; (1) the proportion of poultry owners that experienced predation by wild carnivores; (2) the probability of an individual poultry owner experiencing poultry loss to predation within the previous year (2008–2009). We restrict the data to an annual time scale to increase the validity of the inference (Golden, Wrangham & Brashares, 2013). Explanatory variables in the first analysis included landscape and community features described previously. In the second analysis, we included three household-level variables that were considered pertinent to animal husbandry and predation risk: number of poultry owned (*#Poultry*), whether an individual owned dogs (*Dog*) and whether poultry were kept inside the house or in an outdoor enclosure at night (*PoultryNight*). Model selection and parameter inference for both analyses followed as previously described.

Lastly, we explored local perceptions of carnivores and livestock predation prevention methods in different communities. We grouped related responses and report the percentages of interviewees expressing different views; we used Pearson's χ^2 test of independence to determine whether perceived effectiveness varied among predation prevention methods.

Results

We interviewed 182 male heads of households in 17 communities; interviewees were aged 21 to 85 years (mean 44 ± SD 14) and had lived in their respective communities for 33 ± SD 16 years. Participants per community ranged from 8 to 13 (mean 11 ± SD 1.3). Interviewees were primarily agricultural cultivators (89%) and/or animal breeders (21%); wood cutting (5%) and iron forging (3%) were also reported as primary occupations. Fewer than five people (< 3%) each reported honey collection, crayfish collection/fish, carpentry, vendor, paid labor or other occupations as their livelihood. The mean maximum distance traveled by interviewees to field or forest locations at least once a week was 2531 ± SD 1000 m. Thus, we considered a community to comprise the land within a 2500 m radius from the community center.

Interviewees identified all five native and two exotic carnivores known to occur in RNP, while the maximum distances each species was observed from the continuous rainforest varied (Table 1; Supporting Information Fig. S1). For all species except *E. goudotii*, the majority of reported observations occurred within 2500 m of the community center and in habitat types outside of the natural forest (Supporting Information Fig. S2). The two exotic species (*Felis. sp.* and *V. indica*) and the endemic *G. elegans* were the most commonly observed and widespread carnivores reported. *Cryptoprocta ferox* was observed during the last five years (2004–2009) by only 15 of 182 interviewees within communities at a maximum distance of 4.9 km from continuous rainforest. Few people observed the highly nocturnal endemic species, *E. goudotii*, *F. fossana* and *G. fasciata*, even at close proximity to continuous forest; we summarized observations and responses for these species, but could not include them in statistical analyses.

We found *DistForest* was an important explanatory variable in models of the proportion of interviewees reporting observations of three carnivore species within their community in the last five years (2004–2009, Table 2 and Supporting Information Table S1). For *C. ferox* ($RI_{DistForest} = 1.00$) and *G. elegans* ($RI_{DistForest} = 1.00$), the probability of occurrence decreased significantly with increasing distance to continuous forest, while for *Felis sp.* ($RI_{DistForest} = 0.97$), the opposite trend was observed (Table 2; Fig. 2). There was no clear explanatory variable for the proportion of interviewees observing *V. indica* (Table 2).

Table 2 Relative importance of landscape- and community-level factors in explaining proportion of interviewees observing different carnivore species within their communities in central-southeastern Madagascar

Variable[a]	*Cryptoprocta ferox*	*Galidia elegans*	*Felis sp.*	*Viverricula indica*
DistForest	**1.00 (–)**[b]	**1.00 (–)**	**0.97 (+)**	0.18
#Houses	0.59	0.14	0.32	**0.50**
Spread	0.10	0.60	0.08	0.28
Dogs	0.06	0.02	0.09	0.20
Poultry	0.09	0.17	0.07	0.28
Cats	N/A[c]	0.05	0.07	N/A[c]
DistRoad	0.07	0.01	0.30	0.20

Values are shown in bold for the variable with the highest relative importance for each species. Variables for which the 95% confidence intervals around the model-averaged β coefficient did not contain zero are indicated as negative (–) or positive (+) to show the directionality of the relationship.

[a]DistForest, distance to continuous forest; DistRoad, distance to national highway; #Houses, number of households; Spread, area of the minimum convex polygon containing all interviewed households (ha)/100; Dogs, proportion of interviewees owning dogs; Cats, proportion of interviewees owning cats; Poultry, proportion of interviewees owning poultry × mean flock size.

[b]Relative importance, the sum of the Akaike model weights of all tested models containing the variable.

[c]Variable not included in candidate models for a species.

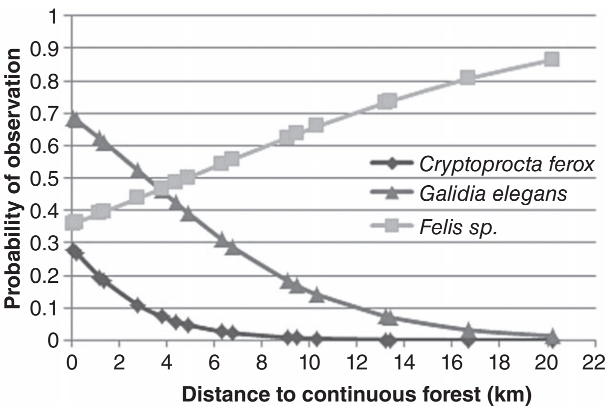

Figure 2 Model-averaged predicted probability of local inhabitants observing two native carnivores (*Cryptoprocta ferox* and *Galidia elegans*) and exotic wild or feral cats (*Felis sp.*) with distance to the continuous humid rainforest in central-southeastern Madagascar from surveys conducted October–December 2009.

Table 3 Livestock and poultry predation in central-southeastern Madagascar

Predator	%
Any predator	45.4
Any wild carnivore	21.3
Felis sp.	14.4
Galidia elegans	7.5
Cryptoprocta ferox	0.6
Viverricula indica	0.6
Any raptor	19.0
Domestic dogs	4.0
Snakes	1.7
Other	1.7
Unknown	5.2

Values represent the percentage of interviewees owning poultry and livestock (*n* = 174) who reported predation of their animals within the previous year (2008–2009). Only reports in which the predator was directly observed or identified by signs were included.

Almost all interviewees (95.6%) owned livestock; 45.4% of these interviewees reported personal loss to predation within the previous year (2008–2009; Table 3). The most common livestock owned by interviewees were poultry (93.4%), cattle (53.3%) and pigs (44.0%). Of the interviewees reporting recent losses, 96.4% reported loss of poultry, while only small percentages reported loss of other animals. We did not find strong support for any of the candidate models or variables to explain the variation in proportion of interviewees within each community, or the probability of individual households, losing poultry to wild carnivores within the previous year (Supporting Information Tables S2, S3, S4).

Nearly all interviewees (99%) discussed methods of preventing poultry predation. The most common methods were (1) watching over poultry; (2) restricting their ranging during the day; (3) keeping dogs; (4) keeping poultry indoors at night; (5) non-lethal predator deterrence (e.g. scaring or chasing potential predators, clearing shrubs); (6) using secure outdoor coops at night. A small number of interviewees described lethal methods of predator control, including trapping or killing predators directly when seen. Most interviewees reported that all predation prevention methods were ineffective. Keeping dogs and keeping poultry indoors at night were the methods most frequently regarded as effective (Supporting Information Fig. S3); however, perceptions of the effectiveness of predation prevention did not depend on the method used ($\chi^2 = 9.60$, $P = 0.09$).

We found 40–65% of interviewees familiar with *C. ferox*, *G. elegans*, *Felis sp.* and *V. indica* responded that they were harmful or both harmful and beneficial (Table 4). Negative perceptions primarily related to the species' predation of their poultry. Our interviews revealed more utilitarian values, such as food and rodent control, for the introduced wild cat, *Felis sp.*, which was often described as beneficial and harmful for killing mice and rats, but also poultry.

Table 4 Percentage of interviewees in central-southeastern Madagascar reporting perceptions of wild and exotic carnivore species

Perceptions	*Cryptoprocta ferox* (*n* = 36)	*Eupleres goudotii* (*n* = 6)	*Fossa fossana* (*n* = 6)	*Galidia elegans* (*n* = 89)	*Galidictis fasciata* (*n* = 6)	*Felis sp.* (*n* = 143)	*Viverricula indica* (*n* = 49)
Beneficial	16.7	66.7	16.7	27.0	33.3	28.7	22.4
Intrinsic/educational	8.3	0.0	0.0	12.4	33.3	2.1	6.1
Environmental	2.8	0.0	0.0	6.7	0.0	0.7	2
Endemism/tourism	5.6	0.0	0.0	3.4	0.0	1.4	6.1
Food	0.0	66.7	0.0	1.1	0.0	2.8	2
Rodent control	0.0	0.0	0.0	3.4	0.0	18.9	4.1
Other	0.0	0.0	16.7	0.0	0.0	3.5	2
Harmful	58.3	0.0	16.7	46.1	16.7	65.0	40.8
Harms livestock	55.6	0.0	0.0	46.1	16.7	64.3	32.7
Harms people	5.6	0.0	0.0	0.0	0.0	0.0	0.0
Harms crops	0.0	0.0	0.0	0.0	0.0	0.0	8.2
Other	0.0	0.0	16.7	0.0	0.0	0.7	0.0
Neutral	30.6	33.3	66.7	36.0	50.0	18.2	42.9
No importance	22.2	16.7	50.0	22.5	33.3	11.9	30.6
Unknown	8.3	16.7	16.7	13.5	16.7	6.3	12.2

The variable sample size (*n*) reported for each species indicates the total number of interviewees from the 17 communities samples who were familiar enough with the species to describe their perceptions of its value. The sum of the percentages may exceed 100 as some interviewees described species as beneficial and harmful, and/or listed more than one positive or negative value.

Table 5 Reported hunting of carnivores in central-southeastern Madagascar

Species	Interviewees		Communities		Primary reason(s)[b]
	n_I[a]	%	n_C[a]	%	
Fossa *Cryptoprocta ferox*	31	32.3	6	66.7	Poultry predation (25.8%)
Small-toothed civet *Eupleres goudotii*	6	66.7	3	66.7	Bushmeat (66.7%)
Malagasy civet *Fossa fossana*	6	16.7	3	33.3	Unreported
Ring-tailed mongoose *Galidia elegans*	91	15.4	13	61.5	Poultry predation (7.7%), bushmeat (7.7%)
Broad-striped mongoose *Galidictis fasciata*	5	0.0	2	0.0	Not applicable
Wild cat *Felis sp.*	143	44.1	18	94.4	Poultry predation (21.7%), bushmeat (21.0%)
Small Indian civet *Viverricula indica*	47	29.8	15	66.7	Poultry predation (16.7%), bushmeat (16.7%)

[a]The variable sample sizes reflect the number of interviewees (n_I) familiar enough with each species to comment, and the number of communities (n_C) where at least one interviewee had observed the species within the last five years (2004–2009).
[b]The most frequently given reasons for hunting a species, shown with the percentage of interviewees (n_I) reporting that reason; the percentages may exceed percent of interviewees reporting hunting as some interviewees provided multiple reasons.

Less than half of the interviewees familiar with each species reported they were hunted or killed within their communities, with the exception of *E. goudotii* (Table 5). However, for every species reported in a community, there was almost always one interviewee who reported that the species was hunted in the community recently (2004–2009). We found that nearly half of interviewees (44.1%) and almost all communities (94.1%) reported that *Felis sp.* was hunted within their communities, either because the animal preyed on poultry or for bushmeat. We also found that *G. elegans* and *V. indica* were killed for food or because of their role in poultry predation, while *C. ferox* was almost exclusively reported as killed because of poultry predation.

Discussion

The observations and perceptions reported by interviewees in our study suggest that native carnivore use of Madagascar's human-dominated landscape is limited and potentially risky, especially for the largest native species, *C. ferox*. The probability of observing *C. ferox* decreased as distance to continuous forest increased and all observations were limited to communities near continuous forest (< 5 km) from 2004 to 2009. The small-bodied *G. elegans* was more widely distributed, having been reported in a majority of communities 0–16.7 km from continuous forest. However, the probability of observing this species also decreased with increasing distance to continuous forest. It is difficult to determine whether the low numbers of sightings of the native nocturnal carnivores (*E. goudotii*, *F. fossana* and *G. fasciata*) are due to their absence or lack of people encountering them. The sensitivity of all three carnivores to degraded and fragmented habitats (Gerber *et al.*, 2012; Farris, Z., unpublished data) would suggest that they are unable to occupy the most disturbed human-dominated landscape. Of the exotic carnivores, *Felis sp.* appeared to have a strong affinity for the human-dominated landscape. They were observed in all villages and the probability of observing them increased with increasing distance to continuous forest.

The mechanisms that limit carnivore distribution in these highly disturbed landscapes are likely many. However, hunting for bushmeat or lethal predator control may be important drivers (Brashares *et al*., 2011; Jenkins *et al*., 2011). Carnivores may best persist in human-dominated landscapes where strict wildlife laws and a culture of tolerance for these species limit their killing (Athreya *et al*., 2013). Current legislation and certain local taboos provide some protection to Madagascar's carnivores, but the wildlife laws are often poorly understood and legal sanctions are rarely applied (Jones, Andriamarovololona & Hockley, 2008*a*; Jenkins *et al*., 2011). While most interviewees did not report hunting of native carnivores in their communities, at least one interviewee in most communities reported it and thus hunting was reported in the majority of communities where *C. ferox* and *G. elegans* occur. This suggests that native carnivores traversing communities in the human-dominated landscape risk being killed for food or to reduce livestock predation. We assume that not all interviewees were willing to report illegal or perceived illegal activity, such that the occurrence of carnivore hunting is likely underreported in this study.

Despite extensive domestic and international conservation efforts focused on protecting Madagascar's biodiversity (Myers *et al*., 2000; Fritz-Vietta *et al*., 2011), there has been little research into human–carnivore conflict on the island. In other continents and in mainland Africa, where larger carnivore species pose direct threats to both humans and their livestock, researchers are using local ecological knowledge to identify the extent and implications of the conflicts, as well as options to mitigate them (Dar *et al*., 2009; Hemson *et al*., 2009; Inskip & Zimmermann, 2009; Treves *et al*., 2009). Our results suggest that in Madagascar, poultry predation is the primary driver of human–carnivore conflict. Over 20% of interviewed households had experienced poultry loss to wild carnivores within the previous year. Thus, it is not surprising that interviewees reported predominantly negative perceptions of the wild carnivores and frequently cited predation as the reason carnivores were killed in their communities.

Mitigating human–carnivore conflict can be approached directly with methods aimed to reduce the probability or adverse effects of carnivore encounters, or indirectly, by increasing the tolerance of stakeholders to these encounters (Treves *et al*., 2009). Our results suggest the need for both approaches in this region of Madagascar, as interviewees (mostly poultry owners) perceived carnivores as threats and were not confident in the effectiveness of the predation prevention measures they discussed. We did not find that the probability of households losing poultry to wild carnivores could be significantly decreased by reducing flock size, keeping a dog or keeping poultry indoors at night, but future studies could investigate whether these and/or other methods may reduce the frequency of attacks or number of animals predated. Use of traditional husbandry techniques can decrease livestock losses to wild carnivores, with benefits for carnivore conservation (Ogada *et al*., 2003; Woodroffe *et al*., 2007). In this area, programs to determine and implement practical and effective methods to protect poultry may help inhabitants reduce their risk of losing poultry to wild carnivores, thereby reducing the motivation for lethal predator control and possibly improving local perceptions of the species (Ogada *et al*., 2003; Woodroffe *et al*., 2007). Additionally, education about the endemism and conservation status of the native carnivores can place local observations into a global context and engender a sense of involvement in species conservation by local residents (Steinmetz *et al*., 2006; Romanach, Lindsey & Woodroffe, 2007).

With increasing study and application of local knowledge in conservation planning, there has been increasing demand to validate this information using other types of data collection, such as traditional ecological surveys (Gilchrist *et al*., 2005). Studies that incorporate both types of information indicate that local ecological knowledge may be limited or partially inaccurate and should not be the sole source of data to inform conservation practices. However, it fulfills a purpose often complementary to other forms of information gathering (Gilchrist *et al*., 2005; Msoffe *et al*., 2007). The local ecological knowledge recorded in our study provides important insights concerning the distribution of carnivore species in central-southeastern Madagascar that are congruent with and complementary to other data collected in the same region. Recent surveys conducted in RNP, IFS and additional fragmented forests indicate a range of tolerance among these species to human-disturbed habitats (Gerber, 2010; Gerber *et al*., 2012), similar to that suggested by this study. Using photographic sampling, *C. ferox* was observed within protected, continuous forest sites in RNP and forest fragments ≤ 2.5 km from continuous forest. Also, *G. elegans* was detected in continuous forest and forest fragments 2.5 and 15 km from the continuous forest, and was observed using primarily rainforest patches, but also matrix habitat consisting of burned shrub areas with interspersed pine (Gerber *et al*., 2012). *Viverricula indica* was detected in fragmented forest, surrounding matrix of open burned shrub, shrub and interspersed pine, and in the edge of continuous forest near a national highway, while *Felis sp.* was detected only in fragmented forest and matrix habitat (Gerber *et al*., 2012).

Unlike photographic sampling and other ecological surveys, which have assessed conditions within specific forest sites over relatively brief periods of time, our survey investigated species distribution and interaction with humans over a large landscape and a longer temporal scale. Conducting empirical studies using traditional ecological surveys at a similar spatiotemporal scale would be logistically and financially challenging. Local knowledge surveys also revealed novel distributional patterns, such as the occurrence of *G. elegans* in several communities at intermediate distances 6–14 km from the forest and with relatively low rainforest cover (Center for Applied Biodiversity Science, 2010; Moat & Smith, 2007). The lack of observations of *C. ferox* in communities > 4.9 km from the continuous forest also provides previously missing information on the limited ranging of *C. ferox* outside of the continuous forest. This is critical for population modeling used to assess species' threatened status (Gerber *et al.*, 2012; IUCN, 2013).

Carnivores are often sensitive to habitat loss and fragmentation, but may be able to occupy or use highly disturbed landscapes if human–carnivore conflict within this landscape is minimal. Conservation efforts directed at protecting poultry in rural communities may significantly benefit native carnivore distributions and their perceptions by local people in Madagascar. The sensitivity of many of Madagascar's carnivores to landscape scale habitat change emphasizes the need for adequate protected areas to sustain these unique species, as well as the involvement of local residents in conservation beyond protected areas. Incorporating local ecological knowledge of carnivores in Madagascar with data from traditional ecological surveys can strengthen multitaxon conservation planning and practices.

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Figure S1. Distribution of reported observations of wild carnivores in 17 communities in central-southeastern Madagascar from 2004 to 2009. The displayed percentages are based on interviews conducted with eight to 13 heads of household in each community. Results are shown for two native species, fossa *Cryptoprocta ferox* and ring-tailed mongoose *Galidia elegans*, and two exotic species, small Indian civet *Viverricula indica* and wild/feral cat (*Felis* sp.).
Figure S2. Reported use of habitat types by carnivores in central-southeastern Madagascar. Values shown above stacked bars represent the total number of interviewee reports of habitat use by the species and may exceed total number of interviewees observing each species because many interviewees reported seeing a species in multiple habitat types. Habitat types included: (1) natural forest, composed primarily of native species; (2) other forest, including eucalyptus (*Eucalyptus spp*.) and pine (*Pinus spp*.) plantations; (3) other natural areas which included grasslands, shrubs and riparian zones; (4) agricultural fields; (5) villages and roads.
Figure S3. Reported methods of preventing predation of poultry and their perceived effectiveness by interviewees in central-southeastern Madagascar ($n = 170$).
Table S1. Competitive models (likelihood > 0.125) explaining variation in the proportion of interviewees in central-southeastern Madagascar reporting observations of each carnivore species within 2.5 km of their community in the last 5 years (2004–2009).
Table S2. Competitive models (likelihood > 0.125) explaining variation in the proportion of interviewees in communities in central-southeastern Madagascar ($n = 17$) reporting predation of their poultry by wild carnivores within the last year (2008–2009).
Table S3. All candidate models explaining variation in the probability of individual households ($n = 170$) in central-southeastern Madagascar experiencing predation of their poultry by wild carnivores within the last year (2008–2009).
Table S4. Relative importance of community- and household-level characteristics in explaining variation among interviewees reporting poultry predation by wild carnivores within the past year (2008–2009) in central-southeastern Madagascar.