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Human-Dog Relationships across Communities Surrounding Ranomafana and Andasibe-Mantadia National Parks, Madagascar

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Abstract. Domestic dogs (*Canis lupus familiaris*) are estimated to be one of the most globally abundant invasive carnivores that threaten wildlife. Madagascar is home to large populations of free-roaming dogs and is a highly diverse and anthropogenically threatened environment, making it one of the world's top conservation priorities. Comparatively little is known about human-dog relationships in developing countries such as Madagascar. We surveyed non-dog owners and dog owners visiting free mobile veterinary clinics in their communities around Ranomafana National Park (RNP) and Andasibe-Mantadia National Park (AMNP) to understand human-dog relationships, gain insight on free-roaming dog behavior, and to assess the feasibility of humane population control measures. Amongst dog owners, the vast majority of respondents reported owning their dog for protection and a significant number had dogs for companionship. Our results indicate that free-roaming (owned, unconfined) dogs may be an underappreciated threat to endemic wildlife in the National Parks of Madagascar, as nearly half of dog owners reported that their dog killed at least one wild animal a month. Most dog owners in surveyed communities approve of spay/neuter/vaccine programs and state that they would use them if freely available, indicating that veterinary intervention can be an important tool in humanely controlling free-roaming dog populations in these regions.

Keywords: Madagascar, dogs, carnivore-predation**,** conservation, human-animal interaction

Introduction

Madagascar is a global hotspot for biodiversity and wildlife endemism (Yoder and Nowak 2006). The island owes this status in part to its extended period of geographic isolation (Yoder and Nowak 2006). It is also one of the last landmasses to be inhabited by humans (Dewar and Wright 1993). Home to a mammalian fauna that is highly diverse and threatened, Madagascar is considered to be one of the world's top conservation priorities (Evans et al. 2013).

Dogs (*Canis lupus familiaris*), one of the world's most abundant carnivores (Young et al. 2011), are the only domestic animals to have accompanied humans to every continent since the earliest times and are ubiquitous today (Ardalan et al. 2015; Frucht et al. 1990). Dogs and humans are mutually dependent, and evidence shows that both species may be "hard-wired" for this co-dependence (MacLean et al. 2017; Powell et al. 2019). While dogs benefit humans, free-roaming dogs also threaten global ecosystems and wildlife (Hughes and Macdonald 2013). Free-roaming dogs are those owned by one or more individuals or families that spend the majority of their time unconfined, able to roam freely away from their owner, and may acquire some or most of their food from a source

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other than their owner. Free-roaming dogs can negatively impact native wildlife by harassment, chasing, direct predation, indirect competition, and disease transmission (Young et al. 2011). The role of dogs as invasive predators of native fauna is clearly seen in unsustainable dog predation of the marine iguana (*Amblyrhynchus cristatus*) in the Galapagos Islands (Kruuk 1979; Kruuk and Snell 1981; MacFarland et al. 1974) and the rock iguana (*Cyclura carinata*) in the West Indies (Iverson 1978). Dogs further threaten wildlife by the transmission of novel diseases (Butler et al. 2004), and by outcompeting native carnivores (Farris et al. 2017). Madagascar's endemic carnivores, the Eupleridae, are considered the least known and most threatened family of carnivores in the world (Brooke et al. 2014).

Communities around the world have sought effective management strategies for populations of free-roaming invasive species and the public response to such efforts tends to vary by species, as well as cultural norms (Rand et al. 2019). Although methods, such as culling and Trap-Neuter-Vaccinate-Return (TNVR) programs, effectively control the population of free-roaming dogs, there is little agreement on what is most effective or which methods might be acceptable to the communities where interventions are taking place (Smith et al. 2019). Since community-level acceptance can drive community-level compliance (Creţan 2015), understanding local attitudes towards free-roaming dogs and efforts to control their populations are critical.

Here, we report data on human-dog relationships, and the behavior of free-roaming dogs across two of Madagascar's flagship protected areas: Andasibe-Mantadia and Ranomafana National Parks (Figure 1). Understanding local people's attitudes towards free-roaming domestic animals and their willingness to participate in veterinary intervention is an important first step in developing appropriate management strategies to benefit conservation. Our results inform the complex and understudied human-dog relationships in rural landscapes of the developing world and highlight the negative impacts of free-roaming dogs on native wildlife in one of the world's most important biodiversity hotspots.

The Origin and Culture of Dogs in Madagascar

The domestic dog was introduced to Madagascar intentionally by humans; dogs also reached the island by swimming ashore from shipwrecks, and from offshore islands where passing ships abandoned them (Campbell 2012). The domestic dog, along with chickens and pigs, was an essential part of the Austronesian culture of some of Madagascar's first human settlers (Bellwood 2005), and the presence of dogs in Madagascar is considered one of the few remaining contributions of that culture (Ardalan et al. 2015). However, mitochondrial DNA (mtDNA) analysis of dogs from Madagascar showed that Malagasy dogs originated entirely in Africa, in contrast to its human population (Ardalan et al. 2015).

The attitudes toward dogs and human-dog relationships in Madagascar have historically varied and might at least partially help to explain the origins of some of our findings. Dogs were valued and revered by some but were considered unclean and a curse by others. The domestic dog was known as *amboa* (derived from the Kiswahili term *mboa*) in the kingdom of Merina, and the word "dog" was considered a term of abuse in early nineteenth-century Imerina (Campbell 2012). When the Merina king Andrianampoinimerina returned victorious in the Civil Wars and a dog correctly prophesized that he would reign as the sole king, it was rewarded with the hindquarters of a bullock to eat on every market day. Its litters were subsequently cared for by his successor, Radama I (Campbell 2012). On the west coast and in the extreme

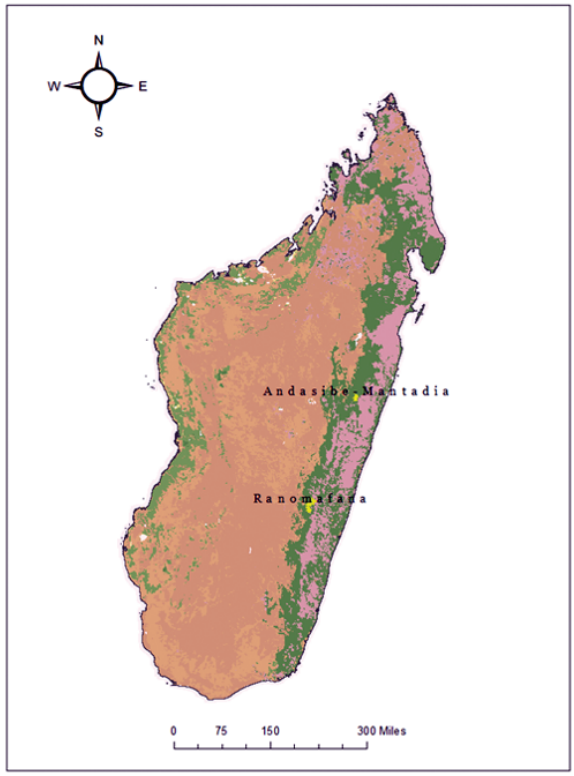

Figure 1. Locations of the National Parks (Andasibe-Mantadia and Ranomafana) around which the surveyed communities are situated in Madagascar.

south, dogs were highly valued for different purposes—hunting, herding, guarding, as human substitutes in *tangena* (a tree species which produces highly toxic nuts) poison ordeals, against sorcerers, and for medicinal purposes (Campbell 2012). *Alika mpandambo* was the term used for hunting dogs in Imerina, and the ethnic Sakalava and Bara groups in the West and South of Madagascar, respectively, used them to not only hunt native animals, such as wild boars (*Sus ethiopicus*), tenrec (shrew- or hedgehog-like, insectivorous mammals belonging to family Tenrecidae), and the Madagascan hedgehog (*Setifer setosus*), but also to track and attack men (Campbell 2012). As guard dogs, the dogs protected cultivated fields from being ravaged by wild boars, as well as rich men's houses against thieves (Campbell 2012). There were significant populations of the wild dog (*amboadia*; *dia* = wild) on the edges of the forest by the eighteenth century. On the edges of the forests, wild dogs preyed on mammals and birds. Close to human populations, they fed on ewes, discarded food, slaughtered cattle, and dead or wounded humans; this included executed criminals, wounded and abandoned soldiers, and babies discarded from being born on an "unlucky" day (Campbell 2012). Today, among the Sakalava ethnic group of northwest Madagascar, dogs are prohibited from entering the tomb in the village (*Mahabo*) and must be killed if they enter (Sharp 1996). Even today, many consider dogs to be unclean, keeping them out of areas meant for rituals by exclosures. Dogs are still generally considered to be dirty and belonging to the very bottom of society throughout the country. However, in the capital city Antananarivo, they are considered more

as pets in the middle-class community (Ratsitorahina et al. 2009). In 2007, in Antananarivo, an estimated 90% of middle-class households owned pet dogs (Ratsitorahina et al. 2009), a rate twice as high as the United States, where pet dog ownership is estimated to be 46% (Applebaum et al. 2020). In contrast to other parts of the country, these middle-class dog owners interact with their dogs, name them, take them to veterinarians, feed them industrial food, and dress them in dog clothes, etc. (Randriana, unpublished data).

Dogs are embedded in Malagasy culture in the system of *fady*. *Fady,* also termed "*faly*," both singular and plural, are a system of beliefs, prohibitions, and taboos that form an integral aspect of the Malagasy identity and regulate daily life (Dahl 1999; Gennep 1904; Lambek 1992; Ruud 1960; Sharp 1996). *Fady* include rules for what cannot be touched, approached, worn, done, or eaten, and can also refer to people, days of the week, animals, and places (Dahl 1999). *Fady* work at multiple levels, with particular *fady* for each of the 18 Malagasy ethnic groups, and also for smaller groups, such as kin groups or communities (Merson et al. 2019a; Sharp 1996). According to Linton (1928), dogs were *fady*, as they were not to be eaten and considered unclean.

The importance of *fady* in conservation is disputed. *Fady* has benefited the preservation of endemic species and habitats in Madagascar; for example, by preventing the killing of animals that should not be consumed, such as the radiated tortoise (*Geochelonia radiata*) in the Adroy region in the south (Lingard et al. 2003), *Tenrec ecaudatus* in Antakarana (Nicoll 2003), and crayfish (*Astocoides* spp.) in RNP, which are prohibited from being sold (Jones et al. 2005). *Fady* has also negatively impacted wildlife conservation, as seen with the killings of aye-aye (*Daubentonia madagascariensis*) that stray too close to communities in northern Madagascar, due possibly to the belief that seeing them results in sickness and death (Simons and Meyers 2001). Thus, it is possible that *fady* can protect some species of wildlife while endangering others.

Despite the high rate of dog ownership in Madagascar, and the existence of a large body of research related to human-dog relationships in the developed world (primarily the United States, United Kingdom, and Australia) (Payne et al. 2015), human-dog relationships, and their effects on local environments, remain poorly studied in Madagascar. We provide insight on attitudes to dogs in the rural communities of Eastern Madagascar and discuss the possible implications of these attitudes for conservation.

Methods

We surveyed communities in several villages, towns, and communes surrounding two national parks in eastern Madagascar—Andasibe-Mantadia (AMNP) and Ranomafana National Park (RNP). Culturally, these communities are composed of mixed ethnicities—the Tanala and Betsileo tribes predominating around RNP, and Betsimisaraka, Bezanozano, and Merina predominating around AMNP (Serva et al. 2012). We surveyed dog owners participating in free spay/neuter/vaccine clinics conducted by the Mad Dog Initiative (MDI), a local TNVR organization, as well as those who did not own dogs.

We collected survey data by interviewing residents of these communities from 2014–2016 (RNP) and 2018–2019 (AMNP) using filter questions (Rennekamp and Nall 2000) to establish essential survey questions and gain focused responses (Supplementary Tables 1 and 2). The surveys took about 10–15 minutes each to conduct and were comprised of up to 23 possible questions, with respondents allowed to select multiple responses for several of them. All respondents were above 18 years of age and informed consent was obtained

from each prior to administering the survey. No personally identifiable information was collected, and each participant's data were kept confidential by assigning alphanumeric codes.

All survey respondents were categorized into two types: (i) dog owners who brought their dog(s) to the free mobile veterinary clinic (N = 329 in communities around AMNP; N = 206 in communities around RNP), and (ii) non-dog owners who were surveyed by local team members (N = 63 in communities around AMNP; N = 216 in communities around RNP). Two Malagasy veterinary professionals administered the surveys in the local Malagasy dialect (N = 814; N_{RNP} = 422 and N_{AMNP} = 392).

At each village site, we collaborated with the village president, the village mayor, and other elders, asking them to share the goals of the free spay/neuter/vaccine initiative and the accompanying survey questionnaires with local people. We asked the elders to inform the residents that free spay/neuter surgeries, along with anti-rabies vaccinations, de-worming, and medical treatment, would be provided at the clinic. We began the surveys only after the village president, mayor, and elders had given their permission.

In this paper, we consider *owned* dogs to be those identified as such by people. The *unowned* dogs were those whose owners were not identifiable. *Free-roaming* dogs are owned by one or more individuals or families and spend the majority of their time unconfined, can roam freely away from their owner(s), and may acquire some or most of their food from a source other than their owner. *Free-roaming* (owned, unconfined) dogs also differ from *domestic* and *feral* dogs. *Domestic* dogs are owned and spend the majority of their time confined, acquiring all or most of their food from their owner (owned, confined) and *feral* dogs are unowned and spend no time confined, acquiring all resources, including food and shelter, from a source other than an owner (unowned, unconfined).

For the two study areas, we only observed domestic and free-roaming dogs. Dog owners at these sites rarely, if ever, owned or used leashes for dogs, and most of the dogs could roam freely. Domestic dogs either lived inside the home or lived within a fenced area near the home. We were unable to collect detailed data on the percentage of dogs that were exclusively domestic versus free-roaming.

All research adhered to the laws of Madagascar and received research permits issued by the Government of Madagascar, Madagascar National Parks, La Direction des Services Vétérinaires (DSV), and the local veterinarian. The research adhered to North American University ethics boards (IRB Protocol #202000004, University of Florida).

Study Sites

Around AMNP in eastern Madagascar (E 048° 46′, S 18° 84′), we surveyed 11 communities: Ampangalatsary, Andasibe, Andasifahadimy, Andasifahatelo, Berano, Falierana, Mahatsara, Menalamba, Mitsinjo, Sahavarina, and Torotorofotsy. We surveyed eight communities bordering RNP (E 047° 42′, S 21° 26′) in southeastern Madagascar: Ambatolahy, Ambodiaviavy, Ankevohevo, Masomanga, Morafeno, Mahatsinjorano, Ranomafana, and Vohiparara. All these sites represent rural communities and are characterized by predominantly subsistence agriculture, high rates of poverty, high disease burdens, and low educational levels (Gaffikin et al. 2007).

AMNP primarily protects a dense humid forest (Merson et al. 2019a; Styger et al. 1999), but also comprises a range of vegetation types, receives an average rainfall of 1700 mm per year, and has a mean temperature of 19 °C (Styger et al. 1999). RNP protects a tropical rainforest, receiving 2300 to 3000 mm of rainfall per year, with most precipitation occur-

ring between December and March, and an average annual temperature of 21 °C, with the lowest temperatures from June to September (0–12 °C) (Pochron et al. 2005; Styger et al. 1999).

AMNP and RNP contain some of the highest levels of biodiversity in Madagascar and are home to some of the island's most endangered wild species (Ferraro 2002; Rakotozafy et al. 1987). They are also the closest national parks to the capital, Antananarivo, and are among Madagascar's most visited protected areas (Carret and Loyer 2003). Traditional beliefs tend to be influential for the people that live in the communities closest to the biodiverse-rich habitats in Madagascar (Jones et al. 2008). Commands from ancestors and culturally accepted behavioral norms influence the interactions of people with natural resources and wild species in these settings (Jones et al. 2008). Communities near and within protected areas have a higher number of taboos linked to wild species (Sodikoff 2012). These study sites are also located near Madagascar's most visited protected areas, and wildlife tourism is a significant contributor to their local economies (Carret and Loyer 2003).

Results

Detailed results are contained in Supplementary Tables 1 and 2.

The average number of dogs per household was 3.23 (S.D. 2.751) for AMNP and 1.55 (S.D. 1.214) for RNP. Our findings suggest that the reasons for dog ownership are diverse, with the two most commonly cited reasons being instrumental (i.e., protection [AMNP: 64.4%; RNP: 52%], hunting [AMNP: 1.2%; RNP: 1%]) and emotional uses (i.e., companionship [AMNP: 8.2%; RNP: 12.1%]), or a combination of companionship and protection (AMNP: 14%; RNP: 28%), hunting and protection (AMNP: 8%; RNP: 3%), companionship and hunting (AMNP: 1%; RNP: 2%), or companionship, protection, and hunting (AMNP: 3.3%; RNP: 2.4%). Twenty-nine percent and 22% of the dogs at AMNP and RNP, respectively, spent between six hours and all day away from their owners (Figure 2). While the majority of dogs across RNP (62%) spent lesser than or equal to three hours away from their owners, only 41% of dogs across AMNP did so. Most dogs around AMNP (52.3%) and slightly fewer around RNP (42.8%) traveled one or more days into the forest with their owners (Figure 3).

As for the manner in which the dogs were acquired, the majority of them were adopted, either as puppies or feral dogs (AMNP: 45.3%; RNP: 72.8%), and only a small percentage of them (AMNP: 21%; RNP: 4.4%) were purchased. Most people in these communities (AMNP = 98.5%; RNP = 93.2%) fed their dogs left-overs or scraps of food that included rice, vegetables, meat, corn, milk, cassava (*mangahazo*), *tsaramaso* (a type of bean), *isan-tsakafo* (a mixture of left-over food), and *ampango* (a local preparation of boiled, burnt rice). They were alternatively

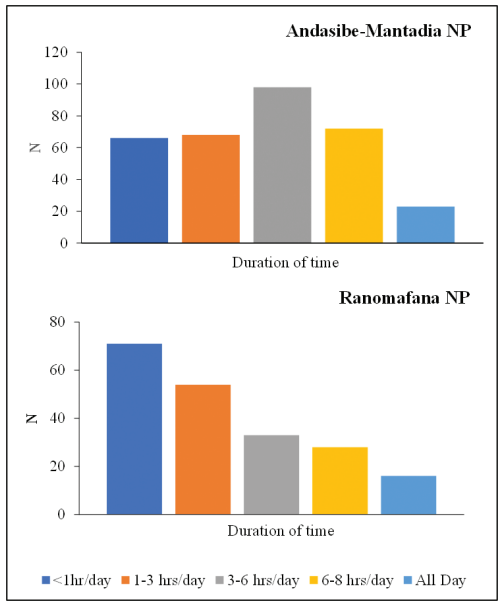

Figure 2. Reported hours per day that dogs spend away from their owners in communities around Andasibe-Mantadia NP (N = 329) (above) and Ranomafana NP (N = 206) (below).

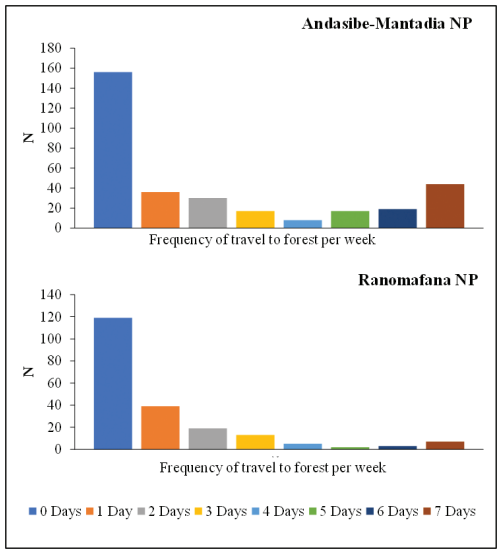

Figure 3. Number of days per week that respondents in communities around Andasibe-Mantadia NP (N = 329) (above) and Ranomafana NP (N = 206) (below) reported traveling into the forest with their dogs.

fed "dog food," which comprised commercial preparations of pet food and bones.

Surrounding AMNP, there was a significant association between a community's location and whether or not owned dogs killed domestic animals ($\chi^2 = 93.580$, $p = 0.002$), with most domestic animal killings occurring in Ambohibary (N = 7; 19.4%), followed closely by Sahafitana (N = 5; 13.9%). Similarly, surrounding RNP, there was a significant association between the location of the community and whether or not dogs killed domestic animals ($\chi^2 = 54.365$, $p = 0.004$), with the majority of killings occurring in Ranomafana commune (N = 19; 76%). Whereas a community's location surrounding RNP had an important role ($\chi^2 = 441.129$, $p < 0.001$) on the type of domestic animals killed by dogs, surrounding AMNP, community location did not affect the kind of domestic animals killed by dogs. In communities surrounding both (AMNP [N = 29; 79%] and RNP [N = 19; 78%]), the chicken was the most commonly killed domestic animal (Supplementary Table 1 and Figure 4).

In both study locations, dogs killed wild animals, such as snakes, mice, rats, tenrecs, wild birds (i.e., pigeon and quail), chameleons, frogs, hedgehogs, bats, fossa (*Cryptoprocta ferox*, family Eupleridae), and *lambo* (a type of wild hog) (Figure 5). In AMNP, there was a significant association between the community's location and whether or not dogs killed wild animals ($\chi^2 = 123.697$, $p < 0.001$), with the most killings occurring in Sahafitana (N = 17; 11.8%), followed equally by Mahatsara, Ambohibary, and Ambohitrakanga (N = 11; 7.6%). However, the association between community locations in RNP and whether the dogs killed wild animals was not significant. Around RNP, dogs killed most wild animals in Ranomafana commune (N = 51; 63%).

Attitudes toward dogs and their owners' care practices can also vary within nations by region and urban/rural geographic areas (Ortega-Pacheco et al. 2007). In both RNP and AMNP, dog owners' attitudes to other

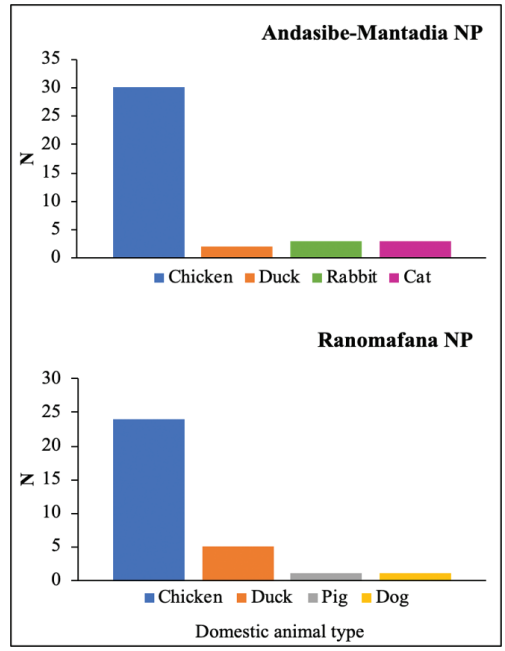

Figure 4. Reported dog predation on domestic animals in communities around Andasibe-Mantadia NP (above) and Ranomafana NP (below). This figure represents 38 reported predation events across AMNP and 31 reported predation events across RNP.

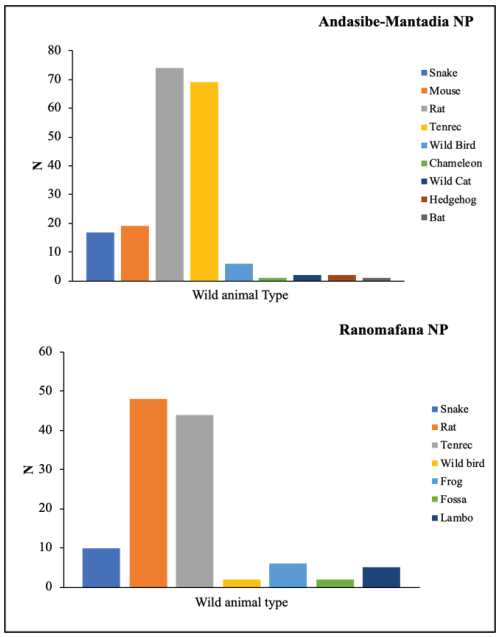

Figure 5. Reported dog predation on wild animals in communities around Andasibe-Mantadia NP (N = 329) (above) and Ranomafana NP (N = 206) (below). This figure represents 191 reported predation events across AMNP and 117 reported predation events across RNP.

dogs (those not owned by the respondents) depended on whether the dogs were domestic or free-roaming. Interestingly, in our study, dogs were never mentioned as *fady* in our interactions and experience with the residents of these communities.

In the communities surrounding AMNP, we found there to be a significant association between dog ownership and how dog owners and their families treated feral dogs ($\chi^2 = 210.747$, $p < 0.001$). Dog ownership was significantly associated ($\chi = 289.099$, $p < 0.001$) with how individuals and their families felt about feral dogs in their village, but non-dog ownership was not. Among communities around AMNP, Ambohibary commune had the highest proportion of dog-owners (N = 22; 12.4%) that viewed free-roaming dogs negatively, that is, considered them to be either a nuisance or problematic, and also felt their life would be better without the presence of free-roaming dogs in their village (N = 32; 11.2%). The communities surrounding AMNP are significantly associated with how individuals and their families felt about free-roaming dogs in their communities ($\chi^2 = 382.727$, $p < 0.001$), and also stated that their life would be better without free-roaming dogs in their community ($\chi^2 = 165.829$, $p < 0.005$).

In the communities surrounding RNP, there was a significant association between non-ownership and how individual non-dog owners and their families treated free-roaming dogs ($\chi^2 = 71.881$, $p < 0.001$). Both dog-ownership ($\chi^2 = 61.733$, $p = 0.049$) and non-ownership ($\chi^2 = 40.983$, $p < 0.001$) were significantly associated with how individuals and their families felt about free-roaming dogs in their communities. Among communities around RNP, non-dog ownership was significantly associated ($\chi^2 = 33.378$, $p = 0.001$) with how individuals and their families felt about free-roaming dogs in their community, with the majority of the non-dog owners within these communities viewing them negatively, as either a nuisance or problem (N = 117; 54.2%). Ranomafana commune had the highest proportion (N = 72; 61.5%) of those finding dogs to be a nuisance or problematic. Most of the dog-owners (AMNP: 66.5%; RNP: 79%) considered free-roaming dogs to be either a nuisance or ignored them, and reported treating them poorly (shooing them away) (AMNP: 71.4%; RNP: 60.2%). At RNP, this can be explained, at least partially, by the general dislike of dogs there (Valenta et al. 2016).

Dogs owners around AMNP (N = 326; 94%) and RNP (N = 202; 88%) said they would access any free vet care made available to their owned dog(s), including spay/neuter services.

Discussion

Due to the complex nature of human-dog interactions, a dog can serve many simultaneous purposes for its caretaker (Dotson and Hyatt 2008). In terms of motivations for dog ownership, the majority

of the survey respondents cited protection, which is consistent with previous findings in Antananarivo (Ratsitorahina et al. 2009) and in another study of rural areas surrounding protected areas in the Coquimbo region in Chile, where 81.1% and 59% of owned dogs, respectively, were reportedly kept for protection (Acosta-Jamett et al. 2010). In both regions, dogs help protect both property and livestock. While most dogs in our study are owned but free-roaming, some dogs are tied with a rope in the backyard to provide protection. Second to protection was a combination of protection and companionship followed by companionship, similar to findings in the rural parts of the Coquimbo region of Chile, where companionship was the second most-common reason to own a dog (Acosta-Jamett et al. 2010). Dogs are also used for companionship and protection during pastoral work. Although used for protection against other people, and sometimes against predators in other sites in Madagascar, these dogs are not trained to attack (Randriana, unpublished data).

Consistent with findings in rural parts of the Coquimbo region in Chile (2%), very few dogs were actually used to hunt in AMNP and RNP (~1%) (Acosta-Jamett et al. 2010). With respect to dogs hunting wildlife, since hunting within protected areas is illegal, survey respondents may have been hesitant to provide complete information for fear of incriminating themselves or being negatively judged by their community. In some parts of Madagascar, dogs have been used for hunting lemurs and Perrier's sifakas (*Propithecus perrieri*) (Anania et al. 2018). Thus, the number of residents who hunt with their dogs may be higher than what we found. Similarly, the number of owners reporting that their dogs had killed domestic animals may be an underestimate, as respondents may avoid reporting that their pet killed a neighbors' livestock. The higher number of wild animals killed around AMNP might at least partially be explained by the finding that just over 50% of the dogs around AMNP (Figure 3) traveled one or more days into the forest with their owners, whereas the proportion was lower (~42%) at RNP.

The low number of respondents who purchased their dog(s) may reflect the economic status and rural location of these communities and was similar to findings in rural parts of the Coquimbo region of Chile, where purchasing had been the least common (7%) form of dog acquisition. Also, given the low economic status of these communities, and their rural locations, it was not surprising to find that people mainly obtained their dogs by adopting puppies and strays or keeping the offspring from their previously owned dogs (AMNP: 22.5%; RNP: 17.5%). Our findings about what people fed their dog(s) are quite similar to those in urban dog samples in Antananarivo, where 81.2% and 7.1% of the owned dogs were fed with family food and not fed by the owners, respectively (Ratsitorahina et al. 2009).

In two cases, around RNP, owners reported that their own dogs killed fossa (a cat-like mammal endemic and unique to Madagascar), Madagascar's largest carnivore, and a top predator with no known natural enemies. Previous studies of human attitudes toward fossa indicate that many people view them negatively, because they are perceived threats to poultry (Albignac 1973; Hawkins 1998; Jones et al. 2008) and small livestock, such as lambs (Gardner and Davies 2014), due to *fady* that they resemble dogs (Gardner and Davies 2014), and consume the remains of villagers' ancestors (Jones et al. 2008; Ruud 1960). Across four sites (comprising deciduous forest and rainforests) in Madagascar, respondents had killed fossas, sometimes by training dogs to kill them to retaliate for the consumption of their poultry (Merson et al. 2019b). It is quite possible that fossa deaths caused by dogs were either unreported or under-reported by their owners because fossa are an endangered and protected species (IUCN).

A rising global human population encroaching on the remaining natural habi-

tats results in higher numbers and more extensive ranges of exotic commensal carnivores, such as dogs, and mounting interactions with native wildlife species (Farris et al. 2015a). Future research may investigate where owned dogs roam when separated from their owners. Our overall results related to predation on other animals are similar to those previously observed in different studies and sites. Previous studies in north-eastern Madagascar (Farris et al. 2015a) have shown that exotic carnivores have a strong, negative influence on native carnivores, ranging from competitive exclusion—wherein dogs outcompete native carnivores—to complete replacement. In some areas of Madagascar, dogs killed the Perrier's sifaka (*Propithecus perrieri*), a diurnal lemur species, attacking them as they descended trees to cross open areas (Anania et al. 2018). Free-roaming dogs that preyed on the fawns of the endangered blackbuck (*Antilope cervicapra*) in India also competed with the Indian wolf (*Canis lupus pallipes*) (Jhala 1993; Jhala and Giles 1991), while, in Africa, they compete with the highly endangered Ethiopian wolf (*Canis simensis*) for rodents (Gottelli and Sillero-Zubiri 1992; Sillero-Zubiri and Gottelli 1994, 1995). Free-roaming dogs have also been found to have killed argali (*Ovis ammon*) and the Mongolian saiga (*Saiga tatarica mongolica*) and chased and fragmented, post-calving aggregations of Mongolian gazelles (*Procapra gutturosa*) in Mongolia (Young et al. 2011). They have also killed the endangered chiru (*Pantholops hodgsonii*) and the Tibetan gazelle in Tibet (Schaller 1998).

In addition to their potential to prey on and competitively exclude native species (Farris et al. 2017) as they come in close contact with both humans and wildlife, dogs can also potentially transmit zoonotic diseases that might not appear in humans otherwise (Salb et al. 2008). A 2019 study highlights this and found molecular evidence of canine heartworm (*Dirofilaria immitis*) in the mouse lemur (*Microcebus rufus*), a wild primate found only in Madagascar. Such dog-lemur disease transmission holds additional significance for human health, as *D. immitis* can result in severe and often fatal cardiac and pulmonary reactions in humans (Zohdy et al. 2019). Furthermore, dogs not only form a link for the exchange of pathogens between humans, livestock, and wildlife, but they are also an important source of emerging diseases (Macpherson 2005). Together with cats, dogs share at least 60 parasitic species with humans (Macpherson 2005); this underscores the importance of conducting more studies that assess wildlife-dog interactions and the impacts of dogs on wildlife.

Although the majority of owners across both sites negatively perceived free-roaming dogs (i.e., finding them a nuisance or ignoring them), dog owners reported providing care and companionship to their owned dogs that included a willingness to participate in veterinary care. This behavior is consistent with previous research amongst Australians (Taylor and Signal 2009), as well as Americans (Spencer et al. 2017). This could indicate how the Malagasy may expect dogs to be treated. Across AMNP and RNP, people also shared similar feelings about the health and welfare of their dogs, with most of them agreeing to access any free vet care made available to their dog(s), including spay/neuter services.

This research indicates that human attitudes towards and relationships with dogs in Madagascar are diverse and varied and need to be understood before implementing targeted control or management solutions. In particular, peoples' perceptions of dogs, population-level effects of dogs, predatory behavior towards domestic animals and wildlife, how dogs interact with wildlife habitats and protected lands, and dog behavior are particularly important to consider when planning any kind of conservation effort in Madagascar.

Our findings from two critical conservation sites show that human-dog

relationships vary and may be crucial for effective management and conservation solutions in this tropical biodiversity hotspot. Free-roaming dogs are very much a part of daily life for people living around RNP and AMNP, and the long-term conservation of native wildlife requires not only a commitment to the local communities but also stricter enforcement of laws and regulations. Finally, across both sites, not only were free-roaming dogs considered to be a nuisance or problematic, but survey respondents indicated that their absence would improve people's lives.

On the issues of dog welfare, and potentially reducing dog population size, communities living around both RNP and AMNP are willing to participate in spay-neuter-vaccination programs, with the majority of those who owned dogs stating that they would utilize veterinary (including spay/neuter) services for their dogs if they were made freely available. While our results do not allow us to infer the attitudes of dog owners across Madagascar, this survey may be useful as a means of establishing the suitability and potential success of spay/neuter/vaccination programs in other areas of Madagascar. A spay/neuter/vaccine program could be a highly effective method to control the dog populations in these areas. This is indicated by the interest of the majority of respondents in veterinary services, together with a generally negative attitude of non-dog owners towards free-roaming dogs.

In contrast, capture-kill efforts would likely not be either popular or seen as a viable option across this region, where people have ownership relationships with dogs. Thus, spay/neuter/vaccine programs, in addition to increased enforcement of leash and anti-hunting laws, are likely to be the most locally appropriate response to reduce free-roaming dog populations. In these regions, hunting is equivalent to poaching because the wild, endemic animals live within the bounds of a national park and, in many cases, are a protected species. Our surveys might at least partially support previous camera trapping data, which indicate that dogs may be engaging in predatory behavior or competitively excluding wild animals (Gerber et al. 2012a, 2012b; Farris et al. 2015a, 2015b, 2015c). Additionally, given that 40% or more of the dog-owners report traveling with their dogs into the forest at least once during the week, targeted educational and outreach programs on the threats of dogs to local wildlife are necessary. Dog presence within the forest is associated with numerous deleterious effects on native wildlife, and the most effective measure to diminish or eliminate these effects is to curb this practice (Valenta et al. 2016).

Sterilization surgery (spay/neuter, also referred to as "desexing") is generally considered the most humane option for population control of dogs in the United States and most developed countries; it is widely practiced with dogs that can be adopted or owned, present in animal sheltering agencies, and utilized at veterinary hospitals (Trevejo et al. 2011). Trap-Neuter-Vaccinate-Return (TNVR) programs have been proven effective for humane management of free-roaming cat populations in the United States (Hamilton 2019) and dog populations in India (Reece and Chawla 2006). Since culling free-roaming cat and dog populations tends to receive strong opposition due to citizens' concern for animal welfare, TNVR may be a viable option for free-roaming population control of dogs in RNP and AMNP, particularly in light of our survey results.

Relatedly, many dog owners in our sample indicated that their dogs had litters, further contributing to the local unwanted dog problem. In light of a growing body of evidence highlighting the detrimental effects of dogs on wildlife, a comprehensive sterilization and vaccination program for owned dogs in the study communities may be very effective, particularly if implemented alongside a TNVR program for free-roaming dogs. The residents con-

sider free-roaming dogs a nuisance. Hence, implementing a public awareness campaign highlighting how the reduction of puppy litters via TNVR would ultimately reduce populations of free-roaming dogs in the communities (and thus, the nuisance they cause) could also be beneficial.

Human perceptions may be critical to conservation efforts that focus on reducing wildlife-dog interactions as close human-dog relationships characterize many societies (Young et al. 2011). Hence, for any conservation actions to be successful, public awareness campaigns focusing on the problems created by dogs and culturally appropriate and acceptable interventions are critical (Young et al. 2011).

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