ORIGINAL ARTICLE

First evidence of male spatial associations and roadkill mortality in the Fosa *Cryptoprocta ferox* in Ankarafantsika National Park, Madagascar

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Abstract.

Historically, the Fosa *Cryptoprocta ferox* has been considered solitary outside of the mating season. Recent work in Kirindy Forest suggested that males in this species may interact more than previously recognized, yet it was unclear whether that association reflected unique conditions of the population and/or habitat at Kirindy or more generalized behavioural plasticity in the species. Here we document the first evidence of spatial association patterns in Fosa males in the northern deciduous forest of Ankarafantsika National Park, Madagascar, collected using GPS-collars to precisely record positional data at fine temporal scales. These data reveal intriguing patterns, including a male dyad that travelled together on multiple occasions over a two-week period. Results suggest that male associations in the keystone carnivore of Madagascar may be more common than previously recognized, especially in areas of high competition or (invasive or endemic) carnivore density. Notably this paper also documents the first published account of road kill mortality for this keystone predator species, raising awareness regarding a need for better roadkill mitigation strategies within the park.

Keywords: Fosa, conservation, GIS, roadkill, association behavior.

Introduction

Among Carnivora, social organization varies broadly from solitary individuals up to complex multi-male multi-female family units (Macdonald 1983). Many species, including leopards, jaguars, and Eurasian lynx *Lynx lynx*, are well-known to remain solitary outside the mating season (Gittleman 1989, Jackson 1996, Schmidt et al. 1997). Variance in cooperation has been documented in other carnivores such as the Red fox *Vulpes vulpes* (MacDonald 1979, von Schantz 1981). Others still, such as wolves, hyaenas, giant otters, and lions, form cooperative groups containing related individuals as well as newcomers (Kruuk 1972, Duplaix 1980, Macdonald 1983, Mech et al. 1998). Overall, however, at least 85% of carnivore species are considered solitary (Bekoff et al. 1984, Gittleman 1984). The social behaviour in smaller-bodied and rarer carnivores, however, remains largely understudied. In

particular, relatively few studies document sociality in the seven genera and ten extant species of endemic euplerid carnivores occupying Madagascar today (Yoder & Flynn 2004, Farris et al. 2015).

The Fosa *Cryptoprocta ferox* (Figure 1) is Madagascar's largest endemic predator. This small to medium sized species (5-9 kg) occurs throughout the country's forested areas, including high elevations of the Adringitra Mountains (2,000 m) and on the small Isle Saint-Marie (Köhncke & Leonhardt 1986, Hawkins 2003). Despite the species' large natural range (Hawkins 1998), estimated population densities are comparatively low for tropical carnivores at about 1.24 animals per km^2 in some areas (Peters 1983, Hawkins & Racey 2005). In Kirindy Forest, a dry deciduous habitat, the estimated population density is still lower, at one animal per 4 km^2 (Hawkins 1998).

Figure 1. Study individual M1 of *Cryptoprocta ferox* in Ankarafantsika National Park, Madagascar. Credit: Eileen Wyza.

Fosa spatial ecology appears broadly similar to that of other hypercarnivorous (where diet is comprised of over 70% meat) and polygynous species in that males typically occupy larger home ranges and often overlap with other males, whereas females occupy smaller home ranges and rarely overlap with other females (Hawkins 2003). Despite home range overlaps, Fosas were, until recently, assumed to be solitary outside of the mating season (Hawkins 1998, Dollar 1999, Hawkins 2003, Hawkins & Racey 2009, Lührs & Dammhahn

2010, Lührs & Kappeler 2013). Because IUCN currently lists Fosa as vulnerable due to a 30% or greater population drop over the past three generations (Hawkins 2016), low population densities and presumed solitary behaviour are a great cause of concern when considering the species' ability to adapt to continued habitat degradation, persecution hunting, and conflicts with introduced species (Farris et al. 2015).

Anecdotal sightings of Fosas traveling together outside of the mating season, however, have raised questions regarding the generality of solitary behaviour in this species (Hawkins 2003, Lührs & Dammhahn 2010, Lührs & Kappeler 2013), and recent work in Kirindy Forest found evidence of cooperative hunting and strong associations in radio-tracked Fosa males (Lührs & Dammhahn 2010, Lührs et al. 2012, Lührs & Kappeler 2013). Association between male carnivores for territorial defence and access to females has been documented in other species, including cheetahs and Kinkajous *Potos flavus* (Caro & Collins 1987, Gehrt & Fritzell 1998, Boydston et al. 2001, Kays & Gittleman 2001). It is also possible that associations form for heightened efficiency in hunting (Clark & Mangel 1986, Creel & Creel 1995, Lührs & Dammhahn 2010, Lührs et al. 2012).

Global Positioning System (GPS) evidence of Fosa spatial associations have never been reported outside Kirindy Forest. Hence, it remained possible that Fosa ranging and association patterns observed at Kirindy reflect unique conditions of that particular population and/or habitat. Alternatively, *C. ferox* as a species may be capable of greater behavioural plasticity in spatial associations than has previously been appreciated. We explored these alternative possibilities using high-resolution spatial data gathered using GPS collars in a different forested habitat, Ankarafantsika National Park, Madagascar. Documentation of male associations in this paper supports the latter interpretation, indicating Fosas may exhibit some degree of behavioural and associative flexibility in the face of anthropogenic environmental changes, making them a plausible candidate for successful conservation interventions.

Materials and methods

Study area

Ankarafantsika National Park is a dry deciduous forest in north-western Madagascar with distinct wet and dry seasons (Figure 2). The dry season occurs from May to October, and the wet season occurs from November to April (Alonso et al. 2002). Ankarafantsika National Park has experienced an alarming rate of deforestation in recent years, with 20% of its forest disappearing in the decade between 1990 and 2000 (Dollar 2006). Additionally, a major roadway (RN4) bisects the park into eastern and western areas, potentially hindering wildlife movements and significantly increasing threats of wildlife loss due to roadkill.

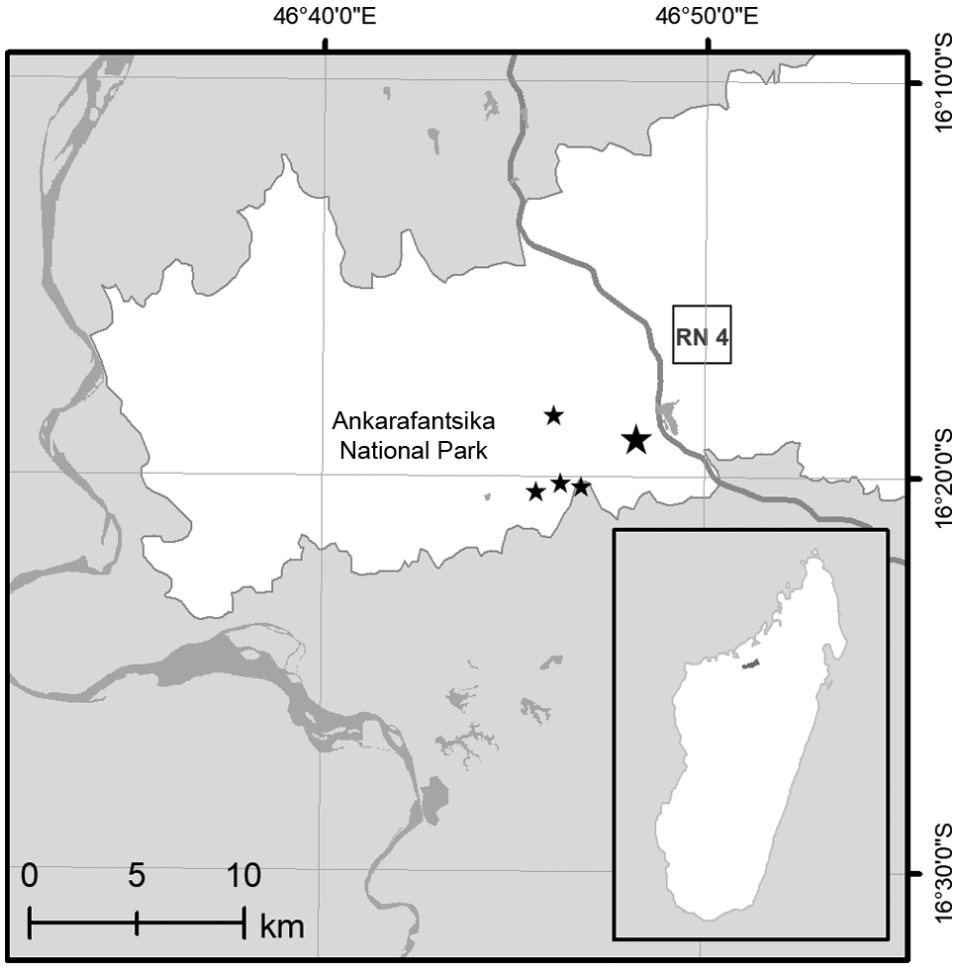

Figure 2. Location of Ankarafantsika National Park in Madagascar and location of RN4 that bisects the park. Locational fixes where the male dyad travelled closer than the critical distance (250 m) are starred. The largest star shows the location where the initial sighting of the association was captured via camera trap, depicted in Fig. 3.

Methods

Fosas were captured and fitted with GPS collars in Ankarafantsika National Park in June, 2016. All data were collected following procedures approved by the Institutional Animal Care and Use Committee (IACUC). Individuals were trapped using Tomahawk bobcat traps (107 x 38 x 51 cm). Forty traps were placed along two trap lines that extended across 20 km. Once captured, Fosas were sedated with Telazol following methods published by Dollar (2006), then fitted with Telonics TGW-4277-4 GPS Iridium collars (220 g, 5.7 x 3.5 x 2.7 cm). Collars were placed only on adult animals large enough that the collars comprised ≤5% body mass. Animals were placed in a recovery cage until the anaesthetic wore off, then released at the capture site.

GPS collars were programmed to take QFP (Quick Fix Pseudoranging) spatial data every 20 minutes. Activity counts were simultaneously measured using the collar's accelerometer. Mortality was identified by an Activity Count registered at 0 for a 24-hour

period. GPS data were supplemented with ten camera trap images using 12 Reconyx HC500/HC600 cameras placed along the trap lines and in close proximity to trap locations.

Doncaster's method of dynamic interaction (Doncaster 1990) was used to explore for association patterns among individuals using the wildlifeDI package in R 3.3.2 (Long 2015). For this study, association was defined by two individuals coming within a critical distance of 250 m from each other within a one-hour period. The default critical distance of 50 m used in prior studies examining association behaviours in foxes (Doncaster 1990) was increased to 250 m due to a comparatively larger body size (e.g., Dollar 2006), and acute sense of olfaction in the Fosa (Köhncke & Leonhardt 1986, Wright 1998).

Results

Two males were captured over the duration of the trapping portion of the study. The male Fosas were initially documented together using camera traps posted along the trap lines and in close proximity to traps. They were first observed traveling together on June 2nd at 17h56, following when one of the males (M1) entered a trap. The second male (M2) remained for nearly 3 hours just outside the apparatus with the trapped male until M1 was removed from the trap at 20h49 (Figure 3), and in fact approached to within 10 m of the capture team when quietly stopped in the vicinity of the capture trap.

Figure 3. Camera trap capture of two male fosa traveling together, with M1 (circled) captured in one of the traps and M2 (foreground) remaining nearby.

This second male (M2) was captured the following morning less than 1 km away from the first capture location. Both males were fitted with GPS collars and released and were then intensively radio-tracked simultaneously for two weeks. Unfortunately, M2 was fatally

injured on the roadway (RN4) by a vehicle only two weeks into the study, severely limiting data collection and calling attention to the direct impacts humans have on Fosa populations as well as the need for continued research and conservation efforts that address roadways.

Over the period of data overlap, however, M1 and M2 travelled together at least two additional times. On June 10th, they travelled for one hour and 20 minutes in the same direction with a measured distance from one another varying between 75-120 m throughout that interval. Four hours from the initial association, M2 ceased activity and M1 continued to travel. The male dyad came together again on June 13th and were measured less than 50 m from each other. They travelled together for two hours until M1 ceased activity and M2 continued traveling.

Doncaster's (1990) method of dynamic interaction was used to determine whether the movements between the dyad statistically showed mutual attraction. The test revealed that the individuals interacted nonrandomly ($p < 0.001$). During the GPS collar study, the two males came within critical distance (250 m) three times simultaneously, and twelve times within one hour of each other. When considering spatial positions during the study period, the probability that the individuals were within 2 km of each other were greater than predicted by chance alone.

Discussion

GPS data document a significant degree of spatial association between the M1-M2 male Fosa dyad at Ankarafantsika. Within a two-week period during the dry season, the two individuals travelled together at least three times. The coordinated movements between the M1-M2 dyad at Ankarafantsika occurred at a higher critical distance than the previous study (Lührs & Kappeler 2013), perhaps due to the larger size of Ankarafantsika National Park relative to the other study locale. Notably, the 50 m critical distance utilized in the Lührs & Kappeler (2013) study is perhaps conservative, as it was based upon the sensory abilities of foxes in urban environments rather than Fosa (Doncaster 1990). Additional studies regarding the sensory abilities of Fosa in forested environments are necessary to determine the ideal critical distance measurement to use for this species in future statistical analyses. Unfortunately, simultaneous data collection of the Ankarafantiska male dyad was truncated due to the death of M2, reducing the opportunity to observe spatial associations over a longer time and across seasons.

Because temporal intervals used in GPS data collection were optimized to extend the overall study duration by recording positions only at 20-minute intervals, it is possible that the individuals also travelled together more frequently for bouts lasting less than 20 minutes. Fosas are able to cross their entire home range in a short period of time (Hawkins 2003), so individuals can certainly travel more than 250 m in 20 minutes. Understanding the speed of travel for Fosa across varying landscapes in order to determine what movement patterns may

have occurred between GPS fixes requires further study to confirm the possibility of greater association.

Documentation of travel associations in male Fosas is rare and has only been recorded to date in dry deciduous forests (Lührs & Kappeler 2013). It is possible that spatial association provide advantages in environments with higher seasonality relative to habitats in more even climates, like tropical rainforests, but this will need to be confirmed through additional data. Previous studies have demonstrated that carnivores exhibit increased social flexibility during times of resource abundance (Silva et al. 1993, Eide et al. 2004). In contrast, the dyad in this study have to date exhibited spatial associations only during the dry season, when overall resource availability is somewhat lower. Therefore, Fosa associations may support the hunting efficiency hypothesis (Creel & Creel 1995, MacNulty et al. 2011), as also suggested by Luhrs & Kappeler (2013).

Alternatively, spatial associations may reflect behavioural plasticity in the face of known threats, such as competition with rising populations of introduced carnivore species such as feral cats and dogs (Farris et al. 2015). Interestingly, associations have been suggested as a means of reducing predation risk in Madagascar's Narrow-striped Mongoose *Mungotictis decemlineata* (Schneider 2015). Although dogs and cats may not prey directly on the Fosa, it is possible that Fosa spatial associations may assist with coordinated defence of kills and other resources in light of the larger overall carnivore populations in the forest. This hypothesis would be supported should sociality increase hunting success or decrease conflict/competition with larger bodied carnivores, particularly considering increased numbers of dogs encountered in and around this (Barcala 2009, Dollar, unpubl. data) and other study areas (Farris et al. 2015) in recent years. Additional studies of larger numbers of Fosa across different seasons and in different parks will help to test among these possibilities, but it is interesting to speculate on the impact of the roadkill on the surviving Fosa male.

Conclusions

Understanding the ranging and behaviour patterns in species of critical conservation priority is paramount to effective habitat and population management. This article affirms recent observations that male Fosa may exhibit flexible cooperative or association patterns, forming temporary coalitions for territorial or hunting purposes (Lührs & Kappeler 2013), contrary to previous interpretations of Fosa as exclusively solitary predators (Hawkins 1998, Dollar 1999, Hawkins 2003). It is also possible that association behaviours could arise from pressures such as introduction of invasive species, as has been documented in the Narrow-striped Mongoose, another Malagasy carnivore (Schneider 2015). As anthropogenic and invasive species pressures increase throughout Madagascar, our results underscore critical topics for intensified study to better integrate research with conservation and management strategies, and ultimately policy governing natural resource protection.

Moreover, this paper provides the first published report of Fosa succumbing to roadbed mortality, with M2 in this study tracked via GPS collar to the point where it was hit by a car and its death by roadkill subsequently investigated and confirmed by villagers living nearby. Roadkill is a well-documented threat to wildlife elsewhere in the world. With roadbed mortality being a significant cause of non-natural death for some carnivores including Florida panthers *Puma concolor* (Taylor et al. 2002, Pimm et al. 2006), Iberian lynx *Lynx pardinus* (Ferreras et al. 1992), wolves (Paquet 1993), and European badgers *Meles meles* (Clarke et al. 1998), recognition of this threat in Madagascar naturally leads to awareness of the need to mitigate roadkill threats in protected areas.

Results of this study encourage deeper investigation of the type and degree of sociality exhibited by male Fosa and suggest a need for focused attention to mitigate the impacts of roadkill on Fosa throughout Madagascar in order to promote the best, most informed conservation efforts and strategies possible.

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