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Threats to a rainforest carnivore community: A multi-year assessment of occupancy and co-occurrence in Madagascar

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ABSTRACT

Protected areas (PA) aim to eliminate many of the threats that species face on the greater landscape. In the last three decades, PA's have expanded considerably; however, quantitative assessments of how well they have mitigated threats to habitat and biodiversity are very limited. Habitat bordering PA's and the wildlife that use it are threatened by a wide-range of anthropogenic pressures (e.g., edge effects, fragmentation, and introduced predators) and this situation is particularly acute for low-density, poorly studied carnivore communities. From 2010 to 2015, we photographically sampled within (contiguous forest) and bordering (degraded, fragmented forest) a UNESCO World Heritage rainforest PA in Madagascar - Ranomafana National Park (RNP). We investigated the effects of invasive predators, local people presence, and habitat quality on the endemic rainforest carnivore community using static, dynamic, and co-occurrence models. We found native carnivores to be absent or have a low probability of occurrence in degraded forest bordering the PA, while local people and dogs (*Canis familiaris*) had high occurrence. Madagascar's largest endemic carnivore, the fosa (*Cryptoprocta ferox*) and the much smaller ring-tailed vontsira (*Galidia elegans*), occurrence in RNP declined rapidly over six years; their strong co-occurrence with dogs suggests interspecific competition, direct aggression/mortality, or disease as the cause. We highlight the dangers posed to biodiversity, particularly carnivores, from anthropogenic pressures bordering PA's and present recommendations to address increased human and dog activity, including programs to control dogs and their impact on biodiversity.

1. Introduction

Protected areas (PAs) aim to conserve the world's biodiversity and rarest species, while covering just 15% of earth's terrestrial surface (Farris et al., 2017). The number of PAs has grown considerably in the last three decades, particularly in tropical, developing countries (Naughton-Treves et al., 2005; Tittensor et al., 2014). Since 1992, PAs have increased annually by an average of 2.5% in total area and 1.4% in the total number of sites (Butchart et al., 2010; Rands et al., 2010). By 2006, PAs covered 24,000,000 km^2, in 133,000 designated areas (Butchart et al., 2010; Rands et al., 2010). However, this positive development for biodiversity conservation needs to be viewed from a balanced perspective. For example, it is estimated that 20% of vertebrate taxa recognized as threatened by the International Union for Conservation of Nature (IUCN) do not live in PAs (Rodrigues et al., 2004). Furthermore, despite formal protection, many PAs do not fully mitigate threats to habitats and biodiversity, due to chronic under-staffing, underfunding, and political instability (Brown et al., 2016; Naughton-Treves et al., 2005).

Despite the proliferation of PAs worldwide (Di Marco et al., 2014;

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Wolfe et al., 2015), attempts to quantify the effectiveness of these critical areas are greatly limited (Dickman, 2013; Rosenblatt et al., 2014; Tittensor et al., 2014; Valenta et al., 2016a). While data indicate that PAs generally curb forest loss within their boundaries, many areas suffer the effects of deforestation and biodiversity loss from surrounding areas, where managers lack the authority, resources, and funding to respond to adjacent biodiversity threats (Bauer et al., 2015; Lindenmayer et al., 2012). The actions in these bordering areas often harm PAs (e.g., watershed degradation). The failure to develop targeted measures to assess effective conservation and inadequate resources to conduct management activities (i.e., enforcement, boundary demarcation, and compensation to local communities; Bruner et al., 2001) prevents managers and conservationists from evaluating progress and incorporating adaptive management strategies (Panek, 2013).

Developing effective and practical management plans for protecting wildlife within PAs is particularly important for carnivores, as they are fundamental drivers of trophic functioning (Ripple et al., 2014) and can increase ecosystem resilience (Tittensor et al., 2014) through stabilizing consumer populations (Bruner et al., 2001). As a guild, carnivores are arguably the most vulnerable species because of their typical-low densities and wide-ranging movements, which increases their interaction with local human communities (hereafter human), and thus conflict. Human-carnivore conflict can be a significant source of mortality for carnivores living in, but ranging beyond, PAs (Koziarski et al., 2016; Lindsey et al., 2017; Woodroffe and Ginsberg, 1998) and recent research has highlighted the effects of fragmentation, edge effects, and introduced predators on native carnivores (Brodie et al., 2015; Chanchani et al., 2016; Gerber et al., 2012b; Sleeman, 2013; Vanak and Gompper, 2010; Vanak et al., 2013; Young et al., 2011). In particular, forest fragmentation means that wide-ranging carnivores must move among habitat patches and thus face dangers found in the matrix. This results in low fragment occupancy for many native carnivore species, when human and introduced carnivore populations increase (Chanchani et al., 2016; Crooks, 2002; Farris et al., 2015c; Gerber et al., 2012b; Michalski and Peres, 2005). Introduced carnivores (e.g., feral dogs and cats) can greatly intensify pressure on native carnivores as they alter their temporal activity patterns (Farris et al., 2015b; Farris et al., in press; Gerber et al., 2012a), reduce their spatial distribution and habitat use (see Vanak et al., 2013 for review), and decrease prey availability (see Young et al., 2011 for review).

Long-term surveys of carnivores and their prey are critical to recognize when population changes are occurring (i.e., occupancy, density, survival, recruitment) and to identifying the driving factors. Unfortunately, such studies are rare, with most carnivore studies only providing a small snap-shot of the population, thus missing important dynamics. Carnivores are highly sensitive to disturbances at the borders of PAs and are negatively affected by edge effects, poaching, and human-wildlife conflict (Loss et al., 2013; Sleeman, 2013; Wearn et al., 2012; Woodroffe and Ginsberg, 1998). Thus, carnivore population health is likely driven by species-specific tolerances to habitat variation, human presence, habitat fragmentation, invasive carnivore density, and prey distributions. The complexity of the interactions between carnivores and their habitat and prey means that their management must account for the multiplicity of variables driving population health within and around PAs.

Madagascar contains some of the highest levels of biodiversity and endemism in the world (Ganzhorn et al., 2001), but is home to only nine native carnivore species. These species are endemic and range in conservation status from Least Concern to Endangered (Goodman, 2012; IUCN, 2014). A wide-range of anthropogenic threats has resulted in Madagascar being one of the world's top conservation priorities (Mittermeier et al., 2004; Schwitzer et al., 2014). While 21 national parks have been designated in Madagascar (IUCN, 2015), surveys and population estimates of carnivores are lacking for most of these Pas. For example, Farris and Gerber (unpublished data) estimate that < 20% of PAs have robust surveys, consisting of more than opportunistic sightings or rapid assessments, of carnivore populations. Research from five PAs highlights the threat posed to endemic carnivores as the result of degradation, fragmentation, and human disturbance (Farris et al., 2015c; Gerber et al., 2012b; Wierzbowska et al., 2016), poaching and bushmeat consumption (Farris et al., 2015c; Golden, 2009; Golden et al., 2014; Robley et al., 2014), and introduced carnivores (Farris et al., 2015a; Farris et al., 2015b; Gerber et al., 2012b, a). The long-term effects of these factors and the effectiveness of PAs to diminish their effects remain unstudied.

Here, we provide a six-year evaluation of the effects of invasive predators, human encroachment, and habitat quality on population trends for five native carnivores in one of Madagascar's most important PAs and a UNESCO World Heritage site, Ranomafana National Park (RNP). We document the spatial distribution of native carnivores (fosa *Cryptoprocta ferox*, falanouc *Eupleres goudotii*, spotted fanaloka *Fossa fossana*, ring-tailed vontsira *Galidia elegans*, and broad-striped vontsira *Galidictis fasciata*) over time, by investigating the factors influencing native and introduced carnivore species distributions in contiguous forest and human-dominated sites. Quantifying the effects of spatial habitat variation, edge effects, and species interactions on native carnivores, allows us to evaluate the effectiveness of management actions for carnivore conservation. We hypothesized that all five native carnivores would have higher occupancy in contiguous forest inside the PA, while dogs (*Canis familiaris*) and human occupancy would be higher in degraded forest outside the PA and distance to edge would negatively influence native carnivore occupancy and positively influence dogs and human occupancy. We also hypothesized that native carnivore occupancy would experience little overall change, while dog and human occupancy would show slight increases over the six-years. This prediction is based upon trends observed across the RNP region with growing human and dog populations. Finally, we hypothesized that all native carnivores would demonstrate a lack of co-occurrence, defined as "apparent spatial avoidance" (whether behavioral or habitat-mediated), with both dogs and humans inside the PA.

2. Methods

2.1. Study site

We conducted this study at Ranomafana National Park (41,000 ha) in southeastern Madagascar (21°16′S, 47°20′E; Fig. 1). A small percentage of this submontane rainforest site was selectively logged from 1986 to 1989, but in 1991 the area was designated as a PA (Wright et al., 2012). RNP protects 13 lemur and five carnivore species (fosa *Cryptoprocta ferox*, falanouc *Eupleres goudotii*, spotted fanaloka *Fossa fossana*, ring-tailed vontsira *Galidia elegans*, and broad-striped vontsira *Galidictis fasciata*). This PA, which is bisected into two parcels by the Namarona River and a paved road, is one of four long-term research sites in Madagascar (Wright et al., 2012).

2.2. Photographic sampling

Our photographic sampling results from two efforts: (1) Tropical Ecology Assessment and Monitoring network (TEAM - www.teamnetwork.org; Data Set Identifier: TEAM-DataPackage-20131011121105_2883) surveys (2010–2015) within contiguous forest within the boundaries of the PA and (2) Mad Dog Initiative (MDI; www.maddoginitiative.com) surveys (2014–2015) within degraded, fragmented forest outside the PA (Fig. 1; Table 1). For the first surveys, we followed TEAM protocol (TEAM Murphy et al., in press) and surveyed at 40 (2015) to 60 (2010) sites between the months of August and April (Fig. 1). For the degraded, fragmented forest surveys, we surveyed 23 sites between September and October (2014) and 25 sites between June and July (2015).

At each station we placed one or two cameras on opposing sides of small unmaintained (0–0.5 m) or maintained (> 0.5 m) trails and