



The times they are changin': Multi-year surveys reveal exotics replace native carnivores at a Madagascar rainforest site



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ABSTRACT

Surveys across multiple seasons or years are necessary to evaluate the effects of dynamic processes on long-term persistence of wildlife populations, such as effects of exotic species on native species populations. Unfortunately, multi-year surveys are rare, particularly for rainforest carnivore populations, and managers often rely on single-season/year, 'snapshot' surveys that produce static estimates of population parameters. Here we provide results using single-species, multi-year occupancy modeling from a six-year survey (2008–2013) of a rainforest carnivore community at a 15 km² area study site within the newly established Makira Natural Park, Madagascar. We demonstrate a precipitous decline in the native carnivore community with four of the six native carnivores (falanouc *Eupleres goudotii*, ring-tailed vontsira *Galidia elegans*, broad-striped vontsira *Galidictis fasciata*, and brown-tailed vontsira *Salanoia concolor*) decreasing by at least 60% over this six-year period. In addition, we observed two exotic carnivores (small Indian civet *Viverricula indica* and feral cat *Felis* species) colonize this study site with *Felis* species increasing in occupancy from 0 to 0.68 by the final year. Further, we demonstrate how variables associated with human encroachment (i.e. distance to forest edge and nearest village) are most important for explaining these trends in native carnivore extirpation and exotic carnivore colonization. These findings provide additional evidence on the threat posed to native carnivore populations by the expansion of exotic carnivores worldwide. We highlight the striking increase in extirpation, and the factors influencing such changes, for native carnivores. In this manuscript, we point to the limited number of multi-year surveys to evaluate dynamic processes on long-term persistence of native wildlife populations, as well as the lack of exotic carnivore control programs in threatened ecosystems in many developing nations as factors limiting our ability to effectively conserve biodiversity across the globe.

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1. Introduction

Long-term persistence of species is the ultimate goal of conservation and management science. Dynamic processes affecting long-term persistence include not just intrinsic demographic processes (birth, immigration, death, emigration), but also extrinsic factors including, but not limited to, climate change, habitat change, disease, and additional metrics associated with human encroachment (Bellard et al., 2012; Garcia et al., 2014; Rybicki and Hanski, 2013; Sleeman, 2013). Multi-year and/or multi-season surveys are required to both measure dynamic processes and determine factors that influence persistence and local dynamics of target species (MacKenzie et al., 2006; Magurran et al., 2010;

Rosenblatt et al., 2014). Multi-year surveys allow researchers to investigate environmental drivers and rates of change for various population parameters (Clutton-Brock and Sheldon, 2010; MacKenzie et al., 2003), providing valuable insight into species viability (Dickman, 2013; Lindenmayer et al., 2012).

Unfortunately, long-term or multi-year surveys are especially rare for elusive species occupying tropical forest ecosystems. Tropical environments are important for conservation as they are often associated with high levels of biodiversity; however, high point estimates of biodiversity do not necessarily equate to long-term persistence of species (Sales et al., 2015). Tropical rainforest ecosystems continue to be fragmented and/or degraded as a result of resource demands associated with a burgeoning human population (Hansen et al., 2013). In addition, tropical forest ecosystems face mounting pressure from additional anthropogenic factors including climate change, pathogens, bushmeat hunting and consumption, and exotic species (Laurance, 2015). Despite

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a large increase in the number of protected areas across the tropics in the last three decades (Naughton-Treves et al., 2005), attempts to quantify the effectiveness of these protected areas in conserving these ecosystems and the species therein, remain sparse (Beaudrot et al., 2016; Dickman, 2013). To develop targeted management plans that address these wide-ranging anthropogenic pressures, scientists require long-term or multi-year surveys to evaluate and monitor population trends and ensure the effectiveness of resulting management strategies.

Studies of rainforest carnivore populations are often restricted to single-year photographic (camera-trap) surveys with the aim of estimating population parameters (i.e. occupancy, abundance, and/or density). These single-year, ‘snapshot’ surveys, which provide static parameter estimates (e.g., occupancy and/or density), are of great importance to conservationists working to develop targeted management plans, as these estimates are lacking for many rainforest carnivore communities. However, given the dynamic, ongoing anthropogenic pressures threatening rainforest ecosystems, snapshot estimates may misinform managers regarding the capacity of a forest site to sustain these species (Krauss et al., 2010; MacKenzie et al., 2006; Sales et al., 2015). For example, static estimates may provide a pattern in species occurrence across the landscape, but they fail to identify complex processes such as impending declines via extinction debt (Essl et al., 2015; Kuussaari et al., 2009; Wearn et al., 2012). As a result, static estimates may result in misrepresentative conclusions, which can impair and mislead management efforts (Krauss et al., 2010; Kuussaari et al., 2009).

Madagascar's carnivores (*Eupleridae*) are perhaps the most threatened and least studied carnivore family in the world (Brooke et al., 2014). Recent research has highlighted the threats posed to endemic carnivores as a result of forest loss, degradation, and fragmentation (Farris et al., 2015d; Gerber et al., 2012b; Kotschwar et al., 2014), bushmeat hunting and consumption (Farris et al., 2015d; Golden, 2009; Goodman, 2012; Jenkins et al., 2011), exotic carnivores (Farris et al., 2015a,b,c; Gerber et al., 2012a,b), and alien, invasive prey species (Brown et al., 2016). However, studies on these threatened carnivores to date are confined to single-year, static estimates. Long-term, multi-year surveys are needed to better understand the impacts of dynamic processes on this endemic carnivore community. Our goal was to provide the first multi-year assessment of Madagascar's rainforest carnivore community. To that end, our first objective was to estimate single-species, multi-year occupancy and evaluate changes in occupancy, local extirpation, and colonization. Our second objective was to

evaluate the importance of various habitat, landscape, and co-occurring species variables on parameter estimates.

2. Methods

2.1. Study site

From 2008 to 2013, we conducted photographic surveys at 24 locations over ~15 km² area to sample the carnivore community at a study site within Makira Natural Park (NP), Madagascar (Fig. 1). We are unable to reveal the precise location of this site due to permit requirements resulting from previous work on bushmeat hunting at this location. This study site was established in 2007 as a long-term research study site as it protects at least 12 species of lemurs (Murphy et al., 2016; Rasolofoson et al., 2007), including the critically endangered silky sifaka and red-ruffed lemur *Varecia rubra*. Previous work at this study site (Farris and Kelly, 2011; Farris et al., 2012, 2014) has reported the presence of six native carnivore species, including (with current IUCN Red List status) the fosa *Cryptoprocta ferox* (Vulnerable), falanouc *Eupleres goudotii* (Vulnerable), spotted fanaloka *Fossa fossana* (Vulnerable), ring-tailed vontsira *Galidia elegans* (Least Concern), broad-striped vontsira *Galidictis fasciata* (Vulnerable), and brown-tailed vontsira *Salanoia concolor* (Vulnerable) (IUCN, 2016). Surveys across this region have revealed exotic carnivores (domestic dog *Canis familiaris*, domestic/feral cat *Felis* species, and small Indian civet *Viverricula indica*) to overlap both temporally and spatially with native carnivores and thus potentially negatively impact native carnivore populations (Farris et al., 2015a,b). While the period of colonization is unknown, it is believed that *C. familiaris* and *Felis* species were introduced by the first human colonizers and *V. indica* was introduced by traders during the Islamic period (between 700 and 1200; Goodman, 2012).

The study site is located near the Antainambalana River and lies adjacent to two villages having population sizes of approximately 1500 and 2300. This steep terrain, low elevation rainforest study site is positioned along a hard edge where forest has been cleared for cattle (zebu) grazing and cultivation. Degraded forest and invasive plant species are prominent along the edge, but the forest transitions into secondary forest growth within approximately 100 m. We found evidence of forest cutting and lemur hunting each year within the study site; however, these forms of anthropogenic disturbance were rare and not widespread. Human trails are present throughout the forest with two

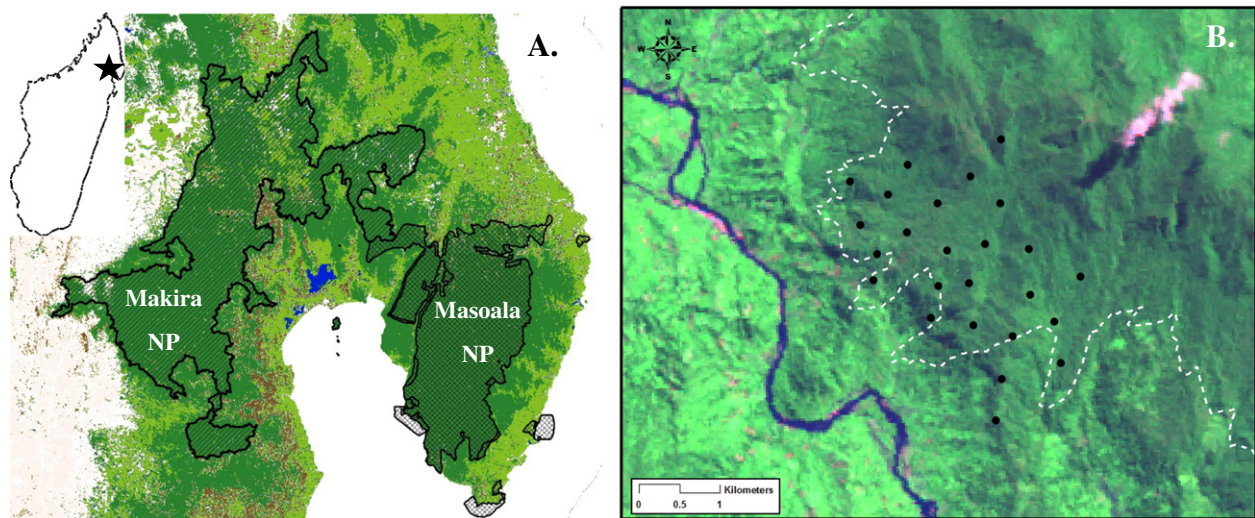


Fig. 1. Land cover maps revealing A) the location of the Makira Natural Park (left) and Masoala National Park (right) and B) the camera trap (black circles) layout used for photographic surveys from 2008 to 2013 and the park boundary (white dashed line) for Makira Natural Park. Maps include forest cover (dark green), degraded forest and/or non-forest (light green), and the location of the Antainambalana River (dark blue).

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