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Post-war recovery of the African lion in response to large-scale ecosystem restoration

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ABSTRACT

We present data from the first, long-term study underway of a recovering population of indigenous, free-ranging *Panthera leo* in Gorongosa National Park (GNP), Mozambique. GNP is undergoing post-war recovery and large-scale ecological restoration under a 25-year private-governmental partnership – the "Gorongosa Project (GP)," – offering a rare opportunity to elucidate the long-term recovery dynamics of a population of lion in response to strategic conservation interventions. GNP forms a core part of the greater Gorongosa-Marromeu Lion Conservation Unit which is designated as a "potential lion stronghold." Within the Park we established an intensive study area of 1100 km^2 encompassing prime areas of herbivore productivity. Between 2012 and 2016, 104 lions were documented and 6 prides and 7 males or coalitions in our study area were satellite-collared and intensively monitored. We describe seasonal male and female home-ranges, prey utilization, estimated *versus* predicted lion densities in relation to recovering herbivore biomass, and anthropogenic factors limiting the population's full recovery potential. The dominant factor observed to be negatively impacting the population was top-down and anthropogenic in the form of by-catch by wire snares and steel-jaw traps set by bushmeat hunters. These findings have since resulted in tangible and measurable interventions to reduce these impacts and resultant future datasets will elucidate detailed demography and how management interventions impacted the trajectory of large-carnivore recovery.

1. Introduction

Despite being one of Earth's most charismatic megafauna and a flagship species critical to eco-tourism on the African continent (Naidoo et al., 2016; Lindsey et al., 2017), free-ranging populations of the African lion (*Panthera leo*) have undergone a precipitous decline in recent decades with only an estimated 20,000–32,000 free-ranging animals remaining in 67 lion areas across a mostly fragmented landscape (Bauer et al., 2016; Riggio et al., 2013). Habitat loss, wild prey depletion, and retaliatory killing of lions in defense of humans and livestock are major contributing factors to the declines of lion populations (Riggio et al., 2013). Unfortunately, anthropogenic threats to the survival of lions are only likely to increase given the human population in Africa is projected to double to 2.2–2.5 billion by 2050 (Melorose et al., 2015; Rosegrant et al., 2009). Apex predator declines will further degrade trophic systems, diminish biodiversity, and cause substantial social and economic costs to nations dependent on wildlife tourism (Ripple et al., 2014; Estes et al., 2011; Brashares et al., 2010; Prugh et al., 2009).

Protection and restoration of remaining free-ranging populations is therefore time-critical. Baseline data on extant populations is urgently needed to document and guide effective and rapid conservation strategies, and to avoid shifting baseline syndromes that result in policy and management actions lagging behind ecological realities (Papworth et al., 2009). Unfortunately, to date very little data have been published on the status and recovery dynamics of free-ranging lion populations with only a few rare exceptions such as the long-term studies of the Gir population of *Panthera leo persica*, the Asiatic lion, in India (Singh and Gibson, 2011; Wegge et al., 2009). Data gaps persist in part because restoration efforts focused on establishing free-ranging lion populations are still quite rare, and significant logistical, financial, and in some cases political barriers exist toward implementing long-term projects. Nevertheless, it is imperative to formulate key baseline parameters to document and assess recovery trends, facilitate effective communication of both the successes and challenges of restoration efforts, spur innovation in institutional and community approaches to wildlife conservation, and rapidly identify emerging threats.

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We establish initial baseline parameters for a free-ranging lion population undergoing recovery in Gorongosa National Park, Mozambique. Once a renowned stronghold for large mammals (Tinley, 1977), the Gorongosa Ecosystem underwent a severe perturbation in the form of three decades of war (1964–1975, 1977–1992) and post-war instability that included wide-spread poaching of wildlife for bushmeat, skins, and trophies. In 1972, just prior to the 1977 war, Tinley (1977) reported 200 lions in the Park (although it is unclear how this estimate was derived), 480 sable (*Hippotragus niger*), 2600 elephants (*Loxodonta africana*), 3300 zebra (*Equus quagga crawshayi*), 7000 wildebeest (*Connochaetes taurinus*), and 13000 buffalo (*Syncerus caffer*) (Tinley, 1977). By the end of the civil war in 1992 populations of large, mammalian herbivores (Daskin et al., 2016) and carnivores had reportedly been reduced by > 95% (Stalmans et al., 2014).

In 2007, a long-term, public-private ecosystem restoration initiative was launched - the "Gorongosa Project (GP)" - with the goal of post-war recovery and restoration of wildlife populations, the region's tourism-based economy, and quality of life for human communities inhabiting the Park and surrounding buffer-zone (Pringle, 2017). And while herbivore populations have been closely monitored and have rebounded significantly over the past two decades (Stalmans and Peel, 2014), until the launch of our long-term carnivore research project in 2012 nothing was formally known about the lion population despite them being the sole large-carnivore species observed to remain in the Park.

We have two main objectives in this paper: i) to quantify a set of baseline descriptors of the lion population and, ii) to evaluate factors limiting full recovery of the population. We report on seasonal male and female home range size, prey-type utilization, primary sources of injury or mortality, and estimated *versus* model-predicted lion densities based on known herbivore biomass. We also discuss anthropogenic impacts on lions related to the ubiquitous bushmeat trade in the region (Lindsey et al., 2017; Lindsey et al., 2013; Lindsey and Bento, 2012) and how we have observed this trade to specifically impact apex predator recovery. Lastly, we describe strategic, measurable interventions underway to mitigate such threats, and outline our longer-term research objectives. Scientific and conservation insights from Gorongosa can help in the strategic design and implementation of predator recovery and ecosystem restoration projects on the African continent as well as contribute to the growing body of applied knowledge on large carnivore restoration globally.

2. Methods

2.1. Study area

Gorongosa National Park (lat. −18.978975°, long. 34.351901°) in Mozambique encompasses a 4067 km^2 mosaic of unfenced wetland, grassland, savannah and woodland and riparian habitats (Stalmans and Beilfuss, 2008) at the southern edge of the Great Rift Valley (Fig. 1). The interior of the Park receives approximately 700–900 mm of rainfall annually and the adjacent Cheringoma Plateau receives > 1000 mm annually. The Park and adjoining 3300 km^2 buffer-zone of rural settlements and complex of forest reserves and hunting concessions are core components of what is defined as the "Gorongosa-Marromeu Lion Conservation Unit," or LCU43, and is currently listed as a "potential stronghold" with an estimated 229 lions across 46,781 km^2 (Riggio et al., 2013; Fusari et al., 2010). Leopard (*Panthera pardus*), spotted hyaena (*Crocuta crocuta*), and wild dog (*Lycaon pictus*) were all historically present (Tinley, 1977) but are currently ephemeral or absent from the Park, although extant populations occur on the Cheringoma Plateau in the eastern sector of LCU43 and their conservation status and habitat corridors connecting them to the Park are currently under investigation (pers. observation, André, 2008).

We established a 1100 km^2 Intensive Study Area (ISA) situated in the core of Gorongosa National Park (Fig. 1) spanning an area of high herbivore biomass for waterbuck (*Kobus ellipsiprymnus*), warthog (*Phacochoerus africanus*), common reedbuck (*Redunca arundinum*), impala (*Aepyceros melampus*), African elephant (*Loxodonta africanus*) and many others (Stalmans and Peel, 2014; Stalmans et al., 2014; Hansen et al., 2013).

2.2. Lion population status

We adopted a time- and cost-intensive methodology utilizing deployment of satellite collars to monitor individuals in prides and coalitions and allowing us to track the life-history of known individuals across the population. With only 15% of the area of the Park accessible by road, locating and estimating lions using more traditional techniques such as spoor counts on road substrate would yield imprecise data and not gain us much needed insight in to the demographics of this population. Similarly, in 2012 a series of call-up trials (with and without bait) for both lion and hyaena were performed across the core area where we knew lions to be, and the call-ups yielded zero lions or hyaena at the stations. Satellite collars on the other hand served as our "anchors" to the population, allowing us to gather GPS data at least every 4 h and also locate prides and coalitions regularly to visually document associations, mating and reproduction, and track survival or mortality.

Beginning in 2013, we began deploying satellite collars (African Wildlife Tracking, and Vectronic Aerospace) across our ISA with a goal of fitting at least one female in each pride and one male in each coalition. Once a candidate lion was discovered, the decision to collar was made by our veterinary team after an assessment that included aging (no lion younger than 2.5 years of age was collared), associations (strategic placement of collars across our ISA and avoiding multiple collars in any single pride unless necessary), and condition (no obvious health defects).

Observations of collared and un-collared lions were compiled from 2012 to 2016 from all sources in the Park thereby maximizing our coverage in a given year. Sources included trained carnivore research personnel, vetted reports from tourism guides, other scientists, and Park rangers. Carnivore research personnel regularly collected detailed demographic (sex, age, survival/mortality), behavioral (mating, reproduction) and prey selection (species, age and sex) data. All prides and coalitions were remotely monitored and observed in the field at least monthly but more typically multiple times per month. As this study occurred during a period of high poaching pressure, signals from collared individuals were monitored daily to ensure no lion signal went "static" indicating mortality or being entrapped in a snare or steel-jaw trap. If a static signal was identified our rapid-response veterinary unit was deployed to rescue and treat the individual.

Monitoring occurred year-round with some exceptions during January–March or high rain periods when conditions severely limited our ability to operate from vehicles. A small area of the Park is accessible by road network, and clay soils and the network of river systems bisecting the Park make access highly challenging. High rain periods necessitated the use of aircraft in some cases and foot patrols where feasible to access and survey more remote prides and coalitions.

All lions sighted were documented and compared to an identification guide of lions compiled from high-magnification photography of each individual's unique whisker-spot patterns and other defining physical features such as scars and ear-notches. All lions were sexed and aged. Aging was achieved either by tracking individuals from birth, or by size estimation and nose coloration (Whitman and Packer, 2006) or estimation utilizing photos captured by tourist excursions from years prior.

To estimate density and carrying capacity for lions in 2014 and 2016, all lions visually detected and identified over the entire calendar year were tallied to establish a "minimum number of known alive," or MNKA (Previtali et al., 2009). The MNKA therefore represents a conservative estimate of the total number of individuals in our ISA pooled together from all sightings in a given year. Only confirmed individuals