Evaluating the prevalence and spatial distribution of giraffes injured by non-target poaching

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HK and RAM conceived the ideas; HK, GJR, RAM designed the field methods; HK collected and organized data and led the writing of the manuscript; DWL designed and fit the model to the data. All authors edited drafts of the manuscript and approve publication.

ABSTRACT

Illegal harvest (poaching) is a geographically widespread threat to animal populations. Wire snares are a common poaching technique used in the Global South and are indiscriminate with respect to species, age, and sex of individual animals that they capture. When caught, relatively large mammals frequently break free from the snares, suffering injuries in the process. The prevalence of snaring injuries as well as the ecological and conservation implications of such patterns, have not been widely investigated for many animal populations. We evaluated the prevalence and spatial distribution of giraffes (*Giraffa camelopardalis*) with snaring injuries in Murchison Falls National Park, Uganda, a system experiencing high rates of wire snare poaching. We conducted photographic spatial encounter surveys along five fixed road transects. We photographed detected giraffes, recorded whether a snaring injury was present, and identified individuals via autonomous image processing of pelage patterns. We fitted a spatial capture-recapture (SCR) model to the encounter history data to estimate abundance and predict the spatial distribution of injured giraffes. We detected 1,306 (sub) adult giraffes from the surveys and predicted 1,941 (±80) via the SCR model. We encountered 26 giraffes with snaring injuries, corresponding to a population-level snaring rate of 1.4%. Individuals with higher movement scales were more at risk of being snared. Though not fatal across the three-month duration of this study, the injuries likely lead to secondary infections, disability, and potentially death in the long term. We explore the implications of bearing snaring injuries for ecology, behavior, and conservation of affected species.

Keywords: *Giraffa camelopardalis,* Murchison Falls National Park, Poaching, Snaring injury, Spatial Capture-Recapture, Wire snare

INTRODUCTION

The illegal harvest of wild animals, commonly referred to as *poaching*, presents an important threat to the conservation of a broad range of species around the world (Madden, 2004; Konig *et al.,* 2020). In this regard, poaching is a proximate factor associated with population declines of approximately 27% of the world's 1,169 threatened species listed by the International Union for Conservation of Nature (IUCN) (Ripple *et al.*, 2016). Broadly, three forms of poaching have been identified including trophy (where animal parts are harvested as possessions), medicative (where animal parts are taken for curative uses), and consumptive (where animal parts are harvested for human sustenance; Montgomery, 2020).

Animals subjected to poaching pressure can experience both behavioral and ecological impacts that may scale from individuals to populations (Ripple *et al.,* 2014; Carter *et al.,* 2017). Some of the behavioral consequences of poaching for animal populations include destabilization of social organization, increased nocturnality, divergence of migration patterns, and changes in habitat selection (Wielgus & Bunnell, 1994; Wielgus *et al.*, 2001; Cappa *et al.,* 2017). Ecological effects include population declines with subsequent impacts on ecosystem function (Milner-Gulland *et al.,* 2003; Challender & MacMillan, 2014; Ripple *et al.,* 2016; Schlossberg, Chase, & Griffin, 2018; Loveridge *et al.*, 2020). Given that large animals are comparatively long-lived, wide-ranging, occur at low densities, and have age-dependent survival and reproduction rates, their populations are potentially at higher likelihood of being destabilized by poaching impacts (Creel & Creel, 2002; Eberhardt, 2002; Packer *et al.,* 2005).

Snares are the most common traps used to illegally harvest animals across the world because they are cheap to produce, easy to set in large numbers, and can capture a diversity of animals (Gray *et al.*, 2017; Mudumba *et al.,* 2020; Belecky & Gray, 2020). Larger-bodied animals, such as ungulates, are often targets for illegal harvest using wire snares (Fa & Brown, 2009). However, wire snares are largely indiscriminate with respect to species, age, and sex of animals that they capture (Noss, 1998; Gray *et al.*, 2018). With one end anchored to a tree, a wire snare trap consists of a noose of a wide diameter, placed at a height sufficient to capture the target animal (Gray *et al.*, 2018; Mudumba *et al.*, 2020). The noose tightens around limbs, neck, or torso when the animal is entangled in the trap.

Animals caught in snares may be harvested by the poachers or, if not recovered, decay or be consumed by predators or scavengers (Noss, 1998). When captured by the limbs, some animals can escape entrapment when they break the wire snare or get mutilated from rigorous fighting (Noss, 1998). However, the prevalence and spatial distribution of individual animals injured after breaking free from entrapment has not been investigated for many species. Consequently, the impacts of snaring injuries on the ecology and conservation of affected species are not widely known. Investigating the prevalence and spatial distribution of animals with snaring injuries would inform targeted rescue operations, veterinary interventions to treat injuries, and facilitate the optimization of snare removal efforts.

Here, we evaluated the prevalence and spatial distribution of Rothschild's giraffes (*G. c. rothschildi*) injured by non-target poaching in Murchison Falls National Park (MFNP), Uganda. We also examined how age- and sex-specific movement rates expose individual giraffes to snaring risks. Given that giraffe taxonomy is still widely contested (Brown *et al*., 2007; Hassanin *et al*., 2007; Groves & Grubb, 2011; Fennessy *et al.*, 2016; 2017; Bercovitch *et al.*, 2017; Bercovitch, 2020; Coimbra *et al.*, 2021), we used the one species/nine subspecies classification recommended by IUCN (Muller *et al*., 2018). Based on that taxonomic classification, giraffes are presently categorized as *vulnerable* while the Rothschild's subspecies is categorized as *Near*

Threatened on the IUCN Red List of Threatened Species (Muller *et al.,* 2018; Fennessy *et al.,* 2018). As such, poaching has been identified as an important threat to giraffe conservation (Strauss *et al.,* 2015; Ripple *et al.,* 2015; Fennessy *et al.,* 2018; Dunn *et al*., 2021). We discuss the implications of bearing snaring injuries for the conservation of giraffes and other large mammals affected by wire snare poaching.

METHODS

Study area

We conducted our study in the northern section of MFNP (Fig. 1) associated with the core distribution of giraffes in this landscape (Brown *et al*., 2019). Located in northwestern Uganda, MFNP is the largest protected area in the country covering a land area of ~3898 km^2 (Kasozi *et al*., 2021). The park is divided into northern (~1680 km^2) and southern sections (~2218 km^2) by the Victoria Nile River which flows 115 km from east to west. The Victoria Nile restricts giraffe movements to the south of the park (Fig. 1). Similarly, the Albert Nile River restricts giraffe movements beyond the western edge of the park (Fig. 1). Vegetation of the northern section of MFNP comprises open grasslands, dense woodlands, and thickets. The park has a hot and dry tropical climate characterized by two distinct weather seasons. The wet season lasts from April to May and then again from August to October while the dry season occurs from December to February and June to September (Mudumba *et al*., 2020; Kasozi *et al*., 2021).

Poaching in MFNP

Murchison Falls National Park experienced high levels of poaching as a byproduct of political instability in the 1970s and 80s, during which animal populations were heavily decimated (Douglas-Hamilton *et al.,* 1980; Lamprey & Michelmore, 1996). Poaching remains at high levels to date, with poachers from adjacent villages commonly accessing MFNP via the Albert Nile and Victoria Nile waterways and on land (Mudumba *et al.*, 2020; Fig. 1). Although the primary targets of poachers are typically antelopes (such as Uganda kob (*Kobus kob*), hartebeest (*Alcelaphus buselaphus*), oribi (*Ourebia ourebi*)), and buffalo (*Syncerus caffer*), non-target species such as giraffes (*Giraffa camelopardalis*) and elephants (*Loxodonta africana*) are also often entrapped.

We suggest that subsistence poachers using wire snares are not targeting giraffes based on three lines of reasoning. First, poachers typically set snare traps to capture target animal species around the neck (Noss, 1998; Gray *et al.*, 2017). Research in MFNP has showed that wire snares are placed with the lower end at an average height of 0.42 m (range 0.00 m – 0.96 m) from the ground (Mudumba *et al.*, 2020). Within this height range, snare traps are optimized to facilitate entrapment of target species (with shoulder heights ~1 m; Kingdon & Hoffmann, 2013) around the neck. In contrast, giraffes have a higher shoulder height (i.e., > 4 m; Kingdon & Hoffmann, 2013). At snare trap heights of < 1 m, giraffes are essentially only trapped around the legs, where they often break free with injuries. Consistent with general protocol, poachers would place snares higher in the trees to trap giraffes around their necks if they were targets (Strauss *et al.*, 2015). Second, within the human communities living adjacent to MFNP, there is no evidence of local consumption of giraffe meat (Mudumba, 2019). Third, there is no evidence of the use of giraffe body parts in cultural practices in Uganda, as is the case in other areas in Africa (Dunn *et* *al.*, 2021). Additionally, there is currently no evidence for giraffe parts sourced from Uganda for international trade (Harrison *et al.*, 2015).

Giraffe surveys

We conducted photographic spatial encounter surveys along five fixed routes between July and August 2019 (Fig. 1). The five transects averaged 73.1 km (SD 3.3) in length and covered all representative giraffe habitats in MFNP. We surveyed each transect 10 times to accumulate capture histories of giraffes among replicate surveys. We randomized start day and direction travelled per transect for each replicate survey, and allowed an interval of at least three days for sampling the same route. With two observers positioned in the vehicle, we scanned both sides of each road transect within 200 m while driving at a consistent speed of 20 km/hr. Given the low speed, large body size of giraffes, and open vegetation characteristic of this landscape, we easily detected giraffes within the 200 m of the transects (*sensu* Muneza *et al.,* 2017). When we encountered giraffe(s), we drove off-road within 200 m to photograph all detected individuals. We obtained georeferenced digital images of the right side of each detected giraffe. We also recorded age (calf (<1 year), sub-adult (1-3 years), or adult (≥4 years)), sex, group size, and presence and location of snaring injuries (Fig. 2) for each detected giraffe. The snaring injuries manifested as open wounds (resulting from deep cuts into the flesh, broken bones, and amputated legs) often coupled with inflammation around the affected area (Fig. 2). We sexed and separated age classes among individuals based on physical characteristics including ossicone size, genitalia, and height (Lee & Strauss, 2016). Adult bulls have two or three prominent ossicones, whereas adult females have smaller ossicones. The ossicones of calves and sub-adults for both sexes are covered with thicker tufts of hair when compared to adults (Ciofolo & Pendu, 2013). Additionally, giraffe bulls are typically larger and taller than females.

We obtained each image at a right angle to the animal, following requirements for post-survey processing. We cropped all images to retain the extent of the giraffe's pelage pattern and uploaded them to the computer program Wild-ID for visual pattern matching (Bolger *et al.,* 2012). We then converted the photographic records into individual spatial encounter histories across the ten replicate surveys for spatial capture-recapture modelling.

Spatial capture-recapture modelling

We estimated spatial configuration of giraffes with snaring injuries using spatial capture-recapture (SCR) modelling for search-encounter designs (Efford, 2011; Royle, Kery, & Guelat, 2011; Royle *et al.,* 2014). In the SCR framework, a spatial point process model of abundance and a spatial model of the detection process (observation model) are simultaneously fitted to individual encounter history data (Royle *et al.*, 2014). For the abundance model, we derived estimates from a distribution of individual activity centers, $\mathbf{s}_i$, within the state space, S. We defined S as a ~1683 km^2 area where giraffes were detected, bounded by the park boundary to the north and east, Victoria Nile to the south, and Albert Nile to the west (Fig. 1). We assumed activity centers to be uniformly distributed within S, $\mathbf{s}_i \sim$ Uniform [S]. Given that the areas of open water (i.e., the Albert- and Victoria Nile Rivers, see Fig. 1), as well as human settlements and agricultural lands across the park boundary are not utilized by giraffes, we expected zero probability of giraffe occurrence beyond S and created no buffer zone. We divided S into discrete

1-km x 1-km grid cells and delineated the intersection between the grid cells and transects as traps where individuals were detected (cf. Muneza *et al.*, 2017).

The observation model involved estimating the Binomial probability ($p[\mathbf{x}, \mathbf{s}]$) of detecting an individual across all surveys as a function of individual attributes, including the distance d_{ij} between a grid cell (i.e., trap), $\mathbf{x}_j$, and the individual's latent activity center, $\mathbf{s}_i$. We defined the detection probability using the half-normal distance detection function:

$$p_{ij}[\mathbf{x}_j, \mathbf{s}_i] = p_{0i} \times \exp(-d_{ij}^2/2\sigma_i^2)$$

where p_{0i} is the baseline probability of detecting an individual at its activity center (i.e. $\mathbf{x}_j = \mathbf{s}_i$); and σ_i (the movement scale parameter) controls the rate of decline in individual detectability as the distance between $\mathbf{x}_j$ and $\mathbf{s}_i$ increases. We allowed both p_{0i} and σ_i to vary according to individual attributes including 1) sex, with female as the reference category; 2) age class, with adult as the reference category vs. sub-adults; 3) an interaction of sex × age class; and 4) the presence/absence of a snaring injury. We estimated these relationships by specifying log-linear models for each parameter, $p_{0i} = 1–\exp(–\exp(\mathbf{X}_i\boldsymbol{\alpha})$ and $\sigma_i = \exp(\mathbf{X}_i\boldsymbol{\delta})$, where $\mathbf{X}_i$ is the design matrix of binary individual attributes and the parameters to estimate are $\boldsymbol{\alpha}$ and $\boldsymbol{\delta}$**.** Note that we chose to model p_{0i} with a complimentary log-log link but could have also used a logit link. The data likelihood was then defined as $y_{ij} \sim \text{Binomial}(K_j, p_{ij}[\mathbf{x}_j, \mathbf{s}_i]z_i)$ where K_j are the number of surveys that overlapped grid cell j, and z_i is an indicator of population membership (*see below*). We eliminated calves from the analysis as their encounters depend on the location of their mothers (*sensu* Muneza *et al.*, 2017), thus violating the assumption of independence among individual detections (Royle *et al.*, 2014).

Following standard SCR models, we estimated abundance (N) as the number of $\mathbf{s}$ within S. To estimate N, we augmented our dataset of n observed individuals with a large number of individuals (M – *n*) having all-zero encounter histories and modeled the augmented dataset as a zero-inflated version of the complete-data model using a zero-inflation parameter (Royle, Dorazio, & Link, 2007). We set M as the super population from which *N* is drawn (i.e., M > *N*), where some of the all-zero encounter histories do not correspond to actual individuals within *N* (Royle *et al.,* 2007, 2011). We assigned each individual in the augmented dataset a partially latent population membership indicator z_i , where $z_i = 1$ corresponded to true members of the population and $z_i = 0$ otherwise. Accordingly, $z_i = 1$ was known for all *n* observed individuals and unknown (z_i = NA) for the M–*n* individuals. We treated demographic attributes (sex, age, presence of snaring injury) as partially latent variables that were known for most observed individuals and unknown for the M–*n* unobserved individuals. The binary individual attributes were considered Bernoulli random variables with a corresponding probability, including that for population membership (ψ) and the other attributes (ψ_{male}, ψ_{subadult}, ψ_{snare}). We derived *N* from $\psi \times$ M and density, D, from dividing *N* by the area of *S*.

We fit the SCR model using a Bayesian framework and Markov Chain Monte Carlo simulations in NIMBLE (de Valpine et al. 2017, 2022) as implemented in R (R Core Team, 2022). We used the nimbleSCR package (Bischoff et al. 2021) to implement efficient SCR estimation (Turek et al. 2021); model code is provided in Appendix S1. We ran three chains of 10,000 iterations each, following a burn-in of 1,000. We used vague priors for all parameters: Uniform (–10, 10) for log-scale intercepts, Normal (0, $\sigma^2 = 10$) for regression coefficients, and Uniform (0, 1) for probabilities. We checked for model convergence using traceplots and R-hat statistics (Gelman & Hill, 2007).

We assessed goodness-of-fit using a Freeman-Tukey statistic (T_1, Royle et al. 2014) where the discrepancy (i.e., sum of residuals) between observed and expected number of trapspecific individual captures was calculated for each iteration and compared to a corresponding simulated dataset. We calculated a lack-of-fit ratio (Molinari-Jobin et al. 2018) as the ratio between observed and simulated fit statistics, where a value of 1 represents perfect fit and larger values can indicate the amount by which uncertainty may be underestimated due to lack of fit.

RESULTS

We generated spatial encounter histories of 1,402 individual giraffes from 5,444 cropped images. Among the 1,402 individuals, there were 729 females and 671 males. We could not identify sex for 2 calves. Additionally, most giraffes in this population were adults (64.0%, *n* = 897), followed by sub-adults (29%, *n* = 409), and then calves (7%, *n* = 96). We encountered 26 individuals with a snaring injury (Fig. 2), including one male calf, eight sub-adult males, 13 adult males, two adult females, and two sub-adult females. All snaring injuries observed were positioned on lower section of the giraffe legs, including metacarpal and phalanx (Fig. 2). Additionally, only one leg was injured for each individual. Majority of the snaring injuries across all individuals were on hind legs (92%, *n* = 24), and the rest on front legs (8%, *n* = 2). Among the females, the injuries were located on the left hind leg (50%, *n* = 2) and right hind leg (50%, *n* = 2). A slight majority of snaring injuries among the males were positioned on right hind leg (50%, *n* = 11), and the rest on left hind leg (41%, *n* = 9) and right front leg (9%, n = 2).

The SCR model estimated a mean adult/sub-adult giraffe population (*N*) of 1,939 individuals (95% CI: 1864, 2023), and a density estimate (D) of 1.152 (95% CI: 1.108, 1.202) individuals/km^2 (Table 1). The estimated giraffe population had a lower proportion of males (ψ_{males} = 0.446 [95% CI: 0.417, 0.476]) compared to females, and sub-adults (ψ_{subadult} = 0.349

[95% CI: 0.320, 0.379]) compared to adults. Neither giraffe sex nor age had strong effects on baseline encounter rates (Fig. 3), though there was some evidence for adult males having higher movement scales ($\delta_1 = 0.075$ [0.000, 0.151]) than adult females, and sub-adults having lower movement scales than adults ($\delta_2 = –0.148$ [–0.252, –0.042]) for both sexes. A relatively low proportion of individuals in this giraffe population had a snaring injury ($\psi_{snare} = 0.014$ [95% CI: 0.009, 0.020]; Table 1). Individuals with snaring injuries had higher baseline encounter rates ($\alpha_4 = 0.470$ [0.112, 0.799]) and movement scales ($\delta_4 = 0.187$ [0.012, 0.381]; Table 1; Fig. 3). Spatial predictions of realized density from our model identified a higher prevalence of individuals with a snaring injury on the western side of the park (Fig. 4), corresponding to areas of high giraffe density between the Albert and Victoria Nile Rivers (Fig. 4). Our diagnostics indicated model convergence with Rhat values <1.1 (Table S1) and traceplots appearing reasonable (Fig. S1). Goodness-of-fit suggested some overdispersion (Fig. S2), with a Bayesian p-value of 0 and a lack-of-fit ratio of 1.14. We caution that this small lack of fit could underestimate posterior standard deviations by ~7% (Molinari-Jobin et al. 2018) and is potentially due to unexplained individual heterogeneity in the probability of encounter.

DISCUSSION

Recent assessments suggest that poaching is a critical threat for Rothschild's giraffe conservation (Fennessy *et al.*, 2018). We observed a small proportion (~1.4%) of the MFNP giraffe population (~1,941 individuals) with snaring injuries, suggesting relatively low rates of incidental poaching. All of the snaring injuries that we observed affected giraffe legs, with majority of individuals snared being adult and sub-adult males (*n* = 21 of 26). These injuries are hobbling and could have negative consequences for life history strategies such as mating and foraging. The density of giraffes varied spatially across the landscape, with majority of the snared individuals concentrated on the western end of the park associated with the Nile River waterways (Fig. 1, 4).

Species targeted by poachers in MFNP are more abundant than giraffes (i.e., Uganda kob (~118,000 individuals), buffalo (*Syncerus caffer*; ~ 15,000 individuals), and hartebeest (~10,000 individuals) (Lamprey *et al.*, 2020). Thus, it is possible that target species have relatively higher rates of getting entangled in the snares. This suggestion could partly explain the relatively low rates by which giraffes are entangled in wire snares in MFNP. However, there is presently no comparative study quantifying relative proportions of species caught in snares or poaching mediated mortality rates across space and time in MFNP. Unregulated illegal hunting has been documented as a leading cause of defaunation in South Eastern Asia, some parts of Africa, and South America (Ripple *et al.*, 2016; Gray *et al.*, 2018; Figel *et al.*, 2021). Thus, studies assessing population-level effects of wire snare poaching among species most susceptible to snare entrapment in MFNP are a critical need. This is necessary to assess community-wide poaching effects and to design effective conservation and adaptive management programs, given the threats posed by unregulated illegal hunting to wildlife (Ripple *et al.*, 2016). Considerably low rates of giraffe poaching have been reported in other landscapes (such as Serengeti where 430 cases were reported from 1997 to 2010, within a population of ~3,500), despite high snare densities (Strauss *et al.*, 2015). Given that a smaller proportion of injured giraffes we detected are females (*n* = 3), the negative impacts of wire snare poaching on recruitment and population growth of MFNP giraffe might be minimal (Suraud *et al.,* 2012; Lee *et al.,* 2016). This is because female survival is considered the most influential demographic rate in giraffe population growth (Strauss *et al.*, 2015; Lee *et al.*, 2016).

The idea that impacts of wire snare poaching on giraffe population growth are likely to be minimal could be supported by the increasing MFNP population trends suggested by recent studies (Fennessy *et al.*, 2018; Brown, 2019; Brown *et al.*, 2019, 2021) and our model estimates. Our SCR model estimates a slightly higher adult/sub-adult population of ~1,939 individuals compared to previous estimates of ~1,318 – 1,692 individuals (Brown *et al.*, 2019, 2021). Overall, these estimates are indicative of increasing population trends from early estimates of 70 – 200 giraffes between the 1970's and 1990's (Olivier, 1991; Sommerlatte & Williamson, 1995; Lamprey & Michelmore, 1996; Rwetsiba, 2006; Rwetsiba *et al*., 2012). While we encountered low incidences of giraffe snare entrapment and signs of snare-related injury relative to the population, the spatial distribution of injured survivors we estimated (Fig. 4) highlights areas of intense snaring pressure within MFNP (Mudumba *et al.*, 2020). In this case, the spatial distribution of survivors could be more useful for management than the overall low rate of giraffe poaching, as giraffes with detectable injuries might act as indicators for areas of intense poaching. Any positive results of targeted management effort directed toward de-snaring would spread across other affected species.

All snaring injuries that we detected were positioned on the legs of affected giraffes (Fig. 2). This was expected because snares are anchored to trees at the approximate height of target animals (Mudumba *et al.*, 2020), species that are considerably smaller than giraffes. In Serengeti National Park, Tanzania, giraffes are targeted by poachers, with snares set higher in trees to trap giraffes around the neck (Strauss *et al.*, 2015). The natural reaction of any ensnared animal is to fight the restraint. As they fight, the snare wire cuts into the skin, flesh and eventually bone, causing fractures in extreme cases (Fig. 2). Tightening wires against tissue during fighting can lead to restricted blood supply to legs (i.e., ischaemia), with eventual death of affected tissues (i.e., necrosis; Kalogeris *et al.*, 2012). Acute limb ischaemia and extensive tissue necrosis cause severe pain (Simon *et al.*, 2018) and expose the tissue to secondary bacteria or parasitic infections by dipterous fly larvae/maggots (i.e., myiasis; Francesconi & Lupi, 2012). Exertional myopathy is also possible when animals experience degenerative or necrotizing muscle damage as they struggle vigorously to escape the snare entrapment (Williams & Thorne, 1996; Cattet, Gordon, & Trent, 2008). We also observed oxpeckers (Red-billed; *Buphagus erythrorhynchus* and Yellow-billed; *Buphagus africanus*) poking into giraffe wounds to feed on maggots, flies, dead skin, and dried blood (Diplock *et al.*, 2018). This has been suggested to prolong wound healing in large terrestrial herbivorous mammals (Weeks, 2000). Given that giraffes are tolerant of the typically symbiotic oxpeckers, which constantly feed on their open wounds (Diplock *et al.*, 2018), the likelihood of wound healing is minimal even with medical intervention (Weeks, 2000). Thus, giraffes might die prematurely from the snaring injury or associated secondary infections. Before death however, these snaring injuries have important implications for giraffe welfare, behavior, and ecology.

Giraffes routinely move in pursuit of their life history requirements (Berry, 1973; 1978; Brown & Bolger, 2020). We found that males had higher movement scales than females (Table 1), which may suggest that males are more likely to encounter wire snares. This corroborates our observation that adult males (*n* = 13) and sub-adult males (*n* = 8) were caught more often by wire snares. This observation is consistent with existing studies demonstrating that male giraffes had comparatively higher movement scales than females (Fennessy, 2009; Bercovitch & Berry, 2013; Strauss, 2014; Muneza *et al.*, 2017; Brown & Bolger, 2020). The fact that males move more than females likely relates to establishing dominance and seeking mates among several groups within the landscape (Berry, 1973; 1978; Dagg, 2014). Female giraffes adopt more philopatric lifestyles to protect calves within matrilineal-based groups (VanderWaal *et al.*, 2014). We therefore infer that lower movement scales might reduce the risk of encountering wire snares. There is a possibility that our observation of fewer females ($n = 4$) with snaring injuries could relate to lower movement scales than males, or from sex differences in mortality prior to detection. The higher baseline encounter rates and movement scales for snared individuals (Fig. 3) is difficult to interpret given that the direction of causality cannot be determined. Additional studies would be needed to investigate these relationships. Such patterns where males are being either targeted or at higher risk of being caught by snares are common among sexually dimorphic mammal species (Holmern *et al.*, 2006; Strauss *et al.*, 2015). Male-biased impacts of human disturbances (including poaching) can lead to female-biased sex ratios and selective loss of secondary sex characteristics of affected individuals within several large mammal populations (Setsaas *et al.,* 2007; Ndibalema, 2009; Marealle *et al.*, 2010).

We detected a clear spatial pattern in the configuration of giraffes with snaring injuries at the population-level. Specifically, we found the highest prevalence of giraffes with snaring injuries in the western end of MFNP, in the delta associated with the confluence of the Albert and Victoria Nile Rivers (Fig. 4). Correspondingly, this area had the highest overall realized giraffe density (Fig. 4). Recent evidence demonstrates that this area of MFNP is a snaring hotspot, with a density of ~5 snares/km^2 (Mudumba *et al.*, 2020). Given that this area provides the main water source within the landscape, it attracts a host of animals including antelopes, the primary target of subsistence poachers. Therefore, it is likely that poachers set more snares in this section of the park to maximize their yield (Mudumba *et al.*, 2020). The waterways are also a primary pathway of poachers into MFNP (Fig. 1). Given the high giraffe density adjacent to the River, a higher proportion of the population is exposed to the risk of incidental poaching. We conducted our photographic spatial encounter surveys during the dry season, and therefore did not include the effect of season in our analyses. Thereby, our predictions of spatial variation of injured giraffes in MFNP reflect dry season dynamics (sensu Muneza *et al.,* 2017). It is unclear whether these patterns should be expected to exhibit seasonal variation. Additional research across other seasons could help to answer that question.

CONCLUSION

Our study presents an application of SCR modelling to estimating the prevalence and spatial distribution of giraffes injured by non-target poaching. These SCR techniques could be similarly deployed across other individually recognizable species for which poaching is a threat. Although a low proportion of the giraffe population was observed with a snaring injury, impacts of living with a snaring injury are broad and may have direct implications for individual functional ecological processes such as mating and foraging (Gray *et al.,* 2017). Examining the individual-level consequences of snaring injuries among affected giraffes was beyond the scope of our study but would provide useful information related to ecological and behavioral modifications resulting from living with snaring injuries. The individual-level consequences of snaring injuries could potentially scale to the population level when a large proportion of individuals are affected. An escalation in the number of affected individuals is likely given the very high rates and density of snare placement in MFNP (Mudumba *et al.,* 2020). For example, since our surveys in 2019, ~200 giraffes are reported to have been rescued from snare entrapment between 2019 and 2021 (GCF, 2021). Timely rescue of snared animals is critical for survival, often with lifelong disability in cases of severe injury. An important area of future inquiry is the examination of both the short- and long term physiological, morphological, and ecological effects of snaring injuries and resultant disability among giraffes and other large mammals that suffer similar fates from wire snare poaching.

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TABLES

Table 1: Parameter estimates (Median and 95% credible interval) from the spatial capture-recapture model fitted to giraffe photographic spatial encounter survey data collected between June and August 2019 in Murchison Falls National Park, Uganda. The parameters represent: probabilities for individual attributes such as population membership (ψ), sex (ψ_{male}), age class ($\psi_{subadult}$), presence of snaring injury (ψ_{snare}); log-linear regression coefficients for the encounter rate (α) and the scale parameter of the half-normal detection function (δ) and derived parameters of population size (N) and density (D).

Parameter	Effect	Median	95% CI
ψ		0.841	(0.805, 0.880)
ψ_{male}		0.446	(0.417, 0.476)
$\psi_{subadult}$		0.349	(0.320, 0.379)
ψ_{snare}		0.014	(0.009, 0.020)
α_0		–5.249	(–5.366, –5.133)
α_1	Male	0.077	(–0.079, 0.233)
α_2	Subadult	–0.045	(–0.277, 0.177)
α_3	Male x subadult	–0.258	(–0.565, 0.047)
α_4	Snare injury	0.471	(0.118, 0.804)
δ_0		1.506	(1.453, 1.561)
δ_1	Male	0.075	(0.000, 0.151)
δ_2	Subadult	–0.148	(–0.252, –0.042)
δ_3	Male x subadult	0.142	(–0.004, 0.287)
δ_4	Snare injury	0.186	(0.011, 0.376)
N		1939	(1864, 2023)
D		1.152	(1.108, 1.202)

FIGURE CAPTIONS

Figure 1. The five road transects used to conduct photographic spatial encounter surveys of Rothschild's giraffes (*Giraffa camelopardalis rothschildi*) in the northern section of Murchison Falls National Park (MFNP), Uganda between June and August 2019. The inset features the location of MFNP in Uganda.

Figure 2. Injuries sustained by giraffes (*Giraffa camelopardalis rothschildi*) as they fight to break free from entrapment by wire snares in Murchison Falls National Park, Uganda.

Figure 3. Expected probability of encounter for an individual across $K = 10$ surveys as a declining function of distance from activity center and differences related to individual attributes.

Figure 4. The posterior predictive map of the realized density and prevalence of giraffes (*Giraffa camelopardalis rothschildi*) with snaring injuries in Murchison Falls National Park, Uganda as inferred from a spatial capture-recapture model fit to detection history data deriving from photographic spatial encounter surveys conducted between June and August 2019. The grid cell resolution of this prediction was 1 km^2.