communications biology

Comment

https://doi.org/10.1038/s42003-024-06796-0

Rangers on the frontline of wildlife monitoring: a case study on African lions in Uganda's Nile Delta

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Regular population monitoring of imperilled charismatic species such as large carnivores is critical for conservation. However, the role of monitoring in conservation is frequently diminished due to: 1) surveys being implemented in isolation, 2) limited on-ground-capacity leading to infrequent monitoring, and 3) inappropriate methods being applied. Wildlife monitoring is often resource-intensive and the utility and cost of different field protocols is rarely reported. In this study we deployed two standard field protocols aimed at collecting data on African lions within a spatial capture-recapture framework. For our first protocol, we trained Uganda Wildlife Authority rangers in search-encounter techniques, the industry gold standard for monitoring lions. The second protocol involved deploying 32 paired stations of state-of-the-art infra-red camera traps. During the search-encounter protocol, two rangers covered 2939 km in 76 days, recording 102 detections (30 individuals) in a ~ 256 km^2 area. The resulting density estimates (13.91 lions/100 km2, posterior SD = 2.34) yielded acceptable precision. Conversely, 64 camera traps over 1601 trap nights yielded two usable lion detections. We argue that where wildlife tourism rangers exist, they could be a powerful addition to future lion and wildlife census attempts across the continent. Our results confirm that the current technology of store-bought infra-red camera traps is not suitable for individual identification of lions, and therefore cannot be applied to analytical models that require unambiguous individual identities. However, we encourage the continued testing and advancement of infra-red camera trap technology since in many instances, this may be preferable to white-flash camera traps, which can yield individual identities for lions. Our study also shows the immense importance of the Nile Delta for African lions in Uganda's Murchison Falls National Park, a protected area with both oil extraction and high rates of anthropogenic snaring pressure.

Population data for some of Earth's most economically critical and threatened species remains tenuous at best and plagues both small species (e.g. butterflies and moths[1]) and large species (e.g. Javan rhinos[2]) alike. It is often the result of unreliable methods being used[3] and for species with large ranging patterns, significant resources are needed to monitor them (eg. large numbers of trail cameras, or intense effort using vehicles or aircraft[4]). This resource expenditure can prohibit regular and robust monitoring, diminishing its role in conservation. Deployment of monitoring programs that include people and organisations with intimate knowledge of local sites and species biology may help address this problem and facilitate regular monitoring and develop on-site capacity. This inclusion of local stakeholders may also improve the integration of monitoring and conservation[5].

In an African context, no species better exemplifies this problem than the African lion (*Panthera leo*). Lions are a charismatic and imperilled species, which play a significant role in consumptive and non-consumptive industries. As such, there is intense interest in their population numbers from a wide variety of stakeholders. However, methods used to monitor lions across Africa have historically been inconsistent and imprecise[3,6]. This is because estimating lion numbers across the large spatial scales at which they exist is notoriously difficult. One solution is to regularly deploy multi-agency teams of local stakeholders for intensive surveys using rigorous methods within smaller areas[3]. In this manner, monitoring is not a stand-along activity, but rather a component of conservation decision-making, improving its utility in adaptive management[7].

Wildlife rangers represent one such group of stakeholders. Some ~286,000 rangers exist globally, representing the backbone of field personnel in protected areas[8,9]. Not only do rangers live and work in the sites where estimates are generated, but they often have a deep and intimate knowledge of these areas and the study species of interest[10,11]. Furthermore, because they work for governments, their involvement may generate support for the outcomes of monitoring. Because rangers frequently have ecological training, they represent a valuable stakeholder group for participation in wildlife monitoring, especially where governments seek to install long term monitoring programs. Indeed, monitoring programs that are collaborative in nature tend to build capacity, share the resource load amongst conservation stakeholders, increase spatial coverage and are often integrated into local and national conservation plans[12–15]. In this study we sought to examine the efficacy and cost of conducting a survey where the data is generated by government tourism rangers and compare this to the utility of infra-red camera traps (a widely used big cat census technology) for obtaining individual identities of lions. In both instances, our study was motivated by the desire to apply the current state of the art methods for abundance estimation (spatial capture-recapture), which require unambiguous and correctly assigned individual identities. A previous study designed to collect such data on lions made use of white flash cameras and suggested that infra-red camera traps were likely to be unsuitable for obtaining individual identities[16]. However, this was not quantified and warrants further investigation since infra-red cameras are often preferable as they are less likely to get stolen due to the fact that they emit much less light when compared to white flash cameras. To provide recommendations and usable information for future surveys, we quantified the cost of both the camera trap survey, and the one conducted by tourism rangers.

Results

Ranger-derived African lion densities in the Nile Delta. The search encounter survey ran from 6 April 2022 - 19 June (with sampling occurring on 60/75 days). Rangers recorded a total search effort of 2939 km in the 255 km^2 area of the Nile Delta during this time (Fig. 1). They detected 30 individual lions 102 times (21 females and nine males). Of the four models we ran, a model which assumed that the spatial scale parameter and the basal encounter rate are independent of sex appeared most parsimonious (Table 1). This model produced a density estimate of 13.91 lions/100 km^2 (posterior SD = 2.34, CV = 23.6).

Detection rates from camera traps. The camera trap survey ran from 23 April 2022–20 June 2022 (59 days). The 32-location camera array recorded a total of 1601 trap nights (camera night failures=287). Lions were photographed 56 times across 16 locations. Fourteen of these photographs were male lions, 35 were females, and for seven photographs we could not ascribe sex to the individual. Only two images were of sufficient quality to discern whisker spot pattern, and only from one side. In a further seven photographs we could see some distinct feature (e.g. some scars, and three were wearing a collar), but we did not consider these to be valid for individual identification. Therefore when generating costs, we only consider the two whisker spot identities. Since these data were insufficient to derive density estimates, we quantify the cost per lion detection instead of drawing comparisons more formally using measures such as root-mean-square-error or CV from estimated densities.

Cost comparisons: rangers vs camera traps. Due to similar duration and temporal overlap of our two surveys, we provide a basic cost comparison. The costs of funding two wildlife tourism rangers for the duration

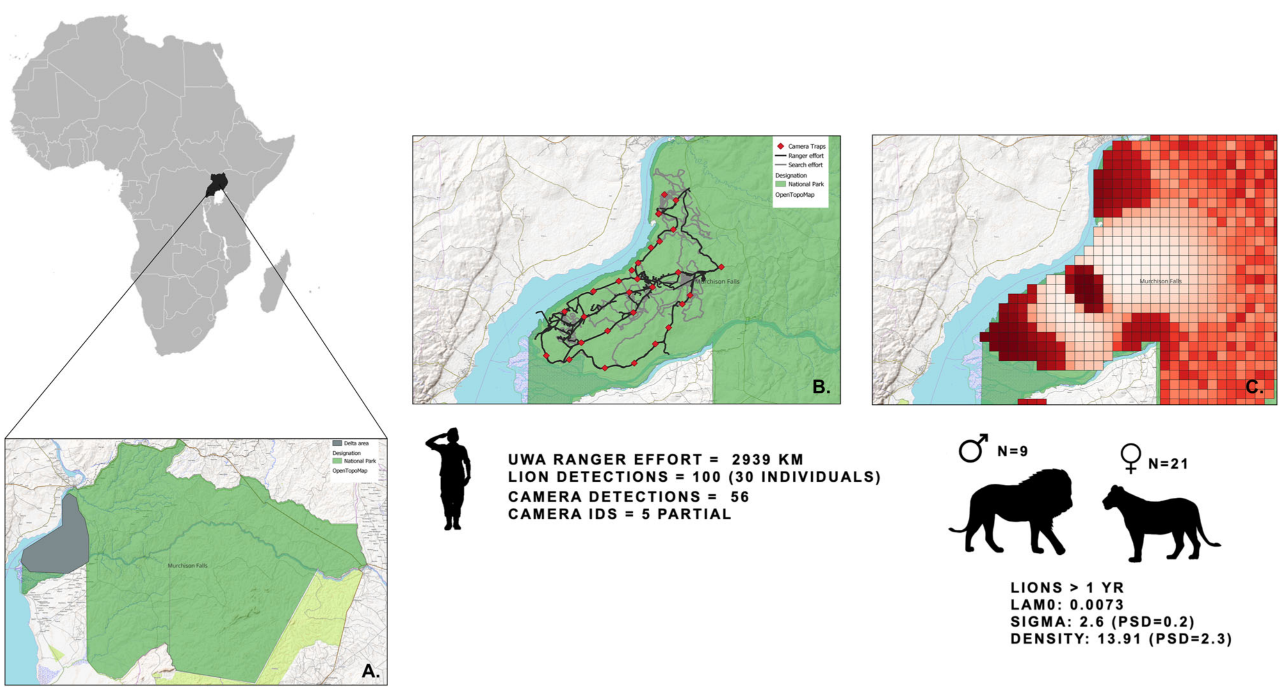

Fig. 1 | The location of the Murchison Falls National Park, Uganda along with the camera trap and search encounter trails recorded during our lion surveys. A shows the location of the Murchison Falls National Park in northern Uganda. **B** shows the ranger search effort with nested camera trap locations in the same study area. **C** shows the pixel specific lion densities across the Nile Delta region of the park. Sex-specific sample sizes of individual African lions are also provided.

Table 1 | Model parameters and results for the lion density survey conducted between April 6th–June 19th (75 days) by UWA rangers in the Nile Delta tourism region of Murchison Falls National Park

Rangers Delta	M1		M2		M3		M4	
scrBayes								
Data summaries								
Area	255							
Search effort	2939							
Indivs	30							
Detections	102							
MODEL SETUP								
Buffer	15							
OP pixel size	1							
SP pixel size	1							
Iterations	11000							
M	1000							
Msex=	1		0		0		1	
Msexsigma=	1		1		0		0	
Call-in	NULL		NULL		NULL		NULL	
Diagnostics								
Convergence (Max GR)	1.05		1.02		1.01		1.03	
Bayes P-value	0.94		0.83		0.70		0.88	
Marginal likelihood	−73660.23		−58017.12		−49446.71		−42514.04	
Estimates	EST	PSD	EST	PSD	EST	PSD	EST	PSD
sigma	2.74	0.27	2.72	0.25	2.66	0.23	2.53	0.21
sigma2	1.51	0.24	1.78	0.39	2.66	0.23	2.53	0.21
lam0	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00
beta1.effort.	0.78	0.13	0.79	0.13	0.79	0.13	0.78	0.13
beta.sex	−2.11	0.49	NA	NA	NA	NA	−1.77	1.21
psi	0.74	0.17	0.17	0.05	0.13	0.02	0.40	0.29
psi.sex	0.86	0.06	0.36	0.13	NA	NA	0.57	0.27
Nsuper	741.95	174.82	169.30	44.92	129.80	21.85	396.58	286.63
D.adj	79.52	18.74	18.15	4.81	13.91	2.34	42.51	30.72

M1 and M4 were rejected since the Bayesian p-value was outside the extremities (0.15 and 0.85) (Royle et al. [38]). M2 displayed significant parameter redundancy, and so M3 was chosen for reporting.

of the survey were 50% cheaper than maintaining a 32-location camera trap array (ranger cost=USD1,633.66 vs camera array cost=USD3,259.77) and the majority of this was owed to the purchase cost of 64 trail cameras (Fig. 2).

Outlook

Wildlife tourism rangers achieve reliable lion density estimates. Our results highlight the benefits of collaborating with local stakeholders (rangers) working in tandem with the tourism sector, to execute scientifically sound lion population surveys. The data collected by wildlife tourism rangers generated density estimates with acceptable levels of precision (CV = 23.6), which could likely be improved by adding more days to the sampling effort. These high lion densities highlight the importance of the Nile Delta as a critical lion population of conservation concern in Uganda. Contrastingly, cameras did not provide images of sufficient quality to identify a decent sample of lions from which to derive SCR estimates. Even if all the camera trap photos of lions were identifiable to individual level, the search encounter survey still yielded almost double the number of detections (56 detections from camera traps, versus 100 from search encounter).

This study adds to the wealth of literature highlighting the power of involving members of the wildlife economy with an intimate knowledge of the target species ecology and behavior[11,17–19]. We illustrate how wildlife tourism rangers can collaborate with a scientific team to achieve robust estimates of a charismatic wildlife species. Such exercises offer wildlife tourism rangers the opportunity to engage with the scientific community and be a part of conservation management decisions, increase their recognition in the wildlife authority, and provide promotion opportunities all of which may improve ranger motivation and satisfaction[20], and thus foster sustainable monitoring programs.

The limitations of using infrared traps to survey African lions. Our experiment to detect and identify African lions using infrared camera traps

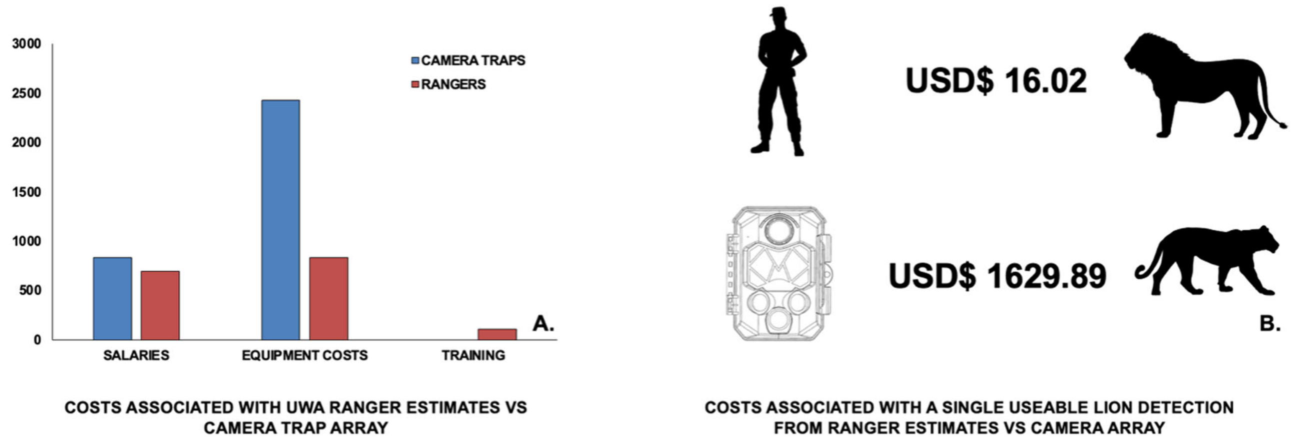

Fig. 2 | Comparisons between UWA wildlife tourism rangers and the 32-location camera trap array nested within the same study area. A illustrates costs associated with salaries, equipment, and training tied to each method (ranger search encounter survey vs camera traps). Rangers cost USD3259.77 to run during the 1603 trap night period. The main costs from the ranger-based estimate was salary top ups (an agreed amount additionally paid to rangers on top of their usual government salary) of USD832.18 (2xNikon Coolpix P90 purchased in Kampala, and 2xsecondhand iPhone 8 smart phones), and training of rangers USD832.17 for the salary of one field assistant to maintain camera traps, and USD227.60 for diesel associated with checking camera traps seven times. **B** shows the costs associated with a single usable lion detection for capture recapture-based analyses from ranger estimates and also for camera traps. We did not incorporate vehicle maintenance costs in our calculations due to (1) short duration of our study and (2) the rangers' use of publicly owned tourism operator safari vehicles, the cost of which was borne by the operator. Full cost calculation details are provided in Appendix 4.

had little success. Although we were able to generate the photographic rates that are consistent with other camera trap-based capture-recapture surveys (eg. tiger, leopard), we could only identify individuals in two out of 56 captures (one sided whisker spot pattern visible). Since SCR models assume that individual identity is assigned correctly in all instances, and that every individual in the population is identifiable (available for sampling), we did not consider scars or collars as identifying features since not all individuals had such features. Indeed, on 49 out of 56 captures (87.5%), the detected lion was unmarked (did not have any obvious identifying feature). This is in sharp contrast to a study on lions in Senegal using flash camera traps[21], and that noted only seven out of 43 captures were unmarked (16.3%), highlighting that large site-specific variation is likely to occur in the proportion of naturally marked and unmarked individuals. Since our goal was to generate encounter history data that could be analysed with SCR models, and our sample size was small, we did not attempt to run models that would be appropriate for these data (counts of unmarked individuals, and recaptures of some individually identifiable animals) such as the spatial mark- resight models used in the Senegal study[21]. Nor did we attempt to combine these data sources since the additional two captures would not add much information.

A multi-site study on lions in Tanzania[16] used white flash camera traps and reported improved success in identifying individuals through whisker spots, with success rates of 67%, 58% and 52% in three different sites. By comparison, our study with infra-red cameras had a success rate of 3.6%. This suggests even the best available store-bought infra-red cameras are unsuitable for obtaining encounter history data necessary for SCR studies. We anticipate that as technology improves, infra-red cameras may become suitable, and we encourage continued testing of new models to produce improved results. This is because infra-red cameras are preferable in many instances since they are less likely to induce behavioural responses by wildlife (e.g. trap shyness). Furthermore, current technology of white-flash camera traps often results in a slow (~15 s) recharge time for the flash. This is important for group living species like lions, since only one individual in a group may be captured on camera trap as they walk past. Finally, lions occur in vast areas where density may be very low, and human persecution may be high. In such places white flash cameras are more likely to be stolen, and search encounter approaches may require massive resources to overcome low detection rates, rendering infra-red cameras as a viable alternative.

Using rangers to scale up lion and wildlife surveys across Africa and Asia. Many protected areas across Africa have a regular flow of safari vehicles driving on developed road networks. Examples of places where wildlife tourism rangers live and work alongside African and Asiatic lions include Botswana's Okavango Delta[22], South Africa's Kruger National Park, Associated Private Nature Reserves and Sabi-Sands complex, India's Gir forest, Uganda's savanna parks, and numerous protected areas managed by the NGO African Parks. These sites represent an opportunity to include wildlife tourism rangers in lion population monitoring exercises, and to build strong scientific monitoring systems with government authorities. A key challenge with lion and other wildlife population monitoring exercises is that they are performed too inconsistently to gain an adequate pulse of densities, sex ratios, and movements of animals. These parameters are what is needed to gauge if populations are stable, decreasing, or increasing. Our study presents a simple scientific capacity building model that could be scaled with government authorities in suitable sites where such ranger teams exist (we do not refer to law enforcement rangers which are a different constituent of the protected area management stewardship, although in theory, they too could be deployed in such exercises for limited periods). We suggest that in areas with poor road networks or low wildlife population densities, more survey effort may be required. Detection boosters like call up surveys to lure lions and then take photographs to determine their identities[23,24] may also help to overcome this problem. Lastly, given that wildlife monitoring is functionally non-existent in many places where it matters the most[6,25,26], we contend that the use of rangers, while by no means perfect given institutional and landscape constraints, provides a means by which to achieve a glimmer of hope for understanding the long-term population trends and health of Earth's most iconic wildlife.

Methods

Study area. The study was implemented in the tourism region of the Nile Delta, Murchison Falls National Park. Murchison Falls (3877 km^2, https://www.protectedplanet.net/956) is located within the Albertine Rift, a biodiversity hotspot[27], and is Uganda's most visited protected area. Elevation ranges from 619–1271 m with temperatures ranging from 22–29 degrees Celsius[28]. Rainfall is bimodal, falling between April-May, and again from August-October reaching 1100–1500 mm annually[29,30]. Main habitats in the park include semi-deciduous rainforest, grasslands, and savanna woodland[31]. The Nile Delta tourism region of the park is comprised mainly of grassland and woodland savanna. Common grasses include thatching grass *Hyparrhenia hirta*, cats tail dropseed *Sporobolus pyramidalis*, nut grass *Cyperus rotundus*, wandering jew *Commelina benghalensis*, and feathered chloris *Chloris virgata* while woody species include white thorn acacia *Vachellia constricta*, baboon apple *Annona glabra*, and Borassus palm *Palmyra palm*[32]. The tourism zone is characterized by large mammals such as African savanna elephant *Loxodonta Africana*, Cape buffalo *Syncerus caffer*, Uganda kob *Kobus kob thomasi*, oribi *Ourebia ourebi*, waterbuck *Kobus ellipsiprymnus*, and Rothschild giraffe *Giraffa camelopardalis rothschildi*.

Ranger derived estimates of lion density and abundance. Two Uganda Wildlife Authority Rangers (LN and SM) were trained during a four-day workshop between 5–8th April 2023 as part of a park-wide and national lion density and abundance estimation exercise implemented in collaboration with the Ugandan government, and several research and conservation partners. Rangers were trained in the fundamentals of African lion density estimation using search encounter and spatial capture-recapture models[33] and equipped with DSLR cameras (Nikon Coolpix P90), and iPhones loaded with the GPS tracking software MapMyDrive[34]. Rangers were then exposed to on-the-job training over the workshop period where they were accompanied by trainers (AB, TM, AG, and NE) and taught the fundamentals of lion identification using whisker spots[35]. Each ranger then collected lion identities and their accompanying GPS locations, while recording their search effort over a 76-day period (6 April–19 June 2022, Supporting Information 1). Of these 76 days, 60 were sampling days (ie. rangers rested on certain days). Lion searches were conducted in publicly owned safari vehicles as part of tourist safaris in the Nile Delta, and each lion search would entail rangers participating in a tourist safari in the Nile Delta. The lion searches were implemented fresh, daily, on tourist roads, as well as off the tracks into the bush, especially when lions were sighted off the road. During the survey AB, OC, and DG helped rangers to catalogue each lion detection and create an identity kit of all detected lions (noting animal ID, sex, date, and location). From this a series of matrices were created for the estimation of density and abundance in R[36] using the code provided by Elliot and Gopalaswamy[33], which uses a Bayesian Markov Chain Monte Carlo (MCMC) procedure using the Metropolis– Hastings algorithm[37]. First, we generated a state space, which was defined by the Delta's northern boundary, the Nile River and a 15 km buffer to the east (total buffer size = 1500 km^2). We generated potential activity centres, represented by 1 km^2 pixels and set the data augmented value of abundance (M) to 1000 (Supplementary data 1), which is the sum of the number of individuals detected during the study (n = 30) and the number of individuals augmented for the analysis[38]. We followed Elliot and Gopalaswamy[35] to describe the observation process which entailed a SCR matrix comprised of individuals (Supplementary data 2), sampling occasions, and 'trap' locations (pixels of size 1 km^2, Supplementary data 3). We also included an effort covariate (logarithm of kilometres driven per trap, per day, Supplementary data 4) to account for the possibility that increased sampling would result in increased detection probability. Sex-specific covariates (supp data 5) were included since males and females have different home range sizes, which might affect the observation process. We created four a-priori models and compared their posterior outputs (Table 1). We set the detection function parameter (θ) to 1, which signifies a fixed, half-normal detection function. The probability of detecting lion i in pixel j on sampling occasion k (π_{ijk}) is defined by a complementary log–log function of covariates[35]:

$$\mathrm{cloglog}\left(\pi_{ijk}\right) = \log\lambda_0 + \beta_{eff}\left[\log\left(\mathrm{effort}_{jk}\right)\right] + \beta_{sex}\left(\mathrm{sex}_i\right) - f\left[\mathrm{dist}(i,j)|\theta,\sigma_{sex}\right]$$

where f[dist $(i,j)|\theta,\sigma_{sex}$] describes how detection rate is a function of distance between the activity centre of individual i and pixel j, which are conditional on θ and σ_{sex}. We ran these models at 11,000 iterations per chain and set four chains for each model with an initial burn in of 1000 iterations. We assessed convergence using the Gelman–Rubin diagnostic and assumed convergence if the r-hat value was <1.05 for each parameter[39]. If nonconvergence persisted, we discarded more initial iterations, or we reran the analysis with more iterations. To select a model to report, first we used a goodness-of-fit evaluation, using the Bayesian p-value based on individual encounters to reject models whose p-value lay outside the extremities between 0.15 and 0.85[38]. Next, we visually assessed pair-wise correlation plots of the posterior outputs to assess parameter redundancy. All R scripts, functions, and data for our analysis are available in Supplementary Information and Supplementary data 1–5, and are also available in Github (https://github.com/alexbraczkowski/Alex-Braczkowski---Rangers-on-the-Frontline-Lion-Density-Code-.git).

Lion detections from camera traps. We placed 32 pairs of camera traps within our 255 km^2 study area in the Nile Delta tourism zone and ran these from April 23rd–June 20th 2022 (59 days). Camera locations were set primarily on tourism roads and trails of the Delta region. We did this because African carnivores are known to travel on these routes to easily traverse their territories[40–42]. Each camera location had a pair of infrared SOLARIS™ WEAPON 4 K 46 megapixel solar-powered camera traps fitted with a 32GB micro sd card (see Supplementary Information for specifications). Camera traps were strapped to wooden poles at a height of 30 cm, and set to 5 image bursts on continuous hour mode. The mean distance between camera traps was 3.31 km, smaller than the radius of the smallest recorded female lion home ranges recorded in the literature (25–50 km^2)[43,44]. Each time a lion walked past a location, its sex (and if possible) identity was noted, and we considered every individual in a pride as an individual detection (the same as our search encounter survey).

Costs: Rangers vs camera traps. We provide a cost estimate for ranger and camera trap surveys, converted to USD at the 2022 average rate. Key costs include: 1) ranger salary top-ups agreed with the Ugandan government (USD$693.48), 2) equipping each ranger with a camera and iPhone (USD$832.18), and 3) training costs for rangers (USD$108). Vehicle costs were excluded as they were covered by tourism budgets. The camera trap survey costs include 64 cameras (divided over three surveys = USD$2200), two months of a research assistant's salary (USD $832.17), and diesel (USD$1.57/litre, calculated for a Toyota Landcruiser with 7 km/litre usage, covering 144.97 km per trip, with traps checked seven times). We present the raw survey costs and cost per usable lion detection for density analysis.

Reporting summary. Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The raw data in this study is provided in supplementary information and is also available on https://github.com/alexbraczkowski/Alex-Braczkowski---Rangers-on-the-Frontline-Lion-Density-Code-.git.

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Received: 15 January 2024; Accepted: 28 August 2024;
Published online: 15 October 2024

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Acknowledgements
The Uganda Wildlife Authority is thanked for its ongoing support of the lion and large carnivore research being implemented by the lead author and his team. Funding for this work was provided from multiple sources: Griffith University's Centre for Planetary Health and Food Security, Griffith University's Media and External Communications centre, Northern Arizona University, the Siemiatkowski Foundation, and the Southern University of Science and Technology.

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Competing interests
The authors declare no conflict of interest excepting the first authors ownership of the SOLARIS TRAIL CAMERAS company of which the WEAPON 4 K model was deployed in this study.

Ethics Statement
We have complied with all relevant ethical regulations for animal use and our work was cleared by the Ugandan National Council for Science and Technology (registration number NS331ES) and the Uganda Wildlife Authority (UWA, permit number COD/96/05).

Additional information
Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s42003-024-06796-0.

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Peer review information *Communications Biology* thanks the anonymous reviewers for their contribution to the peer review of this work. Primary Handling Editors: Luke Grinham and Tobias Goris. A peer review file is available.