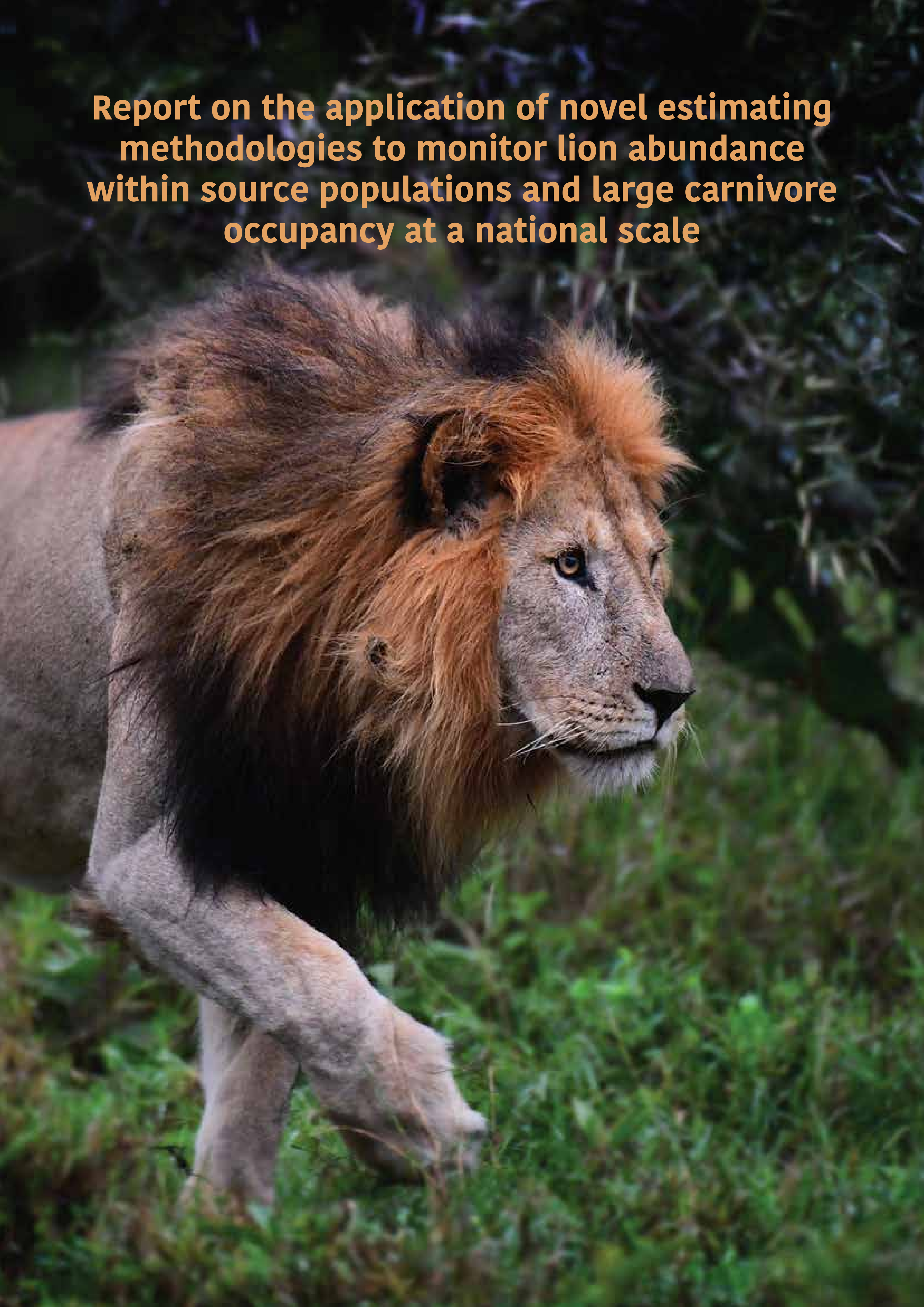
Report on the application of novel estimating methodologies to monitor lion abundance within source populations and large carnivore occupancy at a national scale



Report on the application of novel estimating methodologies to monitor lion abundance within source populations and large carnivore occupancy at a national scale

RECOMMENDED CITATION

Elliot, N.B., Broekhuis, F., Omondi, P., Ngene, S., Kariuki, L., Sankan, K., Chege, M., Wato, Y., Amoke, I., Dolrenry, S., Kuloba, B., Gopalaswamy, A. M. (2021). Report on the application of novel estimating methodologies to monitor lion abundance within source populations and large carnivore occupancy at a national scale. Wildlife Research and Training Institute and Kenya Wildlife Service.

Concept and Design by Nic Elliot, Femke Broekhuis and Shadrack Ngene

Front and Back Cover Photo: © Philip J. Briggs

Published in December 2021 By Wildlife Research and Training Institute (WRTI), Kenya Wildlife Service (KWS), World Wildlife Fund-Kenya (WWF-K), and Kenya Wildlife Trust (KWT), Kenya.

ISBN: 978-9914-40-516-3

Contents

Acknowledgement

This first national lion and large carnivore survey could not have been realised without the support of many individuals and stakeholders. We are thankful to the Cabinet Secretary, Ministry of Tourism and Wildlife Hon. Najib Balala for his initiative to ensure the population status of lions in Kenya is well documented with current survey methodology. We acknowledge support by the Principal Secretary, State Department of Wildlife Prof. Fred Segor; the Director General, Kenya Wildlife Service Brig. (Rtd). J.M. Waweru; and Deputy Director – Finance and Administration Japheth Kilonzo for their personal commitment that ensured the survey was a success. Similar appreciations go to the Kenya Wildlife Service's Field Assistant Directors' of Coast, Tsavo, Southern, Western, Mountain, Eastern, Northern and Central Rift Conservation Areas for ensuring security within the survey areas during the survey period.

We thank the collaborators who co-funded the survey together with the Kenya Wildlife Service (KWS) and their partner in this initiative, the Kenya Wildlife Trust (KWT). These included the World Wildlife Fund-Kenya, Wildlife Conservation Network's Lion Recovery Fund, Liz Claiborne Art Ortenberg Foundation and the National Geographic Society. Valuable contributions and support were also received by ICEA Lion Insurance Group, the African Wildlife Foundation, Siemiatkowski Foundation, Wildlife Conservation Society and Remembering Wildlife. Without your support, the survey could not have been a success.

We express our gratitude to the non-governmental organizations that participated in the fieldwork: KWT, Lion Guardians, Ewaso Lions, Wildlife Works, Zoological Society of London, Laikipia Wildlife Forum, Northern Rangeland Trust, Southern Rift Association of Landowners (SORALO), Tsavo Trust, Lion Landscapes and Born Free Foundation for providing vehicles and personnel during the survey. The community and private ranches and conservancies in Taita Taveta, Laikipia, Samburu, Marsabit, Isiolo, Meru, Tana River, Lamu and Kwale Counties supported the survey by providing resources (personnel, vehicles and/or equipment) and we thank them for their support that resulted in a successful survey.

For the many teams that worked in the different ecosystems, we thank you all for making this survey a success and refer readers to the end of this document for a full list of people who participated. Because of your contribution, we generated the data that have been presented in this report, which will benefit large carnivore conservation throughout Kenya.

We extend our indebtedness to the logistics team that included mechanics, fuel attendants, drivers, security personnel, accountants, banda attendants and cooks for their amazing support during the planning and implementation of the activity. Your support ensured that the activity was implemented without drawbacks. Finally, we also appreciate the entire management and staff of KWS' eight Conservation Areas for their support and friendly services during the survey.

Abstract

To effectively manage and conserve wildlife populations, it is essential to establish their abundance and distribution reliably and regularly. However, obtaining accurate estimates of large carnivores is difficult, since they are cryptic, wide ranging, nocturnal and naturally occur at low density. The challenge of surveying most animal populations is that individuals cannot be perfectly detected or observed. As a result, obtaining total counts of large carnivores is all but impossible, except potentially in small, fenced areas and scientists have devised a myriad of monitoring techniques in order to sample a proportion of a population and estimate what has not been counted.

To estimate abundance and distribution of African large carnivores, various methods have been used within and between sites, which makes it difficult to quantify population trends – the key parameter of interest to any wildlife programme. In addition, the techniques typically used for Africa's large carnivores do not account for imperfect detection, which may result in flawed estimates, with high uncertainty, especially across large spatial scales.

To rectify this, the Kenya Wildlife Service initiated a national survey of lions and other large carnivores and made use of cutting-edge scientific methods to obtain reliable and precise estimates.

Between 2018 and 2020 we conducted field surveys within ten of Kenya's most important source populations of lions, and analysed these data using spatially-explicit capture-recapture models. At the same time, we collected data on the presence and absence of all large carnivores and predicted their distribution across Kenya using occupancy models which account for false-positives and false-negatives.

In this report, we present the results of this endeavour, contextualise them from a national perspective, and discuss their implications for conservation. Kenya is the first country in Africa to adopt rigorous scientific methods and apply them at a national scale. This report proposes guidelines and protocols to be developed to ensure that regular monitoring is conducted using the frameworks presented.

An initiative of

In partnership with

Lion Abundance in 10 of Kenya's Key Source Populations

Africa's Largest Science-Based Lion Survey

We asked:

How many lions are there in 10 of Kenya's key populations

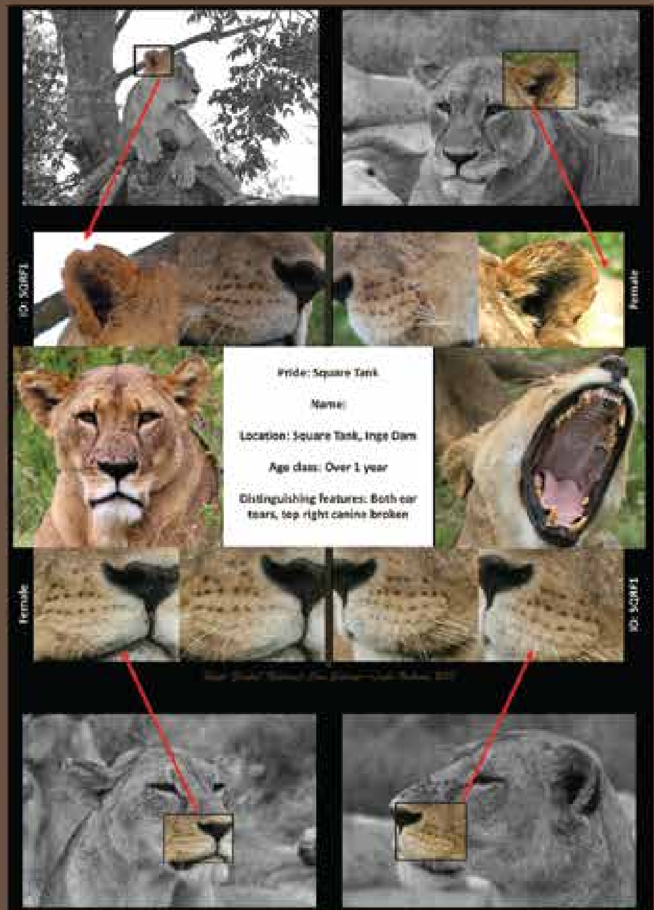
Fieldwork:

More than 400 people were involved. We used different field techniques to find as many lions as possible and took photos to identify different individuals based on unique features. Most surveys lasted 90 days, while smaller areas were shorter.

105,000km driven

200 Call-ins

40,000km walked



Spatially Explicit Capture-Recapture (SECR)

We used Bayesian SECR models to estimate the the total number of lions (including those we missed) based on the lions we did see and the effort we invested to find them. These models provide reliable density estimates and are widely used for large carnivores.

No Cubs:

Cubs less than 1yr old were excluded as they frequently suffer high mortality.

Outputs

	Area surveyed	Area of inference (km^2)*	Lion Abundance and (SD)
1	Lake Nakuru National Park	135	11 (1.5)
2	Maasai Mara Ecosystem	3,115	556 (24)
3	Amboseli Ecosystem	4,867	141 (11)
4	Shompole & Olkiramatian	488	27 (5)
5	Nairobi National Park	334	25 (6)
6	Tsavo Conservation Area	31,254	460 (40)
7	Laikipia & Meru Ranches	5,133	306 (16)
8	Sections of Samburu, Isiolo and Laikipia Counties	3,274	17 (3)
9	Meru Conservation Area	1,202	55 (8)
10	Sibiloi National Park	1,571	0

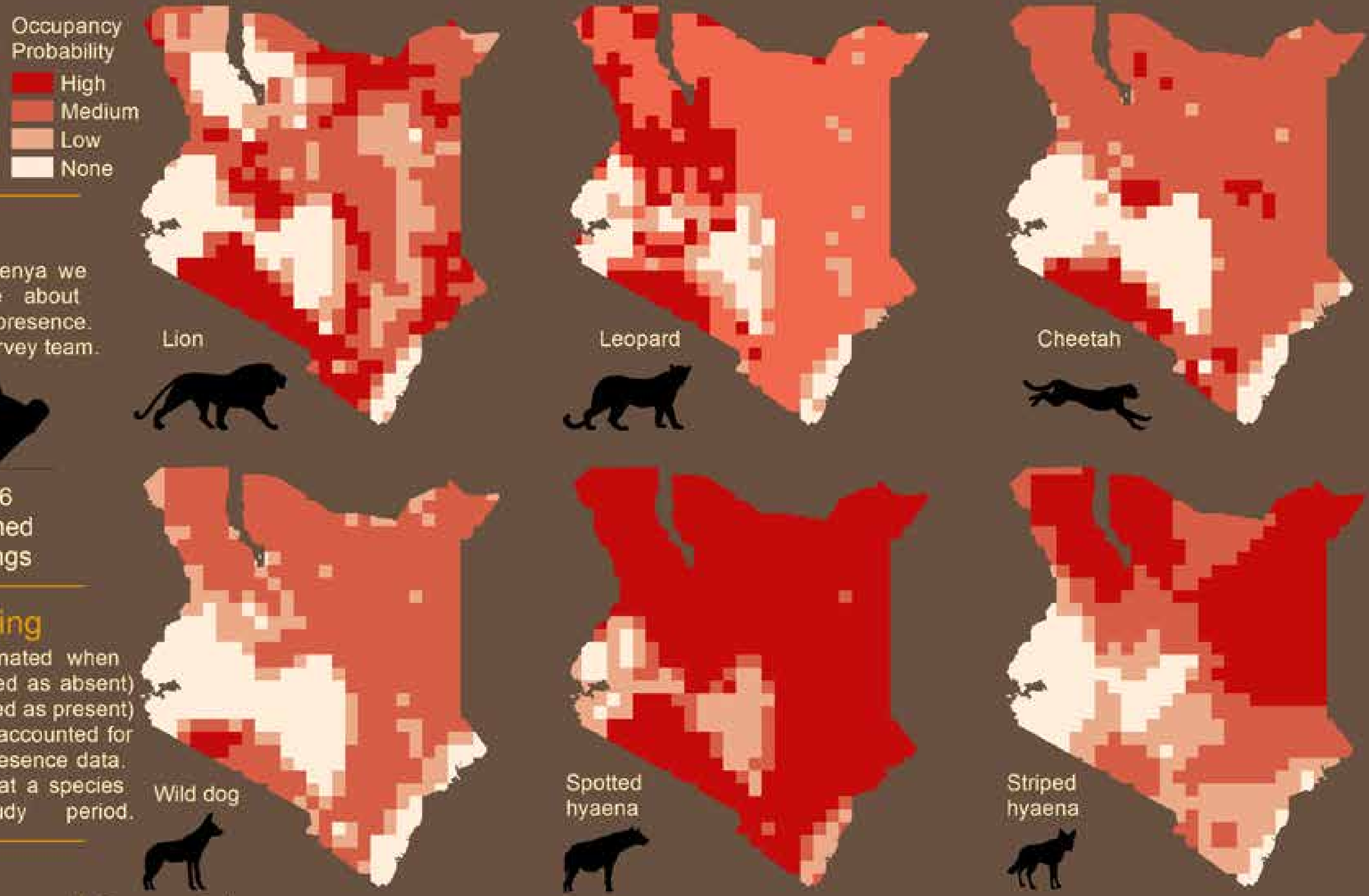
* Includes areas masked out as unsuitable habitat

For the last two years we have been working with a host of partners to estimate lion abundance within key source populations. This initiative was a multi-agency collaboration involving local and international scientists and conservationists from governmental and non-governmental sectors. In particular, we acknowledge the tremendous support from the following: Lion Guardians, SORALO, Wildlife Works, ZSL, Tsavo Trust, Born Free, Ewaso Lions, Lion Landscapes, WildCRU and the multitude of teams who took part.

Additional support provided by:

Predicted Distribution of Kenya's Large Carnivores

We asked: ? **What is the distribution of large carnivores in Kenya?**



Data Collection

To map the distribution of large carnivores in Kenya we interviewed people who were knowledgeable about particular areas and wildlife and about carnivore presence. We also included sightings of carnivores by the survey team.

1,437 face to face interviews

176 online interviews

2,616 confirmed sightings

False-Positive Occupancy Modelling

Species distribution can be over or underestimated when false negatives (a species is present, but reported as absent) and false positives (a species is absent but reported as present) are not accounted for. Our occupancy modelling accounted for both these error types and included confirmed presence data. The results are interpretted as the probability that a species occupied each pixel during the study period.

Conservation Implications

The results will be used to guide conservation and research. Encouragingly, the distribution of all carnivores is predicted to be more widespread than previously thought, especially across vast areas in the north and north-east of Kenya, which have traditionally received little attention. Research and conservation initiatives are encounraged in such areas to asertain their true conservation status and mitigate against threats.

An initiative of Kenya Wildlife Service

In partnership with KWT Kenya Wildlife Trust

Additional support provided by: Lion Recovery Fund, National Geographic

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Glossary

Term	Definitions in the context of estimating carnivore numbers and distribution
Abundance	Total number of individuals within a specified area at a given time.
Accuracy	Measure of how close a population estimate is to the true population size.
Activity centre	The average of an individual's locations during a given time period. Synonymous with home-range centre.
Bias	Difference between the estimated and the true population size.
Capture-recapture	This refers to the capturing and recapturing of an individual. In this case it is synonymous with sighting and resighting an individual.
Density	Number of individuals per unit area (e.g. number of individuals per 100km^2).
Detection	A detection is a positive identification of an individual on a particular day.
95% HPD	The narrowest interval that contains at least 95% of the posterior probability mass.
Occupancy	The probability that a selected sampling unit in an area of interest is occupied by a species.
Population closure	Assumption that the population does not change during the estimation procedure. This includes both demographic closure (no births and deaths) and geographic closure (no immigration or emigration).
Population estimate	An approximation of the true population size based on some method of sampling and modelling.
Precision or Variance	Measure of how close a population estimate is to the expected value.
PSD	The standard deviation of the derived posterior distribution.
Robust	An estimate that is close to the truth even if some of the assumptions of the estimation procedure are violated.
Source population	A resident population that is breeding and recruiting new individuals.
Trap	Traditionally a physical trap in capture-recapture studies, referred to in this report as a grid cell within the survey area where effort was expended in an attempt to detect lions.
Weighted mean	A mean where the contribution of the values being averaged is unequal.

Abbreviations and Acronyms

Term	Definition
a.s.l.	Above sea level
CR	Capture-recapture
GPS	Global Positioning System
GR	Group Ranch
HPD	Highest Posterior Density
ID	Identification
IUCN	International Union for Conservation of Nature
km	Kilometres
KWS	Kenya Wildlife Service
KWT	Kenya Wildlife Trust
LEK	Local Ecological Knowledge
LNNP	Lake Nakuru National Park
MCA	Meru Conservation Area
MMNR	Maasai Mara National Reserve
NGO	Non-Governmental Organisation
NMK	National Museums of Kenya
No.	Number
NP	National Park
NR	National Reserve
PSD	Posterior Standard Deviation
SECR	Spatially-explicit capture-recapture
SGR	Standard Gauge Railway
SORALO	South Rift Association of Land Owners
TCA	Tsavo Conservation Area
WildCRU	Wildlife Conservation Research Unit
ZSL	Zoological Society of London


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Chapter 1

Background

Recent figures suggest that lions (*Panthera leo*) have undergone a 43% decline between 1993-2014[4] and that remaining lions in West, Central and East Africa may decline by 50% over the next two decades[5]. Furthermore, lions may occupy as little as 8% of their historic range[4]. While such figures are clearly alarming and the plight of African lions cannot be doubted, no systematic survey has ever been conducted at a national level, let alone across the continent. This lack of information on lion numbers has hindered the strategic and adaptive management of lions.

The lion is classified by the International Union for Conservation of Nature as 'Vulnerable', with suggestions that the East African population is 'Endangered' (due to an estimated 57% decline between 1993-2014[5]). Kenya also categorises lions as endangered and is home to two of Africa's last lion 'strongholds'[6]. The 'Conservation and Management Strategy for Lions and Spotted Hyenas in Kenya (2009-2014)' provided lion numbers and distribution maps which were sourced by experts in the field. According to these experts there were 1,970 lions of all ages in Kenya. This number was largely based on expert opinion and various ad hoc survey techniques that often produce unreliable estimates. As such, the estimates were prefixed with a cautionary note that some figures were "little more than guesses". As a result, a target was set for standardised protocols and the Kenya Wildlife Service (KWS) identified a national lion survey as being a priority exercise. Figure 1.1 illustrates the steps taken to develop and implement this initiative, each of which is elaborated upon below.

Planning Workshop

In July 2017, KWS convened a workshop that brought together a large group of scientists and conservationists (both KWS and independent) to discuss and begin planning the survey. During that workshop, a variety of survey methods

Previous strategy	Kenya's 'Conservation and Management Strategy for Lions and Spotted Hyenas in Kenya (2009-2014)' set targets for standardized protocols for lion monitoring and KWS identified a national survey using standardized methods as being a priority exercise.
Planning workshop	In 2017 KWS convened a multi-stakeholder workshop to begin planning the national survey. A key outcome was that lion numbers would be estimated in potential source populations and distribution would be estimated throughout the country.
Technical team assembled	KWS assembled a technical team that included KWS and independent scientists. The technical team were tasked with overseeing the survey and ensuring that a science-based approach was used throughout.
Methods Review	Methods used to estimate lion numbers and distribution were reviewed, with spatially-explicit capture-recapture (SECR) models and occupancy models being identified for trials for the national survey.
Pilot study	A pilot study of Lake Nakuru National Park was conducted using an SECR framework and the results published in a peer reviewed scientific journal.
Adoption of methods	SECR was adopted to estimate lion numbers in all potential source populations. An occupancy framework was adopted to estimate large carnivore distribution throughout Kenya.
Survey design	The technical team collaborated to produce a survey plan document that detailed the survey design and required resources to successfully implement the survey. A set of Goals and Objectives were identified to ensure that the surveys would evolve into long-term monitoring.
Adaptation	The survey plan was adapted following in-depth consultations with local stakeholders regarding the presence of a source population of lions and security concerns.
Implementation	The technical team worked with local stakeholders to implement the survey plan.

Figure 1.1: *A chronological summary of the steps taken during development and implementation of the survey.*

(see Methods Review section) were discussed as were potential strategies for conducting a national survey. During a participatory mapping exercise, participants were presented with a map of Kenya. First, they were asked to draw the area within which they work and answer questions relating to how much time they spend within that area. Next, they were asked to score cells within their area of operation based on their expert knowledge according to whether lions were resident, occasionally present or absent (Figure 1.2). These data were then analysed with occupancy models[7] that accounted for false positives in order to map the potential distribution of lion source populations (Figure 1.3).

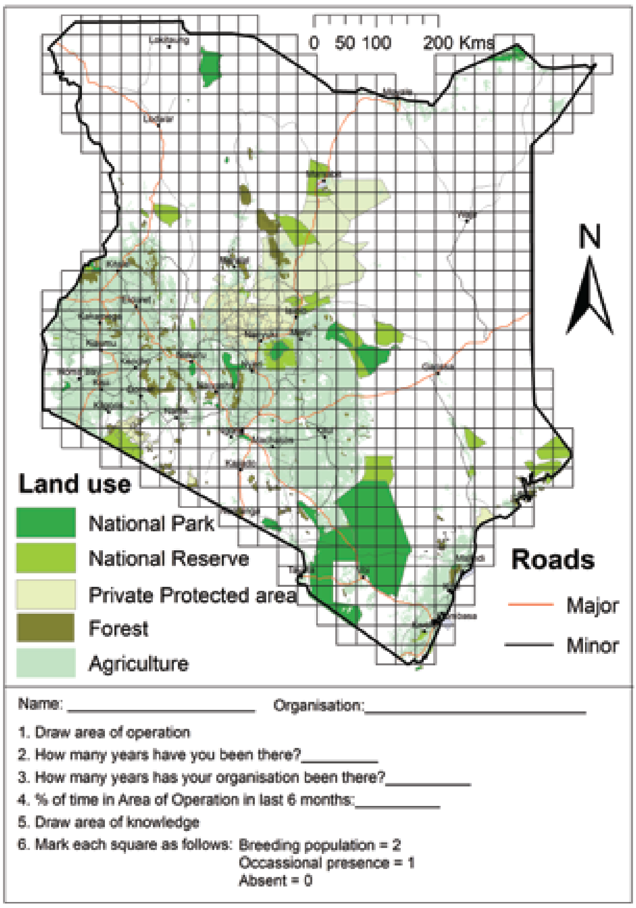


Figure 1.2: *Participants of the workshop were asked to fill in the map as per the instructions. These data were then analysed within an occupancy framework to provide a spatial representation of potential lion source populations (see Figure 1.3) which was subsequently used to design the survey (see Figure 2.1).*

Consensus was reached that it would be impractical and require massive resources to accurately estimate lion numbers with systematic surveys throughout such a vast country. Since source populations frequently form the basis of conservation, it was decided that one approach would be used to accurately estimate lion numbers within potential source populations and another approach would be used to estimate large carnivore distribution and to identify other potential sources throughout the country (see Figure 2.1).

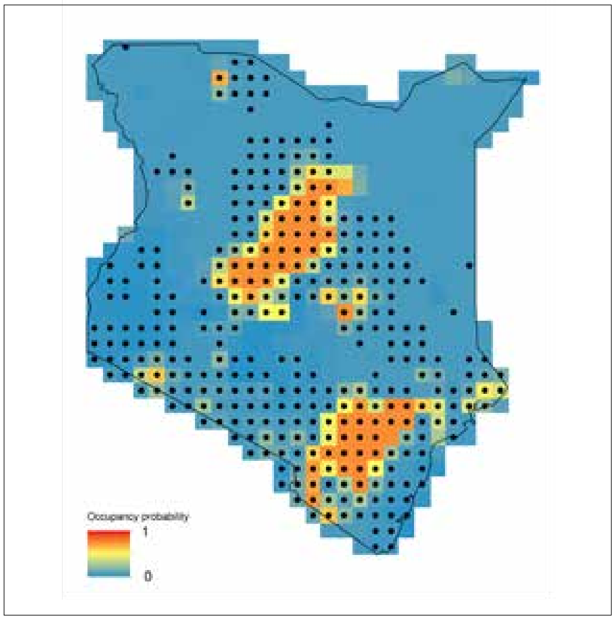


Figure 1.3: *Outputs from the participatory mapping exercise during the planning workshop. This map shows the probability of occupancy for source populations of lions based on the expert opinion of key stakeholders. This map was used to inform the national survey plan (see Figure 2.1).*

Technical team

KWS assembled a technical team that included KWS and independent scientists (Table 1.1). The technical team was tasked with overseeing the survey and ensuring that a science-based approach was used throughout. This included all aspects of the survey including survey design, fieldwork implementation, data management, data cleaning, data analysis, interpretation, and write-up. The technical team (refer to the 'Contributors' section for affiliations and contact information), while being engaged throughout, focussed on and were involved in differing aspects of the initiative (Table 1.1)

Methods review

Lions are notoriously difficult to count and since total counts of lions are usually unfeasible, sampling methods are commonly used to estimate their number or density. The chosen method often varies depending on local conditions such as perceived lion abundance or detectability[8]. However, our ability to detect lions or their signs may depend on many factors and failing to account for this sampling heterogeneity can lead to flawed inferences[9]. Traditional methods generally

***Table 1.1:** Members of the technical team and their roles*

KWS	Survey design	Fund-raising	Logistics	Data Collection	Data management	Data analysis	Training	Interpretation	Writeup
Patrick Omondi, PhD	✓	✓	✓					✓	✓
Shadrack Ngene, PhD	✓	✓	✓					✓	✓
Linus Kariuki, MSc	✓	✓	✓					✓	✓
Bernard Kuloba, MSc *	✓	✓	✓	✓					
Monica Chege, MSc *	✓	✓	✓	✓					✓
NGO									
Nic Elliot, PhD	✓	✓	✓	✓	✓	✓	✓	✓	✓
Femke Broekhuis, PhD	✓	✓	✓	✓	✓	✓	✓	✓	✓
Kasaine Sankan, BA	✓			✓	✓		✓	✓	✓
Stephanie Dolrenry, PhD	✓	✓	✓	✓	✓				✓
Irene Amoke, PhD		✓	✓						✓
Yussuf Wato, PhD *	✓	✓	✓						✓
Jenny Cousins, PhD *		✓							
Arjun Gopalaswamy, PhD	✓	✓				✓	✓	✓	✓

*Involved in surveys of southern Kenya.

do not incorporate the probability of detecting lions, which is likely to vary within and among study areas.

Due to the difficulties associated with counting lions, researchers have historically used a variety of different methods (Table 1.2). This use of different methods, especially those that are unreliable, within and between sites has made it difficult to accurately assess changes over time. To rectify this, KWS sought to adopt a science-based approach where cutting-edge methods are used within a standardized framework. To aid the decision on which methods to adopt, the merits and concerns associated with different methods were discussed during the workshop and reviewed afterwards. Below is a summary of the different methods that were considered.

Expert opinion

This is when experts take an educated guess as to how many lions there are in an area. Expert opinion is highly subjective and is usually only sought when no other data exists, and while it can assist in guiding future monitoring, expert opinion frequently leads to unreliable figures[10]. This is generally not based on data and there is no statistical analysis involved, meaning that this may not be reliable or repeatable.

Whole counts

This is based on direct observation of lions and the number of individuals seen within a certain timeframe. This is usually, but not always, based on individual identification of animals and researchers frequently assume that all individuals have been counted after a period of time with no new individuals being seen. This timeframe is often prolonged (for example one year), meaning that during the survey some lions may have immigrated or emigrated, been born or died. Thus, a standard assumption of wildlife surveys, 'population closure', is likely to be violated[11]. Furthermore, it is assumed that all lions within the area were counted, but in reality, it is usually impossible to detect all individuals. Typically this method is applied in small ecosystems (e.g. Nairobi National Park[12,13]) where it is conceivably more reliable (but not always[14]) than in larger ecosystems with abundant lion populations where whole counts may produce vastly different figures (e.g.[15-17]). There is no statistical analysis involved and search effort is generally not taken into consideration either within or between surveys. As such, this method generally has very limited applicability to long term monitoring of free-ranging populations since it is frequently not reliable or repeatable.

Track surveys

Track surveys, also referred to as 'spoor surveys', make use of index calibration techniques, whereby an index (lion tracks) is used to calibrate a relationship to actual lion density in order to predict lion density based on lion tracks. A general discussion of track surveys together with its limitations is provided in[1], while a statistical exploration of the technique is undertaken in[9]. The method is briefly described here: A track survey is conducted in a small area where lion density is assumed to be known. The estimated abundance and the putative index are then fit by linear-regression-based approaches with ordinary least-square solutions. It should then be possible to collect index data (number of lion tracks) at a new site and predict lion density based on the index[18]. Thus, the number of lions is estimated based on the number of tracks seen (e.g.[19]).

There are various assumptions made:

- Lion abundance is accurately known at a small scale.
- There is a consistent relationship between track density and abundance.
- Random placement of transects that proportionally represent the habitats.
- Each animal has the same probability of crossing a transect.
- Each set of tracks is detected.
- Accurate numeric assessment of individuals based on tracks (individuals are not double counted).
- Tracks are preserved for 24 hours.

Many of these assumptions are difficult to uphold in real world situations. For example, it is not always straightforward to distinguish whether one set of tracks constitutes the same or different individuals to a set of tracks found further along a transect, especially given the fission-fusion dynamics of lion sociality. As such, a general 'rule of thumb' is that if multiple sets of lion tracks are spaced more than 500m apart they can be regarded as different individuals if observers cannot identify these individually[8] (which inflates estimates if these tracks are in fact left by the same individuals). Because detection probability is not taken into account there is an overdispersion in the associated relationship between true density and the index and the estimates are usually associated with confidence intervals too large to reliably assess population trends over time[9]. Therefore the utility of such methods has been criticised[20], shown to be unreliable for lions[21], even in ideal conditions[22] and a statistical examination of the approach concluded that track surveys may produce faulty results[9].

Call-in/playback surveys

An array of sounds (e.g. buffalo calf in distress) are broadcast using a loudspeaker to attract lions to a fixed area in order to count them (e.g.[17]). Before the survey, a calibration experiment is sometimes conducted to assess response likelihood (which may vary with lion group composition, whether the lions are feeding etc) and area sampled per station (which may vary with speaker type being used, habitat, wind and other environmental variables). Lions are directly observed, but they are not individually identified, and it is therefore possible that individuals will be double counted. Furthermore, variation in either the area sampled, or response likelihood will produce variation in the observed count. Therefore, concerns about detection probability and high variability are similar to those discussed regarding track surveys and small violations of either method's assumptions will lead to marked differences in density estimates. As with track surveys, their wide confidence intervals lack the precision needed to detect population change over time.

Table 1.2: *Summary of different methods for estimating lion numbers.*

		SECR	Track surveys	Call-in surveys	Whole counts	Expert opinion
Data collection	Direct observation of lions needed	Yes	No	Yes	Yes	No
	Individual identification of lions	Yes	No	No	Usually	No
	Possibility of double counting	No	Yes	Yes	No	Yes
Data analysis	Data needed	Yes	Yes	Yes	Yes	No
	Statistical analysis involved	Yes	Yes	Yes	No	No
	Fieldwork effort accounted for	Yes	Yes	Yes	No	No
	Analysis accounts for variation in the probability of detection	Yes	No	No	No	No
	Confidence intervals (measure of precision)	Narrow	Wide	Wide	None	None
Overview	Precise and accurate	Yes	No	No	No	No
	Monitoring population trends and dynamics	Yes	No	No	No	No
	Costs (e.g. resources)	High	Medium	Medium	Medium	Low

Spatially-explicit capture-recapture (SECR)

Hierarchical models, such as spatially-explicit capture-recapture (SECR), distinguish between the observation process (the manner in which individuals were detected) and the state process (the density and distribution of the species of interest). SECR is reliant on being able to identify individuals, which can be achieved via different field methods, even within the same survey (e.g.[23]). Lions are not physically captured, but information on where and when individual lions were sighted and re-sighted during the survey period is accounted for in the model. In addition, by recording fieldwork effort and formally recognizing that an individual is more likely to be detected when a detector is placed close to the centre of its home range, the probability that a lion was detected if it was there is also estimated. This information is used to estimate how many individuals were not seen therefore making it possible to provide an estimate for the whole population. While this approach inevitably leads to a greater field effort, the models produce accurate estimates with high precision and future surveys are able to estimate population trends and rates of survival, recruitment and movement[24]. Thus, SECR is an accurate, precise, comparable and repeatable method for estimating lion densities and numbers[1,14]. Refer to Chapter 2 for more detail on theory, assumptions, field protocols and analysis.

Pilot study

While SECR models have been used for over a decade to reliably estimate carnivore densities[25], they were first extended to lions in 2017[1]. That study was conducted in the Maasai Mara and the researchers involved were co-opted into conducting a pilot study in Lake Nakuru National Park in an initiative that would introduce the field techniques and modelling framework to KWS and NGO scientists. The results of this pilot study gave participants the confidence to adopt this method for estimating lion numbers in potential source populations and were published in a scientific journal[14].

Adoption of methods

Since their emergence, scientists have developed, adapted, and applied spatially-explicit capture-recapture (SECR) models to estimate wildlife densities for a range of taxa (see[2,26-29] for seminal papers highlighting the evolution of this approach). A key advantage of SECR models is their ability to incorporate a wide variety of field data collection protocols (see[30-36] for examples using different approaches within an SECR framework). This flexibility, coupled with a sound theoretical and statistical framework that produces accurate and precise density estimates, has seen SECR methods rapidly emerge as the preferred option for many large carnivore population monitoring programs (*e.g.,* [24,37]). Due to its robust and flexible nature, KWS adopted the SECR framework to estimate lion numbers within source populations not just for this initiative, but also for future monitoring of lion source populations. Lions under the age of one year typically have high mortality[38] and including this demographic in population estimates may be misleading, thus consensus was reached that the SECR surveys would only include individuals over one year old.

Outside the source populations and throughout the rest of the country, it was agreed that an occupancy framework would be used to estimate the distribution of all large carnivores found in Kenya. Occupancy models, like SECR models, are hierarchical and are used to estimate the probability of true presence or absence of a species at a site while accounting for imperfect detection of organisms. The seminal works of MacKenzie et al.[39,40] sparked a proliferation in the development and application of occupancy models aimed at estimating species occurrence and occupancy dynamics (see [41] for a comprehensive reference book and [42] for a brief history, applications and key considerations of occupancy models). Occupancy models make use of information from repeated surveys at each site to estimate detectability, with occupancy being defined as the probability that the species under investigation occupied a site during a specified time period[42]. As with SECR models, a variety of data collection protocols can be employed to collect the necessary occurrence data. Among the key model developments (see [42] for discussion of some of these) has been the extension to account for false-positive detections[43,44] which can arise due to species misidentification. The inclusion of false-positive detections helped to ameliorate concerns associated with using interview data within an occupancy framework[45], as researchers were now able to better account for interviewees misidentifying or misrepresenting the species of interest[46]. This approach of harnessing Local Ecological Knowledge (LEK) through interviews was employed by members of the technical team in the Greater Maasai Mara Ecosystem to determine occupancy of multiple carnivores which was positively validated using telemetry data and both studies were published in scientific journals[7,47].

Chapter 2

Survey Design

The survey design is a result of the standardization workshop highlighted above and consensus among the technical team following in-depth deliberations and field trials. A total of 77,595km^2 was identified by workshop participants as potentially holding source populations of lions (see the black areas in Figure 2.1). These areas were thus identified as potential sites within which to estimate lion numbers within an SECR framework. Throughout the rest of the country (grey areas in Figure 2.1), the distribution of all large carnivores would be determined within an occupancy framework using interview surveys (see [31] for a book that describes the application of SECR and occupancy methods for tigers).

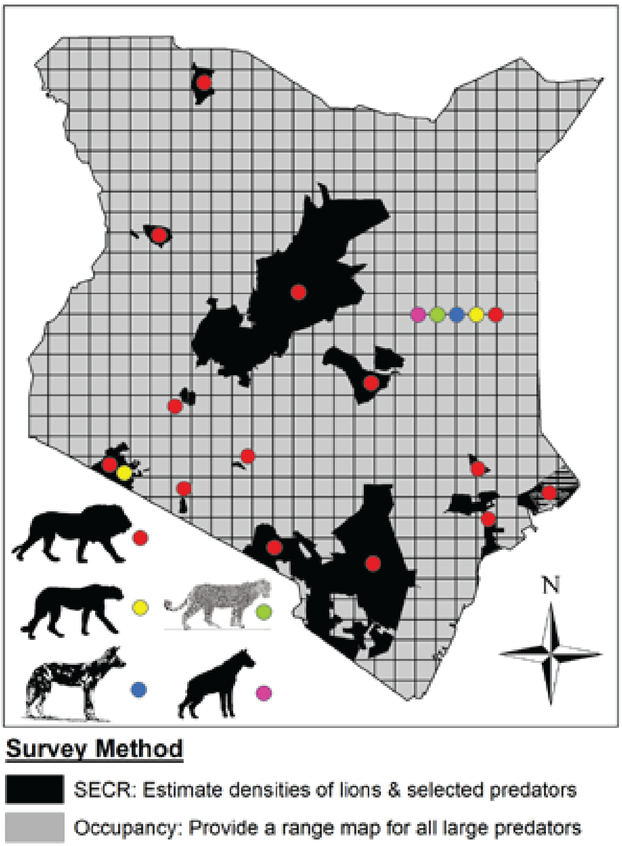


Figure 2.1: *A group of experts identified potential source populations of lions (black areas). For each of these areas, follow-ups were done with local stakeholders to assess (a) whether resident lions occurred and (b) whether security was a concern. Areas that were deemed not to have a source population and/or have security concerns were later shifted to the occupancy-based survey that was conducted throughout Kenya (grey areas).*

Survey goals and objectives

From the outset, the technical team had a long-term vision for this initiative that would ensure it evolved into long-term monitoring to aid decision-making and catalyse support for lion conservation. To this end, the following goals and objectives were set.

Goal

To conduct the first ever national survey of lions to provide decision makers with essential information and to catalyse support for large carnivore conservation.

Objectives

1. Estimate the number of lions over the age of one year in all potential source populations.
2. Estimate occupancy of all large carnivores throughout Kenya.
3. Build capacity to ensure long-term monitoring of lion populations.

These three objectives are reported against in Parts I-III of report respectively.

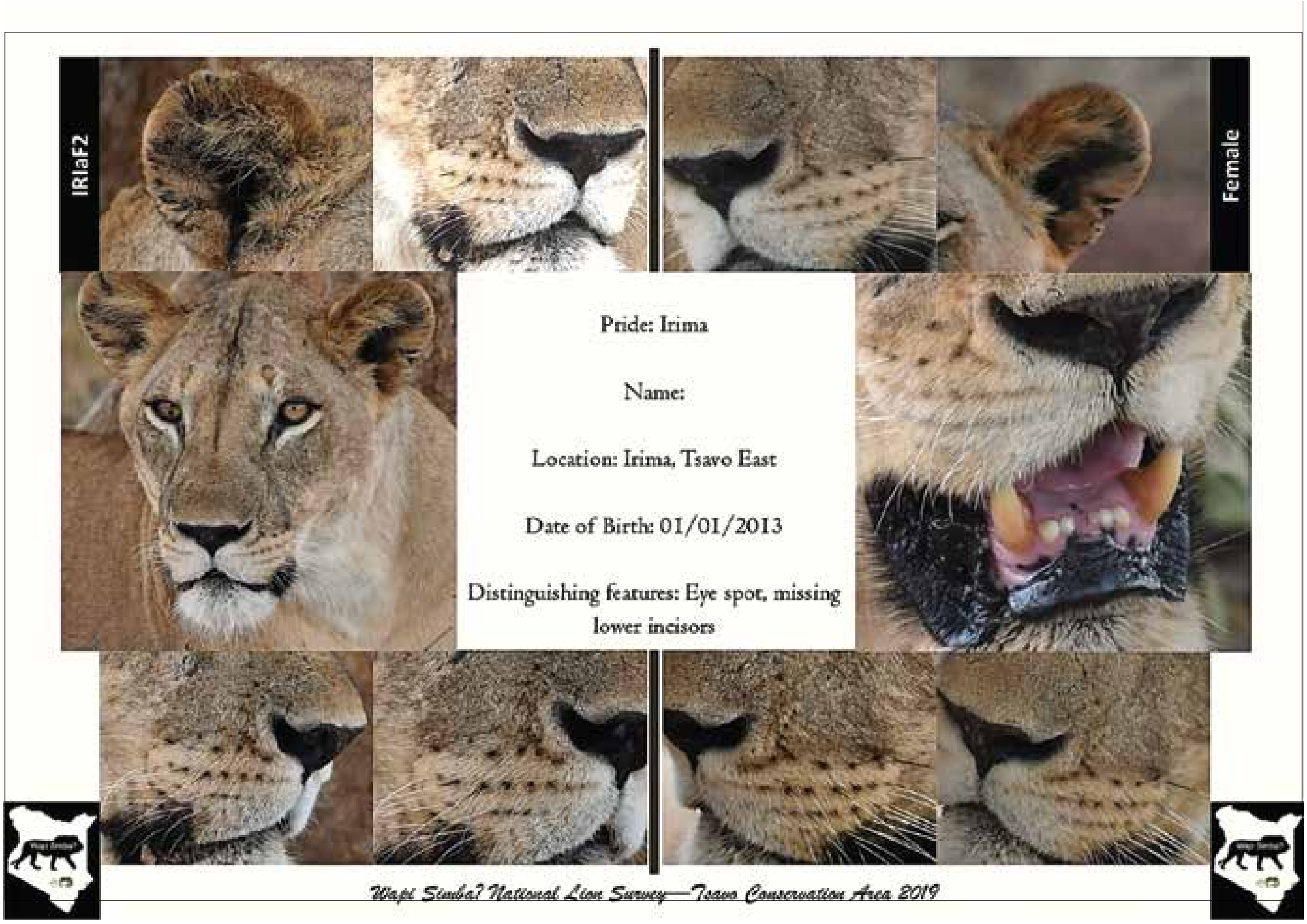
Adaptation

Prior to each survey, in-depth consultations with local stakeholders were used to (a) ascertain whether lions were resident within each area or not and (b) assess the security of the area. If lions were not deemed to be resident and/or the area was insecure, then that particular site was removed from the intensive SECR survey.

Implementation

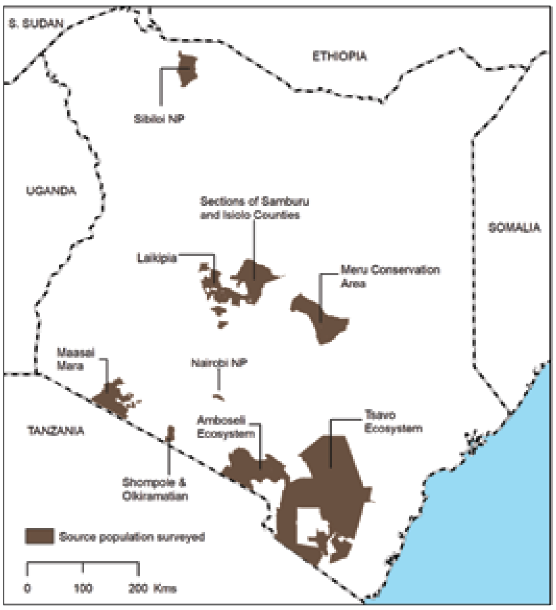
All aspects of the survey were overseen by members of the technical team. During the SECR surveys, collaborations were forged with local stakeholders who variably participated in fieldwork, data entry, analysis, and/or interpretation. This participation was hugely beneficial as stakeholders provided human resources, survey equipment, and vehicles. In return, they received training in theory, fieldwork, and data analysis, and participated throughout. As a result, a variety of stakeholders now have a solid foundation from which to build and continue to be involved in long-term monitoring (see Part III of this report).

The occupancy surveys were also overseen by members of the technical team. Enumerators were identified either by local stakeholders or by KWS scientists. These enumerators were then trained in survey techniques by members of the technical team and conducted the interviews. In addition, interviews were conducted by members of the technical team, and later this survey was moved to an online platform when Covid-19 restrictions made face-to-face meetings problematic.



PART I: Lion Abundance and Density

Estimating Lion Numbers over the Age of One Year within Potential Source Populations using Spatially-Explicit Capture-Recapture



Chapter 3

Spatially-Explicit Capture-Recapture of Lions: Methods

A comprehensive overview of spatially-explicit capture-recapture (SECR) theory and model formulation is beyond the scope of this report (refer to [25] for a reference book that is dedicated entirely to this topic). However, some concepts are key to contextualising the results presented in this report and are therefore broadly and briefly explained. This is then followed by a detailed description of the data collection protocols that were variably used at different sites. The final section deals with *a priori* candidate models, model choice criteria, and calculations pertaining to lion abundance.

Conceptual Underpinnings of SECR

Population Closure

Capture-recapture models assume that the population does not change during the survey[48]. In other words, it is a 'closed population'. The two forms of closure important to consider are demographic closure (no births or deaths occur) and geographic closure (no individuals move into or out of the survey area). To avoid serious violations of demographic closure, we excluded all individuals under the age of one, since this age category experiences high mortality in lions[38]. Furthermore, we aimed to keep the survey period as short as possible to minimise violations of demographic and geographic closure. In addition, Royle et al.[3] found that spatial capture-recapture density estimates are robust even with a fairly large number of transients during the sampling period.

Detection probability

Estimating the number of animals in a population is complicated by the fact that we are unable to perfectly detect every animal that is present in an area. Therefore wildlife ecologists sample the population of interest in a variety of different ways to count the number of animals that are for example seen, heard or caught. These data are a count statistic, C, that represents an unknown fraction of the entire population, N. For the count statistic to be meaningful a reliable estimate of detection probability, p, is required and the expected value of the count is given by $E(C) = Np$. An estimate of the population is therefore:

$$\hat{N} = \frac{C}{\hat{p}}$$

and as such inferences relating to N require inferences relating to p and failure to account for detection probability can lead flawed inferences[49]

Capture-recapture

Capture-recapture (CR) methods are alternatively referred to as mark-recapture, capture-mark-recapture, mark-release-recapture or sight-resight. CR models have their roots in the 16th century and have been widely used since the late 1800s to estimate a variety of demographic parameters such as population size, survival, recruitment, immigration, and emigration[48,50] and have found application in a variety of other disciplines such as epidemiology and criminology[51]. The basic idea of CR is to capture, mark and release a known number of animals within a population. In a follow-up sampling occasion the proportion of marked animals that are captured allows for estimation of detection probability and hence the number of animals that were missed. Historically, CR data was obtained by physically capturing individuals, but modern technology has produced many detection devices such as cameras, camera traps, acoustic devices, and DNA sampling techniques, all of which can provide individual encounter history data.

Two technical and conceptual problems of traditional CR models have consistently concerned population ecologists: (1) they assume that detection probability at a given trap does not vary between individuals; (2) they do not permit for a direct estimate of animal density since there is no clear definition of the area from which the animals were sampled and there is no biologically meaningful way to determine whether animals captured are constrained to the study area or have their home ranges largely outside of it (see [25, Chapter 1] for practical examples of these problems and the workarounds commonly employed).

Hierarchical models and observation and state processes

Hierarchical models are an ideal tool for assessing ecological patterns and processes at multiple scales, and are extremely flexible and able to accommodate a wide variety of data types. A hierarchical model in the context of estimating density or distribution can be defined as '*a model with explicit component models that describe variation in the data due to (spatial/temporal) variation in ecological processes, and due to imperfect observation of the process*'[25]. Hierarchical models allow for the formal recognition that during a survey there are two different processes, one being how the fieldwork was conducted to collect data (the observation process), and the other being the density and distribution of the species (the state process) under survey. The observation process is primarily concerned with detection probability, which is then used to inform inferences about the density and distribution of a species. In other words, hierarchical models recognise that the density and distribution of a species is not in itself a product of how data was collected, but rather that there is an underlying ecological process occurring, which is separate from our imperfect observation of that process. It is important to note that the traditional methods for surveying lions discussed in Chapter 1 do not generally differentiate between these processes and thus changes in detection probability will directly affect the density estimates.

Spatially-explicit capture-recapture

SECR models are a class of hierarchical models which overcome CR-related problems by making use of the spatial information that is inherent in both state processes (the abundance and distribution of animals) and observation processes (the way a survey was conducted). For example, a major source of detection heterogeneity is related to an individual's movement patterns in relation to the trap locations. An animal with only one trap within its home range will likely have a lower detection probability than an animal with ten traps within its home range. Alternatively, the animal with only one trap within its home range may have a higher detection probability if by chance that trap is at the centre of its home range, whereas the individual with ten traps may have a lower detection probability if all those traps are on the periphery of its home range. SECR models incorporate this spatial element by anchoring the approach in a model that assumes that an individual's detection probability decreases with increasing distance between the individual's home range (or activity) centre and the trap (Figure 3.1). Furthermore, the SECR framework overcomes concerns related to direct estimation of density since it formally links individuals and space, and therefore defines *N* within an explicit spatial region, *S*, the state-space, allowing for direct estimation of density with a measure of precision while accounting for individual heterogeneity in detection probability.

Point process

Spatial point process models are widely used for modelling and analysing spatial data[52]. SECR models are predicated on the assumption that individuals are distributed in space according to a point process model. As such, SECR models describe a point process where the location of an individual i within a population, $S_i = (S_{1i}, S_{2i})$, is treated as a latent variable (unobserved random effect) that is estimated in the face of imperfect detection (i.e. via the observation process). The simplest forms of SECR models assume that these point locations are considered as activity centres that represent the realisation of a Poisson (for applications see [28,53]) or binomial point process (for applications see [2,54]).

Activity centre

In SECR models an activity centre can be conceptualised as the centroid of an individual's activity during the time of sampling. For example, the activity centre of an individual involved in a telemetry study could be the average of GPS fixes obtained during the study. The SECR models we have employed for lions assume that a population has *N* individuals exposed to sampling and each individual (i = 1,2,3, ... , N) has an activity centre, $S_i = (S_{1i}, S_{2i})$, which is a two-dimensional coordinate. In practice, the precise location of individual activity centres is not known for any one individual but is inferred via the spatial encounter histories. These point locations represent the realisation of a point process, wherein a population of activity centres are distributed over a larger region, *S*, the state-space of the point process. The state-space becomes part of the model and so density estimates should not practically change if the size of the area is changed, so long as *S* is sufficiently large to include all individuals with non-negligible probability of encounter (but see[3]).

The probability of detecting lion i in pixel j on sampling occasion k (π_{ijk}) can then be defined by a complementary log-log function of covariates[1], where the probability of detecting an individual at a specific trap, given its activity centre, is a function of the basal detection rate (λ_0), the spatial scaling parameter (σ) and the Euclidean distance between the trap and the activity centre of the individual (Figure 3.1). To estimate population density, the objective then becomes to estimate the number of activity centres per unit area of *S*.

Model inference

Data can be analysed within a variety of applications and packages using either maximum likelihood[28], or Bayesian approaches using Markov chain Monte Carlo (MCMC)[2] methods. Under the likelihood approach, the programme DENSITY is available[26] as are several packages within R including 'secr'[53] and 'oSCR'[54]. Under the Bayesian approach, models have been developed using WinBUGS, JAGS and Nimble[23,24], the programme SPACECAP[55] can handle structured sampling (such as camera traps), while the R package SCRbayes (https://github.com/jaroyle/SCRbayes) is more general and was adapted to fit the unstructured sampling of lions presented in this report (see appendices in[1] for complete code and example input files). We note however that the model construction varies between the different programs. Although MCMC methods have higher computational demands, a Bayesian approach was chosen for this initiative for the following reasons: Posterior inference is valid specifically for the sample size obtained, which is important given that most spatial capture-recapture datasets are relatively small; Investigators are not forced to integrate out *S* (individual activity centers) which provide insights into spatial distribution; The entire posterior of each parameter is available and visually informative of parameter redundancy

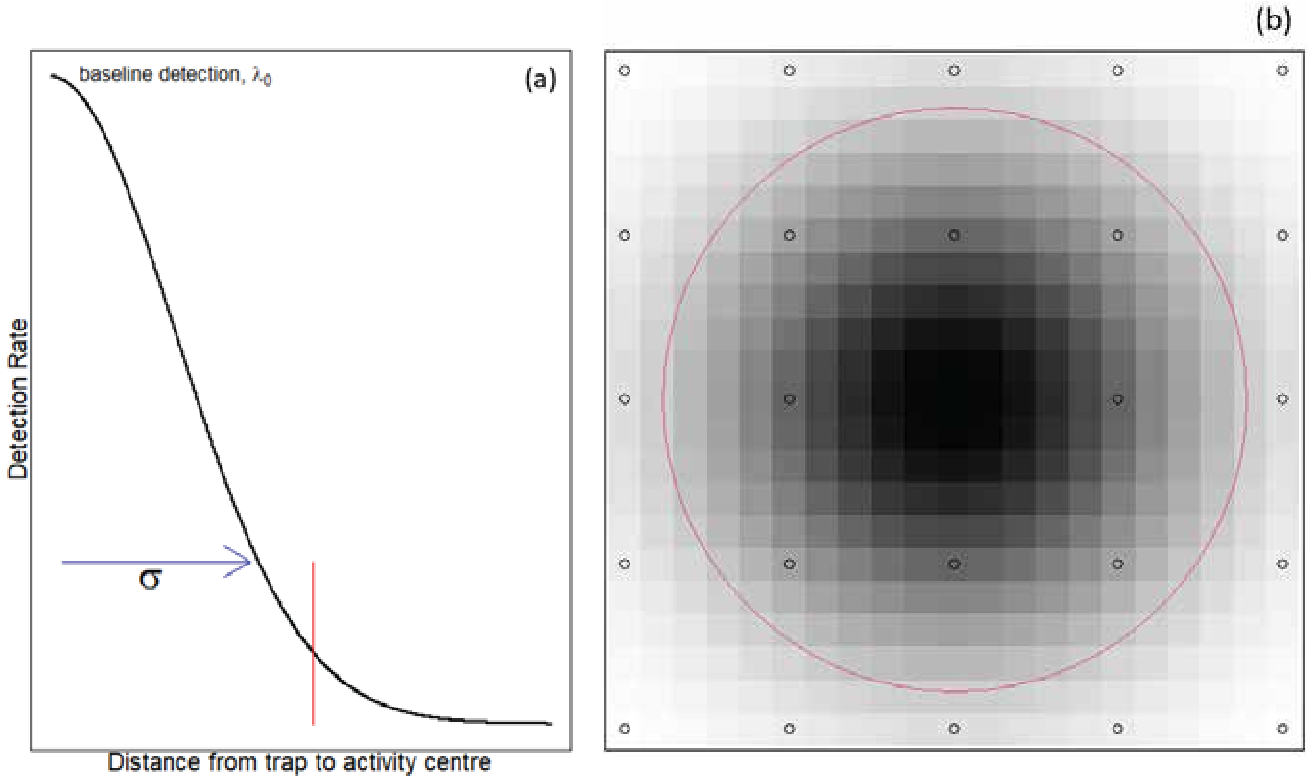


Figure 3.1: *(a) A half-normal detection function was used for all lion SECR analyses. Basal detection rate (λ_0) represents the detection rate when an individual's activity centre (black dot) coincides with a trap location. The spatial scaling parameter (σ) describes how detection rate decreases with increasing distance from an activity centre, thus a larger estimate of σ indicates larger space use during the survey period. Since male and female lions have differing home range sizes there may be different detection rates associated with the different sexes, thus sex-specific covariates were incorporated. A 95% movement radius (red line) is then calculated by $r=\sigma\sqrt{5.99}$; (b) Accordingly, 95% encounter probability can be visualised as a circular area where 95% of the movement outcomes occur within the red circle (calculated via πr^2). Across this area detection decreases with increasing distance from the activity centre as depicted by the gradient of detection probability emanating from the centre of this hypothetical individual's activity centre.*

(or identifiability) as a result of model overfitting relative to sample size.

Sampling design considerations

SECR models are appealing not only because they yield accurate and precise inferences, but also because they can accommodate a variety of field methods designed to obtain individual identities of animals, such as camera trapping, DNA sampling and unstructured search encounter protocols. In the case of lions, obtaining individual identities is not straightforward with camera traps since lions do not have obvious pelage patterns, and DNA methods are costly. As such, search encounter protocols are emerging as a practical and efficient field method[1,14,56]. This field technique relies on vehicle-bound observers that systematically search a given study area, and when lions are found, take close-up photographs so that lions can later be identified through their unique vibrissae spots[57].

Naturally, this field method implies that most of the effort and therefore 'traps', are located along roads. Road networks are unlikely to provide a systematic experimental design where all areas are equally accessible, leading to holes and variability in sampling. In SECR models, holes do not necessarily imply biased results since estimates of abundance are explicitly tied to the state-space and not to the traps, and inferences to individuals that may occur within these holes are only realizations of model predictions which may exclude the holes[25,58].

The nature of these field protocols results in unequal effort being invested both within a single sampling occasion and across the survey period. As such, careful records of effort are typically included as detection covariates in the models e.g. [1,14,59], since investing more effort in a trap is likely to yield more detections (but see[60] for an example where variable effort is not accounted for). Paterson et al.[61] conducted simulations of search encounter data to estimate mountain lion density and concluded that density estimates were unbiased and precise when based on data with high search effort. However, they found that where search effort was correlated with animal density, especially when effort was low, the density estimates had a positive bias. This has important implications in the design of unstructured sampling protocols since effort should not only be focused on areas of high lion density.

Survey implementation

The overall goal of this initiative was to provide information that is used by conservation managers and practitioners and a core objective was for capacity to be built to help ensure long-term, science-based monitoring. To achieve these goals and objectives it was necessary for those organisations and individuals engaged in conservation and research initiatives within each landscape to be directly involved in the entire process of 'their' survey. Therefore, most of the data collection was done by multi-stakeholder teams within each site. The technical team were responsible for overseeing the design and implementation of the survey, trained the data collectors and were data collectors themselves. Those who had participated in the survey were then invited to continue to be involved in data entry and analysis. Two workshops were convened to facilitate and encourage this interest (see Part III). Below is a chronological summary of all the steps undertaken for each survey:

Overseen by the technical team (all steps)

Logistics overseen by KWS area managers, senior scientists and local stakeholders (Stakeholder meeting, Training, Data collection)

Stakeholder meeting	A planning meeting with all relevant stakeholders to (a) define the exact area to be surveyed, (b) develop appropriate site-specific field protocols (c) decide upon what data would be collected, (d) identify data collectors.
Training	Each survey began with all participants attending a four-day workshop: the first day focused on theory and sampling considerations, followed by three days of fieldwork wherein the field protocols were taught.
Data collection	Data collection was aimed at finding and identifying as many individual lions as possible while following the site-specific protocols and keeping a careful record of field effort using customised smartphone applications.
Data management	Photographs were collected regularly by members of the technical team. All other data was sent remotely via mobile data to a central database, which was validated daily to ensure high quality data collection was consistently being collected.
Individual identification of lions	Data collected via smartphone automatically synced to a database. Technical team members (sometimes with assistance from interested local stakeholders) were responsible for sorting and identifying individual lions and inputting those identities according to each sighting.
Data validation	Classification of individual identity at each detection were validated by a second member of the technical team to ensure accuracy. A conservative approach of 'when in doubt, leave it out' was adopted to any ambiguous detections.
Data analysis	Input files were prepared and validated for analysis. A set of candidate models were defined a *priory* and analysis was conducted on advanced computing facilities.
Model diagnostics	A series of model diagnostics were used to assess the MCMC convergence and mixing of chains in addition to model specification.
Model inference	Inference on model choice was informed assessing model adequacy (Bayesian P-value), visual inspection of pair-wise correlation plots between estimated parameters and the harmonic mean estimator of the marginal likelihood.

Figure 3.2: *A chronological summary of the different steps involved in each survey. More details on each section as provided in the following sections.*

Stakeholder meeting

Before each survey began a meeting was held with key local stakeholders. The purpose of these meetings was to (a) decide on the exact area to be surveyed, (b) discuss and define appropriate field protocols that were adapted to each area, (c) decide the duration of the survey while cognisant of not violating assumptions relating to closure[62], and (d) decide upon what data would be collected. Following these decisions, field protocols and data collection systems were formulated. A freely available software, CyberTracker (www.cybertracker.org), was used to collect field data during all surveys. CyberTracker allows users to create customised data collection applications that are installed onto a smartphone and make use of existing systems to record spatial and temporal metadata together with sightings, in addition to recording tracks associated with drive effort. These applications were customised for each survey according to decisions reached in (b) and (d) above.

Training

All primary data collectors undertook a four-day training. The first day was concerned with ensuring that data collectors received a foundational knowledge of the core principles of the study design and a solid grasp of the field protocols. This was achieved via a series of PowerPoint presentations, followed by discussions. Most importantly it was reiterated that search effort must be recorded at all times, and that whenever lions were detected, every effort should be taken to obtain multilateral photographs of each lion present. In other words, detections of lions that were not photographed well enough to unambiguously identify to individual level would not be included in the analysis. Over the next three days a member of the technical team would join the data collector in the field to ensure they understood the protocols, were proficient at using the survey equipment, were correctly entering the data and able to reliably conduct the survey.

Data Collection

The goal of the fieldwork was to find and identify as many individual lions as possible, as many times as possible and ensure maximal coverage of the defined study area. This was achieved by searching for lions, and once located, the observers made every effort to take high-resolution photographs. To locate lions, a variety of different field protocols were deployed. For each survey, a unique field sampling protocol was created that reflected the conditions of fieldwork in each area. These field methods were carefully recorded during fieldwork and incorporated into the statistical framework to estimate and account for detection probability associated with each field protocol. A customised application was created within the CyberTracker software and installed onto GPS-enable smartphones which were carried by data collectors at all times. The following field methods were used, frequently in combination with each other:

Unstructured search encounter

Observation teams actively and systematically searched the survey area for lions. They were not asked to stick to transects or roads but rather to use their knowledge of the area and their field skills in order to find lions. Drive effort was continuously recorded via the CyberTracker application which was customised to take a GPS point every 10 seconds, thus retaining a finely detailed account of the search effort. Efforts were made to cover the survey area in a uniform manner, and the technical team would regularly advise teams as to which areas should receive more attention. When sampling at night, a powerful spotlight was used to scan the surroundings from an elevated position as the vehicle moved. See [1] for a detailed description of this protocol.

Playbacks

In areas where lions were more difficult to find or were more cryptic, playbacks were made use of, in conjunction with the unstructured search encounter protocol. Playback sites were not systematic or pre-determined but chosen either when fresh tracks had been found or in an attempt to improve detection rates. Lions were attracted to the vehicle at night by means of playback sounds broadcast at 95DB. Standard sounds were used that are known to attract lions[63].

Upon arrival at a site, observers selected a site for the vehicle that was relatively concealed yet allowed for photography and waited in silence for ten minutes, then broadcast for five minutes, repeating this cycle and rotating the speaker 90° until four broadcasts had been completed or lions had appeared. In this manner, each playback lasted 70 minutes and the spatial location and date of each playback was recorded. During the night, when lions were found or attracted to the vehicle by playback a spotlight (both white-light and red filter were used) was switched on before slowly focusing it on the animal and taking photographs with the aid of the inbuilt camera flash.

Unstructured foot patrols

If lions were deemed impossible to see while using the unstructured search encounter protocol and playbacks were unlikely to yield many detections, we made use of skilled trackers who conducted foot patrols within an area to search for fresh lion tracks, while recording a track of their walk effort. When tracks were seen a vehicle was called in and would either follow the tracks to the lions or call them out using a speaker in order to take the necessary photographs.

Conditional drive effort

This protocol was only used for the drive effort that was invested between the location at which a tracker had found lion tracks and the eventual detection (or not) of a lion as the tracks were followed.

Data Management

Data was collected via two vital pieces of equipment: A smartphone and a high-quality digital camera. Data from the former was sent daily (if signal permitted) via mobile data to a central database where members of the technical team would receive and manage it. This would also be used to inform which areas required additional subsequent search effort. Data from the cameras was collected regularly by members of the technical team who would then sort the images such that one sighting of lion(s) would be grouped in one folder and named according to date, number of lions seen, the observers initials and the general location of the sighting. Within this folder, sub-folders would later be created to house all the images for each individual that was detected at that sighting.

Individual identification of lions

Whenever possible, a series of close-up photographs were taken of each individual from multiple different angles in order to obtain records of their whisker vibrissae spots. The pattern of these spots is unique to each individual[57], and was used in combination with other distinguishing features, such as ear tears, dental wear, permanent and temporary scars, age and sex, to create ID cards for different individuals. Each individual was assigned a unique ID and a gender based on secondary sexual characteristics and estimated to be under or over the age of one year based on phenotypic features such as body size, shoulder height, nose pigmentation and mane development[64,65]. Photographs taken at subsequent sightings were then visually compared to existing ID cards and if these photographs matched existing ID cards, this was considered a recapture, whereas if it did not match, a new ID card was created (Figure 3.4 and 3.5).

Since lion mortality is highest during the first year[38], we excluded all individuals estimated to be less than one year of age, as including them would likely violate the population closure assumption of mark-recapture models[48].

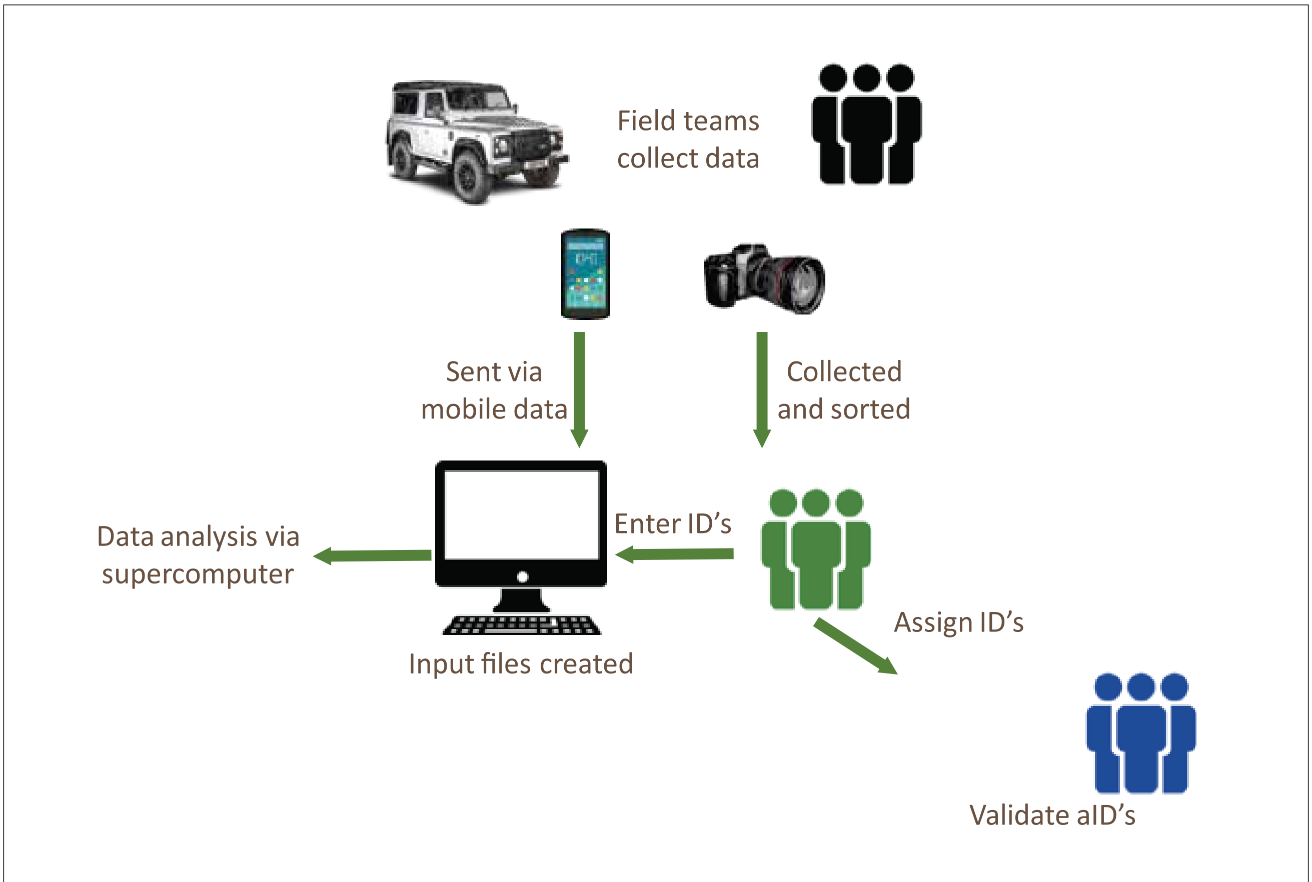


Figure 3.3: *A schematic showing how data collected in the field was inputted into a central database and analysed.*

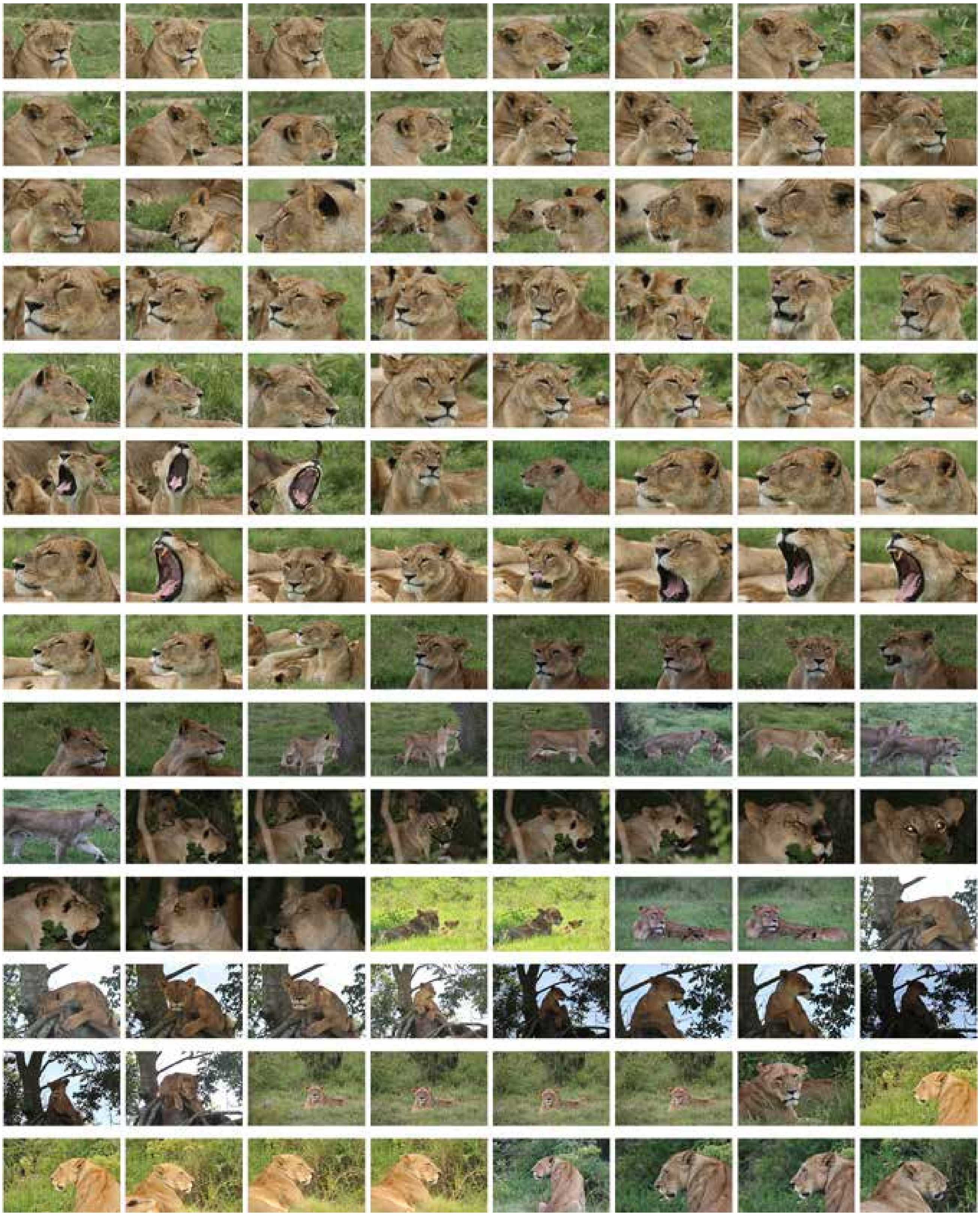


Figure 3.4: *Whenever possible, multiple photographs were taken of each individual lion at each sighting. All field teams had received an intensive three-day training on field protocols for the survey. Once lions were found, field teams were instructed to take as many photos of each lion as possible, from different angles. The above images are a sample of photos taken on seven different occasions of one individual (see Figure 3.5 for the catalogue). All images were later sorted according to individual lion and cropped to extract distinguishing features such as whisker vibrissae spots, ear tears and dental wear that can be used to distinguish individuals[57]. Each individual was assigned a unique ID and a gender based on secondary sexual characteristics and estimated to be under or over the age of one year based on phenotypic features such as body size, shoulder height, nose pigmentation and mane development[64,65].*

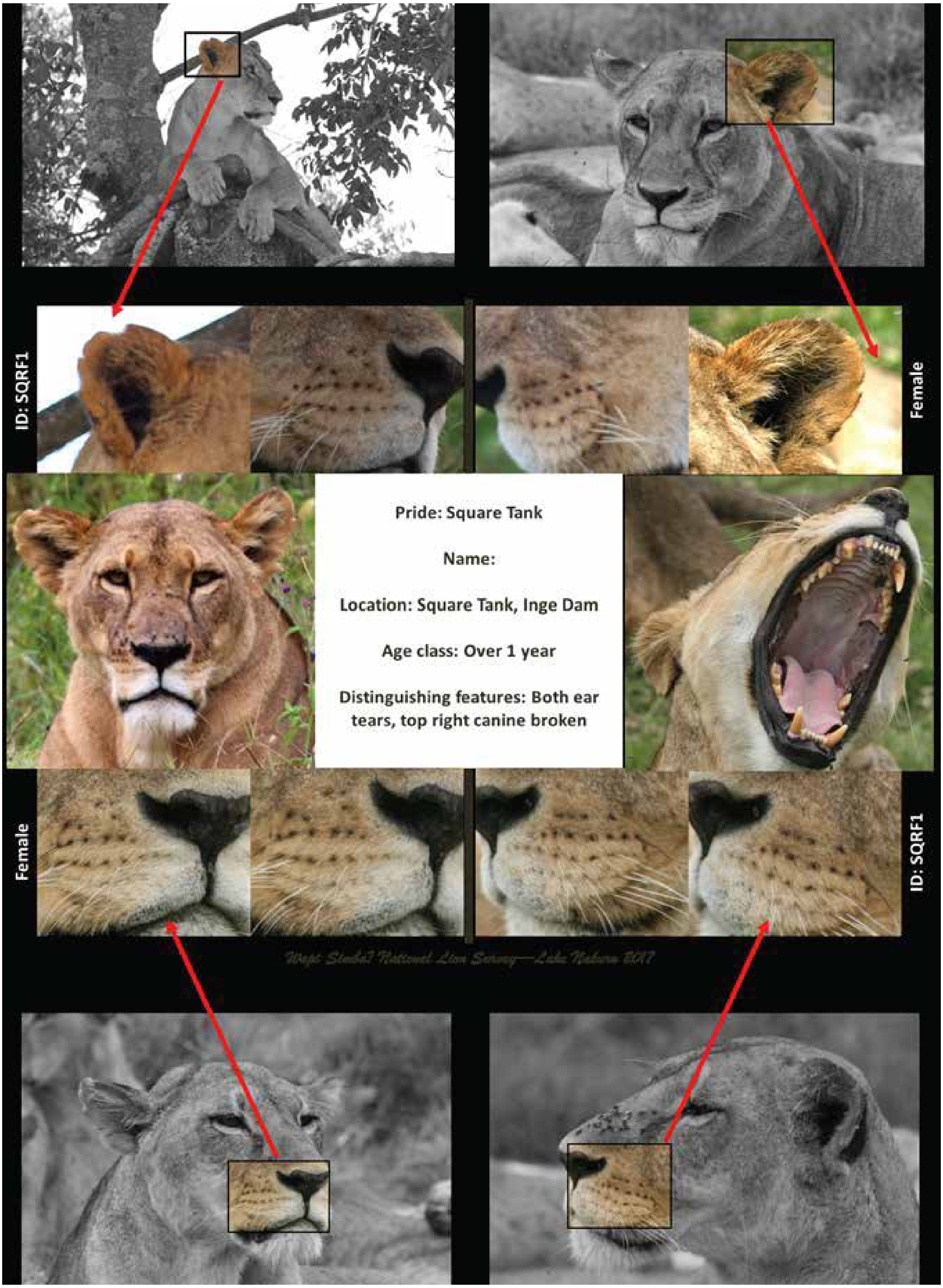


Figure 3.5: *Whenever possible, multiple photographs are taken of each individual lion at each sighting. These images are cropped to extract distinguishing features such as whisker vibrissae spots, ear tears and dental wear that can be used to distinguish individuals[57]. Cropped images are then added to ID cards where each individual is assigned a gender, unique ID and age class. Age class is estimated based on phenotypic features such as body size, shoulder height, nose pigmentation and mane development[64,65]. Photographs taken at subsequent sightings are compared to existing ID cards to distinguish recaptured individuals from new individuals, thus allowing the compilation of a capture history of which individuals were seen, where and when. Figure sourced from[14].*

Data Validation

Each detection was verified by at least one other experienced person to ensure the accuracy of each identification. Where differences occurred, these were discussed and if consensus could not be reached on the identity of a lion at a detection, it was left out of the analysis and a conservative approach was adopted whereby any doubts about identity resulted in omitting that detection from the analysis. A database for each survey was created that included a list of all individuals seen, their unique code, sex, estimated age and a spatial encounter history of each individual. Each sighting contains information on the date and time an individual was seen together with the exact coordinates of the sighting. This database will form the basis of all future surveys in each area that will enable population trend analyses.

Data analysis

For the Observation Process (Figure 3.6)

To define the manner in which individuals were detected during the survey (observation process) we compiled a standard spatial capture-recapture matrix[55] consisting of individuals, trap locations (defined by pixels), and sampling occasions. During fieldwork we recorded which individuals were seen in which pixel on which day. Because the intensity of search effort and the type of search effort could influence the probability of detecting lions, we included additional covariates to account for the intensity and type of effort invested in each pixel on each day. As such, we used an unstructured spatial capture-recapture sampling design[1,59].

Male and female carnivores frequently have variable home range sizes—male lions tend to move more and have bigger home ranges than females, which may influence their detection rates[66]. Therefore, we included sex-specific covariates when defining the observation process to account for potential variation in movement and detection probability between male and female lions.

For the State Process (Figure 3.7)

To define the region for estimating density and spatial distribution of lions (state process) we created a state-space by creating a buffer around the study area. This buffer size varied depending on our expectations and observations of lion movement within a survey area. Theory suggests that the buffer size should be large enough such that individuals which have their activity centre outside this area will have negligible detection probability within the survey area during the survey. However, another study demonstrated that density estimates are robust under some violations of this assumption[3]. Within this buffer, we generated potential lion activity centres represented by equally spaced pixels. Studies have shown that pixel size should not exceed 1.5 times the movement parameter[67] in order to limit estimation bias. Pixels that were not suitable for lions (e.g. agricultural lands, towns) were masked out of the analysis[2].

The value of *M* (which represents the maimum number of lions possible within the state-space and is required under the Bayesian approach) was set prior to analysis and redefined if necessary, based on the outputs.

K. Sankan during the Nakuru Survey © N. Elliot

Figure 3.6: The Observation Process

The observation process models how we carried out the fieldwork (the sampling regime) with the aim of estimating the detection probability of lions.

(a) For example, in the case of NNP, we conducted a search-encounter survey by systematically driving the survey area repeatedly while looking for lions as shown by the tracks driven.

(b) Since we are likely to find more lions with increased search effort we account for this by creating grid cells or 'traps' of where we have driven.

(c) Next, we total up the distance driven per trap per day. For example, the data in red shows that trap number 2 was not sampled during the first two days of the survey while 587m was driven on the third day. For each field protocol a separate matrix is created.

(d) When lions are seen, close-up photographs are taken of each individual. The date and coordinates are recorded so that we know the day and trap a lion was seen, which corresponds to the drive effort.

(e) Once the survey is complete the individual lions are differentiated from their photographs and a 'capture history' is created that details which individuals were seen in which traps on which days. Here the data in red shows that lion number 2 was seen in trap 3 on day 1 and in trap 57 on day 9.

(f) Male lions typically have larger home ranges than female lions and this, together with other potential differences, may mean that there are different detection probabilities associated with each sex. We make note of the sex of each lion while in the field.

(g) This information is included as sex-specific detection covariates in the analysis. The data in red states that individual 2 is a female while individual 3 is a male.

In our models, the probability of detecting a lion i in pixel j on sampling occasion k is defined by a complimentary log-log function of covariates:

$$cloglog(\pi_{ijk}) = log\ \lambda_0 + \beta_{eff}\,[\log(effort_{jk})] + \beta_{sex}\,(sex_i) - f\,[dist(i,j)|\theta,\sigma_{sex}]$$

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}. Call-ups were incorporated as indicator variables.

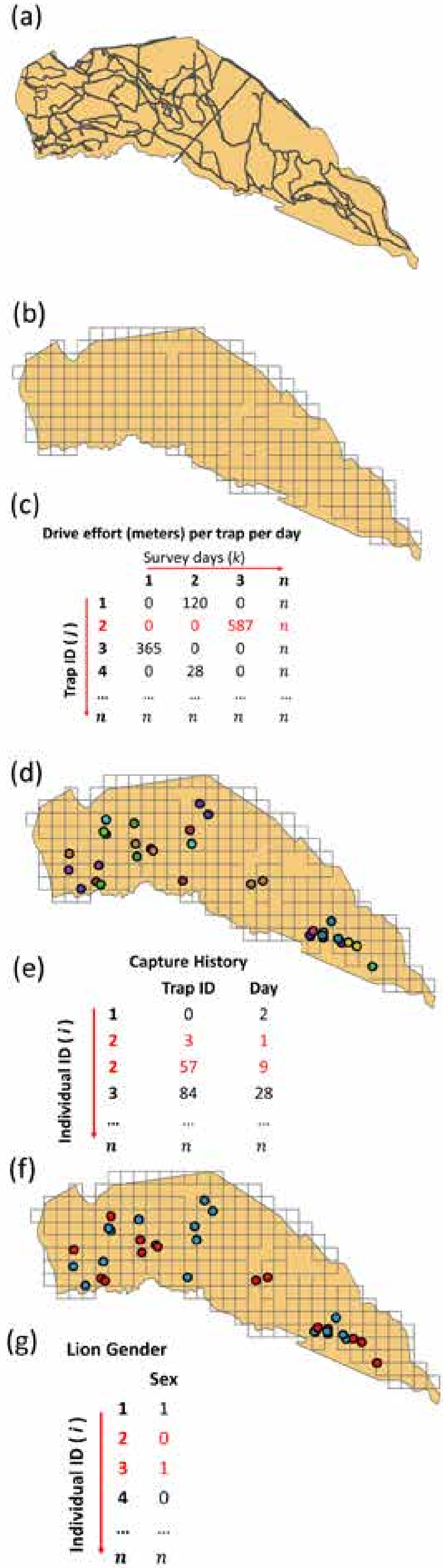


Figure 3.7: The State Process

Our goal was to determine the density and distribution of lions in any given landscape. To do this, we define a state process[1,2]. To illustrate the concepts, Nairobi National Park is used as an example (a).

(b) First, we define a 'state-space', by creating a buffer around the survey area, see the 20km^2 red outline. This area should be large enough such that individuals which have their activity centre outside this area will have negligible detection probability within the survey area during the survey (but see [3]).

(c) Next, we distribute potential activity centres (pixels) of individual lions *i* across the state-space *S*. A fine grid size that approximates a continuous space is preferred, and in the case of Nairobi was 0.25km^2.

(d) Because not all areas of the state-space are habitable by lions, we then mask out certain areas as 'unsuitable habitat', as shown by the greyed-out areas.

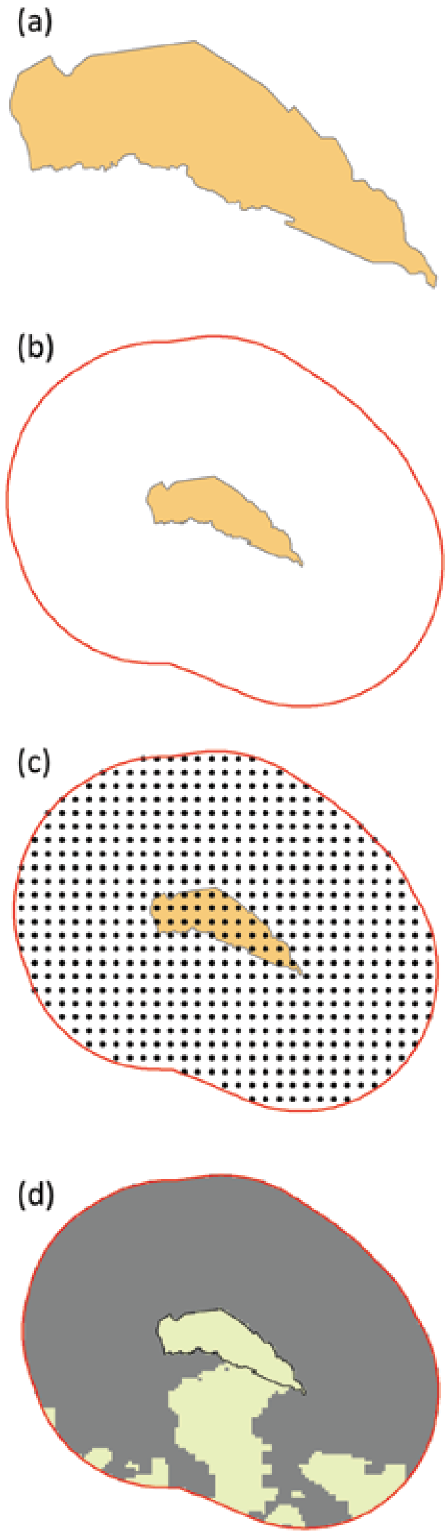
(e) This information is then tabulated, where each potential activity centre is given an X and a Y coordinate and is assigned a value of suitable habitat (1) or unsuitable habitat (0). So, we have R pixels of suitable habitat.

Within the large state-space we then define a data augmented upper bound of lion abundance (*M*), which comprises the number of individuals observed during a survey (*n=22* in the case of Nairobi) and the number of individuals augmented for the analysis n_z=278 in the case of Nairobi.

The state process includes a model component to estimate the abundance of lions *N* and this is defined by

$$[N \mid M, \psi] \sim Binomial(M, \psi),$$

where ψ is the probability that an individual chosen from a fixed *M* is a member of the population. In addition, the *M* individuals are assumed to have their activity centres located in the *R* pixels following a multinomial distribution, with a prior occupancy probability of 1/*R* for each individual.



(e) Potential activity centres

Potential indiv (S_i)	X	Y	Habitat
	270000	9820500	1
	270500	9820500	1
	...	...	...
	n	n	n

Candidate models

To estimate lion density and abundance we used a Bayesian spatially explicit capture-recapture (SECR) framework. Four *a priori* models (see Table 3.1 for parameter definitions) were defined and the detection function parameter was fixed to 1, which implies a fixed, half-normal detection function:

Model 1: $N(.)$, λ_0 $(sex{+}effort), \sigma(sex)$ - based on the assumption that basal encounter rate and the rate of decline in detection probability are sex-specific.

Model 2: $N(.)$, λ_0 $(effort), \sigma(sex)$- based on the assumption that basal encounter rate is independent of sex and the rate of decline in detection probability is sex-specific.

Model 3: $N(.)$, λ_0 $(effort), \sigma(.)$-based on the assumption that basal encounter rate and the rate of decline in detection probability are independent of sex.

Model 4: $N(.)$, λ_0 $(sex{+}effort)$, $\sigma(.)$ - based on the assumption that basal encounter rate is sex specific and the rate of decline in detection probability is independent of sex.

We ran the models in the programming environment R[68], using the same priors as Broekhuis & Gopalaswamy[69] and adapted the code provided by Elliot & Gopalaswamy[1] to include the four field effort types as appropriate. This code implements a Bayesian Markov Chain Monte Carlo (MCMC) approach using the Metropolis-Hastings algorithm (Tierney 1994) to fit the models. We set four chains to run for each model, with each chain defined to initially be between 11,000 and 150,000 iterations. We discarded outcomes from the first 1,000 iterations as burn-in.

Parameters and their definitions

While the primary motivation of the national lion survey was to estimate lion density and abundance at each site, the models implemented also provide other important ecological insights. These provide a valuable snap-shot and serve as a baseline for future comparisons (see Table 3.2).

Model Diagnostics and Inference

We assessed convergence using the Gelman-Rubin diagnostic[70], and by examining trace and autocorrelation plots and discarded more initial iterations if convergence was not achieved. If non-convergence persisted, we re-ran the analysis with longer chain lengths until convergence was achieved.

We used the following approach to draw inference on model choice: First, we checked each model for adequacy using the Bayesian *p*-value assessment based on individual encounters[2]. We employed this tool as a model rejection tool, rather than a model selection tool; second, we created pair-wise correlation plots between estimated parameters from the posterior MCMC draws. These were visually inspected to assess identifiability issues relating to model over-fitting relative to sample size.

Table 3.1: *Parameters estimated during Bayesian spatially explicit capture-recapture (SECR)*

Parameter	Definition
σ_F	Rate of decline in detection probability as a female lion's activity centre increases as a function of her distance from the centroid of a grid cell
σ_M	Rate of decline in detection probability as a male lion's activity centre increases as a function of his distance from the centroid of a grid cell
β_{sex}	The difference of the complementary log-log value of detection probability between a male and female lion
β_{eff}	The rate of change in the complementary log-log value of detection probability as the (log) effort changes by one unit, where effort is measured in kilometers
λ_0	The basal encounter rate of a female lion whose activity centre is located exactly at the centroid of a grid cell
ψ	Proportion of the true number of individuals in the data augmented population M
N_{super}	The total number of lions in the larger state-space *S*
ψ_{sex}	The proportion of lions that are male: $\text{Sex ratio} = \dfrac{1-\psi_{sex}}{\psi_{sex}}$
θ	Determines the shape of the estimated detection function. The value of θ ranges from 0.5 (a version of the exponential form) to 1 (Gaussian)
D	The estimated density of lions/100km^2

We were particularly concerned to explore if any correlation was influencing the abundance parameters; Finally, although there is no established model selection method proven to work well for Bayesian SECR models such as ours, a recent development using simulations shows promise (see equation 2.6 in [71] noting that the SECR models used by them were different from ours). We considered the adequate models obtained from the first step and, as recommended by Dey et al.[71], we applied the harmonic mean estimator of the marginal likelihood using the MCMC draws. As such, our model choice was influenced by all the criteria described above.

Estimating density and abundance

Although, we have described the SECR model involving two distinct processes (the state and observation processes), it should be noted that the Bayesian SECR model is a single model. Hence, all the parameters (see Parameters and their definitions) and latent variables in the model are estimated simultaneously. The state process involves a model component to estimate abundance, N, which is defined by $[N \mid M,\psi] \sim Binomial(M,\psi)$, where ψ is the probability that an individual chosen from M (the data-augmented value of abundance in the larger state-space) is a member of the population. If R is the total number of pixels defined in the state-space, the animals occupy the pixels according to $(c_1, c_2 \ldots c_R) | N,(p_1, p_2 \ldots p_R) \sim Multinomial[N,(p_1, p_2 \ldots p_R)]$, where $(c_1, c_2 \ldots c_R)$ represents the number of animals at each pixel, and $(p_1, p_2 \ldots p_R)$ represents the pixel-specific occupancy probabilities of the R pixels. Before confrontation with the data, we may consider $(p_1 = p_2 = \ldots = p_R)$, so that the prior probability of an individual occurring at a randomly selected pixel is 1/R[25].

Population abundance and density can alternatively be estimated within a subset of S, for example the boundaries of a National Park, conservancy or the study area as a whole. This then is equivalent to estimating the number of activity centres within that boundary or polygon. Therefore, if a polygon P has an area $A(P)$ and the number of activity centres within that polygon is $N(P)$, then density for that polygon is $D(P)=N(P)/A(P)$.

Abundance within each survey area

We calculated posterior mean abundance across each survey area by multiplying the size of the study area by the density of lions (per 1km^2) and computed posterior standard deviation (PSD) and 95% Highest Posterior Density Intervals (HPD) of abundance. We interpret this as an estimate of the number of resident lions within the survey area.

Abundance within the 1 sigma area

The boundary of a survey area may be a little arbitrary since lions do move in and out of wildlife areas and frequently reside on the edges. In order to include these individuals we added a meaningful buffer around the sampled traps. Furthermore, the quality of the lion habitat appeared to drop significantly beyond most areas which were intensively sampled. With the absence of covariates to clearly specify these differences, we expected an overestimation of abundance if we specified a buffer size on the basis of the 95% movement radius[25] (Figure 3.1). Hence, we took the conservative approach of adding a buffer based on only one unit of the scale parameter (σ) estimated in the SECR models. This parameter is indicative of movement and for each survey we created a buffer around the sampled area based directly on the mean (weighted by the sex ratio) of the sex-specific estimate of σ. Within this buffer we took the sum of all pixels based on all iterations of the MCMC output and computed the posterior mean and posterior standard deviation of abundance.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Chapter 4

Lake Nakuru National Park

Note: The Lake Nakuru National Park survey was published in the peer reviewed journal Conservation Science and Practice and is freely available at https://doi.org/10.1111/csp2.217

Survey Area

Lake Nakuru National Park (LNNP, centred at 0.39S, 36E) in Kenya's Rift Valley is approximately 188km², and completely encloses a soda lake (Figure 4.1). LNNP is uniquely important in Kenya as it is a Ramsar Site, World Heritage Site, a Rhino Sanctuary and one of Kenya's most visited National Parks[72]. In recent years, the lake water level has risen dramatically: in 2010, it occupied 31.8km² rising to 53.3km² in 2017. Thus, total land area during the survey was ~134.7km². Long-term mean annual precipitation is 869 mm/year with peaks in rainfall between April–May, August, and November[73]. The study area is bordered by Nakuru city (north), intensive agricultural lands (west and south) and Soysambu Conservancy (east). LNNP was gazetted in 1968 and due to its status as a rhino sanctuary is encompassed by a chain-link fence (1976) and an electric fence (1986), designed to prohibit wildlife movement and deter poaching, but is occasionally breached by lions and other carnivores (KWS, unpublished data). However, such breaches are rare as the fence is patrolled and maintained on a daily basis.

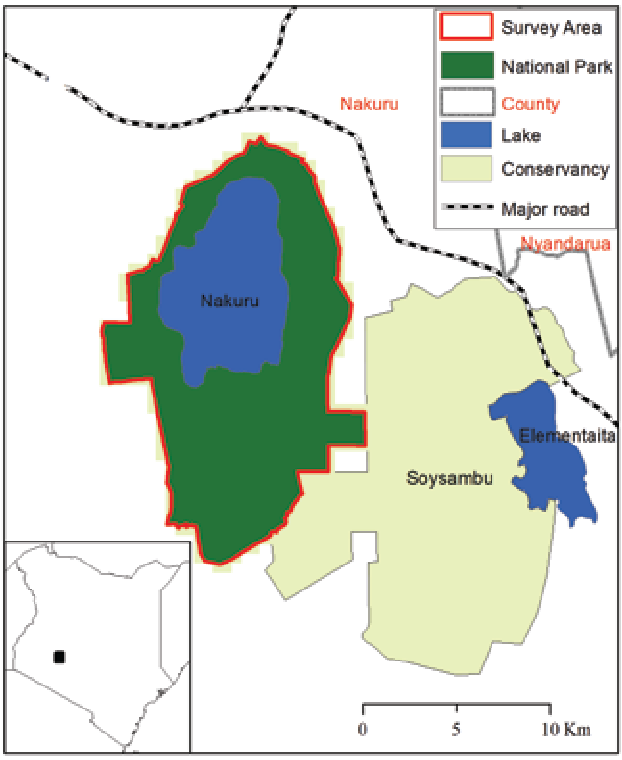


Figure 4.1: *Map showing the survey area. This survey was the pilot study for the national survey and did not include Soysambu conservancy, which at the end of 2019 was thought to contain 5 individuals over the age of one, only one of which is a breeding age female (K. Combes, personal communication, December 2019).*

The resulting genetic isolation of LNNPs wildlife, together with the nearby urban centre, intensive agriculture, altered physiochemical characteristics of the lake water, invasive plants and historic heavy metal dumping have resulted in various threats to wildlife[74-76].

Lion Population

Between 1984 and 1992 a founding population of six lions (one male and three females from Aberdare National Park, one male from Nairobi National Park and one female from Tsavo National Park) were introduced to LNNP[77,78]. Assuming the three females from Aberdare National Park were related (possibly also to the male), it is likely that this translates to three or four founder lineages. No known immigration has since occurred. In June 2014 two adult females breached the fence and settled in neighbouring Soysambu Conservancy. These lionesses occasionally return to LNNP and mate with the resident males. At the time of our survey, Soysambu was thought to contain 14 individuals (eight > one year old, K. Combes, personal communication, September 2017).

In recent times, lions originating from LNNP that have engaged in livestock depredation either within Soysambu or outside LNNP have occasionally been translocated to other wildlife areas (four lions in 2016, two lions in 2017 and two lions in 2018[79]). While no systematic surveys had previously been conducted, reports suggest a population of 65 lions in 2002[80] and 56 lions in 2010[81]. However, both figures were based on raw counts without systematic individual identification of lions, and routine ground mammal counts between 2010 and 2017 recorded opportunistic sightings of between six and 16 individuals[79].

Analysis

Although Soysambu Conservancy is known to be suitable lion habitat, the electric fence separating the two areas precludes movement except on rare occasions when a hole appears briefly (e.g. from animals digging) before being fixed by park fence attendants who regularly patrol the fence while undertaking routine fence maintenance. The non-regularity of these fence gaps prohibits free movement. Thus, an explicit assumption was made that the LNNP population was geographically closed during the survey and all pixels that fell outside LNNP and those that fell within the lake itself were masked out (Figure 4.2). For more details see[14].

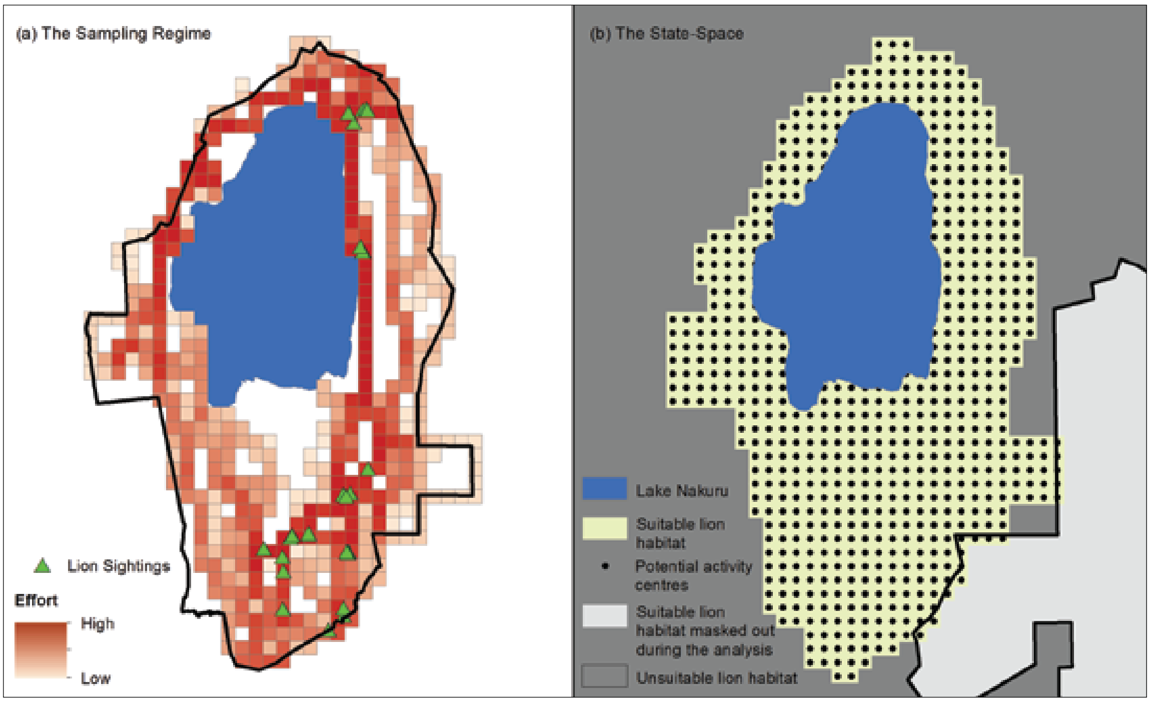


Figure 4.2: *(a) The sampling regime. Search encounter tracks totalling 2,579km were discretised into 0.25km² pixels such that each pixel depicts drive effort per pixel per day. This effort resulted in 54 detections of 10 lions. (b) The state-space. Potential activity centres were represented by equally spaced pixels (0.25km²). Thereafter pixels that were deemed to be unsuitable habitat (Nakuru city to the North and agricultural lands to the West and South) or suitable but inaccessible habitat (Soysambu Conservancy) were masked out prior to analysis.*

Fieldwork Summary

Table 4.1: *Summary data and information for the Lake Nakuru National Park lion survey*

Survey dates	11 September - 02 October 2017
Survey length	22 days
Resources	2 vehicles
Survey area	135km²
Field teams	Kenya Wildlife Service, Lion Guardians and the Kenya Wildlife Trust
Field methods	Unstructured search-encounter
Search-encounter driven	2,579km
Lion detections	54
Km driven for 1 detection	48
Individual lions >1yr identified	10

Survey Results

Table 4.2: *Posterior summaries of parameters estimated from a Bayesian spatially explicit capture-recapture model used to estimate spatial lion density in Lake Nakuru National Park. Posterior summaries presented below are from Model 2 and include the estimate (posterior mean) of each parameter, together with posterior standard deviation (PSD) and highest posterior density (HPD) intervals. Number of posterior samples used was 200,000. Maximum value of potential scale reduction factor = 1. Bayesian P-value = 0.794. See Chapter 3 for more details.*

Lions over 1 year old		Estimate	PSD	95% HPD
Number of lions	within survey area	11	1.5	10-14
	within 1σ area	11	1.5	10-14
Density (lions per 100km^2)		6.7	1	5.9-8.3
ψ_{sex}		0.4	0.2	0.1-0.7
Sex ratio derived from ψ_{sex}		1.4♀: 1♂		

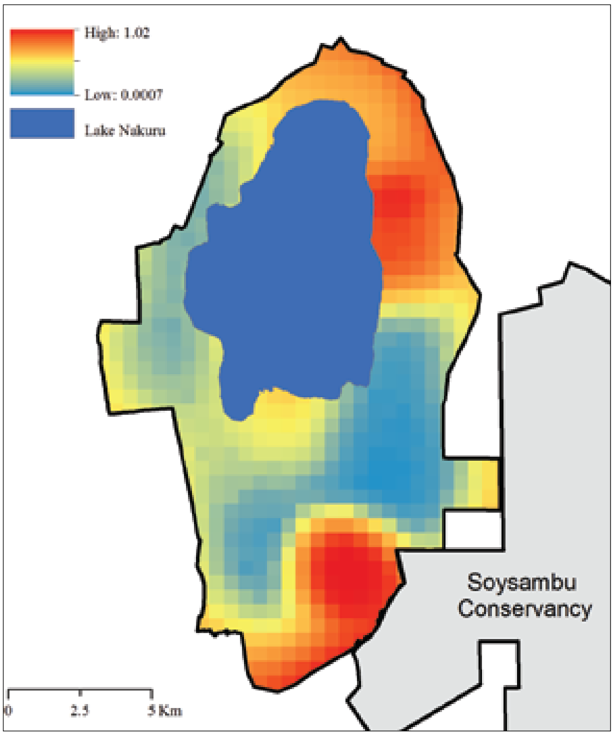


Figure 4.3:*Pixel-specific lion density expressed in units of individual lion activity centres per state-space pixel (0.25 km^2) in Lake Nakuru National Park, Kenya.*

Discussion

Our survey estimated 11 lions over the age of 1 year. A previous report suggested there were 56 lions in LNNP in 2010[81]. However, this was the result of a 'raw count' and every lion seen was considered a new individual. Lions were not systematically identified, and it is extremely likely that double counting occurred.

Furthermore, since lions are regularly seen in LNNP this could have created the perception that lions were more numerous than they were.

Since the previous figure was not based on a systematic survey, we cannot draw conclusions about population trends.

While at the time of our survey neighbouring Soysambu Conservancy was thought to contain eight lions over one year, the Soysambu population was thought to only consist of five individuals over one year and only one of which is a breeding age female (K. Combes, personal communication, December 2019). Future conservation and monitoring efforts should consider both Soysambu Conservancy and LNNP jointly.

The results of this survey have important management implications. Small, isolated lion populations tend to have three things in common: overpopulation, genetic degradation and increased susceptibility to catastrophic events. Although there is no estimate of lion carrying capacity in LNNP, it is possible that the population is supressed due to genetic degradation, resulting from inbreeding which lowers fecundity and increases sperm abnormalities, juvenile mortality, and susceptibility to disease[82-84]. Therefore, the genetic integrity of this population should be explored as a priority. Thereafter, long-term management interventions can be designed to mimic natural processes, such as dispersal, and male tenure over prides. This can be achieved for example, by translocating dispersal-age males out of LNNP and introducing new lions into LNNP. Long-term monitoring using SECR methods should go hand-in-hand with such interventions. Scientific sampling techniques, although more resource intensive than traditional methods, should be an integral component of small reserve management.

This survey has been published in the scientific literature and readers looking for more detail and discussion on the lions in Lake Nakuru National Park can freely access the paper at https://doi.org/10.1111/csp2.217

Chapter 5

Maasai Mara Ecosystem

Survey Area

The survey area (centred at 1° S, 35° E with elevation c. 1,700m) consisted of the Maasai Mara National Reserve (which includes the Mara Triangle) and eleven neighbouring wildlife conservancies (Figure 5.1). The MMNR is managed by the County Government of Narok (east of the Mara River) and Mara Conservancy (west of the Mara River), while the conservancies are managed by different management companies. The conservancies were formed through partnerships between Maasai landowners and tourism companies, whereby landowners receive a fixed, monthly payment for leasing their land for wildlife-based activities[85,86].

The survey area borders the Serengeti National Park in Tanzania to the south, intensive agricultural land to the west and pastoralist settlement to the east. The human population in the areas surrounding the Serengeti-Mara is estimated to have increased by 2.4% per year from 1999 to 2012[87]. The MMNR, wildlife conservancies and surrounding unprotected areas are not separated by physical barriers thus allowing for free movement of animals.

However, land subdivision has resulted in a proliferation of fences being erected outside the wildlife areas to secure grazing for livestock and there are concerns that these fences might impede the movement of wildlife[88].

Precipitation in the area decreases with increasing distance from Lake Victoria (southwest of the study area) and ranges from 1,300 mm in the northwest to 650 mm in the southeast[89]. The dry season spans from July to October and the wet season from November to June with two distinct periods: the short rains (November–December) and the long rains (March-June)[90]. The MMNR is characterised by open plains dominated by Red oat grass (*Themeda triandra*), interspersed by occasional trees (*Vachellia spp.*) or clumps of bushes (*Croton dichogamusand Eulcleadivinorum*). The wildlife conservancies in the north and northeast of the study area consist mostly of *Croton* thickets (*Croton dichogamous*) and *Vachellia* woodlands[91].

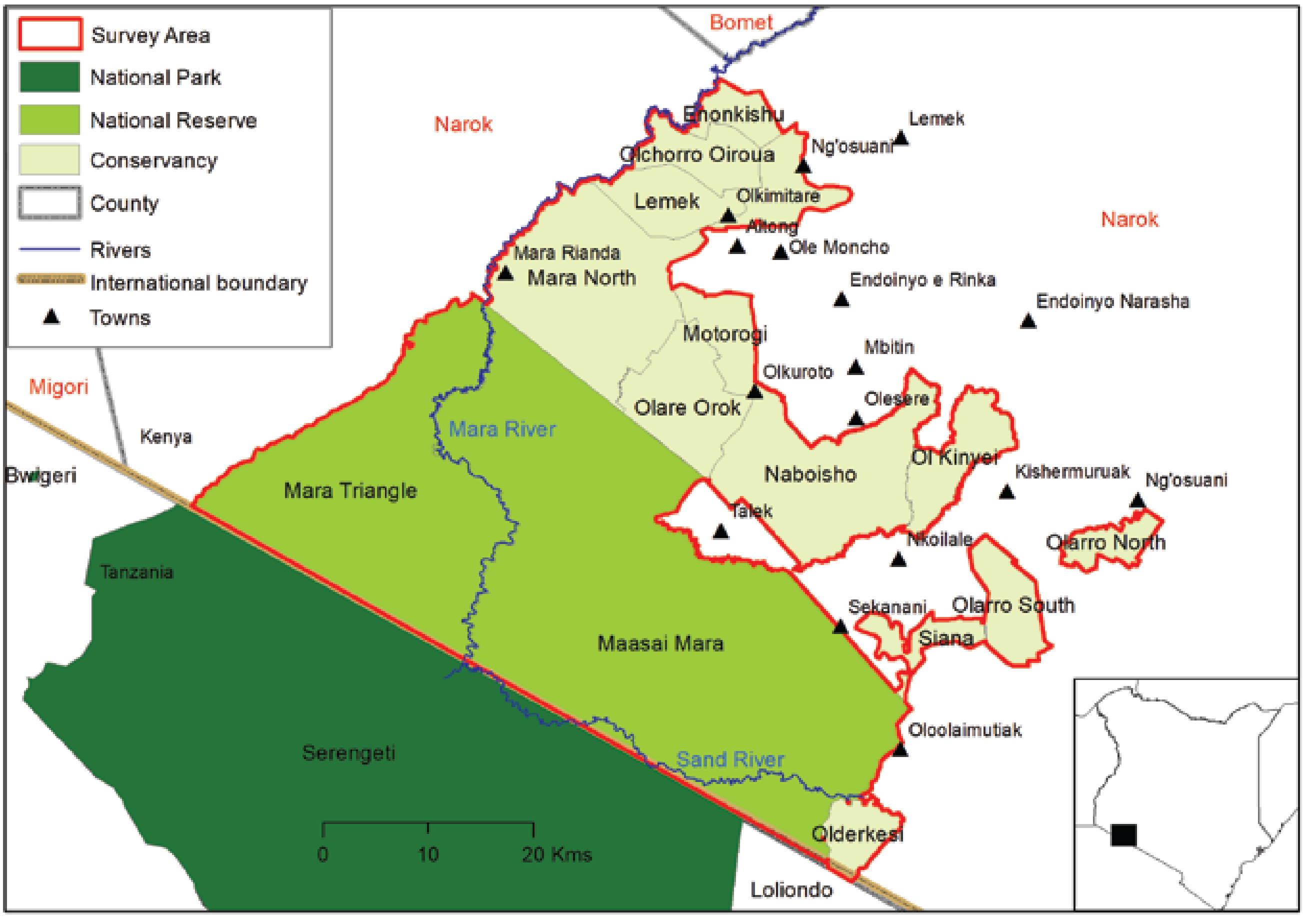


__Figure 5.1:__ Map showing the areas surveyed. This included the Maasai Mara National Reserve, the Mara Triangle and the following conservancies: Mara North, Lemek, Ol Chorro, Enonkishu, Olare Orok, Motorogi, Naboisho, Ol Kinyei, Siana, Ol Derkesi, Olarro North and Olarro South.

Lion Population

Until recently there has been much confusion and indeed concern surrounding lion numbers and population trends in the Mara. This is largely the result of the methods used which did not permit a formal assessment of population trend and more recent evidence suggests that the lion population is stable and at a very high density as explained in the next paragraphs. In 2013 the Kenya Wildlife Trust (www.kenyawildlifetrust.org) initiated a predator conservation programme in the Maasai Mara ecosystem (www.marapredatorconservation.org) and one of their core mandates was to develop cutting-edge scientific methods to monitor lions (and large carnivores) within the Mara in an effort to resolve the confusion and understand long-term population trends in relation to conservation initiatives. The methods developed by this programme were published in scientific journals[1,7,14,47,69] and adopted for the national surveys.

The most recent IUCN classification for lions, inferred that lion numbers had decreased by 54% between 1993 and 2014[92]. This inference was based on two studies[15-17] conducted within the Maasai Mara National Reserve (i.e. not including the surrounding conservancies). The first was a 20-month survey conducted between 1991 to 1992[16,17] and the second was conducted over 10 months in 2005[15]. Both studies relied on whole counts (where an area is searched exhaustively, and it is assumed that all individuals have been detected and identified). The 1991-1992 survey reported 447 lions over 1 year old and the 2005 survey reported 269 lions over 1 year old. However, several fundamental differences exist that make comparisons and analysis of trends problematic. The 1991-1992 and 2005 surveys were whole counts and employed no statistical analysis. Therefore, they did not estimate detection probability or precision and there is no way of assessing the spatial effort invested in either survey. Furthermore, the 1991-1992 survey was conducted over 20 months and the 2005 survey over 10 months – time frames that potentially violate assumptions of closure[62]. It is also intuitive that a longer survey should yield higher numbers since more migration, recruitment and detections will occur at longer intervals, and more effort may be expended. For example, monitoring data from the Maasai Mara shows that during ten months (November 2013-August 2014) 340 unique individuals over 1 year were recorded, while 429 individuals over 1 year were recorded during 20 months (November 2013-June 2015). Timescale is clearly important. More robust estimates garnered through mark-recapture were recently provided for the surrounding conservancies[93]. However, comparison is problematic because this study did not account for search effort, was not spatially explicit and potentially violated assumptions of closure[62]. We therefore caution against comparing our estimates with those of previous surveys in this area[15,17,93,94].

In 2014 Bayesian spatially-explicit capture-recapture models were used to provide robust estimates of lion density (17.08 lions over 1 year per 100km^2) and abundance (418 lions over 1 year) based on unstructured spatial sampling within the Maasai Mara ecosystem[1]. Annual surveys conducted within the area since that time suggest a relatively stable lion population (Elliot, unpublished data).

Analysis

To describe the manner in which individuals were detected during the survey (observation process) we compiled a standard spatial capture-recapture array[55] consisting of individuals, trap locations (defined by pixels of 1km^2), and sampling occasions (Figure 5.2a). During this survey, only the unstructured search-encounter protocol was used. Careful records of drive effort were recorded in the field and included in the models to account for potential differences in detection probability associated with the amount of effort.

To model the spatial distribution of lions (state process) we first generated a state-space by adding a 15km buffer around the sampled area[25]. Next, we generated equally spaced pixels (0.25km^2) representing potential activity centres across the 3,410km^2 state-space and masked out agricultural areas and large towns as unsuitable habitat (Figure 5.2b).

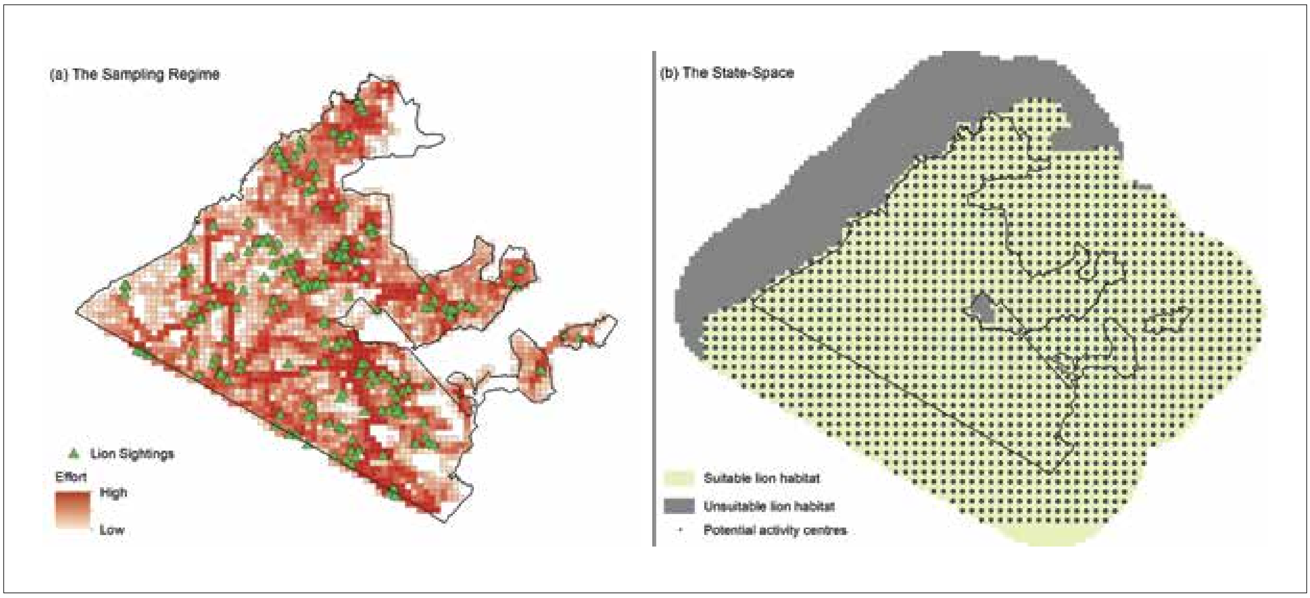


Figure 5.2: *(a) The sampling regime. Search encounter tracks totalling 9,648km were discretised into 1km² pixels such that each pixel depicts drive effort per pixel per day. This effort resulted in 713 detections of 361 lions. (b) The state-space. A 15km buffer was created around the survey area to demarcate the state-space. Potential activity centres were represented by equally spaced pixels (0.25km²), displayed here at 4km². Pixels deemed to be unsuitable habitat (Talek town in the centre, and agricultural lands to the North and West) were masked out prior to analysis.*

Fieldwork Summary

Table 5.1: *Summary data and information for the Maasai Mara Ecosystem lion survey*

Survey dates	01 August - 31 October 2018
Survey length	92 days
Resources	4 vehicles
Survey area	2,541km²
Field teams	Kenya Wildlife Trust
Field methods	Unstructured search-encounter
Search-encounter driven	9,648km
Lion detections	713
Km driven for 1 detection	14
Individual lions >1yr identified	361

Survey Results

Table 5.2: *Posterior summaries of parameters estimated from a Bayesian spatially explicit capture-recapture model used to estimate spatial lion density in the Maasai Mara Ecosystem. Posterior summaries presented below are from Model 1 and include the estimate (posterior mean) of each parameter, together with posterior standard deviation (PSD) and highest posterior density (HPD) intervals. Number of posterior samples used was 28,000. Maximum value of potential scale reduction factor = 1.01. Bayesian P-value = 0.575. See Chapter 3 for more details.*

Lions over 1 year old		Estimate	PSD	95% HPD
Number of lions	within survey area	469	24	423-517
	within 1σ area	556	24	511-602
Density (lions per 100km^2)		18.4	0.95	16.6-20.3
ψ_{sex}		0.4	0.03	0.3-0.5
Sex ratio derived from ψ_{sex}		1.5♀: 1♂		

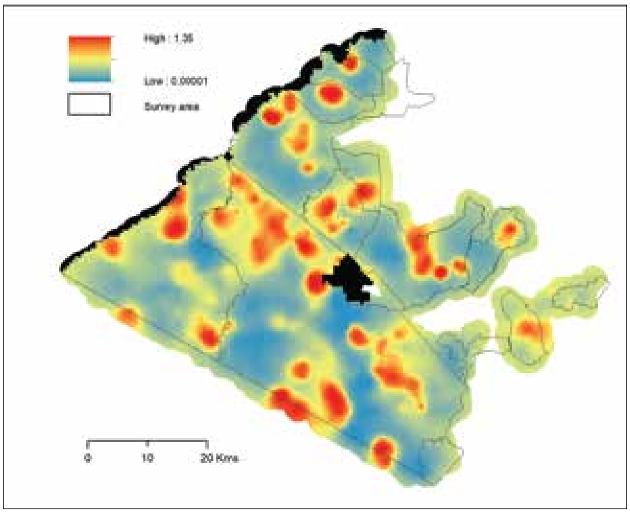


Figure 5.3: *Pixel-specific lion density expressed in units of individual lion activity centres per state-space pixel (0.25km^2) in the Maasai Mara Ecosystem, Kenya. This figure depicts lion density within the wider buffer (2km) that was created around the search effort based on the estimate for sigma (the movement parameter). It is within this area that abundance was estimated to be 556 lions.*

Discussion

Since 2014, the Kenya Wildlife Trust has been conducting annual lion and cheetah surveys using the unstructured search encounter approach[1,69,95]. Indeed it is here that these methods were first applied to cheetahs[69] and lions[1] and later scaled-up to the national level. This approach works well in the Maasai Mara due to the high density of largely habituated lions, good road networks and support from the tourism industry. These estimates compare favourably to a 2014 survey using the same methods that estimated 418 (28.6) lions over the age of 1 year at a density of 17.08 (1.3) lions per 100km^2 [1].

However, a larger area (~150km^2 more) was surveyed during this initiative accounting for some of the increase in abundance. Furthermore, the 2014 survey did not estimate lions in the larger 1σ buffer area. In 2014 the sex ratio was estimated to be 2.2♀:1♂, whereas the current survey suggests a potential shift towards fewer females and/or more males.

Lion populations need to be measured regularly over at least one lion generation (7 years) to explore population trends and the current figures should be viewed as an update rather than a trend. It is therefore essential that long-term monitoring of this species continues so as to understand whether the conservation initiatives in the Mara are having the desired effect on lion population numbers and distribution. This will also allow for tremendous ecological and conservation insight.

Chapter 6

Amboseli Ecosystem

Survey Area

The Amboseli ecosystem is situated in the south-west of Kenya and stretches from Chyulu Hills and Tsavo West National Parks, towards Mt. Kilimanjaro in Tanzania in the south (Figure 6.1). The survey was conducted in Amboseli National Park (390km^2), and three communally-owned Maasai group ranches (Mbirikani, Eselenkei and Olgulului – approx. 3,945km^2).

The area is a semi-arid savannah covered by Vachellia spp.and Commiphora spp. woodlands, interspersed with open grasslands dominated by *Pennisetummezianum, Chrysopogonaucheri, Sporobolus pellucidus, and Digitaria milanjiana*[96,97]. Annual rainfall averages between 200 mm and 500 mm with a bimodal pattern: short rains in November and the long rains spanning from March to May[98]. Two perennial rivers flow in the region, but in the centre of the ecosystem lies the Amboseli Basin, a Pleistocene lakebed. The basin provides a permanent water source resulting from the snow and glacial melt of Mt Kilimanjaro and attracts high concentrations of migratory animals during the dry season[99].

In the wet season wildlife disperses widely to the adjacent group ranches when water and forage is plentiful[97,100].

Lion Population

Since 2006 the Lion Guardians programme (www.lionguardians.org) has been conducting an extensive community-based conservation and monitoring programme of lions in the area. The Amboseli lion population has been persecuted for many decades and are therefore extremely shy. They are generally in the thickest bush and can usually only be seen at night and even then, to get close enough to take photographs can take hours of patient waiting. If a vehicle approaches, the majority of the lions in the ecosystem will run from it, so they need to be approached very slowly and cautiously. However, over the years, Lion Guardians have developed a community-based approach to lion monitoring that sees scientists working with local warriors to follow-up on their foot-based reports and take individual identity photographs of lions[101].

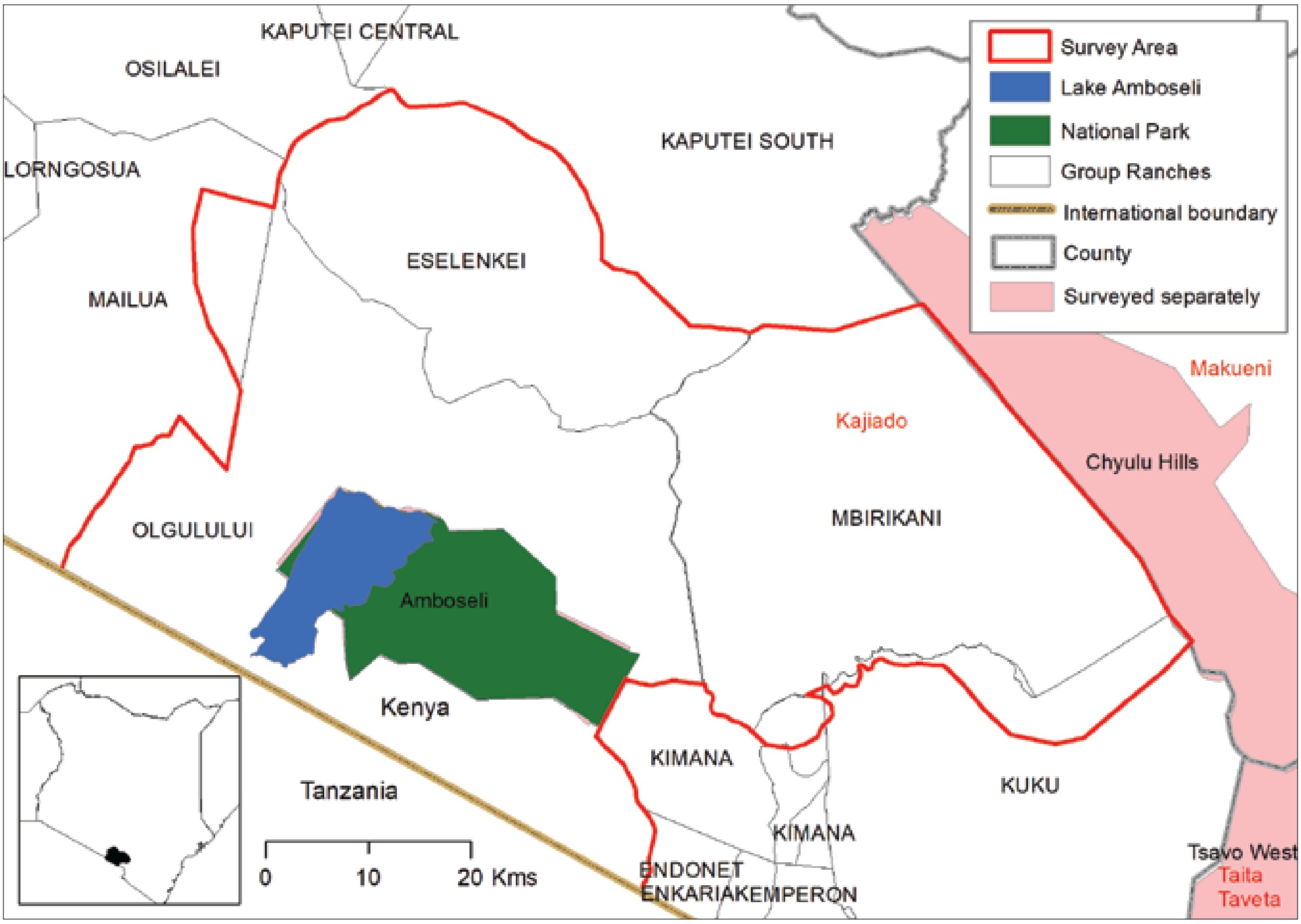


Figure 6.1. *Map showing the areas surveyed which included Amboseli National Park in addition to Olgulului, Mbirikani and Eselenkei Group Ranches. Areas in pink were surveyed separately (see Chapter 9 of this report).*

In this manner, the Lion Guardians program exhaustively searches the ecosystem and estimates population figures for all lions based on the number of individual lions observed during the course of each year. As such, there is now a wealth of data on the lions that are found living beside humans and their livestock[101,102]. Mean group size has been observed to increase from one individual (in 2004) per group to just over five (in 2012)[103] and observed lion density (without correction for detection probability) has gone from ~1 lion per 100km^2 in 2004 to ~6.8 lions per 100km^2 in 2019[104].

Analysis

The field methods used for this survey were designed to reflect the local conditions and maximise lion sightings within the survey area. Within Amboseli NP, lions are habituated and concentrated in a relatively small area, and the search encounter protocol was deployed here. Within the group ranches, lions are shy, nocturnal, and typically within dense bush. To overcome this, 40 Guardians from the Lion Guardians team walked ~34,000km looking for and following fresh lion tracks, and when these were found, a vehicle and field biologists came and took the necessary photographs, sometimes using call-ins to attract the lions.

To describe the manner in which individuals were detected during the survey (observation process) we compiled a standard spatial capture-recapture array[55] consisting of individuals, trap locations (defined by pixels of 1km^2), and sampling occasions (Figure 6.2a). During this survey, four different types of search effort were used. Careful records of these effort types were recorded in the field and included separately in the models to account for potential differences in detection probability associated with the different types of effort.

To model the spatial distribution of lions (state process) we first generated a state-space by adding a 20km buffer around the sampled area[25]. Next, we generated equally spaced pixels (0.5km^2) representing potential activity centres across the 11,946km^2 state-space and masked out agricultural areas and large towns as unsuitable habitat (Figure 6.2b).

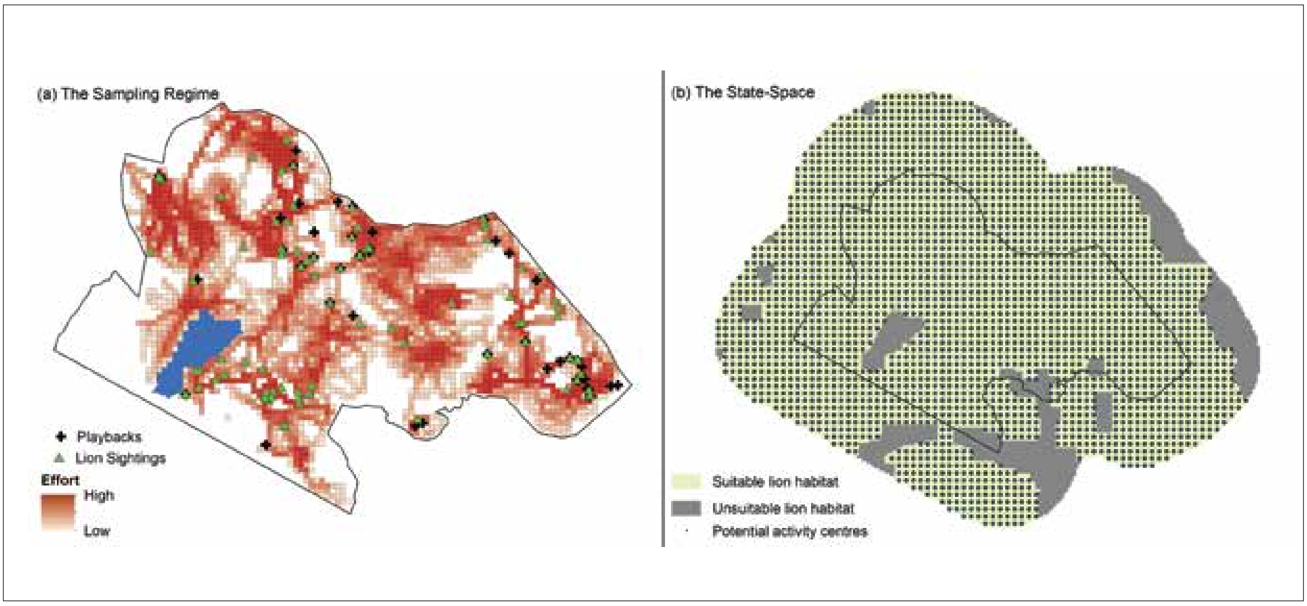


Figure 6.2: *(a) The sampling regime. The search encounter protocol was conducted exclusively in the National Park (1,047km driven). Most of the sampling effort was conducted by observers who searched the area on foot looking for fresh lion tracks (33,966km walked). When these were found, vehicle field teams would meet the foot teams and follow the lion tracks (conditional drive effort, 1,356km) or conduct playbacks (46 occasions) in order to photograph lions. In this figure, the kilometre-based efforts are merged together for display purposes. Each effort type was discretised into 1km^2 pixels such that each pixel depicts effort per pixel per day. This effort resulted in 309 detections of 107 lions. (b) The state-space. A 20km buffer was created around the survey area to demarcate the state-space. Potential activity centres were represented by equally spaced pixels (0.5km^2), displayed here at 4km^2. Pixels that were deemed to be unsuitable habitat (e.g. Amboseli Lake) were masked out prior to analysis.*

Fieldwork Summary

Table 6.1: *Summary data and information for the Amboseli Ecosystem lion survey*

Survey dates	11 August - 11 November 2018
Survey length	93 days
Resources	3 vehicles
Survey area	4,337km^2
Field teams	Lion Guardians, Technical Team
Field methods	Unstructured search-encounter, playbacks, unstructured foot patrols, Conditional drive effort
Search-encounter driven	1,047km
Playbacks	46
Distance walked	33,966km
Conditional drive effort	1,356km
Lion detections	309
Km cumulative effort for 1 detection	117
Individual lions >1yr identified	107

Survey Results

Table 6.2: *Posterior summaries of parameters estimated from a Bayesian spatially explicit capture-recapture model used to estimate spatial lion density in the Amboseli Ecosystem. Posterior summaries presented beloware from Model 1 and include the estimate (posterior mean) of each parameter, together with posterior standard deviation (PSD) and highest posterior density (HPD) intervals. Number of posterior samples used was 40,000. Maximum value of potential scale reduction factor = 1.02. Bayesian P-value = 0.77. See Chapter 3 for more details*

Lions over 1 year old		Estimate	PSD	95% HPD
Number of lions	within survey area	136	13	111-160
	within 1σ area	141	11	119-162
Density (lions per 100km^2)		3.1	0.3	2.6-3.7
ψ_{sex}		0.5	0.1	0.3-0.6
Sex ratio derived from ψ_{sex}		1.2♀: 1♂		

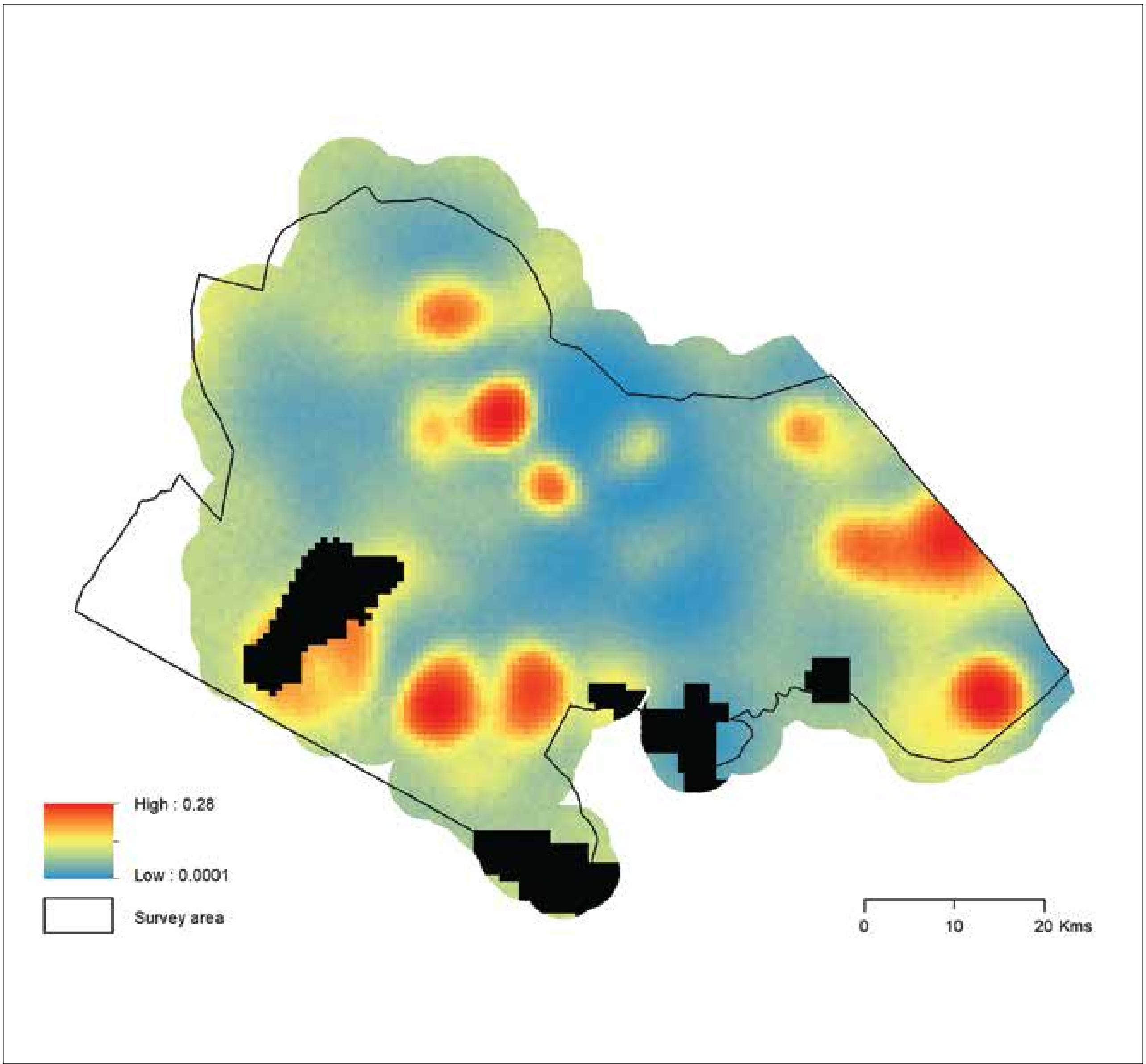


Figure 6.3: *Pixel-specific lion density expressed in units of individual lion activity centres per state-space pixel (0.5km^2) in the Amboseli Ecosystem, Kenya. This figure depicts lion density within the wider buffer (4.3km) that was created around the search effort based on the estimate for sigma (the movement parameter). It is within this area that abundance was estimated to be 141 lions.*

Discussion

During the course of 2018, Lion Guardians conducted their usual intensive lion monitoring and recorded approximately 145 lion individuals over the age of one for the entire survey area. The Amboseli survey produced results that were consistent with the annual finding and estimates from the Lion Guardians program. This strengthens the confidence in both the methods used by the Lion Guardians as well as SECR approach. Additionally, this was the first site for which unstructured spatial sampling combined with SECR models was applied to a population of very secretive lions. Fortunately the Lion Guardians team have been finding and identifying lions for over a decade and are very proficient at this and with the help of 40 Guardians the team were able to identify over 100 lions. This remarkable effort demonstrates the applicability of SECR to lions in most, if not all, situations particularly when blended with the field methods used by Lion Guardians.

Chapter 7

Shompole and Olkiramatian

Survey Area

Almost 100km from the nearest government protected area, this survey was conducted in Shompole (620km^2) and Olkiramatian (270km^2), two communally owned and managed group ranches in Kenya's South Rift Ecosystem on the international border between Kenya and Tanzania. The study area (1°58 S, 36° 21 E, altitude of 600–700m a.s.l.) borders the Nguruman Escarpment and Loita Hills to the west, the alkaline Lake Magadi to the east, and the alkaline Lake Natron to the south[105]. In both group ranches livestock is the predominant form of land-use. The area is bisected by the Ewaso Ngiro river: east of the river is designated for permanent settlement and used for wet season grazing; west of the river is used for dry season grazing and has land set aside as a wildlife conservancy. Crop farming occurs in the north-west of Olkiramatian Group Ranch and in the south-west of Shompole Group Ranch[105]. Roughly 20,000 people reside in the area[106].

This area is semi-arid land, with erratic, annual rainfall that averages between 400–600mm and varies annually by 33%[105,106]. Temperatures are high, ranging from 18 °C at night to 45 °C during the day[105]. High evapotranspiration rates and low rainfall ensures there is little standing water outside the rainy season. The habitat on the group ranches consists of *Vachellia tortillis* woodland, *Salvador persica* bushland and open grasslands dominated by *Sporobolus cordufanos*, *Cenchrus spp*. and *Cynodon plectostachyus*[107,108].

Lion Population

Since 2004 SORALO (www.soralo.org) have been engaged in research and conservation in the area, and more recently have been conducting studies on lions exploring the dynamics of lion attacks on humans and livestock[109], the desire of local communities to coexist with lions[110], home range size variation and the various ecological and anthropogenic factors that create and allow for human-lion coexistence[108].

Between 2008 and 2010 Schuette et al.[111] conducted fieldwork on lions within a 250km^2 area that is entirely encompassed by our survey area. They deployed six radio collars among three prides and two male coalitions and documented an additional pride and two male coalitions that were not collared. They quantified abundance of lions over the age of one year by identifying individuals in all resident groups within their study area based on the final year (2010) of their study. Schuette et al.[111] then reported to having identified 34 lions and converted this to density (13.6 individuals > 1 year/100km^2).

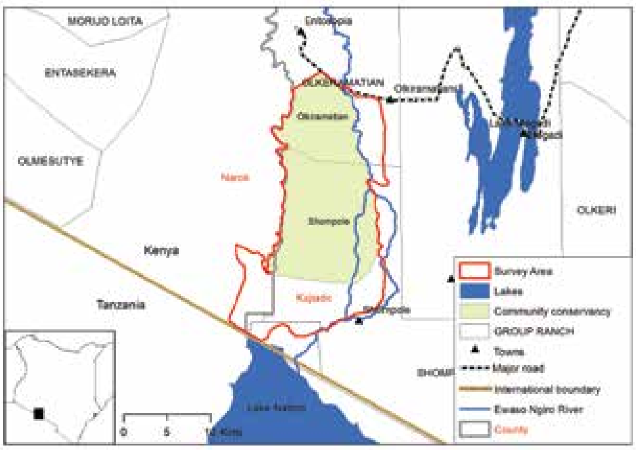


Figure 7.1: *Map showing the areas surveyed which included the Shompole and Olkiramatian conservancies as well as other sections of these group ranches. This survey area was decided upon by key local stakeholders based on their knowledge of the resident lion population.*

Analysis

To describe the manner in which individuals were detected during the survey (observation process) we compiled a standard spatial capture-recapture array[55] consisting of individuals, trap locations (defined by pixels of 1km^2), and sampling occasions (Figure 7.2a). During this survey, the search encounter and playback protocols were used. Careful records of these effort types were recorded in the field and included separately in the models to account for potential differences in detection probability associated with the different types of effort.

To model the spatial distribution of lions (state process) we first generated a state-space by adding a 15km buffer around the sampled area[25]. Next, we generated equally spaced pixels (0.5km^2) representing potential activity centres across the 2,358km^2 state-space and masked out agricultural areas and large towns as unsuitable habitat (Figure 7.2b).

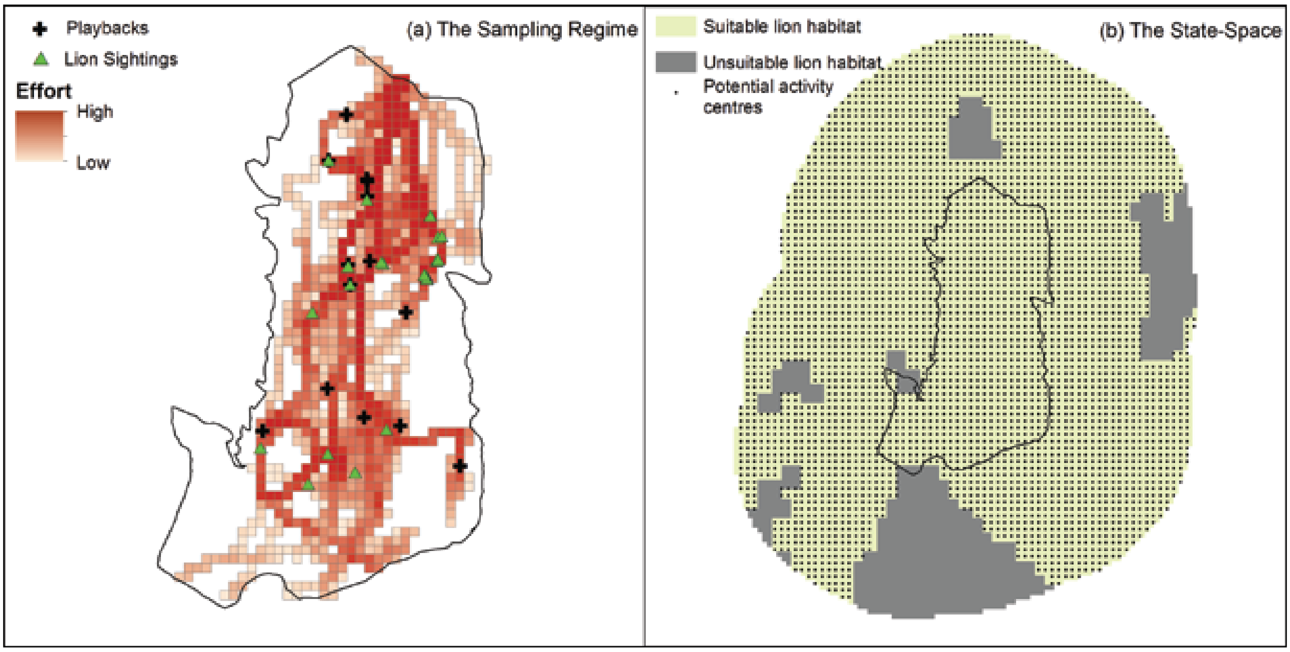


Figure 7.2: *(a) The sampling regime. The search encounter protocol (2,701km drive effort) was conducted in conjunction with the playback protocol (14). Each effort type was discretised into 1km² pixels such that each pixel depicts effort per pixel per day. This effort resulted in 84 detections of 19 lions. (b) The state-space. A 15km buffer was created around the survey area to demarcate the state-space. Potential activity centres were represented by equally spaced pixels (0.5km²). Pixels that were deemed to be unsuitable habitat (e.g. Lake Magadi) were masked out prior to analysis.*

Fieldwork Summary

Table 7.1: *Summary data and information for the Shompole and Olkiramatian lion survey*

Survey dates	17 September – 14 December 2018
Survey length	89 days
Resources	1 vehicle
Survey area	358km²
Field teams	SORALO, Technical Team
Field methods	Unstructured search-encounter, playbacks
Search-encounter driven	2,701km
Playbacks	14
Lion detections	84
Km driven for 1 detection	32
Individual lions >1yr identified	19

Survey Results

Table 7.2: *Posterior summaries of parameters estimated from a Bayesian spatially explicit capture-recapture model used to estimate spatial lion density in Shompole and Olkiramatian. Posterior summaries presented below are from Model 1 and include the estimate (posterior mean) of each parameter, together with posterior standard deviation (PSD) and highest posterior density (HPD) intervals. Number of posterior samples used was 200,000. Maximum value of potential scale reduction factor = 1.01. Bayesian P-value = 0.58. See Chapter 3 for more details.*

Lions over 1 year old		Estimate	PSD	95% HPD
Number of lions	within survey area	21	5	12-31
	within 1σ area	27	5	19-36
Density (lions per 100km²)		5.9	1.4	3.3-8.6
ψ_{sex}		0.3	0.1	0.1-0.6
Sex ratio derived from ψ_{sex}		2.1♀: 1♂		

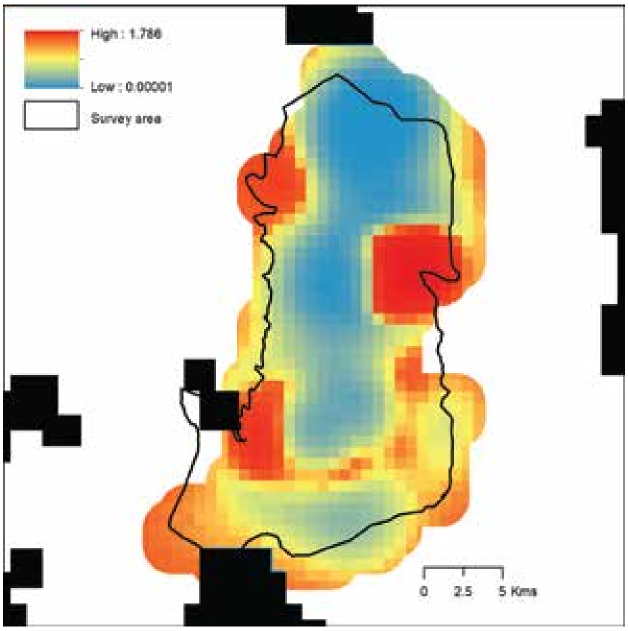


Figure 7.3: *Pixel-specific lion density expressed in units of individual lion activity centres per state-space pixel (0.5km²) in Shompole and Olkiramatian, Kenya. This figure depicts lion density within the wider buffer (1.9km) that was created around the search effort based on the estimate for sigma (the movement parameter). It is within this area that abundance was estimated to be 27 lions.*

Discussion

Our estimated lion density compares favourably to estimates using similarly robust methods within some of Africa's best known protected areas[14,56,112]. The relatively high density of lions in the current study is noteworthy, given the survey area is a landscape shared by wildlife, livestock and people and is more than 100km away from the nearest protected area.

That lions occur at this density may be explained by the tolerance of the local Maasai community for lions as reported by an attitudinal questionnaire survey showing that 88% of respondents expressed a desire for lion numbers to stay the same or increase[110].

Schuette et al.[111] reported a much higher density estimate (13.6 lions > 1 year/100km²) than the current estimate (5.9 individuals > 1 year/100km²) but a somewhat similar abundance estimate (34 lions in 250km²) to ours (27 lions within 474km²) albeit ours was a larger area. However, comparison of these results is problematic: Schuette et al. did not conduct a formal survey, but rather individually identified lions over a period of one year and converted this to density. The prolonged timeframe is likely to have violated assumptions of closure[62] and their approach did not allow them to estimate detection probability, precision or define the linkage between individuals and space. The present survey area does not contain an isolated lion population and likely serves as a vital steppingstone, providing linkages across southern Kenya. For example, the SORALO team have documented lions in Torosei and Musenge (~30-50km east of the survey area), while another study confirmed presence of lions in nearby Naimina Enkiyio Forest[113] (~25km west of the survey area). Thus, some of the lions observed by Schuette et al.[111] may well have had the majority of their home range outside the arbitrary 250km² they defined, potentially invalidating their density estimate. It is therefore not possible to directly compare between these studies, highlighting the value of consistently using robust methods to explore population trends. The results of this study have now been accepted in the scientific journal *Ecology and Evolution*[249].

Chapter 8

Nairobi National Park

Survey Area

Situated in the south-southeast of the city of Nairobi, where the Athi-Kapiti Plains meet the Eastern escarpment of the Rift Valley[114], Nairobi National Park (Figure 8.1) has been dubbed the ‘world’s only wildlife capital’ due to being a protected wildlife area within a capital city. Gazetted in 1945, the park encompasses 117km^2 at an altitude of 1600-1800 m between latitudes 1° 20′ -1° 26′ S and longitudes 36° 50′-36° 58′ E, a transition zone between the pastoral grazing zones in the south-southeast and the highland farming areas in the west-northwest[114,115].

Mean annual rainfall in the park varies from 524 mm (Cheetah Gate) to 912 mm (Wilson airport) and exhibits a bimodal pattern with the long rains spanning March-May and the short rains occurring in November-December[115]. The vegetation within the park consists mostly of open grasslands dominated by *Pennisetummezianum, Bothriochloa insculpta, Themeda triandra* and *Digitaria macroblephora* and interspersed by low *Vachellia drepanolobium* trees, wooded river margins and a forest on the western boundary[116].

The park is separated from the city on its northern, eastern and western borders by a wire fence but is unfenced on the southern border allowing for movement of wildlife between the park and the Athi-Kapiti Plains[117]. The plains host sizable livestock and wildlife populations and are a critical wet season dispersal range for wildlife, including lions, inhabiting Nairobi National Park[117]. However, the movement of migratory wildlife such as wildebeest (*Connochaetes taurinus*) and zebra (*Equus quagga*) is being impeded by the rapid increase of fencing on the plains[117]. The habitat is being further fragmented by the rapid expansion of urban centres and the development of new major roads, such as the Southern bypass, and the Standard Gauge Railway (SGR) line that runs across the park.

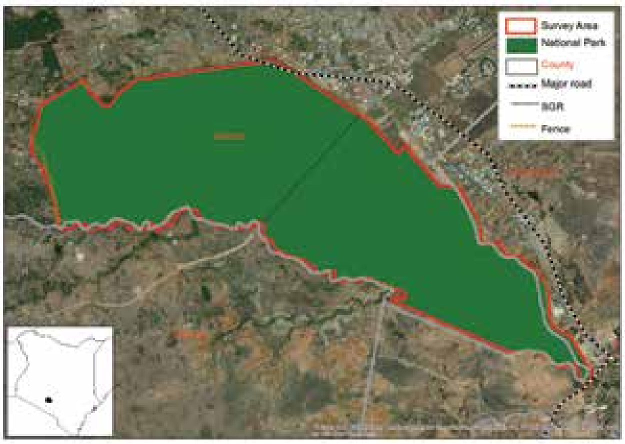


Figure 8.1: *Map showing the survey area, Nairobi National Park. This survey area was decided upon by key local stakeholders based on their knowledge of the resident lion population.*

Lion Population

This national park has a long history of lion and cheetah research[114,118] and an avid local following of the individual lions residing within. Indeed, it is here that in the late 1960s Pennycuick & Rudnai, noting that lions had unique whisker spots, devised a method to identify individual lions[57]. This observation changed the way we look at and monitor lions and is vital to the methodology that was used for the surveys conducted in Kenya.

In 1967 Nairobi NP was thought to contain 25 lions of all ages[119]. Shortly thereafter, Rudnai published a scientific paper[120] based on fieldwork conducted from the beginning of 1968 to the end of 1969 and from August 1970 to December 1972. Using individual identification of lions seen, she documented 27 lions during the first field session and 30 lions during the second (of all ages) and cited personal communication with the then warden, S. I. Ellis, to assert that the lion population averaged 30 individuals for the preceding 20 years (fluctuating between 25 and 35).

More recently, in 2011 a ‘total-area census’ was conducted within Nairobi National Park and found 35 individual lions, including cubs[115]. In 2016 an MSc student, Maria Gatta, identified 30 individual lions (25 over the age of 1 year) during 82 days of fieldwork[121]. Finally, Francis Lesilau conducted bi-annual whole counts of individually identified lions between February-April and July-September during 2012 and again from 2014-2018 and concluded that on average there were 29 individual lions over the age of one year[13].

Analysis

To describe the manner in which individuals were detected during the survey (observation process) we compiled a standard spatial capture-recapture array[55] consisting of individuals, trap locations (defined by pixels of 0.5km^2), and sampling occasions (Figure 8.2a). During this survey, only the unstructured search-encounter protocol was used. Careful records of drive effort were recorded in the field and included in the models to account for potential differences in detection probability associated with the amount of effort.

To model the spatial distribution of lions (state process) we first generated a state-space by adding a 20km buffer around the sampled area[25]. Next, we generated equally spaced pixels (0.25km^2) representing potential activity centres across the 2,494km^2 state-space and masked out agricultural areas and large towns as unsuitable habitat (Figure 8.2b).

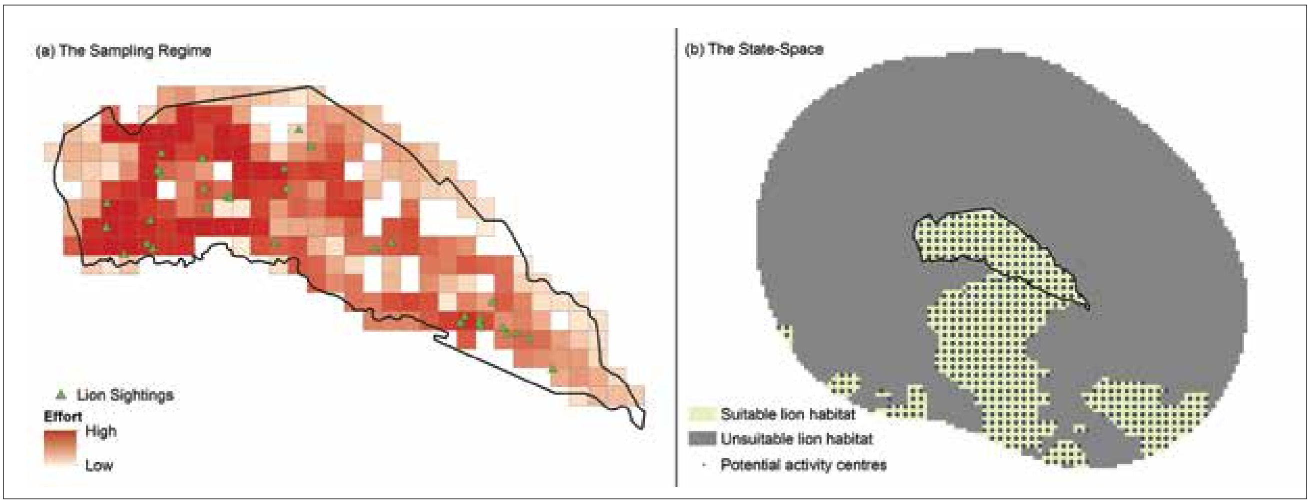


Figure 8.2: *(a) The sampling regime. Search encounter tracks totalling 1,377km were discretised into 0.5km² pixels such that each pixel depicts drive effort per pixel per day. This effort resulted in 64 detections of 22 lions. (b) The state-space. A 20km buffer was created around the survey area to demarcate the state-space. Potential activity centres were represented by equally spaced pixels (0.25km²). Pixels that were deemed to be unsuitable habitat (e.g. Nairobi City) we masked out prior to analysis.*

Fieldwork Summary

Table 8.1: *Summary data and information for the Nairobi National Park lion survey*

Survey dates	08 October - 09 November 2018
Survey length	33 days
Resources	1 vehicles
Survey area	117km²
Field teams	Kenya Wildlife Service, Technical Team
Field methods	Unstructured search-encounter
Search-encounter driven	1,377km
Lion detections	63
Km driven for 1 detection	22
Individual lions >1yr identified	22

Survey Results

Table 8.2: *Posterior summaries of parameters estimated from a Bayesian spatially explicit capture-recapture model used to estimate spatial lion density in Nairobi National Park. Posterior summaries presented below are from Model 2 and include the estimate (posterior mean) of each parameter, together with posterior standard deviation (PSD) and highest posterior density (HPD) intervals. Number of posterior samples used was 600,000. Maximum value of potential scale reduction factor = 1.01. Bayesian P-value = 0.82. See Chapter 3 for more details.*

Lions over 1 year old		Estimate	PSD	95% HPD
Number of lions	within survey area	22	5	12-32
	within 1σ area	25	6	13-36
Density (lions per 100km^2)		18.5	5	10-28
ψ_{sex}		0.3	0.1	0.1-0.5
Sex ratio derived from ψ_{sex}		2.6♀:1♂		

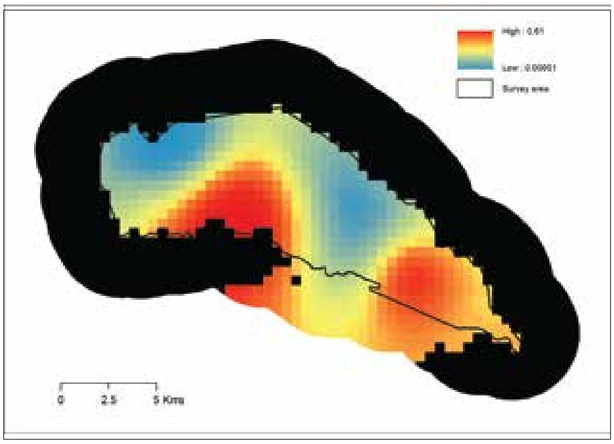


Figure 8.3: *Pixel-specific lion density expressed in units of individual lion activity centres per state-space pixel (0.25km^2) in Nairobi National Park, Kenya. This figure depicts lion density within the wider buffer (3.5km) that was created around the search effort based on the estimate for sigma (the movement parameter). It is within this area that abundance was estimated to be 25 lions.*

Discussion

Nairobi National Park has an excellent road network and receives plentiful visitors, with lions being a key attraction. As a result, the unstructured search-encounter protocol is ideal here. It is conceivable, especially given the relatively small size of Nairobi National Park, that citizen scientists could be enlisted to help conduct future monitoring. This would not only provide valuable insights into the population but also help to motivate public conservation will.

During the survey, the data collection team observed 22 individuals over the age of 1 and our SECR analysis estimated there to be 25 in total. This estimate is similar to historic reports (lions of all ages = 25 in 1967[119], 27 in 1970, 30 in 1972[120]) and to more recent reports (lions over 1 year = 25 in 2016[121], an average of 29 during 2012 and from 2014-2018[13]). Our estimate of 25 lions over the age of one is also similar to a 2011 figure of 35 lions (of all ages)[115], considering we also recorded six cubs under the age of one year that are not included in our estimate.

It is noted that the historic records are all based on so-called 'total counts' that assume all individuals have been seen. Since there is no measure of effort or detection probability, and the surveys all had variable durations, it is not prudent to make direct comparisons among historic reports or to the current SECR estimates. However, Nairobi National Park is relatively small, and the lions are generally well known, leading us to conclude that this population has remained relatively stable since the 1960s, which is remarkable given the extensive urbanisation and changes to the environment.

It is important to view all results in the context of how and when the survey was conducted. The NNP survey was carried out between October and November. Ungulates tend to use NNP as a dry season refuge and disperse outside the park during the wet season (April-June and mid-October to mid-November)[120]. Thus, our survey was conducted at a time when lions are likely to spend more time outside the park, and some lions that use the park at other times of the year may not be included here. Our analysis captured this dynamic (Figure 8.3) and the red areas outside the park conform to known areas of human-lion conflict. A dry season survey is recommended to capture potential seasonal differences. The small size, elongated shape, and hard northern boundary of NNP would ideally be modelled with covariates to more accurately reflect the activity centres. This avenue is currently being explored.

Chapter 9

Tsavo Conservation Area

Survey Area

The Tsavo Conservation Area (TCA), located between -2 to -4° South and 37.5 to 39.5° East in south-eastern Kenya, is a large semi-arid ecosystem spanning an area of ~48,300km^2 [122] that is home to viable populations of elephants, rhinos, lions, and many other species of wildlife[123]. The TCA contains one of East Africa's largest park systems (Tsavo East and Tsavo West National Parks combined cover ~21,000 km^2) that borders Mkomazi National Park in Tanzania. While extensive research has been conducted on elephants in this area[122,124,125], relatively little is known about carnivores. The survey was conducted across 23,902km^2 within Tsavo East and West National Parks, Chyulu Hills National Park, some of the Taita-Taveta ranches and Galana conservancy (Figure 9.1).

The TCA is generally low-lying (400 m a.s.l) characterised by undulating hills and open plains that rise up to 2,188m (a.s.l) in the Chyulu Hills[126,127]. The Yatta Plateau (900 m a.s.l), on the north-western border of Tsavo East NP, extends unbroken for ~300km is possibly the most extensive lava flow ever recorded[128]. Volcanism from Chyulu Hills has encroached into Tsavo West NP, which include the Shetani and Chaimu flows, and this area is often referred to the 'Ancient Land of Lions and Lava', a reference to the 'Man Eaters of Tsavo'[127].

The area's climate is semi-arid with annual rainfall ranging between 200 mm and 700 mm falling in two short rainy seasons from March to May and from November to December[129]. The Tsavo, Athi and Galana are permanent rivers that traverse the ecosystem and eventually flow into the Indian Ocean. There are two major seasonal rivers, the Voi and Tiva, in addition to numerous natural and artificial waterholes that dry up during the long dry season (June-October)[127,130,131]. The primary water sources for Tsavo West NP are Lake Jipe on the western border of the park and the Mzima Springs[132] which are fed from underground sources from the volcanic uplands of the Chyulu Hills[127]. About 10% of the springs' water is supplied to Mombasa by a gravity-driven pipeline before feeding into the Tsavo River at an approximate rate of 280,000 L/min[127].

Most of the TCA is characterised by wooded bushland, shrubland and savannah grassland dominated by species such as *V. tortillis, V. drepanolobium,* and interspersed by trees such as *Adansonia digitata* and *Delonix elata*. Most of the southern part of the TCA and the Galana area are characterised by savanna grasslands whereas bushland vegetation occurs at higher average annual rainfall, higher elevation, closer to surface streams and lower waterhole density[133]. Montane forests are found in high-elevation areas such as the Yatta Plateau and Chyulu Hills.

Riverine species, including *V. elatior, Hyphaene compressa* and *Suaeda monoica*, are found along the permanent rivers while swamps are found around Lake Jipe[126,133]. The area is faced with a rapidly increasing human population, an increase in public infrastructure, such as the SGR and the Mombasa-Nairobi road that separates Tsavo East NP from Tsavo West NP, resulting in increasing heavy traffic, underground and overhead pipelines and power transmission cables, and mining activities including small scale gemstone mining in Taita-Taveta county[134,135].

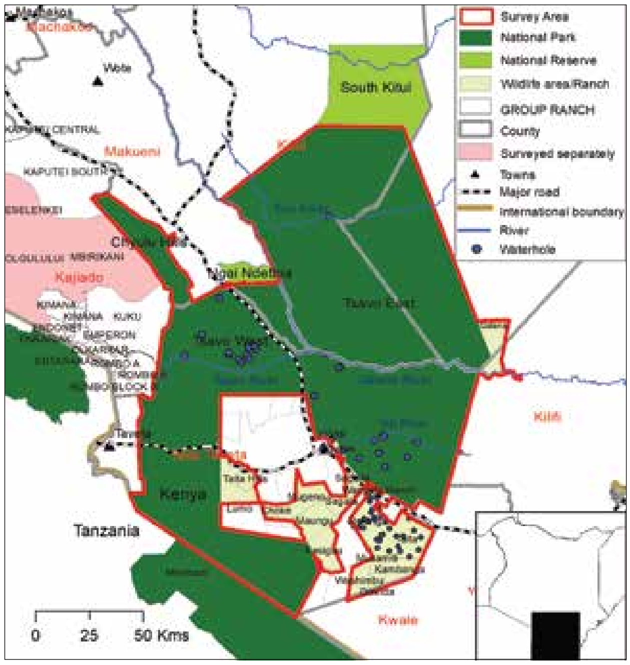


Figure 9.1: *Map showing the areas surveyed which included National Parks (Tsavo East, Tsavo West, Chyulu Hills), and private and community ranches and conservancies (Galana, Taita Hills, Lumo, Rukinga, Ndara, Mugeno, Sagalla, Wangala, Choke, Maungu, Taita, Kasigau, Washimbu, Amaka, Kambanga, Dawida and Ngutuni). The National Reserves (Ngai Ndethia and South Kitui) were not included in this survey based on consultations with key local stakeholders who indicated absence of resident lions within these areas.*

Lion Population

Tsavo lions are known worldwide for two reasons, one being the infamous pair of 'man-eating' lions at the end of the 19th Century[136-143], and the other for harbouring a largely 'maneless' male population[144-146]. Despite the voluminous scientific and popular works on these two aspects, information relating to the status of the lion population is extremely limited, even though this area potentially holds one of Kenya's largest lion populations. Between September and December 1999 Kays & Patterson[144] searched for lions and individually identified 60 adult individuals (87 with 'juveniles') in a 4,150km^2 area of Tsavo East NP (essentially the entire area south of the Galana River within Tsavo East National Park).

In 2002 Patterson et al.[147] searched a section of Taita Ranch (388km^2) for lions using two vehicles over ten 12-day sessions throughout the year and also used playbacks to locate lions. They individually identified 15 lions[147]. In the National Conservation and Management Strategy for Lions and Spotted Hyenas in Kenya 2009-2014[148], a figure of 675 lions was provided for Tsavo for the year 2008. However, this was based on a guestimate by renowned lion biologist, Prof. Craig Packer, after he had spent a week in the area and never felt that it should be treated as reliable (C. Packer, personal communication, 2021). More recently, in 2013 a track (or spoor) survey was conducted throughout Tsavo West and Tsavo East NPs and estimated the lion population to be 706 (±201) individuals of all ages.

Analysis

Kenya's biggest protected area network and surrounding wildlife areas demanded a massive field effort. In total, more than 200 people participated in the largest lion survey of its kind ever conducted. SECR models incorporate space and movement into the analysis. In Tsavo we observed very large differences in the distances between recaptures of lions. As such, we split the analysis into three different areas based on the movement between recaptures (hereafter termed small, medium and large sigma, see Figure 9.2).

To describe the manner in which individuals were detected during the survey (observation process) we compiled a standard spatial capture-recapture array[55] consisting of individuals, trap locations and sampling occasions (Figure 9.2i). During this survey, we made use of the playback protocol and the unstructured search-encounter protocol. Careful records of playback and drive effort were recorded in the field and included in the models to account for potential differences in detection probability associated with the amount of effort. We set trap pixel size to 2km^2, 4km^2 and 8km^2 for the small, medium and large sigma areas respectively.

To model the spatial distribution of lions (state process) we first generated a state-space by adding a buffer around the sampled area[25]. To ensure these buffers were large enough that individuals outside of them would have negligible capture probability during the survey, we set buffer width to 15km, 25km and 55km for the small, medium and large sigma areas respectively. Next, we generated equally spaced pixels representing potential activity centres across each state-space and masked out agricultural areas and large towns as unsuitable habitat (Figure 9.2ii). State-space pixel sizes were set to 0.5km^2, 1km^2, 2km^2 and state-space size was 15,468km^2, 27,875km^2 and 41,593km^2 for the small, medium and large sigma areas respectively.

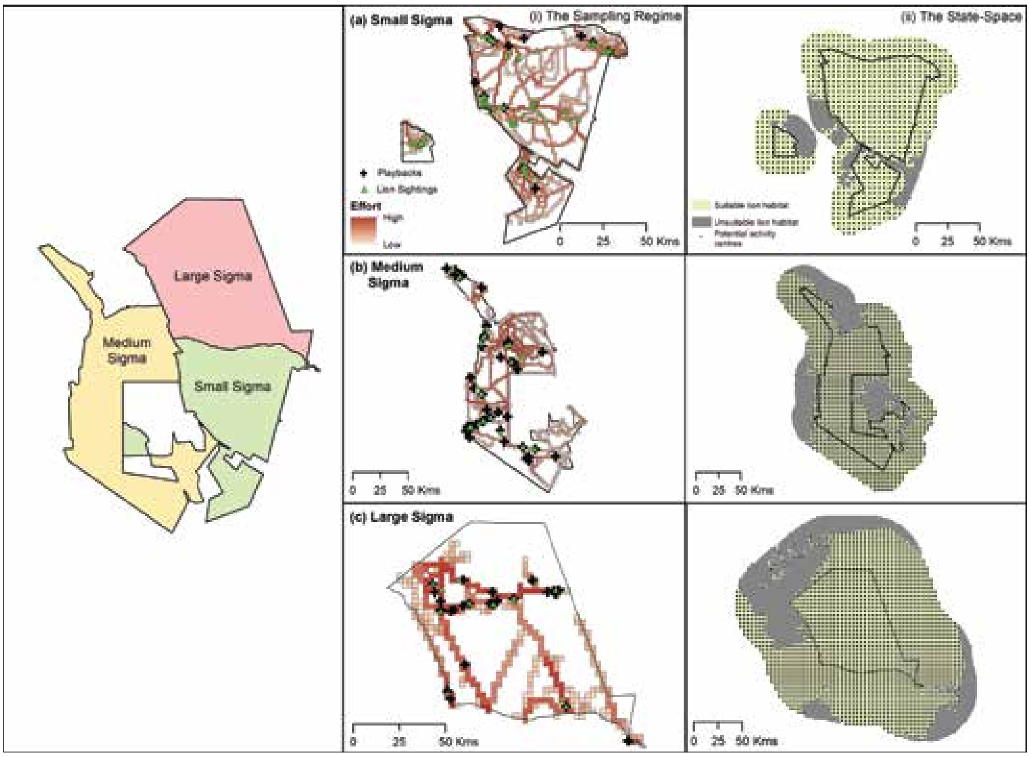


Figure 9.2: (a) The sampling regime. The search encounter protocol was conducted in conjunction with the playback protocol. Each effort type was discretised into pixels such that each pixel depicts effort per pixel per day. (b) The state-space. A buffer was created around the survey area to demarcate the state-space. Potential activity centres were represented by equally spaced pixels (for display all are shown at 16km^2, refer to 'Analysis' for actual sizes). Pixels that were deemed to be unsuitable habitat were masked out prior to analysis.

Fieldwork Summary

Table 9.1: *Summary data and information for the Tsavo Conservation Area lion survey*

Survey dates	16 January - 30 April 2019		
Survey length	105 days		
Resources	9 vehicles		
Field teams	Kenya Wildlife Service, Tsavo Trust, Wildlife Works, Zoological Society of London, Lion Guardians, Technical Team		
Field methods	Unstructured search-encounter, playbacks		
	Small Sigma	Medium Sigma	Large Sigma
Survey area	6,641km^2	8,700km^2	8,560km^2
Mean maximum distance moved between recaptures	4,309km	9,571km	25,321km
Search-encounter driven	17,747km	14,812km	6,667km
Playbacks	14	44	30
Lion detections	440	53	37
Km driven for 1 detection	40	279	180
Individual lions >1yr identified	138	36	18

Survey Results

Table 9.2: *Posterior summaries of parameters estimated from a Bayesian spatially explicit capture-recapture model used to estimate spatial lion density in the Tsavo Conservation Area. Posterior summaries presented below are from Model 3 and include the estimate (posterior mean) of each parameter, together with posterior standard deviation (PSD) and highest posterior density (HPD) intervals. See Chapter 3 for more details.*

(i). Small Sigma. *Number of posterior samples used was 60,000. Maximum value of potential scale reduction factor = 1.01. Bayesian P-value = 0.50.*

Lions over 1 year old		Estimate	PSD	95% HPD
Number of lions	within survey area	320	29	264-378
	within 1σ area	321	27	266-371
Density (lions per 100km^2)		4.8	0.4	4.0-5.7
Observed sex ratio		1.7♀: 1♂		

(ii). Medium Sigma. *Number of posterior samples used was 120,000. Maximum value of potential scale reduction factor = 1.01. Bayesian P-value = 0.37.*

Lions over 1 year old		Estimate	PSD	95% HPD
Number of lions	within survey area	92	25	49-142
	within 1σ area	112	29	60-169
Density (lions per 100km^2)		1.1	0.3	0.6-1.6
Observed sex ratio		1.4♀: 1♂		

(iii). Large Sigma. *Number of posterior samples used was 210,000. Maximum value of potential scale reduction factor = 1.06. Bayesian P-value = 0.47.*

Lions over 1 year old		Estimate	PSD	95% HPD
Number of lions	within survey area	21	7	9-34
	within 1σ area	28	8	14-44
Density (lions per 100km^2)		0.2	0.1	0.1-0.4
Observed sex ratio		1♀: 1♂		

(iv). All areas combined.

Lions over 1 year old		Estimate	PSD	95% HPD
Number of lions	within survey area	433	40	321-554
	within 1σ area	460	40	340-584
Density (lions per 100km^2)		1.8	0.2	1.3-2.3
Observed sex ratio		2.1♀: 1♂		

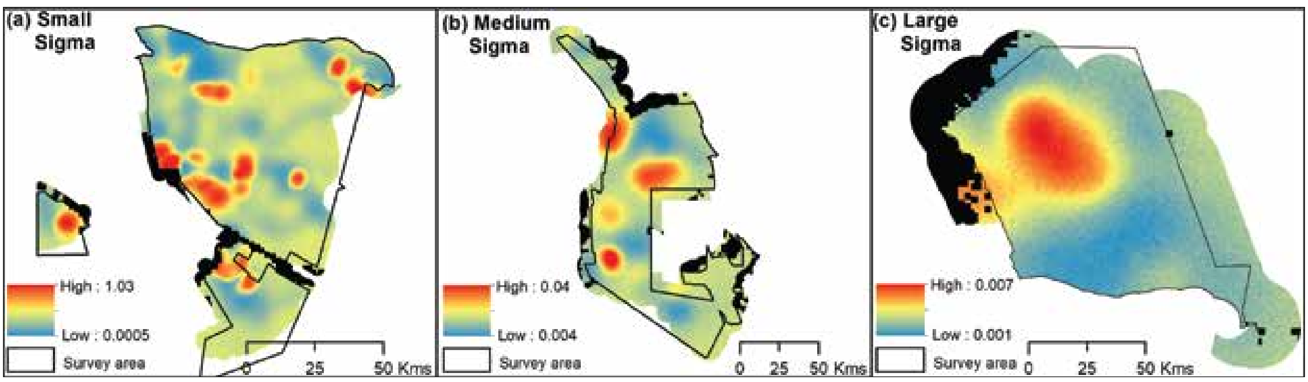


Figure 9.3: *Pixel-specific lion density expressed in units of individual lion activity centres per state-space pixel (0.5km^2, 1km^2 and 2km^2 for small, medium and large sigma respectively) in the Tsavo Conservation Area, Kenya. For display purposes and to aid interpretation, each area is displayed at a full heatmap scale, but readers should take note of the different scales associated with high and low density for each area.*

Discussion

Lion density and abundance varied significantly across the TCA. Within the small sigma area, lion density was higher than the Amboseli ecosystem, while the large sigma area had a very low estimated density. The outputs from our analysis (Figure 9.3) reveal that water is a limiting factor for lion numbers in this ecosystem. While lions themselves are not strictly dependant on water, in arid and semi-arid ecosystems, scarce water sources are a key determinant of lion distribution and abundance since habitats around water sources are frequently ideal for cub concealment and ambush hunting, and the water itself leads to an aggregation of large-bodied herbivores[149-153]. Within the TCA, artificial water sources on Rukinga Ranch and south of the Galana River in Tsavo East National Park, together with the perennial rivers themselves (Galana, Tiva, Tsavo, Voi, Kitani) coincide with areas of high estimated lions density (Figures 9.1 and 9.3), while vast areas of Tsavo East north of the Galana have extremely low estimated lion density (see Figure 9.3, while noting the different scales at which the data are displayed) which is not surprising given the arid nature of this area and subsequent lack of prey, except along the Tiva River. Along the Tiva there are reasonable lion densities, which reduce as you move away from the river. Areas around Lake Jipe in Tsavo West appear favourable for lions since there are relatively high prey densities, however, lion densities in this area were not as high as expected. The reason for this may be due to livestock incursion as livestock was commonly seen in this area. During the survey, a section of Chyulu Hills National Park was settled by a large number of people, which is likely having an impact on wildlife populations in this area. See Chapter 14 of this report for further discussion on potential lion recovery in this and other sites.

The only other on the ground survey that has been conducted in this ecosystem was a track survey, conducted in 2013 by Henschel et al.[19]. That study was restricted to Tsavo West and East National Parks (20,812km²)and reported an estimated lion abundance of 706 (±201) individuals at a density of 3.39 (±0.96)[19] lions per 100km². The present survey was conducted over a larger area (23,902km²) yet estimated a lower abundance of 460 (PSD=40) individuals at a density of 1.8 (PSD=0.2) lions per 100km². When interpreting this difference, there are several important factors to take into account: First, the Henschel et al. study is presumably an estimate of all lions, while the current survey is restricted to individuals over the age of 1 year. Second, some of the assumptions (see the 'Methods Review' section of this report) of track surveys may have been unknowingly violated by Henschel et al. For example, it is debatable whether each lion has the same probability of crossing a transect given the sparse road network in certain areas of the park: an individual south of the Galana River may have multiple transects within its territory, while an individual north of the Galana River may only have one transect.

Furthermore, Henschel et al. used 1km as the minimum distance to distinguish between similar sets of tracks. In other words, if trackers were unable to distinguish whether two sets of tracks were left by the same individuals, these were classed as additional individuals if they were 1km or more apart. In the current survey we found that lions were moving large distances (maximum distance between recaptures was 17km, 20km and 45km within the small, medium, and large sigma areas respectively). It is conceivable therefore that lions were travelling long distances along roads and within certain areas Henschel et al. may have 'double counted' and hence inflated their estimates since they did not consider the large-scale differences in movement and detection probability across the ecosystem. Finally, even under ideal conditions where most assumptions are met, track surveys do not provide reliable estimates[22] and the utility of such methods has been criticized generally[20], and for lions specifically[21], and a statistical examination of the approach concluded that track surveys may produce faulty results[9]. Therefore, the current estimates should not be compared directly to the Henschel et al.[19] estimates and subsequent surveys of this important population should follow the same methods outlined in this report to obtain comparable results and explore population trends.

Chapter 10

Laikipia and Meru Ranches

Survey Area

The survey was conducted within the boundaries of 31 privately-owned ranches within Laikipia County. This survey area was decided upon by key local stakeholders based on their knowledge of resident lion populations within the area. Sadly, during the survey one of the team members from Laikipia Nature Conservancy passed away and the survey of this area was not completed. We therefore do not include this area in our results but note that there are resident lions within this ranch that were almost certainly not captured in adjacent areas.

The survey area is not formally protected and consists of semi-arid bushland and savannah used for commercial ranching, wildlife tourism and small-scale agriculture[154]. A rainfall gradient occurs with annual precipitation of 1000mm at the base of Mt. Kenya to 400mm in the north of the county.

Three vegetation types characterise the area, the most common being *V. drepanolobium* woodlands, with savannahs dominated by perennial grasses and intermittent trees and shrubs and bushlands consisting of perennial grasses and broken canopies of *V. mellifera, A. etbaica, A. brevispica and Grewia tenax*[155].

Lion Population

Since 1998, the research and conservation programme Living with Lions (www.livingwithlions.org) has been documenting lions within this landscape, and since 2016 Lion Landscapes (www.lionlandscapes.org) has also been operational within the area. While no formal survey has been conducted across the ecosystem, Laurence Frank extrapolated from known pride sizes and home ranges to provide an estimate of 230 lions in 2008[148] and in 2011 reported a stable lion population of between 200-250 lions of all ages at a density of 6-7

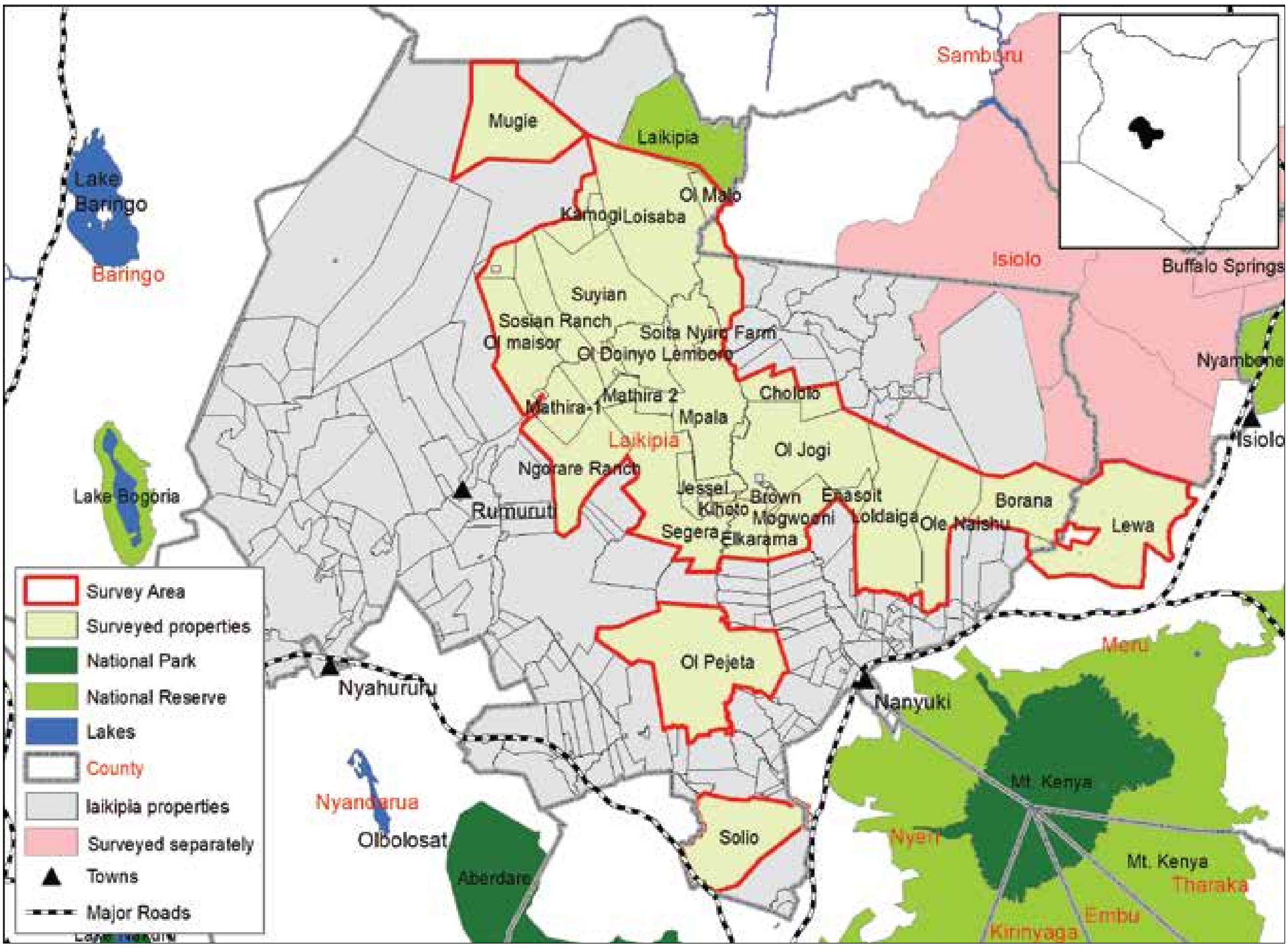


Figure 10.1: *Map showing the areas surveyed. Although Lewa is not within Laikipia County, it was included here for logistical reasons. The pink area to the north-east was surveyed separately, partly due to logistical reasons but also due to the much lower perceived lion density in this area.*

adult and subadult lions/100km^2 within the commercial ranches[156]. More recently, in 2018 a density figure of 5.3 adult and subadult lions/100km^2 was provided[155], while a figure of 300 lions of all ages for 2018 was used in a recent meta-analysis of lion populations[157].

Analysis

The primary income of all the ranches included in this survey is derived from livestock, while some maintain a secondary income through wildlife-based tourism. We therefore anticipated that it would be relatively straightforward to photograph lions in areas where tourism occurs, and more difficult in areas without tourism, due to the behaviour of lions. In order to take this into account and ensure we were able to provide robust estimates we deployed 17 teams to extensively and repeatedly cover the area using search encounter field methods and conducted targeted call-ins in some areas to try and locate lions. In addition, the SECR models we use to analyse the data perform well in the presence of individual variation in detection probability.

During data preparation, we separated the datasets for Solio, Ol Pejeta and the rest of Laikipia and analysed these independently. This analytical decision does not affect the combined estimates and was taken to negate the need for additional covariates to better reflect the fenced nature of Solio and the fenced with corridors nature of Ol Pejeta. Since Solio is completely enclosed by a fence we masked out all areas outside the boundary.

Ol Pejeta is partially enclosed by a fence, with several 'corridors' in the north-western sector, which is reflected by our depiction of suitable lion habitat (Figure 10.2b). We have combined the outputs for this report.

To describe the manner in which individuals were detected during the survey (observation process) we compiled a standard spatial capture-recapture array[55] consisting of individuals, trap locations and sampling occasions (Figure 10.2a). During this survey, we made use of the playback protocol and the unstructured search-encounter protocol. Careful records of playback and drive effort were recorded in the field and included in the models to account for potential differences in detection probability associated with the amount of effort. We set trap pixel size to 1km² for each area.

To model the spatial distribution of lions (state process) we first generated a state-space by adding a buffer around the sampled area[25]. To ensure these buffers were large enough that individuals outside of them would have negligible capture probability during the survey, we set buffer width to 15km, for Ol Pejeta and the rest of Laikipia, while for the analysis of Solio the state-space was represented by the ranch boundary. Next, we generated equally spaced pixels representing potential activity centres across each state-space and masked out agricultural areas and large towns as unsuitable habitat (Figure 10.2b). The state-space pixel size was set to 0.5km² and state-space size was 161km^2, 2,203km^2 and 15,468km^2 for Solio, Ol Pejeta and the rest of Laikipia respectively.

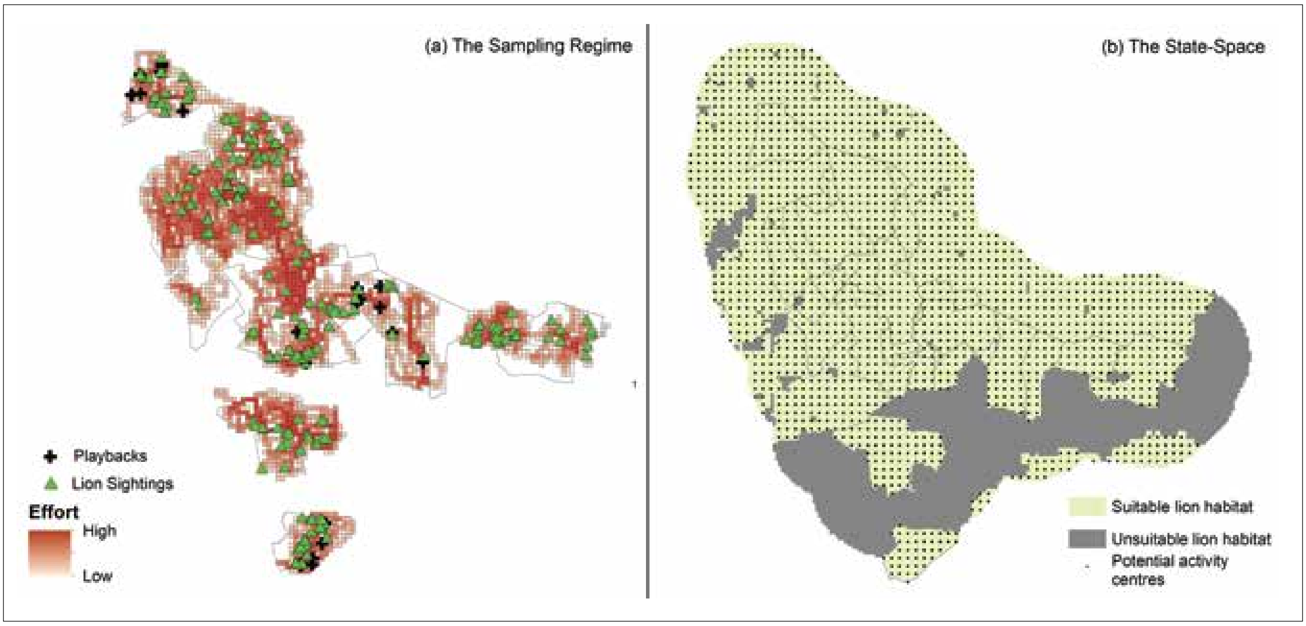


Figure 10.2: *(a) The sampling regime. The search encounter protocol (total drive effort was 21,854km) was conducted in conjunction with the playback protocol (25 playbacks). Each effort type was discretised into 1km2 pixels such that each pixel depicts effort per pixel per day. This effort resulted in 658 detections of 221 lions. (b) The state-space. To demarcate the state-space a 15km buffer was created around Ol Pejeta and the rest of Laikipia, the survey area, while for Solio, the ranch boundary represented the state-space. Potential activity centres were represented by equally spaced pixels (0.5km²), displayed here at 4km². Pixels that were deemed to be unsuitable habitat (e.g. agriculture) were masked out prior to analysis.*

Fieldwork Summary

Table 10.1: *Summary data and information for the lion survey within the Laikipia and Meru Ranches*

Survey dates	08 August - 05 November 2019
Survey length	90 days
Resources	17 vehicles
Survey area	3,366km^2
Field teams	Lion Landscapes, Lion Guardians, and personnel from the following ranches: Lolldaiga, Mugie, Mpala, Loisaba, Lewa, Borana, Solio, Sosian, Suyian, Ol Jogi, Laikipia Nature Conservancy, Ol Doinyo Lemboro, Segera, Ol Pejeta, Technical Team
Field methods	Unstructured search-encounter
Search-encounter driven	21,854km
Playbacks	25
Lion detections	658
Km driven for 1 detection	33
Individual lions >1yr identified	221

Survey Results

Table 10.2: *Posterior summaries of parameters estimated from Bayesian spatially explicit capture-recapture model used to estimate spatial lion density in the Laikipia and Meru Ranches. Posterior summaries presented below are the combined results from three separate analyses (Solio, Ol Pejeta and the rest of Laikipia) and include the estimate (posterior mean) of each parameter, together with posterior standard deviation (PSD) and highest posterior density (HPD) intervals. Number of posterior samples used (Solio=192,000, Ol Pejeta=200,000, rest=60,000). Mean maximum value of potential scale reduction factor (Solio=1.01, Ol Pejeta=1.02, rest=1). Bayesian P-value (Solio=0.48, Ol Pejeta=0.65, rest=0.83). See Chapter 3 for more details.*

Lions over 1 year old		Estimate	PSD	95% HPD
Number of lions	within survey area	245	15.7	195-298
	within 1σ area	306	16	255-358
Density (lions per 100km^2)		7.3	0.5	5.8-8.8
ψ_{sex} excluding Ol Pejeta		0.5	0.1	0.5-0.9
Sex ratio derived from ψ_{sex}		1.1♀: 1♂		

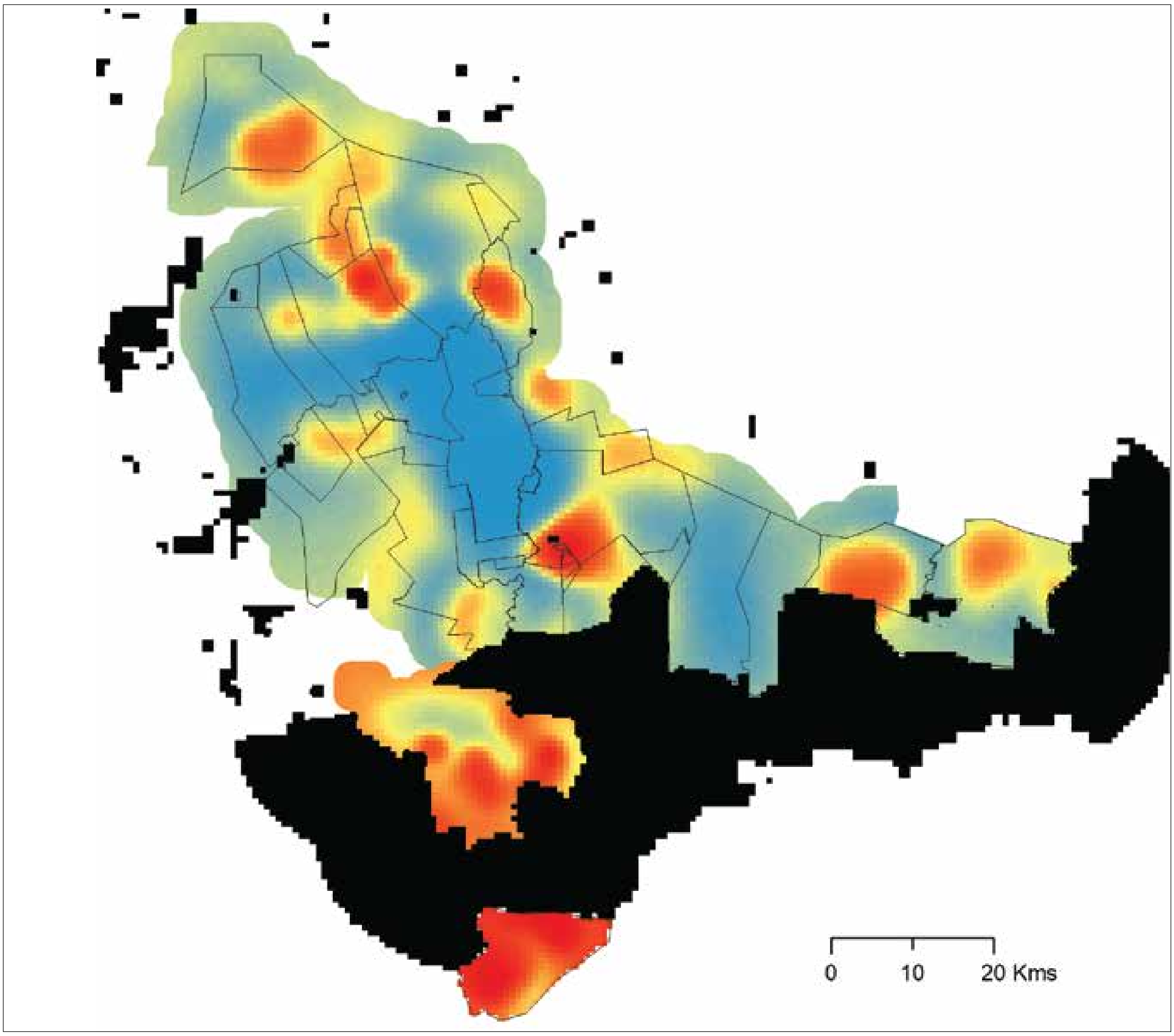


Figure 10.3: *Pixel-specific lion density expressed in units of individual lion activity centres per state-space pixel (0.5km²) in Laikipia and Meru Ranches, Kenya.This figure depicts lion density within the wider buffer that was created around the search effort based on the estimate for sigma (the movement parameter). It is within this area that abundance was estimated to be 305 lions. It should be noted that the absence of covariates in our analysis (e.g. a resource selection function informing the models on what lions select and avoid) has likely led to some misplacement of the activity centres presented here and this therefore should not be taken too literally when looking property by property.*

Discussion

The Laikipia ranches are a remarkable and unique example of commercial livestock ranching co-occurring alongside wildlife and carnivore conservation. Landowners use traditional and low-cost methods of livestock husbandry to protect their livestock, and actively conserve carnivores and the relatively high density of lions across the ecosystem serve as an example that livestock production does not inevitably lead to carnivore extirpation[156].

The average overall lion density was estimated to be 7.3 lions over the age of 1 year/100km², which is consistent with previous reports of lion density within the area (6-7 adult and subadult lions/100km² in 2011[156]and 5.3 adult and subadult lions/100km² in 2018[155]), while noting that those figures were not the product of systematic surveys and nor did they cover all known lion range in the area. One notable property is not included in our survey (Laikipia Nature Conservancy), as sadly the person who was conducting the fieldwork in this ranch passed away shortly after the survey began. Future surveys should include this property as several sightings of lions have been reported there.

While this ecosystem consists of numerous privately-owned ranches, lions are thought to move throughout the properties despite some of them being fenced, since many of these fences are not designed to stop lion movement, and those that are consist of fence gaps to allow movement (e.g. Ol Pejeta maintains fence gaps that collared lions utilise). Solio Ranch has an exceptionally high lion density, which is consistent with many fenced populations[158]. Similar to Lake Nakuru National Park[14], this lion population will require intensive long-term management to ensure its viability. Management interventions can be designed to mimic natural processes such as male tenure length over prides, dispersal and mortality by translocating selected lions into and out of Solio. Prior to that, genetic testing of a sample of the population could determine current levels of inbreeding and the best source for potential future translocations into Solio[159]. Furthermore, as advised by Miller et al.[158], translocated lions should be vaccinated against key diseases such as canine distemper. As a short-term management tool, a translocation exercise was carried out to reduce lion numbers in Solio and in June 2020 a total of 30 lions (9 adult males, 15 adult females and 6 cubs) were captured and moved to various national parks. While this measure reduces the overall density of lions within Solio it is likely to only have a temporary effect since lions will continue to breed and likely suffer low mortality with little to no emigration.

More recently, a contraception experiment has been undertaken in Lewa and Borana to address the high lion densities in these areas. A toolkit for management of isolated lion populations would be beneficial. Interestingly, in all three areas, the sex ratio is estimated to be close to 1:1 (for Ol Pejeta the sex ratio could not be estimated due to limited data, but the observed sex ratio was 1.3♀:1♂). Lion sex ratios are typically equal at birth and arrive at approximately 2♀: 1 ♂ when considering a population over the age of one[160] at most source populations. Our estimate is potentially significant and indicates either a high survival of males or a high mortality of females. A potential hypothesis for this sex ratio is that cub survival was particularly high following 2017 since there was a glut of prey in the form of livestock that moved into the area. Alternatively, male dispersal may be increasingly restricted by growing human and livestock populations in the surrounding areas, thus increasing the survival of this typically vulnerable demographic[161]. Local stakeholders are actively investigating these hypotheses.

Chapter 11

Sections of Samburu, Isiolo and Laikipia Counties

Survey Area

This survey was conducted within parts of the counties of Laikipia, Samburu and Isiolo (Figure 11.1) and included specific National Reserves (Samburu, Buffalo Springs, Shaba) and community conservancies (Westgate, Nanapisho, Naapo, Kalama, Nasuulu, NakupratGotu, Leparua, Il Ngwesi and Lekurruki). Due to insecurity the survey of Shaba NR was prematurely halted, and plans are underway to conduct a thorough survey of this area at a later date. As such, the results presented here do not include Shaba NR. During planning meetings with key local stakeholders prior to the start of the survey, it was decided that these areas could be done concurrently with a plan to complete surveys north of this area in future.

This semi-arid area receives an annual rainfall of less than 400mm which falls in two seasons (April-May and November-December[162]. The Ewaso Nyiro River is the largest semi-permanent river in the area, originating from tributaries on Mt. Kenya and the Aberdares range and draining north through the study area. Within the reserves, river acacia (*V. elatior*) and doum palm (*Hyphaene coriacea*) are dominant along the river and elsewhere, the primary vegetation communities in the area are *Vachellia-Commiphora* semi-arid scrub woodland and *Vachellia* wooded grassland[163]. Samburu NR falls under that management of Samburu County Government, whereas Buffalo Springs NR and Shaba NR fall under Isiolo County Government. The community conservancies surveyed here are community-led initiatives that were created to support the management of community-owned land for the benefit of livelihoods and wildlife. They are legally registered entities that are governed by a Board of Directors and run by local management teams and are all members of the Northern Rangelands Trust.

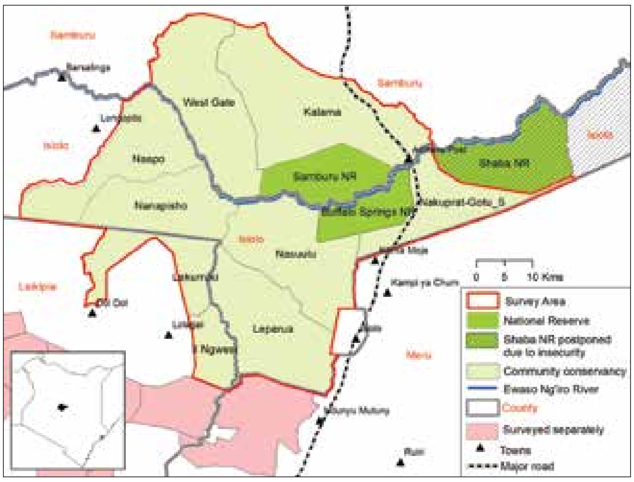


Figure 11.1: *Map showing the areas surveyed. Survey efforts in Shaba NR were halted after the first week due to insecurity in the area. This survey area was decided upon by key local stakeholders based on their knowledge of the resident lion population. Areas in pink to the south-west were surveyed separately, partly due to logistical reasons but also due to the much lower perceived lion density in this area. Note: MpusKutuk has recently been renamed Ol Donyiro.*

Lion Population

Ewaso Lions (www.ewasolions.org) has been monitoring the lion population within this region since 2002 - initially through Shivani Bhalla's Masters and subsequent PhD[164,165]. Changes over the past decade include increased presence and breeding of lions outside the Reserves as lions moved out and settled in Conservancies. Cub survival has been high over the years. Males have been seen to move from Lewa Wildlife Conservancy to the Reserves, highlighting the key dispersal routes that lions take through Leparua and Nasuulu Conservancies. Core Conservation Areas that exist including in Westgate have shown how important these critical safe refuges are for lions that live solely in the Conservancies. Overall, Ewaso Lions estimates a current population of approximately 40 individuals moving in and out of the Reserves and immediate surrounding Conservancies. In 2020, new resident populations have been reported in Sera and Namunyak Conservancies – highlighting the need to potentially survey these areas in the future.

Analysis

To describe the manner in which individuals were detected during the survey (observation process) we compiled a standard spatial capture-recapture array[55] consisting of individuals, trap locations (defined by pixels of $1km^2$), and sampling occasions (Figure 11.2a). During this survey, two different types of search effort were used. Careful records of these effort types were recorded in the field and included separately in the models to account for potential differences in detection probability associated with the different types of effort.

To model the spatial distribution of lions (state process) we first generated a state-space by adding a 15km buffer around the sampled area[25]. Next, we generated equally spaced pixels ($0.5km^2$) representing potential activity centres across the $8{,}281km^2$ state-space and masked out agricultural areas and large towns as unsuitable habitat (Figure 11.2b).

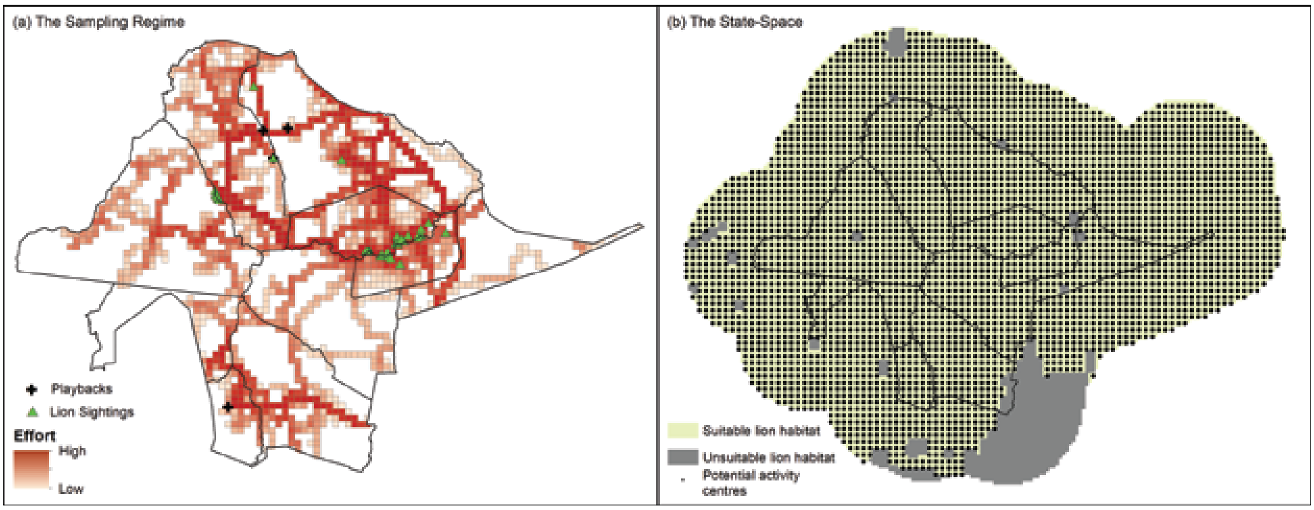


Figure 11.2: *(a) The sampling regime. The search encounter protocol (11,632km drive effort) was conducted in conjunction with the playback protocol (4). Playbacks did not result in any lion detections and thus were removed from the analysis. Search effort was discretised into 1km² pixels such that each pixel depicts effort per pixel per day. This effort resulted in 107 detections of 13 lions. (b) The state-space. A 15km buffer was created around the survey area to demarcate the state-space. Potential activity centres were represented by equally spaced pixels (0.5km²), displayed here at 2km². Pixels that were deemed to be unsuitable habitat (e.g. agriculture and towns) were masked out prior to analysis.*

Fieldwork Summary

Table 11.1: *Summary data and information for the lion survey within sections of Samburu, Isiolo and Laikipia Counties*

Survey dates	19 August - 16 November 2019
Survey length	90 days
Resources	3 vehicles
Survey area	2,859km²
Field teams	Ewaso Lions, Technical Team
Field methods	Unstructured search-encounter, playbacks
Search-encounter driven	11,632km
Playbacks	4 (excluded from analysis as no lion detections)
Lion detections	107
Km driven for 1 detection	108
Individual lions >1yr identified	13

Survey Results

Table 11.2: *Posterior summaries of parameters estimated from a Bayesian spatially explicit capture-recapture model used to estimate spatial lion density in sections of Samburu, Isiolo and Laikipia Counties. Posterior summaries presented below are from Model 1 and include the estimate (posterior mean) of each parameter, together with posterior standard deviation (PSD) and highest posterior density (HPD) intervals. Number of posterior samples used was 200,000. Maximum value of potential scale reduction factor = 1. Bayesian P-value = 0.69. See Chapter 3 for more details.*

Lions over 1 year old		Estimate	PSD	95% HPD
Number of lions	within survey area	15	3.5	9-22
	within 1σ area	17	2.8	12-22
Density (lions per 100km²)		0.5	0.1	0.3-0.8
ψ_{sex}		0.5	0.2	0.2-0.8
Sex ratio derived from ψ_{sex}		0.9♀: 1♂		

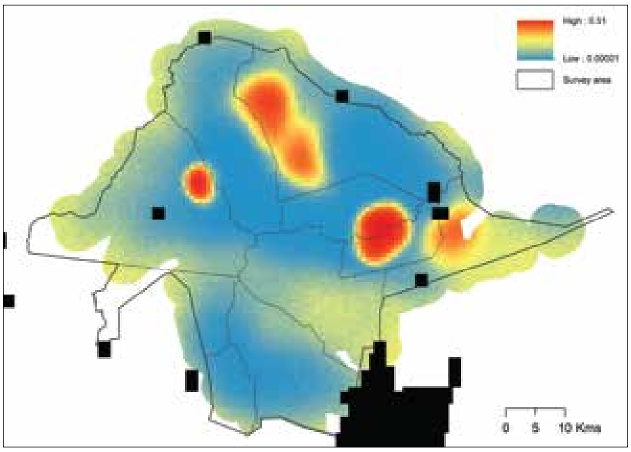


Figure 11.3*:Pixel-specific lion density expressed in units of individual lion activity centres per state-space pixel (0.5km²) in sections of Samburu, Isiolo and Laikipia Counties, Kenya.This figure depicts lion density within the wider buffer (3.4km) that was created around the search effort based on the estimate for sigma (the movement parameter). It is within this area that abundance was estimated to be 17 lions. As with the Laikipia spatial lion density figure, it is noted here that the depiction of activity centres would be improved would the addition of covariates in the analysis. For example, the activity centre within MpusKutuk (now called Ol Donyiro) is likely to fall along the Ewaso Ngiro River and within Westgate.*

Discussion

This survey area connects to the Laikipia survey area detailed elsewhere in this report. In addition, community conservancies to the north (in both Samburu and Isiolo counties) such as Namunyak (both Sarara and Milgis areas), Biliqo Bulesa, Sera and Melako are known to contain lions, likely at similar/lower densities to those reported for the current survey.

Reports from KWS also indicate that there are resident lions near Maralal/Kirisia/Suguta that have been sighted over the past year. Therefore, this area forms part of a much larger ecosystem that contains a large population of lions and it is noted that the survey results presented here only cover a subset of these counties and further surveys in the above-mentioned areas are recommended.

The biggest challenge affecting the fieldwork during this survey was insecurity. Firstly, this resulted in field teams pulling out of Shaba NR earlier than anticipated. Secondly, it affected the team's ability to work at night, which may have reduced sightings as this area is known for elusive nocturnal lions. Lastly, pastoral transhumance due to insecurity pushed livestock into known lion areas, potentially leading to lions becoming more elusive or leaving those areas during the census period. Despite these challenges, the dataset was more than adequate to produce reliable estimates that are consistent with on the ground knowledge. It is hoped that future survey efforts can include some areas that were not surveyed due to insecurity and/or Covid-19 which include Shaba National Reserve, Biliqo Conservancy, Mathew's Range, Namunyak Conservancy and the Milgis area.

Chapter 12

Meru Conservation Area

Survey Area

The Meru Conservation Area is the second largest protected area complex in Kenya. This survey was conducted within the boundaries of Meru NP, Kora NP, Mwingi NR and Bisanadi NR (Figure 12.1). During planning meetings with key local stakeholders prior to the start of the survey, Rahole NR was also considered as a potential survey area. However, this area was excluded due to extensive human settlement and a perceived lack of a source population of lions. Administratively, the study area lies within Meru, Isiolo, Tana River and Kitui Counties and borders Garissa and Tharaka-nithi Counties. Rainfall in the area occurs in two seasons, with the short rains from October-December and the long rains from March-May[166]. Within the study area, rainfall decreases with increasing distance from Mount Kenya, with Meru NP receiving an annual average rainfall of 724mm and the eastern parts of Kora NP as little as 200mm[167]. Altitude decreases along a similar gradient from 820m in the north-west to 270m in the south-east. Vegetation changes accordingly with the western boundary dominated by *Combretum* and *Terminalia* wooded grasslands, the north and north-eastern parts of Meru NP being dominated by Acacia woodlands, and moving south-east up to 80% of Kora NP is dominated by dense *Commiphora-Lannea-Boswellia* thickets[168]. Meru NP has a network of 14 permanent rivers, although almost half of these now dry up during the dry seasons due to water extraction upstream[169]. Vegetation along the Tana River in this area is sparse and characterised by stands of Doum palm (*Hyphaene coriacae*), while beyond the eastern boundary of the study area, below the Kora Rapids, a broad riparian forest occurs[168].

The western boundary and part of the southern boundary of Meru NP is fenced to reduce human-wildlife conflict and cases of carnivore depredation are rare[169]. To the west of Meru NP, agriculture is the primary human livelihood while to the east south and north of the study area, communities are dependent on pastoralism, and livestock incursions into the study area do occur, particularly during the dry season[169].

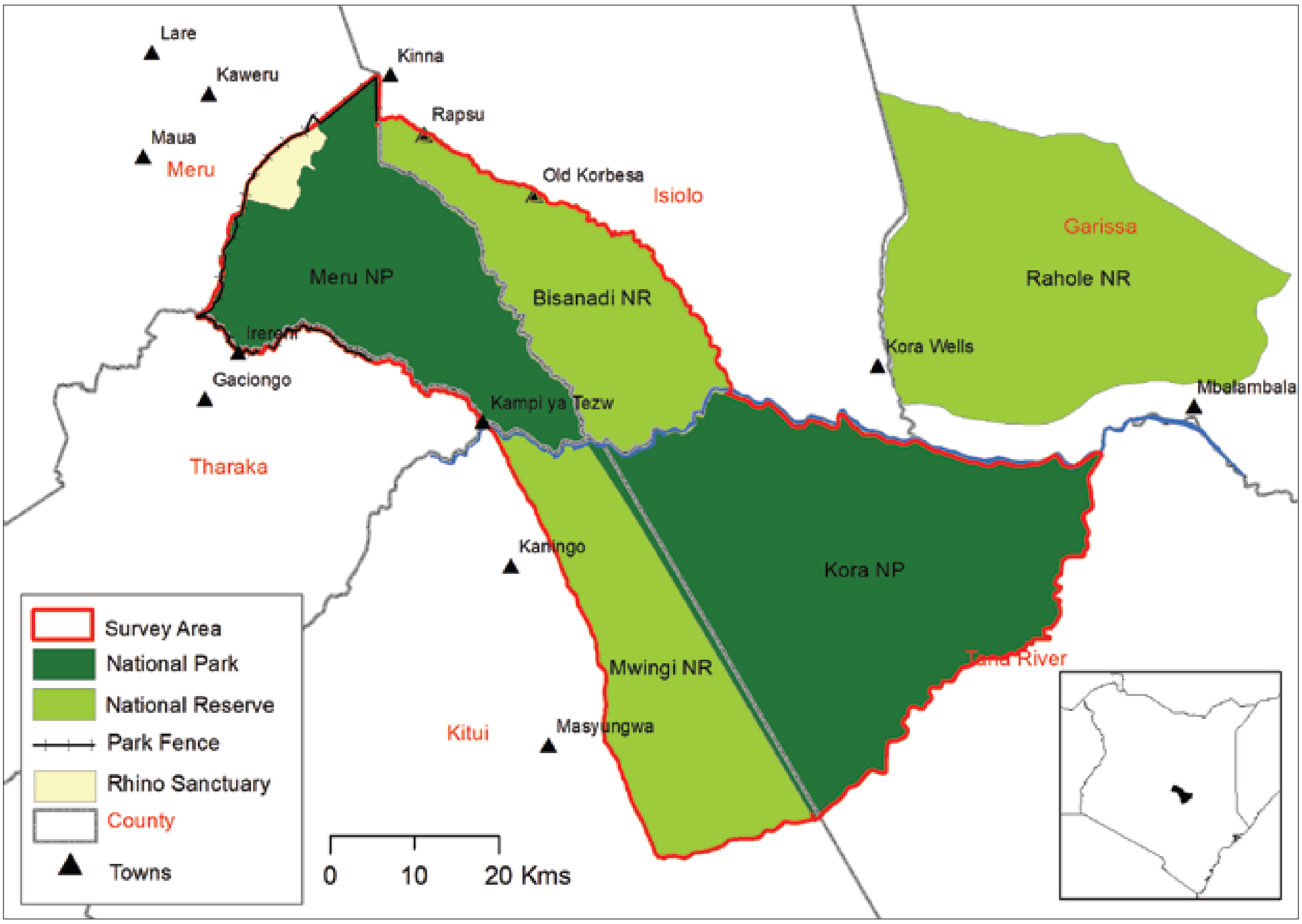


Figure 12.1: *Map showing the areas surveyed, which included Meru and Kora National Parks and Mwingi and Bisanadi National Reserves. Rahole National Reserve was not surveyed based on consultations with key local stakeholders relating to the absence of resident lions in the area.*

Lion Population

In the 1960's, after the release of Joy Adamson's book Born Free and subsequent film of the same name, this area and some of the lions within became household names throughout the world. In 1967 Meru was gazetted as a National Park and proved to be a popular tourist attraction throughout the 1970s[170]. However, in the 1980s the area's wildlife was decimated by poachers, with 90% of elephants being lost together with the entire rhino population[169]. In 1999 a comprehensive rehabilitation programme was initiated that involved restocking herbivore species and bolstering security[169]. Unfortunately, no reliable estimates of lion numbers exist for this time period.

In 2004 Bauer & van de Merwe[171] provided a figure of 80 lions for Meru NP and cited a 'best guess' from Laurence Frank as the source. In 2006 the IUCN's Regional Lion Conservation Strategy for Eastern and Southern Africa sought expert opinion for lion numbers throughout Africa and reported a figure of 100-250 lions for 'Meru'[172], and Bauer et al.[157] recently used the mid-point of this figure (175) as lion abundance for 2005 together with an updated expert opinion figure of 40 lions for 2018. It is however noted that the area under question in these two documents[157,172] is loosely defined as 'Meru' and it is unclear whether this is specific to the NP or a wider area.

There are several records resulting from on the ground fieldwork: John-Henry Welton identified 48 individuals in three prides within Meru NP in 2004[169]. Later, in 2008 a Masters student estimated a population of 40 individuals in four prides based on the identification of 15 lions during six months of fieldwork[169]. In 2016 a three-day playback survey estimated 58 (±21) lions in Meru NP1[69]. Finally, the Born Free Foundation (www.bornfree.org.uk) have been conducting lion monitoring in the Meru Conservation Area since 2014 and maintain a catalogue of all identified individuals in the ecosystem. As of September 2019 Born Free had documented 60 individuals, including 9 under the age of 1 year, from 5 prides and 2 male coalitions, with territories falling within Meru National Park, while noting that this does not necessarily imply that all individuals were still within the ecosystem.

Analysis

Based on consultations with local stakeholders prior to the survey it was understood that lions in Meru NP were relatively easy to find, whereas in the other three management areas (Kora NP, Bisanadi NR and Mwingi NR) lions were scarce, and perhaps only transitory, with no recent sightings. As such, our field protocols included search encounter methods and call-ins.

In addition, we added an experienced tracker to the team based in Kora and Mwingi and conducted several 'spoor transects' with the intention being that if lion tracks were found, call-ins would be used to sight and photograph the lions. In addition, all teams were continuously searching (by vehicle and on foot) for lion tracks. No sightings (and indeed no signs) of lions were recorded anywhere other than Meru NP. As such, we only considered Meru NP in our analysis. To describe the manner in which individuals were detected during the survey (observation process) we compiled a standard spatial capture-recapture array[55] consisting of individuals, trap locations (defined by pixels of $1km^2$), and sampling occasions (Figure 12.2a). During this survey, the search-encounter and playback protocols were used. Careful records of these effort types were recorded in the field and included separately in the models to account for potential differences in detection probability associated with the different types of effort.

To model the spatial distribution of lions (state process) we first generated a state-space by adding a 15km buffer around the sampled area[25]. Next, we generated equally spaced pixels ($0.5km^2$) representing potential activity centres across the $9,355km^2$ state-space and masked out agricultural areas and large towns as unsuitable habitat (Figure 12.2b).

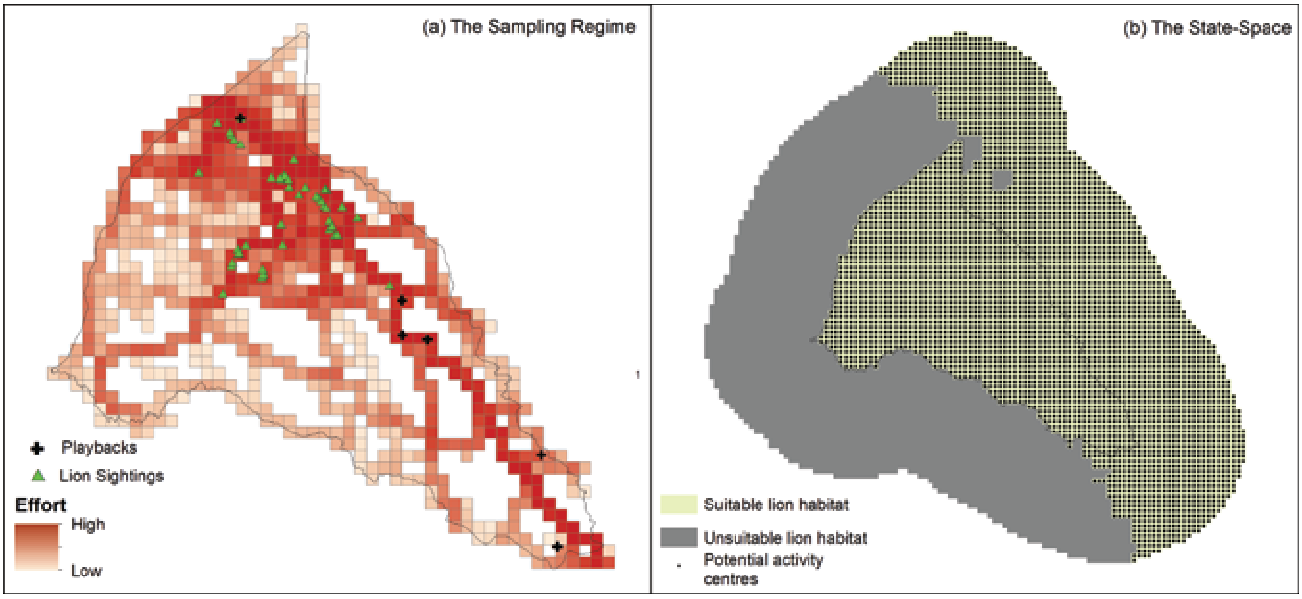


Figure 12.2: *(a) The sampling regime. The search-encounter protocol (12,922km drive effort in total, 9,875km in Meru NP) was conducted in conjunction with the playback protocol (20 in total, 6 in Meru NP). Each effort type was discretised into 1km² pixels such that each pixel depicts effort per pixel per day. This effort resulted in 116 detections of 30 lions. (b) The state-space. A 15km buffer was created around the survey area to demarcate the state-space. Potential activity centres were represented by equally spaced pixels (0.5km²). Pixels that were deemed to be unsuitable habitat (e.g. agriculture) were masked out prior to analysis. No lions were recorded outside Meru NP and thus only this area was retained for analysis.*

Fieldwork Summary

Table 12.1: *Summary data and information for the lion survey within the Meru Conservation Area*

Survey dates	03 September - 01 December 2019
Survey length	90 days
Resources	3 vehicles
Survey area	3,810km² (Meru NP = 877km²)
Field teams	Born Free Foundation, Kenya Wildlife Service, Technical Team
Field methods	Unstructured search-encounter, playbacks
Search-encounter driven	12,922km (Meru NP = 9,875km)
Playbacks	20 (Meru NP = 4 which led to no lion detections)
Lion detections	116
Km driven for 1 detection	85
Individual lions >1yr identified	30

Survey Results

Table 12.2: *Posterior summaries of parameters estimated from a Bayesian spatially explicit capture-recapture model used to estimate spatial lion density in the Meru Conservation Area. Posterior summaries presented below are from Model 1 and include the estimate (posterior mean) of each parameter, together with posterior standard deviation (PSD) and highest posterior density (HPD) intervals. Number of posterior samples used was 200,000. Maximum value of potential scale reduction factor = 1. Bayesian P-value = 0.91. See Chapter 3 for more details.*

Lions over 1 year old		Estimate	PSD	95% HPD
Number of lions	within survey area	48	8.1	33-64
	within 1σ area	55	7.7	41-70
Density (lions per 100km²)		5.4	0.9	3.6-7.1
ψ_{sex}		0.3	0.1	0.2-0.5
Sex ratio derived from ψ_{sex}		1.9♀: 1♂		

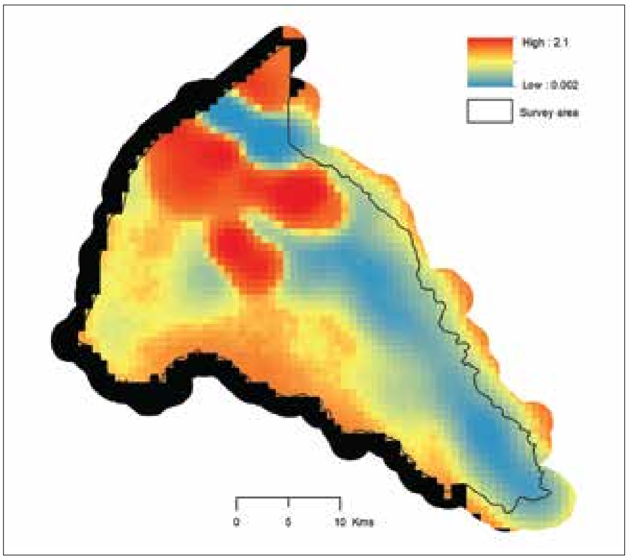


Figure 12.3: *Pixel-specific lion density expressed in units of individual lion activity centres per state-space pixel (0.5km²) in the Meru Conservation Area, Kenya.This figure depicts lion density within the wider buffer (1.9km) that was created around the search effort based on the estimate for sigma (the movement parameter). It is within this area that abundance was estimated to be 55 lions.*

Discussion

Our estimate of 55 lions over the age of one is consistent with that of Bundotich et al.[169] who estimated there to be 58 (±21) lions of all aged within Meru NP in 2016. The lion population within MCA is restricted to a relatively small area within Meru NP (Figure 12.3), which was also apparent in Bundotich et al.[169]. Within this same area the highest concentration of wild prey occurs and regular sightings of large herds of livestock were recorded outside of this area. Indeed, in Kora NP, Mwingi NR and Bisanadi NR, wild prey was only recorded on a small number of occasions while livestock (cattle, camels and goats) were regularly recorded throughout these areas. Over a period of 21 days an experienced tracker conducted ~700km of spoor surveys within Kora NP (vehicle and foot-based) and did not locate a single set of lion tracks. In total 60 days of field effort were invested (always scanning for lion tracks), over 3,000kms driven and 13 call-ins conducted within Kora NP, Mwingi NR and Bisanadi NR with no visual or audible indication of lion presence. While we do not discount that lions may occasionally utilise these areas, our extensive efforts in the area lead us to conclude that it is unlikely that lions were present in these areas during the survey period. It is also noted that during the survey a large number of livestock were present, a situation which apparently eases after the rains arrive as livestock moves out. See Chapter 14 of this report for further discussion on potential lion recovery in this and other sites.

Despite the extensive anthropogenic disturbance in Kora NP and lack of evidence of wild herbivores and lions, it is interesting to note that the teams did observe other carnivores in this area, including black-backed jackals, common genet, bat-eared fox, spotted hyaena, striped hyaena, leopard and cheetah. Indeed, the teams found cheetah marking trees quite widely within Kora NP, these being quite easy to find due to the abundance of Commiphora trees in the area that make cheetah scratchings and scats highly visible. This does not necessarily imply high abundance since the markings remain for long periods of time and cheetahs have large home ranges. A dedicated cheetah survey in Kora NP would be extremely valuable to ascertain their abundance and gain an understanding of what they are feeding on.

Chapter 13

Sibiloi National Park

Survey Area

Frequently referred to as 'the Cradle of Humankind', Sibiloi National Park (hereafter Sibiloi NP) is located in Marsabit County, northern Kenya, on the eastern shore of Lake Turkana and is part of the Lake Turkana National Parks (consisting of Sibiloi NP, Central Island and South Island). This remote area is characterised by a hot (26°-37°) and dry climate with an annual precipitation of ca. 130mm that falls between March-May and October-December[173,174]. Sibiloi NP covers 1,570km² and was gazetted as a National Park in 1973 and as a National Monument in 1982 for the protection of its wildlife and archaeological sites. In 1997 it was inscribed as a UNESCO World Heritage Site since its geology and fossil records represent major stages of the Earth's history – "The Kobi (sic) Fora deposits contain pre-human, mammalian, molluscan and other fossil remains and have contributed more to the understanding of human ancestry and paleo-environment than any other site in the world." (https://whc.unesco.org/en/list/801/). Sedimentary deposits formed by volcanic eruptions and extensive lava flows, together with geological faulting within the Great Rift Valley have resulted in the preservation of fossil remains and over 100 archaeological and paleontological sites have been identified since the 1960s. Humanoid fossils include the remains of five species (*Austrolophithecusanamensis, Homo habilis/rudolfensis, Paranthropus boisei, Homo erectus and Homo sapiens*)[175]. Other outstanding fossil finds in the area include the shell of a giant tortoise (3 million years old), a set of jaws from a crocodile that is thought to have been 14m in length (1.5 million years old), a forebear of the elephant, the extinct Behemoth, with massive tusks still intact (1.5 million years old) and a petrified cedar forest (7 million years old)[176].

The area features diverse habitats ranging from terrestrial to aquatic and desert to grasslands. Sibiloi NP serves as a stopover for migrant waterfowl and over 350 aquatic and terrestrial birds have been identified[175]. Lake Turkana is alkaline and supports large populations of giant Nile perch (*Lates niloticus*) and is a major breeding ground for the Nile crocodile (*Crocodylusniloticus*)[175]. Dwarf shrublands and grasslands occupy most of the area, with yellow speargrass (*Imperata cylindrica*), *Commiphora sp.*, *Accaciatortilis, A. elatior* and other Acacia species dominate along with Desert date (*Balanites aegyptiaca*) and doum palm (*Hyphaene coriacea*)[175,177].

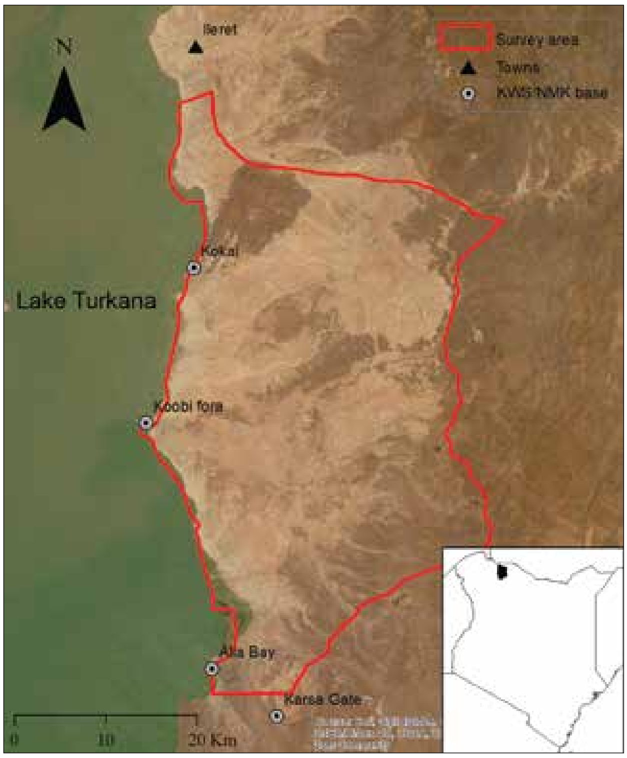


Figure 13.1: *Map showing the area surveyed, Sibiloi NP.*

Lion Population

While there have been extensive archaeological and paleontological studies conducted within this area since the 1960s, historical scientific knowledge on lions specifically and wildlife more generally is somewhat anecdotal. In 1969, Wilfred Thesiger, a renowned explorer and naturalist, travelled in what is now Sibiloi NP for two weeks. He did not see a single person and wrote of abundant wildlife including beisa oryx (*Oryx beisa*), grevy's zebra (*Equus grevyi*), reticulated giraffe (*Giraffa camelopardalis reticulata*), Grant's gazelle (*Gazella granti*), topi (Damaliscus lunatus), rhino and lion[178]. Between November 1979 and February 1980, prominent carnivore biologist Hans Kruuk conducted a survey to establish the extent of livestock depredation by carnivores[179]. His study area did not include what is now Sibiloi NP but was located in an area of approximately 20,000km² between the south-east shore of Lake Turkana and Marsabit Mountain. He made notes on the presence and absence of carnivores using direct observations, tracks and scats and confirmed the presence of all of Kenya's large carnivores (lion, leopard, cheetah, spotted hyaena, striped hyaena and African wild dog). Of lions in the area, Kruuk noted "Lions occur near BalesaKulal, Kurkum, and in an area north-east of Ngurunit; from tracks and sightings by myself and others, it was estimated that there are at least 10 in the study area, probably fewer than 50"[179].

So scarce is our research evidence of wildlife past and present in this area that the University of Helsinki has initiated a project using Indigenous and Local Knowledge (ILK) to better understand past changes and the current status of Sibiloi's fauna[180-182]. It is apparent that Sibiloi NP is facing many challenges and that poaching and livestock incursions have decimated wildlife populations and species such as elephant, buffalo, greater kudu, reticulated giraffe and rhino have seemingly disappeared[181]. In 2016 researchers at the University of Helsinki reported: "In a recent expedition in the area, we found only a handful of oryxes, a dozen zebras, a few topis and two gerenuks, all restricted to the southern part of the park"[181]. Miquel Torrents-Ticó, a PhD student from the University of Helsinki has conducted several site visits to establish carnivore presence and trends within Sibiloi NP between 2016-present[182]. To date, he has used a combination of monitoring techniques (camera traps, track surveys, faecal sampling, playbacks) and has confirmed the presence of the African golden wolf (*Canis aureus or C. anthus*), black-backed jackal (*Canis mesomelas*), spotted hyaena, striped hyaena, African wildcat (*Felis silvestris*), Common genet (*Genetta genetta*), bat-eared fox (*Otocyonmegalotis*), white-tailed mongoose (*Ichneumiaalbicauda*) and caracal (*Caracal caracal*)[183]. More recently he obtained a camera trap picture of a cheetah within Sibiloi NP but has not noted any sign of lions[182,183].

Analysis

Consultations with local stakeholders prior to the survey suggested that lions were likely not to be present in Sibiloi NP. Our efforts therefore focused on attempting to establish their presence or absence as well as to document signs of other carnivores and wildlife and livestock more generally. Our fieldwork strategy was to access as much of the park as possible (by road and foot), as many times as possible to search for tracks and signs of lions. Among the survey team was an experienced Maasai tracker and at all times while driving we scoured the roads looking for lion tracks and extensively walked in the dry riverbeds to search for signs of lions. In addition, we randomly used the playback protocol in areas that we deemed most likely to contain lions (e.g. close to water and wild prey). Playbacks are only effective at night and due to security concerns these were restricted to the southern section of Sibiloi NP. All sightings of herbivores and livestock were recorded and sightings of all carnivores and tracks of large carnivores were recorded. Tracks of spotted hyaena were distinguished from striped hyaena, since tracks of the latter are smaller and have narrower pads (in particular the hind pad)[184].

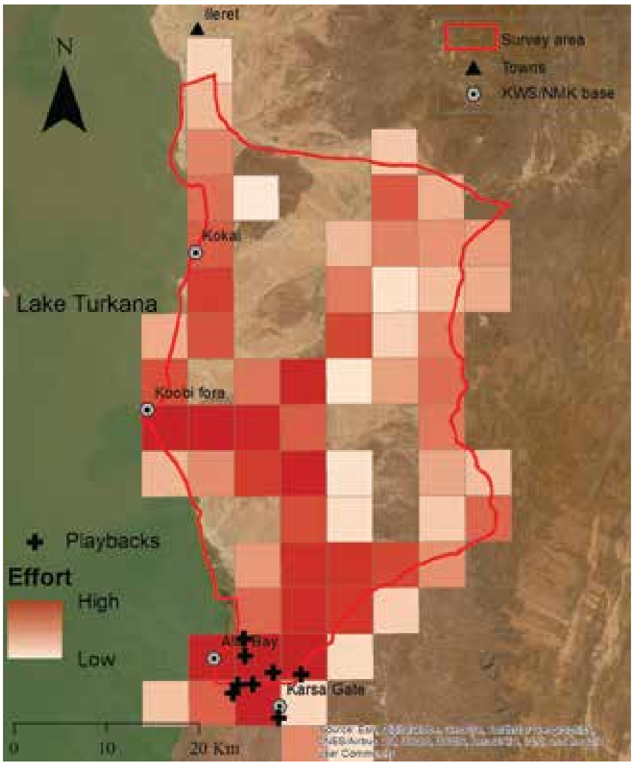


***Figure 13.2:**The search encounter protocol (total drive effort was 1,613km) was conducted in conjunction with the playback protocol (8 playbacks). Each effort type was discretised into 25km^2 pixels such that each pixel depicts effort per pixel per day. This effort resulted in no detections of lion presence.*

Fieldwork Summary

Table 13.1: *Summary data and information for the lion survey within Sibiloi NP.*

Survey dates	01 March - 14 March 2020
Survey length	14 days
Resources	2 vehicles
Survey area	1570km^2
Field teams	Kenya Wildlife Service, Technical Team
Field methods	Unstructured search-encounter, playbacks
Search-encounter driven	1,613km
Playbacks	8
Lion detections	0
Km driven for 1 detection	-
Individual lions >1yr identified	0

No sign of lions was observed during the survey. All our discussions with rangers and other local stakeholders in the area indicate that the last known occurrence of lions within Sibiloi NP was in 2017, when one or two transient lions moved through, and even then, lions were not thought to be resident.

Wildlife sightings, and especially herbivores, were restricted to a very small area in the southern section of the park, close to Alia Bay (Figure 13.3). The following species were recorded during fieldwork:

Herbivores: Topi, Grant's gazelle, Plains zebra, generuk, warthog.
Carnivores: African golden wolf, black-backed jackal, caracal, honey badger, leopard, spotted hyaena, striped hyaena, white-tailed mongoose, African wildcat.
Other: Aardvark.
Notable bird species: Egyptian vulture, White-headed vulture, hooded vulture, lappet-faced vulture, white-backed vulture, Osprey, Eurasian marsh harrier, Imperial eagle, fish eagles, Heuglin's bustard.

The below figures depict our sightings of various species and include the tracks recorded of large carnivores.

These are offset against our drive effort to produce index of abundance maps that provide a somewhat crude depiction of the distribution of the various species that were encountered, weighted by search effort.

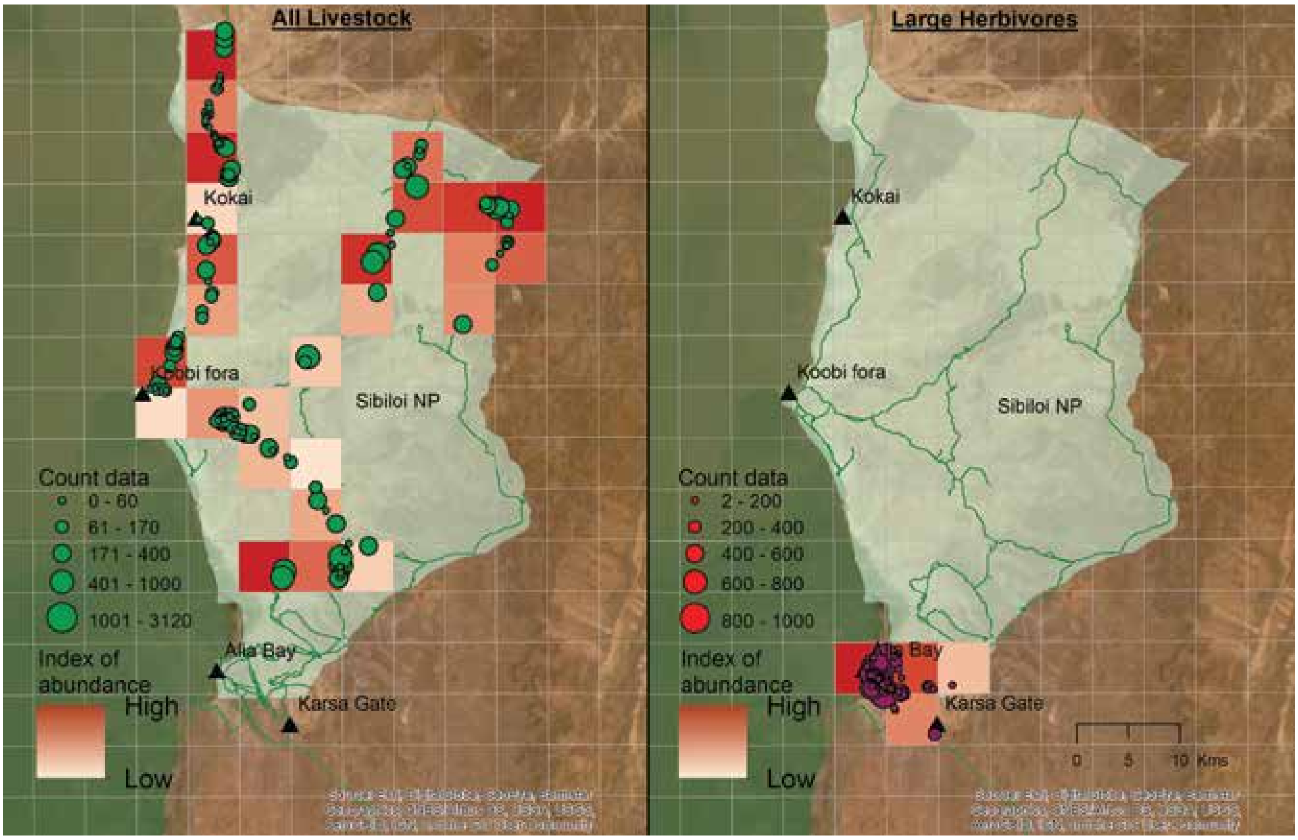


Figure 13.3:*Livestock was encountered throughout Sibiloi NP except for the area around Alia Bay, which is the only place large herbivores (topi and plains zebra) were encountered. Cattle, shoats and donkey were observed throughout the park, while only one sighting of camels was recorded within the park.*

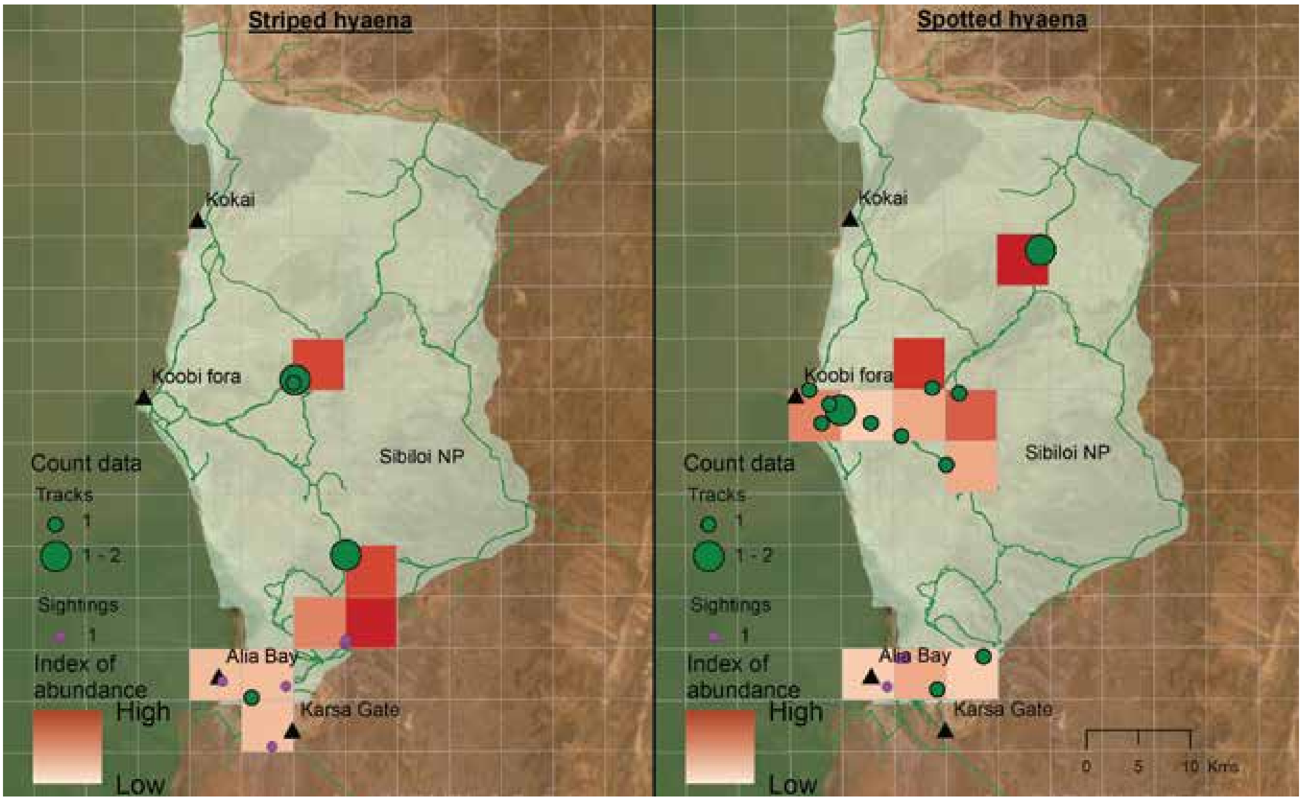


Figure 13.4: *Large carnivores (spotted and striped hyaenas) were only sighted close to Alia Bay, but their tracks were observed across a wider area.*

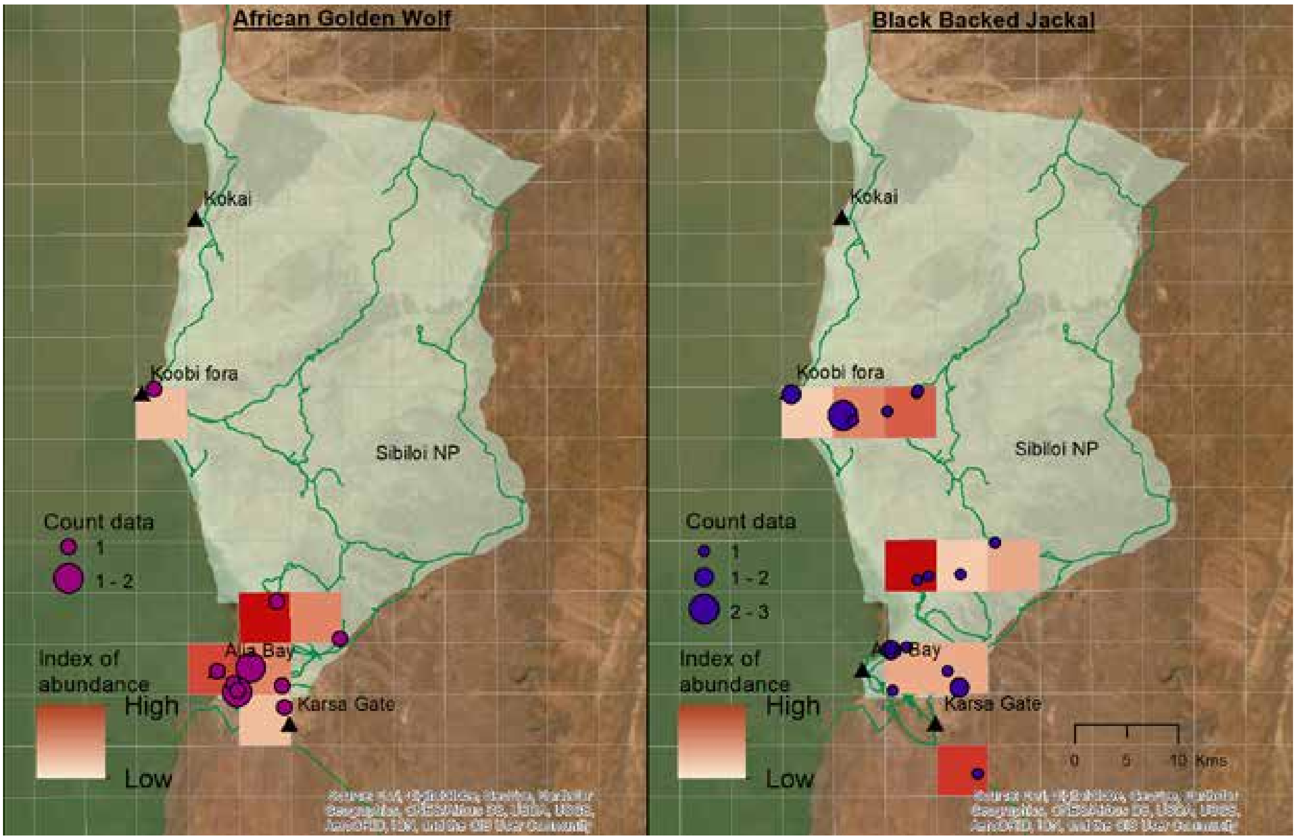


Figure 13.5:*African golden wolves and black-backed jackals were frequently sighted around Alia Bay, with black-backed jackals also being frequently sighted close to Koobi Fora, where only one African golden wolf was seen.*

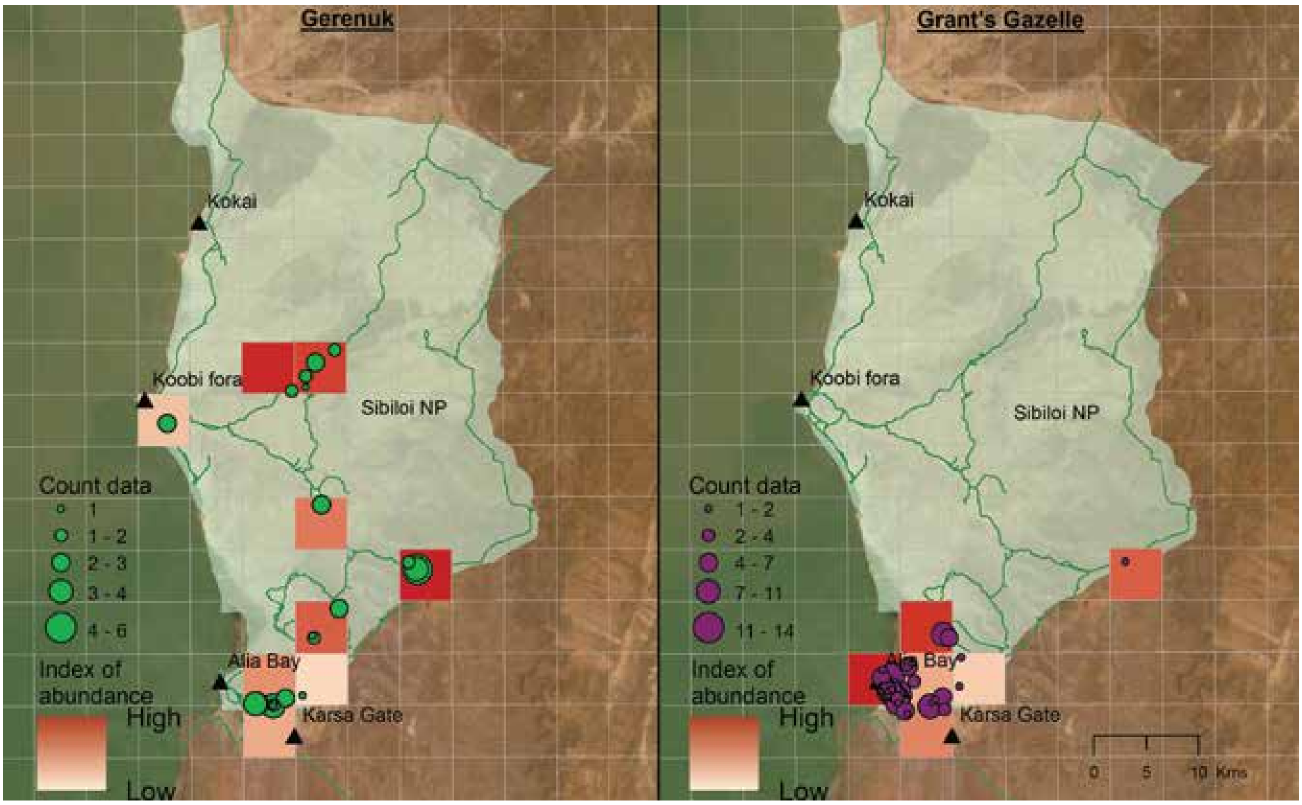


Figure 13.6:*Gerenuk were the most widely distributed herbivore species, while Grant's gazelle were restricted to the area around Alia bay (similar to topi and zebra) although one sighting was recorded in the south-east of the park.*

Discussion

Despite our extensive field effort, we did not detect the presence of lions, which corroborates the local stakeholder's view that lions were likely absent within Sibiloi NP. However, it is likely that lions occur in nearby areas adjacent to Sibiloi NP as predicted by our site occupancy study (see Chapter 15 of this report). Whereas lions typically favour localities close to water sources due to the concealment offered for denning and ambushing of prey that frequently congregates close to water[152,153], we found that areas close to Lake Turkana (east and west of the lake) had very low probability of site use (see Figure 15.3). It is possible that this scarce water source in an otherwise arid environment serves to attract livestock which displaces wildlife. Similarly, Torrents-Ticó did not find any field evidence of lions, but interviews with ILK holders suggested lions were present in the more general area, with a decreasing population trend[182]. See Chapter 14 of this report for further discussion on potential lion recovery in this and other sites.

Consistent with other reports[181,183], we found that wildlife was largely restricted to a small (~10km^2) area in the southern section of part of the park, while livestock (cattle, shoats and donkeys) was widely distributed throughout (Figure 13.3). Our field observations suggest that spotted hyaenas were more widely distributed compared with striped hyaenas, black-backed jackals and African golden wolves (Figures 13.4, 13.5, while noting that Torrents-Ticó found a wider distribution of black-backed jackals). Small herbivores were largely restricted to the southern section (especially Grant's gazelle), while small groups of gerenuk were also sighted in the centre of the park. Taken together, these evidences suggest that wildlife is restricted to the proximities where either KWS (Alia Bay) or NMK (Koobi Fora) maintain permanent bases. We did not record the presence of any wildlife in the northern section of the park.

Torrents-Ticó identified a few species that we did not record notably cheetah, beisa oryx, common genet and bat-eared fox[182,183]. Our survey revealed additional species within the order Carnivora that Torrents-Ticó did not document: leopard tracks were seen in two distinct locations and a honey badger was visually sited. Consistent with Torrents-Ticó, we also observed caracal, white-tailed mongoose and African wildcat.

Sibiloi NP remains a hugely important National Park for Kenya, not just due to its fossil records, but also because of its unique flora and fauna, which all contributed to its listing as a World Heritage Site[173]. However, there is clearly much competition between livestock and wildlife for the limited resources that exist in this harsh environment.

Historic records suggest that this area, despite being arid, can contain relatively abundant and diverse wildlife populations[178]. However, hydrological developments within Ethiopia's Omo River (Lake Turkana's major water source), together with increasing human population pressure, poverty, lack of infrastructure development, poaching and overgrazing have led to a conservation outlook of 'critical' in the last three assessment cycles (2014, 2017, 2020) of the IUCNs World Heritage Outlook[185-187] and Sibiloi NP being inscribed on the List of World Heritage in Danger since 2018[175].

It is important to note that our survey was targeted at establishing the presence or absence of lions and should not be regarded as a thorough assessment of other wildlife. However, we present our findings of other species to motivate a full-scale assessment of wildlife within the area as a critically important and urgent exercise.

Chapter 14

Discussion and Contextualisation of Kenya's Lion Numbers

In total we conducted rigorous surveys of ten lion source populations to estimate population density and abundance. Our knowledge of lion numbers and population trends has historically been hindered by the use of different methods that are frequently unreliable. Here we have shown that it is possible and indeed desirable to utilise cutting edge methods within a standardised framework and apply these to a great variety of landscapes. By making use of different field techniques, all of which were designed to fit within a spatially-explicit capture-recapture framework, we produced accurate and precise estimates of lion density and abundance in sites ranging from national parks to conservancies to community land. Our collective experience in this endeavour suggests that all source populations of lions can be surveyed in this manner, with the likely adaptation of field protocols to suit local conditions. It is however recognised that resources are required, notably in the form of personnel and vehicles to carry out fieldwork across such extensive ecosystems. Kenya is fortunate to have a great variety of local stakeholders that were all too willing to engage in this process.

Sites with potential for lion recovery

Obtaining meaningful estimates of carrying capacity for each site would have involved thorough assessments of prey populations and should ideally include assessments of anthropogenic variables (such as human population density, land conversion and attitudes). While this was beyond the scope of the current exercise, as was a thorough threat assessment to chart a path for recovery, we make the following observations regarding potential lion recovery sites.

The Meru Conservation Area consists of two National Parks (Meru and Kora) and two National Reserves (Bisanadi and Mwingi), with a third National Reserve (Rahole) close by. Our fieldwork and results show that lions (and indeed wildlife more generally) are restricted to a relatively small area within Meru NP. We did not find any sign of lions outside of Meru NP, where livestock was commonly encountered. Regardless of anthropogenic impacts, Meru NP is likely the most productive part of this ecosystem since it contains numerous perennial streams and rivers and habitats suited to grazers. Kora NP is more arid and dominated by *Acacia-Commiphora* bushlands. The only permanent water source is the Tana River which attracts wildlife and domestic stock alike, and a large section of this river forms the boundary between Kora NP and the adjacent community, thus making it an area for potential human-wildlife conflict.

We did not record any sign of lions during the survey of Sibiloi National Park and anecdotal evidence suggests they have not been resident within this park for some time. A small area in the south of the park appears to support the only population of large herbivores. However, this small area (~10km^2) is too small to hold the home range of even one pride of lions. Lions can survive off smaller bodied prey, but these were not observed in most of the park and at very low densities elsewhere. Interestingly, the site occupancy study (see Chapter 15) indicates that lions do likely occur in the areas adjacent to Sibiloi NP. The two evidences combined (no lions inside a protected area that has a ready water source, yet lions outside a protected area with no ready water source) is at first counter intuitive. The most likely explanation is that the water and pasture associated with Sibiloi NP is an attractant to people and their livestock in an area that is largely devoid of both of these critical resources, and that this anthropogenic disturbance has displaced the lions. What is unclear is whether there is a wild prey population supporting these lions, or whether their populations are threatened due to human-lion conflicts. It is likely that if the level of anthropogenic disturbance inside Sibiloi NP were reduced, lions would return, however it is largely unknown as to whether there is an existing large-bodied prey base in the larger area that can sustainably support large carnivores.

The Lake Jipe area of Tsavo West yielded surprisingly few large carnivores (visual sightings and tracks) given the wild prey abundance in the area: large herds of plains zebra and buffalo were commonly observed. However, livestock was sighted with relative frequency. While we did find some lions in this area, they appeared to have large home ranges (we observed a coalition of four males on separate occasions 20km apart). Furthermore, female lions were always observed alone, suggesting a fragmented population. Large home ranges and movement of lions was also observed in the Ithumba area, in the northern section of the Tsavo Conservation Area. Large home ranges in lions are indicative of low prey density as lions are forced to move large distances in search of scarce resources. Since lions are territorial, large home ranges typically correspond to low lion densities.

During the survey, a section of Chyulu Hills NP was settled by people and is part of a long-running land dispute. The settlement occurred in the grassland areas between Mkururo and Kilinyeti ranger bases in an area that is otherwise relatively productive for wildlife. The areas adjacent to the settlement were observed to contain wild prey animals and it is in these areas that the teams sighted lions.

For lion recovery to be achievable in these areas a variety of factors would need to be considered such as minimising the levels of anthropogenic disturbance, human-lion conflict mitigation and in some cases potentially restocking herbivore populations. However, these areas do represent a real opportunity for lion recovery and wildlife recovery more generally.

Conservation organisations have tended to focus their efforts on southern Kenya in addition to several areas in central Kenya. While these areas are critically important to Kenya's lions, our surveys have revealed several areas that would greatly benefit from concerted lion conservation efforts and that have historically received little attention. In all cases, a thorough assessment of the threats would need to be undertaken to fully explore the conservation interventions required at each site before lion recovery can be considered.

Inferring population trends

A major goal of wildlife monitoring is to understand population trends and dynamics over time. The aim of this initiative was to provide a baseline for key source populations using robust methods that can be repeated to begin to explore population trends in future. Indeed, when selecting the methods used for this initiative a key criterion was that accurate and precise figures should be prioritised despite being more resource intensive. A fundamental advantage of SECR methods compared to other methods, is that in time, open population models can be formulated to deepen our understanding of population dynamics by estimating key vital rates such as survival and recruitment (e.g. [24]). As such, future surveys undertaken at key lion source populations should make use of the same methods and the development of a full set of monitoring guidelines has been identified as a priority to aid long-term monitoring of lion populations and set the agenda for rigorous and frequent monitoring.

Contextualisation of results within the National Recovery and Action Plan for Lion and Spotted Hyena in Kenya (2020-2030) and the National Wildlife Census 2021 Report

The current report presents the details and results from robust SECR lion surveys conducted within 10 of Kenya's important known and potential source populations. Preliminary results from a progress report pertaining to these 10 surveys were summarised and incorporated into Table 1 in the 'National Recovery and Action Plan for Lion and Spotted Hyena in Kenya (2020-2030)'[148], which is duplicated below in Table 14.1 for ease of reference. An abridged version of this table was also presented in the 'National Wildlife Census 2021 Report' (see Table 22 in [250]). Since the release of these documents, the data analyses were improved in terms of model fitting. we have made improvements in data analysis relating to model fitting. These improvements have resulted in the slightly different abundance estimates provided in the current report. A comparison between the results in this report (see page vii for a summary) with Table 14.1 below shows very small differences for Shompole and Olkiramatian, Tsavo, and a combined estimate for Laikipia (which is now combine with Ol Pejeta and Solio). However, these differences are practically insignificant; total number of lions in the 10 source populations = 1,598 (SD 52) in this report compared to 1,588 (SD 56) in the previous documents[148,250].

Although we covered most of the important lion populations within Kenya, it is acknowledged that other potential source populations of lions need to be surveyed using SECR. Potential sources that we had aimed to survey but could not due to insecurity and/or Covid-19 (Kuku Ranch, Shaba National Reserve, Biliqo Conservancy, Mathew's Range, Namunyak Conservancy, Milgis area and several coast properties) should be surveyed as a priority to estimate lion numbers rigorously. Beyond these potential sources, lions are likely distributed widely across Kenya (see Chapter 15), which is acknowledged within the 'National recovery and action plan for lion and spotted hyena in Kenya (2020-2030)', which states:

'Thus, for areas which were not surveyed using rigorous methods, guess estimates were acquired from honorary wardens and other researchers working in Wajir, Garissa, Mandera, Tana River, Marsabit, Turkana, West Pokot Baringo, Lamu Counties and other areas in Samburu and Isiolo Counties. The surveys established that Kenya has an estimated population of about 2,489 lions. It is noted that comparisons between sites and over time are valid only when using data that have been collected and analysed using the same rigorous methodologies. Future surveys using SECR methods are currently being planned and will be useful to assess population trends. Producing regional or national totals by adding up estimates of different quality could be justified to give a general total, but should not be relied upon for accurate descriptions of lion status. Future lion surveys should focus on strategies to best understand the status of lions in areas listed with guess estimates.'

Table 13.2: *This table and the caption below are duplicated from the National Recovery and Action Plan for Lion and Spotted Hyena in Kenya (2020-2030)[148]. The SECR estimates cite a progress report compiled while this initiative was underway. Since then, improvements to model fitting have resulted in very small differences in estimates for Shompole and Olkiramatian, Tsavo Conservation Area and Laikipia & Meru Ranches (in the current report this is combined with Ol Pejeta and Solio). Refer to Page viii of the current report for a comparison.*

	Area surveyed	Area size (km^2)	Survey Method	Number of lions	Year of Estimate	Source
1	Maasai Mara Ecosystem	3,000	SECR	556 (24)	2018	Elliot et al., 2020a
2	Shompole and Olkiramatian	409	SECR	25 (4)	2018	Elliot et al., 2020a
3	Amboseli Ecosystem	4,512	SECR	141 (24)	2018	Elliot et al., 2020a
4	Tsavo Conservation Area	28,419	SECR	459 (40)	2019	Elliot et al., 2020a
5	Nairobi National Park	147	SECR	25 (6)	2018	Elliot et al., 2020a
6	Lake Nakuru National Park	135	SECR	11 (1.5)	2017	Elliot et al., 2020b
7	Laikipia & Meru Ranches	3,752	SECR	184 (8.3)	2019	Elliot et al., 2020a
8	Ol Pejeta	365	SECR	49 (10.5)	2019	Elliot et al., 2020a
9	Solio Ranch	161	SECR	66 (8.3)	2019	Elliot et al., 2020a
10	Sections of Samburu, Isiolo, Laikipia and Meru Counties	3,204	SECR	17 (2.8)	2019	Elliot et al., 2020a
11	Meru Conservation Area	1,016	SECR	55 (8)	2019	Elliot et al., 2020a
Total estimated by systematic SECR surveys				**1,588 (56)**		
13	Soysambu Ranch	190	IndID	~5	2020	KWS Database, 2020
14	Southern Rift Region	1,200	Guess	~45	2020	Guy *Pers. Comm.*, 2020
15	Kuku Ranch	960	Guess	~60	2020	Muller *Pers. Comm.*, 2020
16	Machakos Ranches	280	Guess	~10	2020	Mbithi *Pers. Comm.*, 2020
17	Greater Nairobi National Park Ecosystem	401	Guess	~20	2020	KWS Database, 2020
18	South Turkana –Nasalot Ecosystem	2,191	Guess	~5	2020	KWS Database, 2020
19	Garissa County	44,753	Guess	~150	2020	HCP Database, 2020; Ali *Pers. Comm.*, 2020; NRT, Database 2020
20	Wajir County	55,841	Guess	~200	2020	HCP Database, 2020; Ali *Pers. Comm.*, 2020; Sharmake Mohame*d Pers. Comm.*, 2020
21	Mandera County	25,798	Guess	~130	2020	Hussein Ahmed Mahat *Pers. Comm.*, 2020 (Honary Warden, Mandera)
22	North Horr Sub-County	38,953	Guess	~10	2020	Lesilau *Pers. Comm.*, 2020
23	Moyale Sub-County	9,390	Guess	~15	2020	Lesilau *Pers. Comm.*, 2020
24	Lamu County	6,273	Guess	~40	2020	NRT, Database 2020 & KWS Database, 2020
38	Kiunga/ Awer conservancies, Lamu	1,869	Guess	~20	2020	NRT, Database 2020
26	Tana River County	35,000	Guess	~15	2020	NRT, Database 2020 & KWS Database, 2020
25	Tana River Conservancies & Tana River Primates Reserve	376	Guess	~25	2020	NRT, Database 2020 & KWS Database, 2020
27	West of Marsabit	14,775	Guess	~10	2020	Lesilau *Pers. Comm.*, 2020
28	Nairobi Ranch, Lamu	47	Guess	~9	2020	Raabia Hawa of Ulinzi Africa Foundation, 2020
29	Hanshak-Nyongoro Community Conservancy, Lamu	779	Guess	~17	2020	Raabia Hawa of Ulinzi Africa Foundation, 2020
30	Shaba National Reserve/ Nakuprat Gotu	130	Guess	~10	2020	NRT, Database 2020; Ewaso Lions 2020
31	Biliqo Bulesa Conservancy	3,773	Guess	~20	2020	NRT, Database 2020; Ewaso Lion, 2020
32	Sera and Melako conservancy	8,896	Guess	~10	2020	NRT, Database 2020
33	Songa, Shurr and Jaldesa conservancies	6,329	Guess	~15	2020	NRT, Database 2020
34	Greater Namunyak conservancy	8,500	Guess	~30	2020	NRT, Database 2020; Ewaso Lions, 2020
35	Meibae/ Nkotieya conservancies	1,171	Guess	~5	2020	NRT, Database 2020
36	Naibunga conservancy	466	Guess	~15	2020	NRT, Database 2020
37	Ishaqbini conservancy	899	Guess	~10	2020	NRT, Database 2020
Total estimated by guesses				**~901**		
Total estimated population in Kenya				**~2,489**		

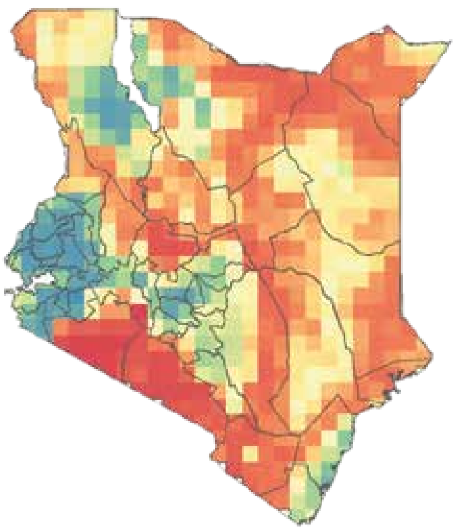
Table caption: *The preliminary SECR results are presented with posterior standard deviations in brackets. There are a number of areas known to contain lions within which the systematic SECR surveys were not carried out. The figures listed in areas 13-37 above are based on guess estimates and opinions sought from people who work within the areas listed. These figures are not based on any scientific surveys and are listed here in recognition that lions likely occur in these areas and that systematic surveys should be carried out in some of these areas to provide reliable figures. It is noted that the SECR estimates are for lions over the age of 1 year, while the guess estimates are for lions of all ages. The national total estimates produced by adding up estimates acquired using different methods provides an opinion on the possible number of lions in Kenya. Future lion surveys should focus on producing more accurate lion numbers in areas with guess estimates.*






PART II: Large Carnivore Distribution

Predicting large carnivore distribution across Kenya



Chapter 15

Distribution of Large Carnivores in Kenya

Introduction

Understanding the occurrence and distribution of species is crucial for conservation. However, obtaining robust data for cryptic species is often difficult, especially across large spatial extents[189,190]. This is indeed the case for large carnivores as they are generally wide-ranging, elusive and occur at low densities[191-193]. Various field methods have been developed to determine the occurrence of large carnivores, including camera trapping, DNA monitoring, sign surveys and collars[194]. While these methods can provide accurate representations of occurrence and changes over time, they are frequently resource intensive and therefore only applicable for relatively small areas (e.g. at the landscape-level). In contrast, harnessing local knowledge, also known as Local Ecological Knowledge (LEK), is a relatively quick and cost-efficient method of collecting data on species presence over larger areas (e.g. at a country-wide level) and can provide important information to identify areas for future interventions and intensive monitoring to assess declines or recovery[45,46,195]. A common method of collecting LEK is by interviewing knowledgeable people about a landscape with which they regularly interact, usually through their daily activities[196-198]. In the last decade, the use of LEK has proliferated and been used to determine species distributions at scales that range from local[7] to national[195] and multi-national[198]. Nevertheless, using LEK-based data to determine large carnivore distribution has been questioned due to challenges related to species misidentification and the reliability of reporting[199]. However, issues relating to over- or underestimating species distribution as a result of false negatives (when a species is present but reported to be absent) and false positives (when a species is absent but reported to be present) can be accounted for. In fact, when these measurement errors are corrected for, LEK data can produce similar outputs to those from GPS-collar data, especially for less common carnivore species[47]. Carnivore occurrence is often influenced by natural and anthropogenic factors such as vegetation structure, prey availability, topographic features (e.g. elevation), water availability and the presence of people and livestock[7,200,201]. Here we use LEK, in combination with the carnivore sightings that were obtained through the sightings-based surveys (Chapters 3-14), to determine the impact of both natural and anthropogenic factors on species presence to make model-based predictions of occurrence and distribution of lion (*Panthera leo*), leopard (*P. pardus*), cheetah (*Acinonyx jubatus*), spotted hyaena (*Crocuta crocuta*), striped hyaena (*Hyaena hyaena*) and African wild dog (*Lycaon pictus*) across Kenya.

Methods

Sampling approach

Due to the large spatial extent of the survey (580,367 km²), the study was designed such that a large proportion of Kenya could be covered in the given timeframe while using a resolution that is biologically meaningful. As such the country was divided into 1,000 km² grid cells (n = 603) where presence and absence of six large carnivore species (lion, leopard, cheetah, spotted hyaena, striped hyaena and African wild dog) would be determined using data obtained through structured questionnaires and sightings-based surveys. The aim was to obtain 6-8 data points in 480 randomly selected grid cells.

Questionnaire and data collection

A questionnaire was used to collect data through in-person interviews between October 2018 and March 2020. In March 2020 the in-person interviews were discontinued due to the COVID-19 pandemic and the questionnaire was shifted to an online platform where data collection occurred between July and December 2020.

In-person interviews

The in-person interviews were conducted by trained enumerators. Enumerators had to be 20 years or older and were selected based on whether they were resident in the area of interest, their knowledge of large carnivores, their ability to read and interpret maps and their proficiency in using an Android-based smartphone needed for data collection. Preference was given to those who had a degree and experience in conducting research-oriented interviews. Each recruited enumerator attended a one-day workshop to ensure that they were well-versed in the data collection methods.

The data were collected using a custom-built application for Android phones that was created using the CyberTracker software (www.cybertracker.org). Prior to data collection, each enumerator spoke to the necessary authorities about the questionnaire that was being conducted. We used a targeted sampling approach where respondents who had knowledge that was most relevant to the study (e.g. herders, government chiefs, wildlife researchers, photographers, wardens and safari guides) were selected[202].

Using detailed maps that were overlaid with the sampling grid, the enumerators described the grid cell of interest and its boundaries to the respondent using geographic features (e.g. rivers and hills), human development (e.g. roads and towns) and administrative areas (e.g. counties and sub-counties). Once this was done, the enumerator commenced with data collection as described later on.

Online Survey

When the in-person interviews could no longer be conducted due to the COVID-19 pandemic, an online map-based survey was created through Maptionnaire (www.maptionnaire.com). The format of the online survey was similar to the phone-based application that was used for the in-person interviews with the exception that the respondent had to place a location marker in the grid cell of interest. The respondents were asked to provide information on only one grid cell per session. The online survey was distributed through email, WhatsApp, blog posts, social media platforms (Facebook and Twitter) and newsletters to key informants who were asked to complete the survey and share it with their networks.

To ensure that the data were reliable, the respondents were presented with photographs of the target species which they were asked to identify, including that of a tiger (*P. tigris*) which does not occur in the wild in Kenya. If the respondent correctly identified the species in the photograph, then they were asked whether they thought that that species had been present in the grid cell of interest since January 2018. If the respondent said yes, then they were asked how they knew this (e.g. they physically encountered the target species, they saw tracks, they heard reports from other people etc.). If the respondent identified the species correctly but thought that it had not been present in the grid cell of interest since January 2018 then a photograph of the next target species was presented, and the process was repeated until data was obtained on all seven species (the six large carnivores that occur in Kenya and the tiger which does not occur in Kenya). All data collection conformed to the Kenyan Data Protection Act (2019) and all individual responses were anonymous.

Sightings-based survey

Between January 2018 and December 2020, nine sightings-based surveys were carried out in sections of the following ecosystems: Maasai Mara, Amboseli, Shompole and Olkiramatian, Tsavo Conservation Area, Laikipia, Meru Conservation Area, Samburu and Isiolo Counties, and Sibiloi and Nairobi National Parks (see Chapters 5-13 for more details). Data were collected using unstructured search-encounter protocols, playbacks, unstructured foot patrols and conditional drive effort (See Chapter 3 for more details). Whenever lion, leopard, cheetah, spotted hyaena, striped hyaena or African wild dog were sighted, the GPS location, date and time of day were recorded.

Data processing

Only data from respondents who correctly identified the target species during the interviews and online surveys were included in the analyses and any data where tigers were said to be present were removed prior to the analyses. Furthermore, only data points where the target species were reported to be detected based on actual sightings (dead or alive), vocalisations (only for lion and spotted hyaena), collar data and camera trap data were used and those based on less reliable data (e.g. scat, conflict reports etc.) were removed.

In the online survey there were cases where respondents had placed more than one location marker during a session. If the markers were placed in the same grid cell, then these additional locations were removed. If markers were placed in multiple grid cells, then it was not clear which grid cell the respondent was providing data for and these data were removed prior to the analyses.

To aid in model fitting and convergence, the sightings surveys were condensed into 7-day sampling occasions, except for the African wild dogs where 21-day sampling occasions were used due to the small number of sightings (Table 15.3). A target species was classified as 'detected' if it was sighted at least once during a sampling occasion.

Data analysis

Like with the spatially-explicit capture-recapture (SECR) models that were used to estimate lion numbers (Chapters 4-13), it is important to account for detection probability, which is the probability of detecting the target species if it is present. Not accounting for detection probability can lead to underestimates of species distribution and potentially inaccurate assumptions about the influence of covariates on the probability of occurence[203]. When dealing with data that have been obtained indirectly, such as through interviews, there is also a possibility that false positives, when a species has been reported but is not present, can occur. This is likely to arise when respondents misidentify or misremember sightings[204]. Not accounting for false positives can result in an overestimation of occurrence[46]. False positives can be minimised during the data collection stage by, for example, using photo cards to ensure the interviewee can correctly identify focal species[7,45] and carefully selecting the most experienced interviewees[205], as was done during this survey. False positives can further be accounted for by using appropriate analytical methods[204,206,207]. In particular, single-season multiple detection method false-positive occupancy models[206] were used to determine species-habitat relationships to predict potential occurrence[206]. All analyses were done using the *unmarked* package[208] in R[68].

Detection probability

We assumed that the probability of detection was likely to be lower during the sightings surveys compared to the two questionnaire-based surveys since the sightings surveys were conducted during a relatively short timeframe (1-3 months). Therefore, we included the survey type as a categorical variable (questionnaire or sightings) to calculate the detection probability for each.

False positives

To account for false positives, multiple detection methods[206] were used where detections of the target species that were obtained through the interview and online surveys were classified as 'uncertain', as they could still contain false positive detections, and those obtained through the sightings surveys were classified as 'certain'.

Covariates

Covariates were selected based on anthropogenic and environmental factors such as land use, vegetation, water availability, topography and prey availability that are known to influence carnivore presence (Table 15.1). All covariates were used in the original form provided by the source with the exception of prey availability. Prey data were obtained from Ogutu et al.[209] and densities of wild prey were calculated at a county level by dividing the total prey numbers by the size of the county. This did not include data provided by Ogutu et al.[209] on livestock, elephant (*Loxodonta africana*), giraffe (*Giraffa camelopardalis*) and ostrich (*Struthio spp.*).

Each variable was averaged per 1,000 km^2 grid cell and all variables, except those that were proportions, were standardised using a z-score transformation with a mean of 0 and a standard deviation of 1. The covariates that were included in the models were species-specific depending on *a priori* hypotheses as summarised in Table 15.2. For each species a set of candidate models was generated using all possible combinations of the covariates. This resulted in 15 candidate models for lions and seven for the other carnivore species.

Table 15.1: *Sources for the covariates used to determine species-habitat relationships and occupancy for large carnivores across Kenya.*

Category	Variable	Source
Anthropogenic	Land conversion	Jacobson et al.[210]
Vegetation	% non-tree vegetation	MODIS (MOD44B Version 6 Vegetation Continuous Field)
	% trees	
Water availability	Annual precipitation	www.wordclim.org
Topography	Terrain ruggedness	https://www.earthenv.org/topography[212]
Prey availability	Prey density	Ogutu et al.[209]

Table 15.2: *Summary of the covariates that were included for each species-specific analysis based on previous research.*

Species	Occupancy covariates	References
Lion	Prey + Land conversion + Proportion non-tree + Annual precipitation	48, 217
Leopard	Prey + Land conversion + Ruggedness	199, 218
Cheetah	Prey + Land conversion + Proportion Tree cover	199, 201, 219
African wild dog	Prey + Land conversion + Proportion Tree cover	199, 202
Spotted hyaena	Prey + Land conversion + Annual precipitation	199
Striped hyaena	Prey + Land conversion + Annual precipitation	220, 221

Model selection

Candidate models were ranked using AIC and relative support was assessed using the ΔAIC and AIC weights. If the top model AIC weight was < 0.9 then the probability of site use was averaged using a weighted method for all the models with ΔAIC < 2[213]. All statistical analyses were performed in R 3.4.3[68] and AICs were compared using package AICcmodavg[220]. Parameter estimates are presented with standard errors and were considered statistically significant if the 95% confidence intervals (CIs) did not overlap zero.

Predictive maps of large carnivore occurrence and species richness

For each of the target species the parameter estimates were used to predict the probability of occupancy (ψ) for grid cells where no data were collected using the following equation:

$$\psi = \frac{\exp\left[\propto + (\beta * D_1) + (\beta * D_2) \ldots (\beta * D_4)\right]}{1 + \exp\left[\propto + (\beta * D_1) + (\beta * D_2) \ldots (\beta * D_4)\right]}$$

Where D_{1-4} = occupancy covariates and β_{1-4} = estimated coefficients.

If there were multiple top models then ψ was calculated for each model and averaged in proportion to their AIC weights. The predictive maps of species-specific occupancy were converted to categorical maps where potential presence was classified as follows: none (ψ = 0.00 - 0.25), low (ψ = 0.26 - 0.50), medium (ψ = 0.51 - 0.75) and high (ψ = 0.76 - 1.00).

Results and species-specific discussions

In total, 264 of the 603 (43.78%) grid cells were sampled. While the design aim was to randomly sample 480 grid cells, this was not possible due to accessibility, insecurity and the COVID- 19 pandemic (Figure 15.1).

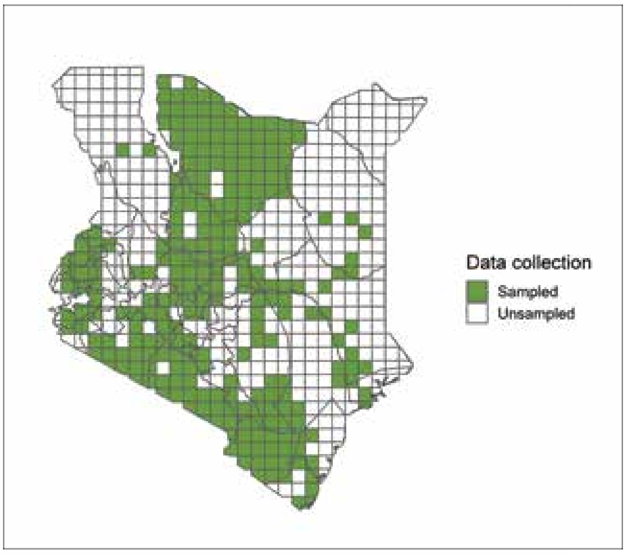


Figure 15.1: *A map of the grid cells that were sampled using three different data collection methods (in-person, online and sightings-based surveys).*

The number of data points and grid cells that were sampled varied per survey method. During the in-person interviews, 1,437 responses were obtained across 214 grid cells (35.49%) with a mean of 6.81 interviews conducted per grid cell (range: 1 - 28). The online survey resulted in 112 grid cells being sampled with a mean of 1.89 responses per grid cell (range: 1-16). In total, 99 grid cells were sampled during the sightings surveys and the number of sightings varied per species with lions being sighted most frequently (n = 1,351) and African wild dogs the least (n = 40).

The total number of data points from the interview and online surveys that were used for the species-specific analyses varied as this was dependent on the number of correct identifications (Table 15.3).

Table 15.3: *Summary of the data that were used for the analyses. For the in-person and online surveys only data where the respondent correctly identified the target species were used.*

Target species	Correct identification		Sighting	Total data points used for the analysis
	In-person (n = 1,437)	Online		
Lion	1,375 (95.69 %)	176/176 (100 %)	1,351	2,902
Leopard	1,358 (94.50 %)	154/162 (95.06 %)	118	1,630
Cheetah	1,360 (94.64 %)	164/168 (97.62 %)	174	1,698
African wild dog	1,264 (87.96 %)	158/164 (96.34 %)	40	1,462
Spotted hyaena	1,401 (97.49 %)	166/166 (100 %)	846	2,413
Striped hyaena	1,160 (80.72 %)	137/158 (86.71 %)	87	1,384

Lion

Correct identification of lions was high with 95.69% of the in-person and 100% of the online surveys resulting in correct identification (Table 15.3). When the data points where lions were correctly identified and the data from the sightings surveys were combined, a total of 245 grid cells (40.63%) were sampled. The naïve occupancy (which is the proportion of sampled grids where lions were detected without accounting for false positives or negatives) was 72.20% for the interview survey (n = 205), 66.67% for the online survey (n = 84) and 58.33% for the sightings survey (n = 96). This resulted in naïve occupancy of 71.02% for all the surveys combined. In other words, lions were reported to be detected in 71.02% of the grid cells that were sampled (Figure 15.2).

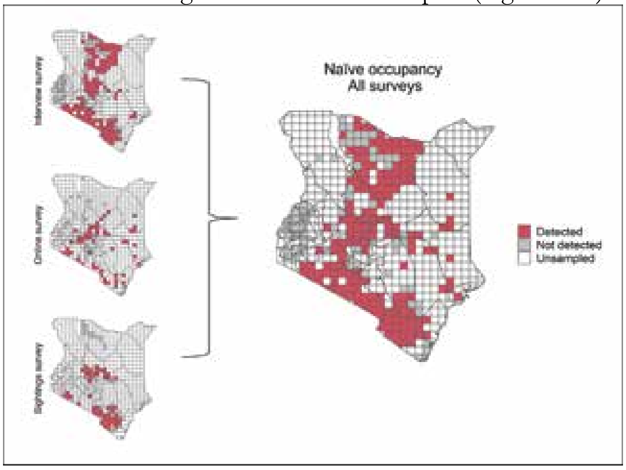


***Figure 15.2:** Naïve occupancy for lions in Kenya derived from the traditional presence/absence approach (this assumes perfect detection (p_{11} = 1) and no false positives (p_{10} = 0)).*

Model outputs

The probability of detecting a lion varied according to survey method with the probability of detection being higher for the questionnaire-based surveys (88.46%; CI: 85.65 – 90.79) compared to the sightings-based surveys (47.20%; CI: 43.20 – 51.24). Despite misidentification of lions being low (Table 15.3), the probability of falsely detecting a lion (saying that it was present when it was not) was 12.45% (CI: 9.19 – 16.80; Table 15.4).

The top models that best described lion occurrence across Kenya included the proportion of land conversion, the proportion of non-tree vegetation, prey density and annual precipitation (Table 15.4). The proportion of non-tree vegetation and prey availability had a positive influence on occupancy whereas this was negatively influenced by the amount of land that was converted. Annual precipitation was included in the top models but its contribution to determining the probability of lion occupancy was minimal (CIs overlapped 0).

***Table 15.4:** Untransformed model averaged coefficients from the single-season false-positive occupancy models for lion occupancy in Kenya. For each parameter, the estimated coefficient (β), standard error (SE) and the 95% Confidence Intervals (CI) are provided.*

Parameter	β	SE	Confidence intervals	
			2.5 %	97.5 %
Probability of occupancy (Ψ)				
Intercept	-2.79	0.79	-4.33	-1.25
% land conversion	-3.79	0.83	-5.41	-2.16
% non-tree vegetation	5.81	1.28	3.30	8.32
Prey	0.56	0.20	0.18	0.95
Annual precipitation	-0.07	0.27	-0.60	0.46
Probability of true detection				
Intercept (Sightings)	2.04	0.13	1.79	2.29
Questionnaires (online + in-person)	-2.15	0.15	-2.44	-1.86
Probability of false detection				
Intercept	-1.95	0.17	-2.29	-1.61

Predicted lion occupancy

The probability of predicted lion occupancy (Ψ) ranged from 0.03 – 0.99 (Figure 15.3a). Based on this, 20.73% (n = 125) of grid cells are predicted to be unsuitable for lions and 60.20% (n = 363) of the grid cells are predicted to be of medium or high suitability for lions (Figure 15.3b).

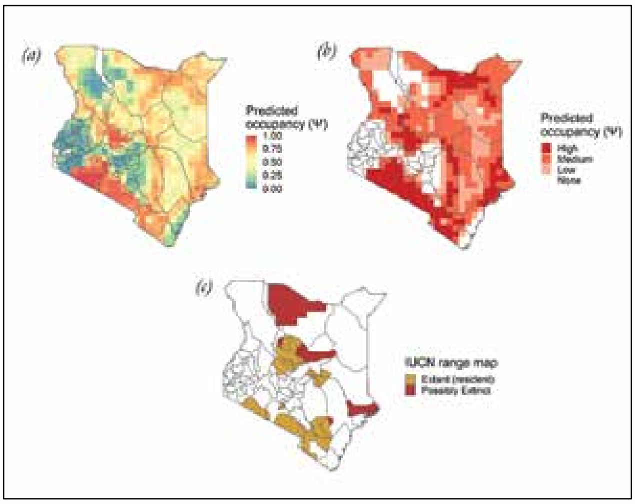


***Figure 15.3:** Predictions from the single-season false-positive occupancy models for lions in Kenya. The outputs are presented as a) continuous (ψ = 0.00 – 1.00) and b) categorical: none (ψ = 0.00 - 0.25), low (ψ = 0.26 – 0.50), medium (ψ = 0.51 - 0.75) and high (ψ = 0.76 – 1.00). The map at the bottom is the IUCN Red List range map for lions in Kenya for comparison[221]. The county boundaries are overlaid on the maps for reference.*

Discussion

Based on the IUCN Red List range maps[221], lions are believed to be resident in 12.25% of Kenya. The results from the false-positive single-season occupancy, however, predict that 20.73% of Kenya is unsuitable for lions and that 60.20% of the country is likely to be of medium to high suitability (Figure 15.3). Some notable areas for lions lie between the Tsavo Conservation Area and the Meru Conservation Area, which could potentially be an important corridor between southern and northern populations, sections of north-eastern Kenya, and in Garissa and Lamu counties in the east. High levels of human-lion conflict have been reported by KWS in the north-east of the country (personal communication A. Maumo - KWS) and recent guestimates suggest that Garissa and Lamu counties could contain decent lion numbers[188], and their presence has been supported by recent photographic evidence in these areas (Figure 15.4). Based on this, it is possible that lions are more widespread than suggested by the IUCN Red List range maps[221]. It would therefore be of utmost importance to survey areas that lie outside the areas that the IUCN Red List have classified as containing resident populations and where habitat suitability is predicted to be high (e.g. Garissa, Tana, Mandera, and Lamu counties).

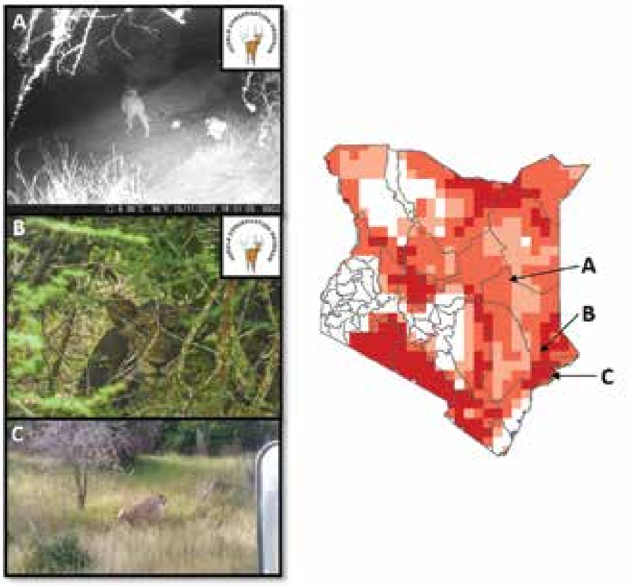


Figure 15.4: *Photographic evidence of lions in areas that are predicted to be suitable based on the analyses presented in this report A) a lion captured on a camera trap in November 2020 in Garissa county (Photo credit: Hirola Conservation Programme) B) a lion sighted in Garissa county (Photo credit: Hirola Conservation Programme) and C) a lion sighted near the Lamu Port site in 2019 (Photo credit: Kenya Wildlife Service). Locations are approximations.*

Leopard

Correct identification of leopards was high with 94.50% of the interview and 95.06% of the online surveys resulting in correct identification (Table 15.3). When the data points where leopards were correctly identified and the data from the sightings surveys were combined, a total of 235 grid cells (38.97%) were sampled. The naïve occupancy (which is the proportion of sampled grids where leopards were detected without accounting for false positives or negatives) was 77.61% for the interview survey (n = 201), 57.69% for the online survey (n = 52) and 32.29% for the sightings survey (n = 96). This resulted in naïve occupancy of 72.77% for all the surveys combined. In other words, leopards were reported to be detected in 72.77% of the grid cells that were sampled (Figure 15.5).

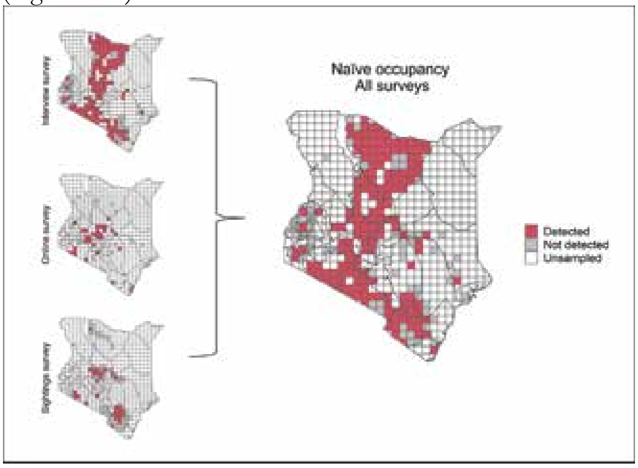


Figure 15.5: *Naïve occupancy for leopards in Kenya derived from the traditional detection/non-detection approach (this assumes perfect detection (p_{11} = 1) and no false positives (p_{10} = 0)).*

Model outputs

The probability of detecting a leopard if it was present varied according to survey method with the probability of detection being higher with the questionnaire-based surveys (89.28%; CI: 81.91 – 93.93) compared to the sightings surveys (15.71%; CI: 12.56 – 19.47). Despite misidentification of leopards being low (Table 15.3), the probability of falsely detecting a leopard (saying that it was present when it was not) was 17.22% (CI: 13.01 – 22.44; Table 15.5).

The top models that best described leopard occurrence across Kenya included the proportion of land conversion, prey availability and terrain ruggedness (Table 15.5). The ruggedness of the terrain had a positive influence on the probability of a site being used by leopards whereas the probability of occupancy was negatively influenced by the amount of land that was converted. Prey availability was included in the top models but its contribution to determining the probability of leopard occupancy was minimal (CIs overlapped 0).

Table 15.5: *Untransformed model averaged coefficients from the single-season false-positive occupancy models for leopard occupancy in Kenya. For each parameter, the estimated coefficient (β), standard error (SE) and the 95% Confidence Intervals (CI) are provided.*

Parameter	β	SE	Confidence intervals	
			2.5 %	97.5 %
Probability of occupancy (ψ)				
Intercept	0.93	0.22	0.50	1.35
% land conversion	-3.39	0.80	-4.96	-1.82
Prey	0.27	0.19	-0.09	0.64
Terrain ruggedness	0.79	0.26	0.28	1.30
Probability of true detection				
Intercept (Sightings)	-1.68	0.13	-1.94	-1.42
Questionnaires (online + in-person)	3.80	0.18	3.45	4.16
Probability of false detection				
Intercept	-1.57	0.17	-1.90	-1.24

Predicted leopard occupancy

The probability of predicted leopard occupancy (ψ) ranged from 0.06 – 0.98 (Figure 15.6a). Based on this, 11.01% (n = 67) of grid cells are predicted to be unsuitable for leopards and 79.06% (n = 480) of the grid cells are predicted to be of medium or high suitability for leopards.

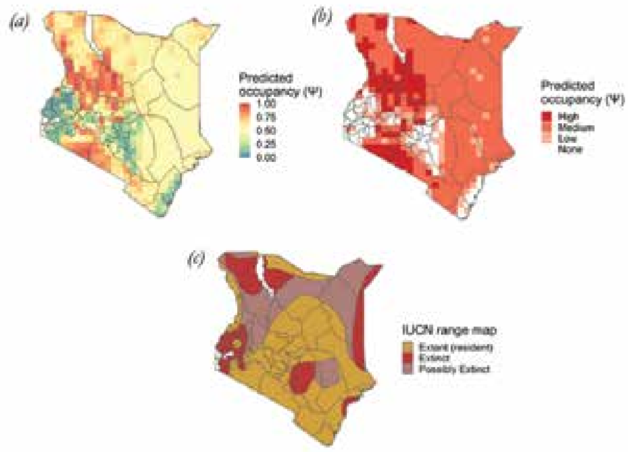


Figure 15.6: *Predictions from the single-season false-positive occupancy models for leopards in Kenya. The outputs are presented as a) continuous (ψ = 0.00 – 1.00) and b) categorical: none (ψ = 0.00 - 0.25), low (ψ = 0.26 – 0.50), medium (ψ = 0.51 - 0.75) and high (ψ = 0.76 – 1.00). The map at the bottom is the IUCN Red List range map for leopards in Kenya[222]. The county boundaries are overlaid on the maps for reference.*

Discussion

The probability of detecting a leopard if it was present was low compared to the other carnivores and is likely due to the fact that leopards are elusive, predominantly solitary and crepuscular, but they do occasionally hunt during the day[216]. Based on the IUCN Red List range maps[222], leopards are believed to be extinct or possibly extinct in much of Turkana and Mandera, and parts of Marsabit, Wajir and Garissa counties, yet it is predicted that leopards do occur in these areas (Figure 15.6). During the sightings-based survey in Sibiloi NP (where leopards are extinct according to the current IUCN Red List range map) the field teams observed leopard tracks on two occasions, one along the Rocodoni River and the other near to Darate. In the southern tip of Turkana County, bordering Baringo County, leopards have been captured on camera traps and in Marsabit a young male leopard attacked livestock and was subsequently captured by the community (Figure 15.7). A GPS collar was fitted to this individual but was killed in November 2020 by people just outside Marsabit National Park. It is possible that the conflict between pastoralists and leopards in some of these areas is high, contributing to population declines. It is likely therefore that leopards persist in large parts of Kenya and outside the range provided by the IUCN Red List. Where possible, it is recommended that extensive surveys are conducted in these areas and more broadly that there should be a focus on leopard research beyond the Laikipia landscape[216,223,224].

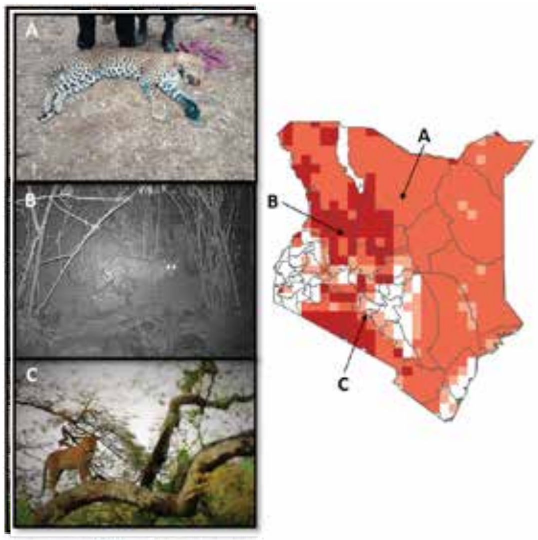


Figure 15.7: *Examples of photographic evidence of leopards in areas that are predicted to be medium to high suitability based on the analyses presented in this report A) A young male leopard that was captured near Marsabit National Park by residents in September 2019 and subsequently fitted with a GPS collar (Photo credit: Yumi Yamane), B) A leopard captured on a camera trap that was placed on the boundary of Turkana and Baringo counties in February 2019 (Photo credit: Yumi Yamane) and C) A male leopard in Nairobi National Park in May 2019 (Photo credit: Yumi Yamane). Locations are approximations.*

Cheetah

Correct identification of cheetah was 94.64% for the interview surveys and 97.62% for the online surveys (Table 15.3). When the data points where cheetahs were correctly identified and the data from the sightings surveys were combined, a total of 247 grid cells (40.96%) were sampled. The naïve occupancy (which is the proportion of sampled grids where cheetahs were detected without accounting for false positives or negatives) was 70.87% for the interview survey (n = 206), 47.62% for the online survey (n = 84) and 28.12% for the sightings survey (n = 96). This resulted in naïve occupancy of 66.5 3% for all the surveys combined. In other words, cheetahs were reported to be detected in 66.53% of the grid cells that were sampled (Figure 15.8).

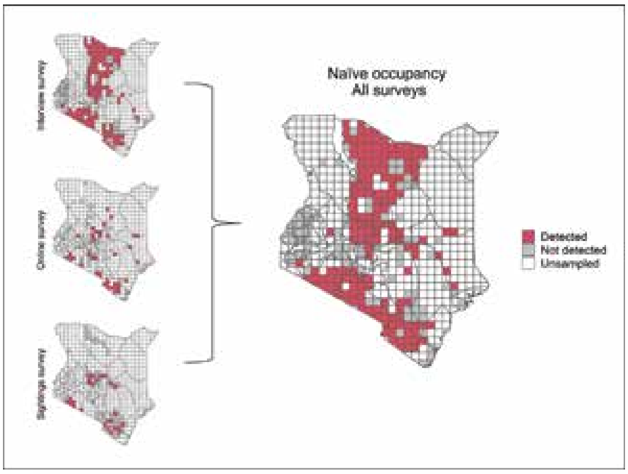


Figure 15.8: *Naïve occupancy for cheetahs in Kenya derived from the traditional detection/non-detection approach (this assumes perfect detection (p_{11} = 1) and no false positives (p_{10} = 0)).*

Model outputs

The probability of detecting a cheetah if it was present varied according to survey method with the probability of detection being higher with the questionnaire-based surveys (81.30%; CI: 70.01 – 88.89) compared to the sightings surveys (14.06%; CI: 10.91 – 17.80). Despite misidentification of cheetahs being low (Table 15.3), the probability of falsely detecting a cheetah (saying that it was present when it was not) was 12.23% (CI: 8.79 – 16.94; Table 15.6).

The top models that best described cheetah occurrence across Kenya included the proportion of land conversion, the proportion of trees and prey availability (Table 15.6). The proportion of trees and land conversion had a negative influence on the probability of a site being used by cheetahs whereas prey availability had a positive influence.

Table 15.6: *Untransformed model averaged coefficients from the single-season false-positive occupancy models for cheetah occupancy in Kenya. For each parameter the estimated coefficient (β), standard error (SE) and the 95% Confidence Intervals (CI) are provided.*

Parameter	β	SE	Confidence intervals	
			2.5 %	97.5 %
Probability of occupancy (ψ)				
Intercept	1.25	0.28	0.70	1.81
% land conversion	-4.24	1.13	-6.45	-2.02
Prey	0.44	0.16	0.12	0.75
% trees	-6.44	3.07	-12.47	-0.42
Probability of true detection				
Intercept (Sightings)	-1.81	0.15	-2.20	-1.53
Questionnaires (online + in-person)	3.28	0.17	2.95	3.61
Probability of false detection				
Intercept	-1.97	0.19	-2.34	-1.59

Predicted cheetah occupancy

The probability of predicted cheetah occupancy (ψ) ranged from 0.00 – 0.95 (Figure 15.9a). Based on this, 20.56% (n = 124) of grid cells are predicted to be unsuitable for cheetahs and 73.30% (n = 442) of the grid cells are predicted to be of medium or high suitability for cheetahs.

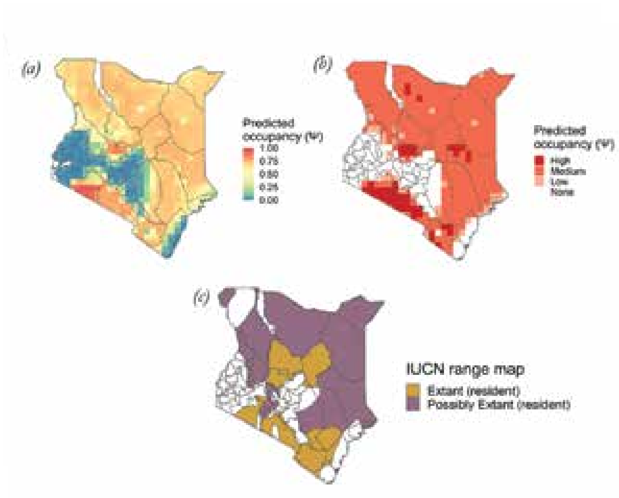


Figure 15.9 *Predictions from the single-season false-positive occupancy models for cheetahs in Kenya. The outputs are presented as a) continuous (ψ = 0.00 – 1.00) and b) categorical: none (ψ = 0.00 - 0.25), low (ψ = 0.26 – 0.50), medium (ψ = 0.51 - 0.75) and high (ψ = 0.76 – 1.00). The map at the bottom is the IUCN Red List range map for cheetahs in Kenya[225]. The county boundaries are overlaid on the maps for reference.*

Discussion

Only 20.56% of Kenya was predicted to be unsuitable for cheetahs whereas 73.30% was predicted to be of medium to high suitability. This is vastly different from previous research that predicted that 65.48% of the country was unsuitable for cheetahs[217]. In that study, detection probability, where an animal is present but not detected, was not taken into account which can result in an underestimation in species' distribution and potentially inaccurate assumptions about habitat use[47,203].

Our results are supported by cheetah occurrence data from KWS[217] and photographic evidence in some of these areas (Figure 15.10). As such, cheetah occurrence is likely to be more widespread than previously reported, including by the IUCN Red List[226]. Most notably, areas in Kenya that have been classified by the IUCN Red List as 'possibly extant' are likely to hold resident populations of cheetahs based on the results presented in this report (Figure 15.9). This widespread occurrence of cheetahs is encouraging for conservation, however it is likely that the cheetah population and their distribution are in decline as a result of habitat loss, prey depletion and human-wildlife conflict[193] and therefore more robust surveys need to be conducted in some of these areas.

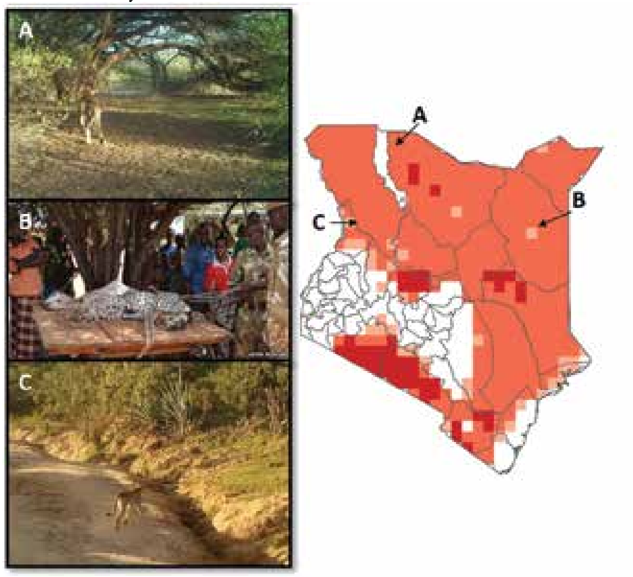


Figure 15.10: *Examples of photographic evidence of cheetahs in areas that are predicted to be suitable based on the analyses presented in this report A) cheetah with a kill captured by a camera trap that was set up in 2017 in Sibiloi National Park by the Global Change and Conservation group (University of Helsinki) B) cheetah captured by herders near Wajir town in 2013 (Photo credit: Aden Bishar) and C) cheetah photographed near Tambalal in West Pokot in July 2019 (Source: West Pokot News). Locations are approximations.*

African wild dog

Correct identification of African wild dogs was high with 87.96% of the interview and 96.34% of the online surveys resulting in correct identification (Table 15.3). When the data points where African wild dogs were correctly identified and the data from the sightings surveys were combined, a total of 245 grid cells (40.63%) were sampled. The naïve occupancy (which is the proportion of sampled grids where African wild dogs were detected without accounting for false positives or negatives) was 56.37% for the interview survey (n = 204), 30.86% for the online survey (n = 81) and 14.58% for the sightings survey (n = 96). This resulted in naïve occupancy of 53.06% for all the surveys combined. In other words, African wild dogs were reported to be detected in 53.06% of the grid cells that were sampled (Figure 15.11).

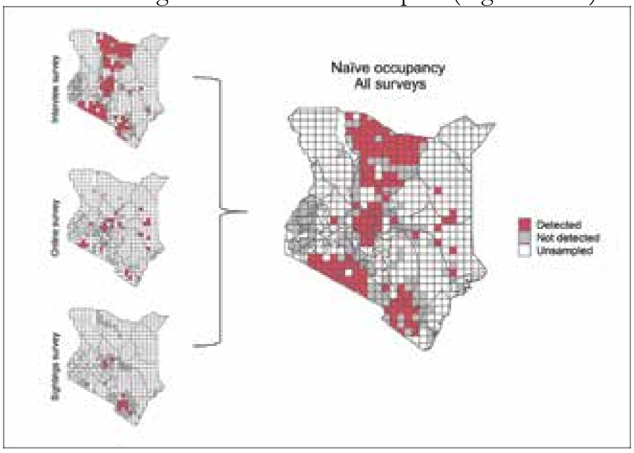


***Figure 15.11:** Naïve occupancy for African wild dogs in Kenya derived from the traditional detection/non-detection approach (this assumes perfect detection (p_{11} = 1) and no false positives (p_{10} = 0)).*

Model outputs

The probability of detecting African wild dogs if they were present varied according to survey method with the probability of detection being highest with the questionnaire-based surveys (82.63%; CI: 64.57 – 92.55) and lowest for the sightings surveys (12.03%; CI: 7.94 – 17.80). Despite misidentification of African wild dogs being low (Table 15.3), the probability of falsely detecting an African wild dog (saying that it was present when it was not) was 7.38% (CI: 5.32 – 10.16; Table 15.7).

The top models that best described African wild dog occurrence across Kenya included the proportion of land conversion, the proportion of trees and prey availability (Table 15.7). The proportion of trees and land conversion had a negative influence on the probability of a site being used by African wild dogs whereas prey availability had a positive influence.

***Table 15.7:** Untransformed model averaged coefficients from the single-season false-positive occupancy models for African wild dog occupancy in Kenya. For each parameter, the estimated coefficient (β), standard error (SE) and the 95% Confidence Intervals (CI) are provided.*

Parameter	β	SE	Confidence intervals	
			2.5 %	97.5 %
Probability of occupancy (Ψ)				
Intercept	0.64	0.24	0.17	1.12
% land conversion	-3.38	1.09	-5.51	-1.23
Prey	0.35	0.14	0.08	0.63
% trees	-7.47	0.14	-14.12	-0.81
Probability of true detection				
Intercept (Sightings)	-1.99	0.23	-2.45	-1.53
Questionnaires (online + in-person)	3.55	0.26	3.04	4.05
Probability of false detection				
Intercept	-2.53	0.18	-2.88	-2.18

Predicted wild dog occupancy

The probability of predicted African wild dog occupancy (Ψ) ranged from 0.00 – 0.87 (Figure 15.12a) and was most strongly influenced by the proportion of trees. Based on this, 23.38% (n = 141) of grid cells are predicted to be unsuitable for African wild dogs and 61.53% (n = 371) of the grid cells are predicted to be of medium or high suitability for African wild dogs.

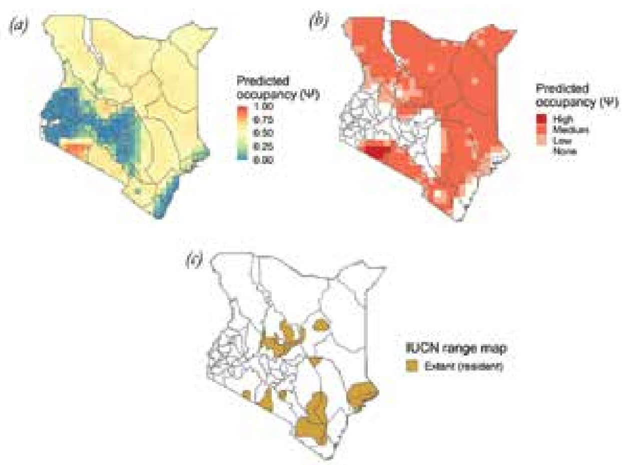
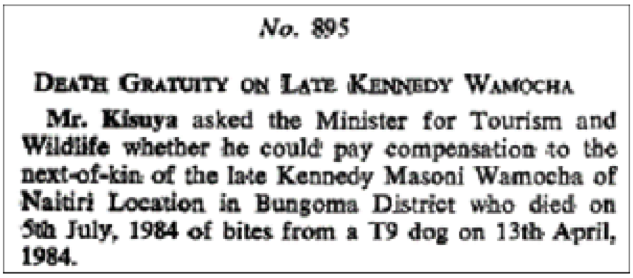


***Figure 15.12** Predictions from the single-season false-positive occupancy models for African wild dogs in Kenya. The outputs are presented as a) continuous (ψ = 0.00 – 1.00) and b) categorical: none (ψ = 0.00 - 0.25), low (ψ = 0.26 – 0.50), medium (ψ = 0.51 - 0.75) and high (ψ = 0.76 – 1.00). The map at the bottom is the IUCN Red List range map for African wild dogs in Kenya[227]. The county boundaries are overlaid on the maps for reference.*

Discussion

During the enumerator training in Western Kenya there was some confusion about what African wild dogs were and during a discussion it appeared that in some cases people referred to domestic dogs that had gone feral as 'wild dogs'. In particular there was mention of dogs referred to as T9 dogs. Upon further investigation it appears that T9 dogs were trained domestic dogs that were attached to the 9th Battalion of the Tanzanian Army used to fight the Government of Idi Amin Dada of Uganda[228] that were later left by the army and became feral. T9 dogs are notoriously aggressive[228] and references to these T9 dogs were found in discussions at the Kenyan National Assembly in the 1980s where concerns were raised about T9 dogs killing and/or injuring both livestock and people[229] (Figure 15.13).

It is unclear how widespread this notion of T9 dogs is. If it is widespread then this would have increased the number of false positives present which could mean that occupancy was overestimated.



No. 895

Death Gratuity on Late Kennedy Wamocha

Mr. Kisuya asked the Minister for Tourism and Wildlife whether he could pay compensation to the next-of-kin of the late Kennedy Masoni Wamocha of Naitiri Location in Bungoma District who died on 5th July, 1984 of bites from a T9 dog on 13th April, 1984.

Figure 15.13: *Excerpt from a National Assembly Official Report in 1986 which continues with a discussion about whether T9 dogs are domestic or wild animals.*

It is therefore recommended that the presence or perceived presence of T9 dogs is addressed in any future questionnaire-based surveys that are to be conducted in Kenya.

61.53% of Kenya was predicted to be of medium or high suitability for African wild dogs. It is however important to note that in the current study the results presented here represent areas that are likely to be suitable for African wild dogs and are by no means an indication of the number (or density) of African wild dogs that could be present in a population. For example, lion densities have been shown to influence both African wild dog space-use[230] and numbers[231]. It is therefore possible that African wild dogs are more likely to be found at higher densities in more sub-optimal habitats, such as those that are predicted to be medium or even low suitability (Figure 15.14), than in areas that are predicted to be highly suitable for African wild dogs but where lion densities are high (e.g. the Maasai Mara – see Chapter 5).

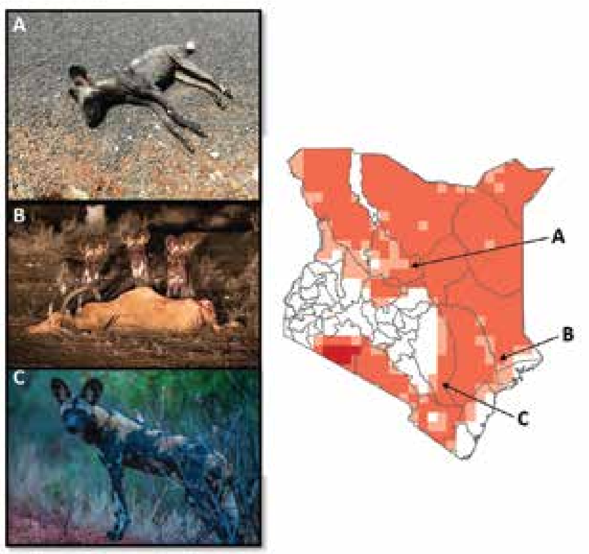


Figure 15.14: *Examples of photographic evidence of African wild dogs in areas that are predicted to be of medium suitability based on the analyses presented in this report A) roadkill of a African wild dog sighted in 2019 on the tarred road to Marsabit (Photo credit: Alberto Borges) B) A pack of African wild dogs feeding on a Hirola antelope in Ishaqbini Hirola Community Conservancy in 2020 (Photo credit: Mark Boyd) and C) a pack of ~17 individuals sighted near Ithumba in Tsavo East National Park in 2019 (Photo credit: Philip J. Briggs). Locations are approximations.*

African wild dogs are also vulnerable to persecution by people and are susceptible to diseases, such as rabies and canine distemper virus (CDV), that spill over from domestic dogs. Three decades ago, the African wild dog populations in the Maasai Mara and Laikipia nearly disappeared as a result of rabies and canine distemper virus[232,233]. In Laikipia the African wild dog population recovered but a severe drought in 2017 led to incursions of livestock and domestic dogs. This resulted in a CDV outbreak which decimated the African wild dog population. The African wild dog population in Laikipia is increasing but the threat of disease has led to several vaccination campaigns[234] including in parts of Samburu and Isiolo where, during the sightings-based survey, the African wild dog population in the area was severely affected by disease-related mortalities. Changes in climatic conditions can also affect the probability of disease outbreaks (as was observed with CDV in lions in Tanzania[235]) and increasing temperatures are likely to have a negative impact on the reproductive success of African wild dogs[236]. In general, African wild dogs in Kenya are predicted to be more widespread than reported by the IUCN Red List[227] (Figure 15.12) and therefore more robust surveys need to be conducted across Kenya.

Spotted hyaena

Correct identification of spotted hyaenas was high with 97.49% of the interview and 100% of the online surveys resulting in correct identification (Table 15.3). When the data points where spotted hyaenas were correctly identified and the data from the sightings surveys were combined, a total of 241 grid cells (39.97%) were sampled. The naïve occupancy (which is the proportion of sampled grids where spotted hyaenas were detected without accounting for false positives or negatives) was 90.48% for the interview survey (n = 210), 88.51% for the online survey (n = 87) and 55.21% for the sightings survey (n = 96). This resulted in naïve occupancy of 89.60% for all the surveys combined. In other words spotted hyaenas were reported to be detected in 89.60% of the grid cells that were sampled (Figure 15.15).

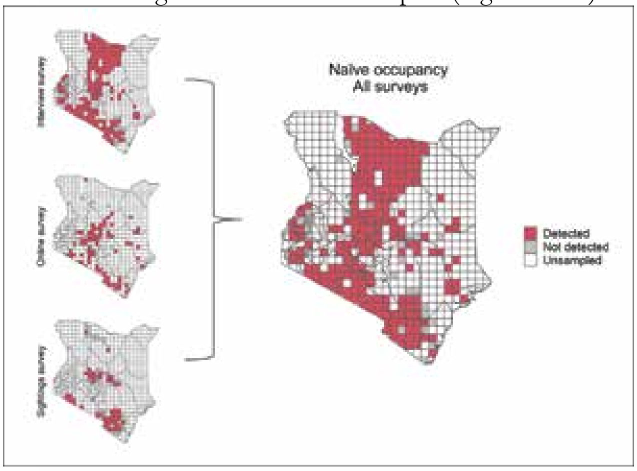


Figure 15.15: *Naïve occupancy for spotted hyaenas in Kenya derived from the traditional detection/non-detection approach (this assumes perfect detection (p_{11} = 1) and no false positives (p_{10} = 0)).*

Model outputs

The probability of detecting a spotted hyaena if it was present varied according to survey method with the probability of detection being higher with questionnaire-based surveys (93.93%; CI: 96.30 – 97.77) compared to the sightings surveys (35.43%; CI: 31.65 – 39.41). Despite misidentification of spotted hyaenas being low (Table 15.3), the probability of falsely detecting a spotted hyaena (saying that it was present when it was not) was high (34.07%; CI: 25.92 – 43.29; Table 15.8).

The top models that best described spotted hyaena occurrence across Kenya included the proportion of land conversion, prey availability and annual precipitation (Table 15.8). The proportion of land conversion had a negative influence on the probability of a site being used by spotted hyaenas whereas prey availability had a positive influence. Annual precipitation was included in the top models but its contribution to determining the probability of spotted hyaena occupancy was minimal (CIs overlapped 0).

Table 15.8: *Untransformed model averaged coefficients from the single-season false-positive occupancy models for spotted hyaena occupancy in Kenya. For each parameter the estimated coefficient (β), standard error (SE) and the 95% Confidence Intervals (CI) are provided.*

Parameter	β	SE	Confidence intervals	
			2.5 %	97.5 %
Probability of occupancy (ψ)				
Intercept	2.09	0.27	1.55	2.63
% land conversion	-2.96	0.78	-4.48	-1.44
Prey	0.57	0.27	0.04	1.10
Annual precipitation	-0.08	0.28	-0.63	0.48
Probability of true detection				
Intercept (Sightings)	-0.60	0.09	-0.77	-0.43
Questionnaires (online + in-person)	3.86	0.18	3.51	4.21
Probability of false detection				
Intercept	-0.66	0.20	-1.05	-0.27

Predicted spotted hyaena occupancy

The probability of predicted spotted hyaena occupancy (ψ) ranged from 0.23 – 1.00 (Figure 15.16a). Based on this, 1.82% (n = 11) of grid cells are predicted to be unsuitable for spotted hyaenas whereas 86.40% (n = 521) of the grid cells are predicted to be of medium or high suitability for spotted hyaenas.

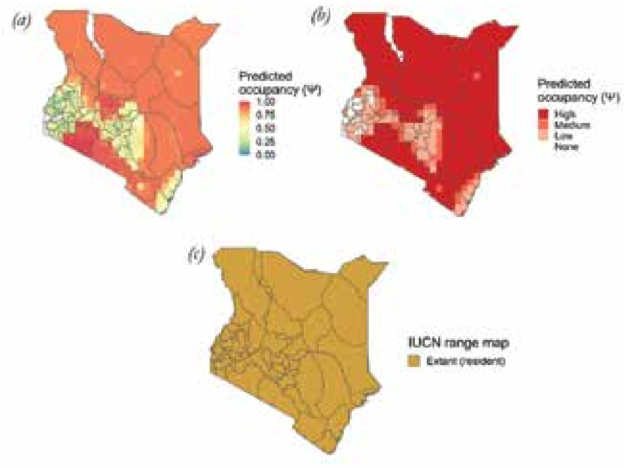


Figure 15.16: *Predictions from the single-season false-positive occupancy models for spotted hyaenas in Kenya. The outputs are presented as a) continuous (ψ = 0.00 – 1.00) and b) categorical: none (ψ = 0.00 - 0.25), low (ψ = 0.26 – 0.50), medium (ψ = 0.51 - 0.75) and high (ψ = 0.76 – 1.00). The map at the bottom is the IUCN Red List range map for spotted hyaenas in Kenya[237]. The county boundaries are overlaid on the maps for reference.*

Discussion

Of the large carnivores in Kenya, spotted hyaenas are likely to be the most widespread as only 1.82% of the country is predicted to be unsuitable. They are the least sensitive to anthropogenic factors and are therefore often found in human-dominated areas including urban areas[238]. Compared to the other large carnivores, spotted hyaenas are likely to cause the most human-wildlife conflict and being hunter-scavengers they are highly susceptible to human retaliation tactics such as poisoning[239].

Striped hyaena

Correct identification of striped hyaenas was 80.72% for the interview and 86.71% for the online surveys resulting in correct identification (Table 15.3). When the data points where striped hyaenas were correctly identified and the data from the sightings surveys were combined, a total of 241 grid cells (39.97%) were sampled. The naïve occupancy (which is the proportion of sampled grids where striped hyaenas were detected without accounting for false positives or negatives) was 65.22% for the interview survey (n = 207), 33.77% for the online survey (n = 77) and 21.88% for the sightings survey (n = 96). This resulted in naïve occupancy of 63.07% for all the surveys combined. In other words, striped hyaenas were reported to be detected in 63.07% of the grid cells that were sampled (Figure 15.17).

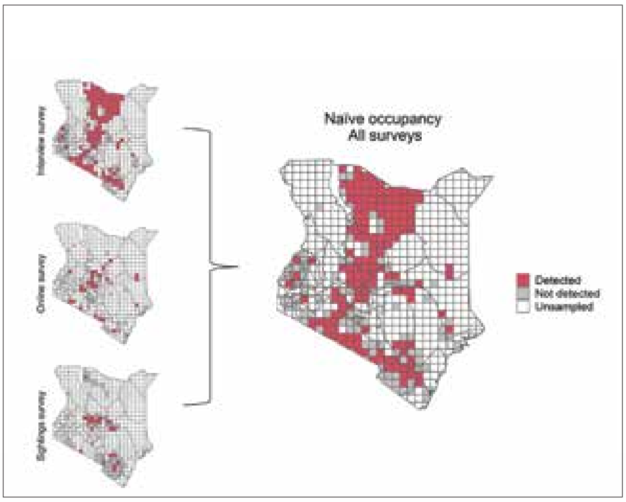


Figure 15.17: *Naïve occupancy for striped hyaenas in Kenya derived from the traditional detection/non-detection approach (this assumes perfect detection (p_{11} = 1) and no false positives (p_{10} = 0)).*

Model outputs

The probability of detecting a striped hyaena if it was present varied according to survey method with the probability of detection being higher with questionnaire-based surveys (82.49%; CI: 69.42 – 90.80) compared to the sightings surveys (14.18%; CI: 10.52 – 19.00). Despite misidentification of striped hyaenas being quite high (Table 15.3), the probability of falsely detecting a striped hyaena (saying that it was present when it was not) was 14.68% (CI: 11.11– 19.30; Table 15.9)

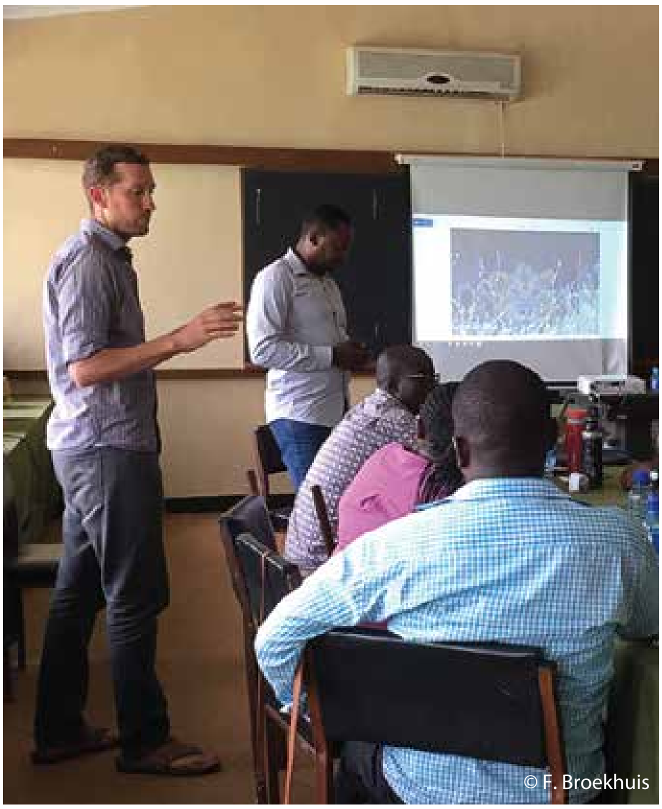
The top models that best described striped hyaena occurrence across Kenya included the proportion of land conversion, prey availability and annual precipitation (Table 15.9). Annual precipitation had a negative influence on the probability of a site being used by striped hyaena. Both prey availability and the proportion of land conversion had a minimal influence on striped hyaena occupancy (CIs overlapped 0).

Table 15.9: Untransformed model averaged coefficients from the single-season false-positive occupancy models for striped hyaena occupancy in Kenya. For each parameter the estimated coefficient (β), standard error (SE) and the 95% Confidence Intervals (CI) are provided.

Parameter	β	SE	Confidence intervals	
			2.5 %	97.5 %
Probability of occupancy (ψ)				
Intercept	0.25	0.19	-0.12	0.62
% land conversion	-0.38	1.13	-2.61	1.84
Prey	-0.07	0.15	-0.36	0.23
Annual precipitation	-1.37	0.28	-1.93	-0.82
Probability of true detection				
Intercept (Sightings)	-1.79	0.18	-2.14	-1.44
Questionnaires (online + in-person)	3.36	0.20	2.97	3.75
Probability of false detection				
Intercept	-1.72	0.16	-2.03	-1.40

Predicted striped hyaena occupancy

The probability of predicted striped hyaena occupancy (ψ) ranged from 0.00 – 0.88 (Figure 15.18a). Based on this, 15.26% (n = 92) of grid cells are predicted to be unsuitable for striped hyaenas and 66.67% (n = 402) are predicted to be of medium or high suitability for striped hyaenas.



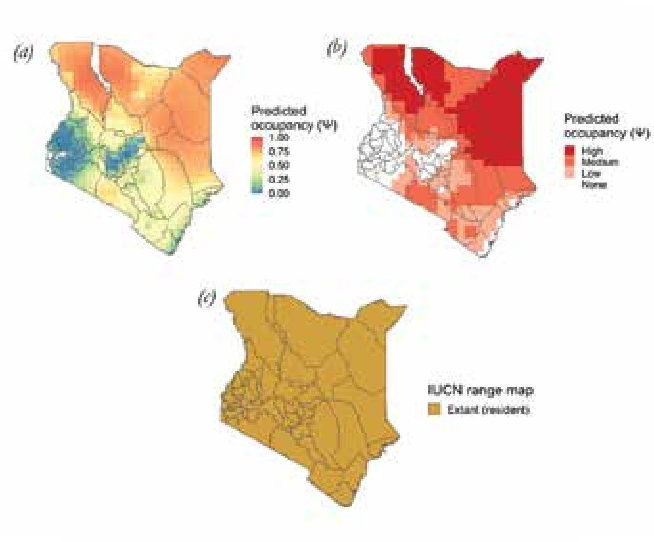


Figure 15.18: *Predictions from the single-season false-positive occupancy models for striped hyaenas in Kenya. The outputs are presented as a) continuous (ψ = 0.00 – 1.00) and b) categorical: none (ψ = 0.00 - 0.25), low (ψ = 0.26 – 0.50), medium (ψ = 0.51 - 0.75) and high (ψ = 0.76 – 1.00). The map at the bottom is the IUCN Red List range map for striped hyaenas in Kenya[237]. The county boundaries are overlaid on the maps for reference.*

Discussion

Of the large carnivores in Kenya, the striped hyaena is probably the least known. Regardless, about half of Kenya is predicted to be suitable for striped hyaenas, particularly in the north with a few patches in the south. This, in part, is attributed to the fact that striped hyaenas are more likely to occur in arid areas (negative relationship with annual rainfall) which corroborates previous findings[219,240]. The IUCN Red List predicts that striped hyaenas are resident across Kenya but results from the false-positive occupancy models indicate that 15.26% of Kenya is unsuitable for striped hyaenas with these areas occurring predominately in the west and south-east along the Kenyan coast (Figure 15.18).

Occupancy Discussion

The two environmental predictors that came out strongly for all carnivore species were related to habitat and anthropogenic pressures, supporting the assertion that habitat loss and human-wildlife conflict are the main drivers of declines in carnivore presence. Indeed, human population density has been found to be a strong predictor for local carnivore extinctions[241]. Prey abundance is generally also a good predictor for carnivore presence[242,243], as was the case for lion, cheetah, African wild dog and spotted hyaena. It is important to note that the effects of the predictor variables are likely to be scale dependent[200] and that coarse scales, like the one used in this study, may not accurately reflect finer-scale relationships that might be present[244].

For some of the carnivore species, e.g. cheetah, the presence of suitable habitat is predicted to be widespread. The maps presented in this report result from predictions that are based on a limited number of anthropogenic and environmental variables. In addition, there are socio-economic variables, that are often difficult to account for, or acquire spatially-explicit data for, that could influence carnivore presence[245]. For example, people's tolerance of predators might influence whether or not they are likely to kill a predator[246], which can vary according to cultural and socio-economic factors[245,247].

In other words, just because a habitat is suitable, does not mean that the species of interest is present as this is likely to be influenced by factors such as the level of human-wildlife conflict, people's tolerance towards predators, the level of habitat fragmentation in surrounding areas and transboundary conservation efforts[248]. As such, a collaborative approach[194,248], using more robust sightings-based surveys, to determine large carnivore densities in areas of high suitability should be encouraged.

When taking into account false positives and negatives, species-habitat relationships based on indirect data (e.g. interviews) can be found to be similar to those obtained through direct methods (e.g. GPS collars)[47] at smaller scales. Data, such as those obtained through GPS collars, are rarely available at country-wide scales and for multiple species[194] so indirect methods, such as those used here, are an efficient and cost-effective means of modelling species–habitat relationships and distribution of multiple species at broad spatial scales. The findings presented in this chapter are useful for identifying knowledge gaps and to guide future research, conservation efforts and the development of land-use plans. For example, there are vast areas in the north and north-east of the country, including Lamu, Tana, Garrisa, Wajir, Mandera, Turkana and Marsabit where carnivore presence is predicted to be medium or high but where there is a dearth of information. As such, conservation and monitoring resources should be invested in these areas especially as threats (such as the possession of weapons, climate change etc.) are likely to be high or increase in the future.

PART III: Training and Capacity for Continued Monitoring

Chapter 16

Capacity Building

The third goal of this initiative was to build local capacity to ensure long-term monitoring of large carnivores in Kenya and was designed such that future surveys can accurately assess population trends and estimate vital rates (e.g. survival and mortality) in different sites. To this end, long-term databases have been established and capacity built through a series of field and analytical training workshops that will help to ensure the survey evolves into long-term monitoring and enable an evaluation of population and distribution trends.

Field training

Before each survey began, local stakeholders were contacted and recruited as collaborators. They were then invited to attend rigorous training sessions that consisted of one full day of scientific theory related to wildlife monitoring with an emphasis on SECR, followed by three days of training in all aspects of fieldwork and data collection.

The following key fieldwork skills were taught:

- Use of CyberTracker to record search effort and all sightings.
- Ageing and sexing of lions.
- Field conduct when observing lions.
- How to take individual identification photographs of lions.
- Conducting playback experiments.
- Data processing and individual identification of lions (building catalogues and capture histories).
- Key elements of SECR survey design.

The enumerators for the interview-based survey underwent a one-day training where the survey was introduced, and key elements of interview techniques were taught. In both cases, when the survey was launched, the technical team remained heavily involved, assisting with data collection, overseeing data quality and troubleshooting. During this time, participants were encouraged to get involved in data sorting and entry.

In this manner, 89 people attended the scientific theory sessions, and 52 were trained in fieldwork. In total more than 400 people participated in the fieldwork.

Analysis Workshops

Two data analysis workshops were held where 40 participants (both KWS and NGOs) were immersed in the theory and practical application of all aspects of the SECR surveys. The workshop consisted of six sessions that were designed to guide participants through the entire process of implementing a wildlife survey with emphasis on unstructured spatial sampling survey designs, combined with a Bayesian SECR modelling. In particular, participants were provided with the skills and materials to design and implement follow-up survey fieldwork.

Participants were also provided with fundamental knowledge that was critical to their involvement in the subsequent data analysis. As such, the workshops were designed to provide a platform for future learning and engagement with the technical team as survey outputs are produced.

Below is a list of the six sessions covered during the workshops that were designed to cover all aspects of the SECR surveys.

Session 1: Introduction and background

- Fundamentals of science-based wildlife monitoring
- Background to KWS lion survey
    - o Key statistical decisions
    - o Key ecological decisions
- Statistical framework
    - o Introduction to hierarchical models
    - o Introduction to Bayesian statistics
    - o Introduction to SECR

Session 2: Fieldwork implementation

- Study design
- Workshop participants present fieldwork and data summa -ries from respective survey
- Data collection
    - o Taking lion photo IDs
    - o Creating a data collection app in CyberTracker (practical)

Session 3: Data processing and management

- Identifying individual lions from photographs
- Building ID catalogues (practical)
- Data management (practical)
- Maintaining an Access Database (practical)
- Maintaining a CyberTracker database (practical)

Session 4: Data preparation

- Cleaning data (practical)
- Formatting data (practical)
- Introduction to R
- Creating input files for analysis (practical)

Session 5: Data analysis

- Defining a-priori SECR models, with detail on model parameters
- Running analysis (practical)
- Model diagnostics
- Model selection
- Interpretation (practical)

Session 6: Next steps

- The future of lion monitoring in Kenya
- Taking SECR beyond numbers – additional applications
- Discussion

Capacity for continued monitoring

At the end of each workshop, we conducted a feedback evaluation to better understand participant's perceptions of their own abilities, skills and knowledge. This provided some insight into whether the workshops had achieved their goals and on the capacity for continued monitoring using similar methods. Based on the feedback received (Figure 16.1 - 16.5) together with our own observations throughout the process it is evident that there are still some knowledge and skill gaps.

While the fieldwork can be challenging and there are some technical elements to conducting the fieldwork and collecting high-quality data, after three days of training we were confident in the ability of the data collectors. As such, future surveys can draw on a pool of 52 people who have already undergone such training, and materials have been developed to train additional persons.

However, it is in the areas of survey design, data management and data analysis that knowledge and skill gaps still exist. While it is not necessary for everyone involved to become experts in these monitoring techniques, ideally several people will continue to improve their skillsets and become Kenyan leaders in the field of carnivore monitoring. To this end, continued training should be held that aims to deepen the knowledge and skills gained so far, with a particular emphasis on survey design, data management and data analysis. It is also apparent that a technical team should remain in place to ensure long term monitoring occurs and training continues. We note, however, that it vital for participants to continue to engage with all facets of the process (from design to fieldwork to analysis) even though some may be tasked with one aspect more than others based on aptitude and interest.

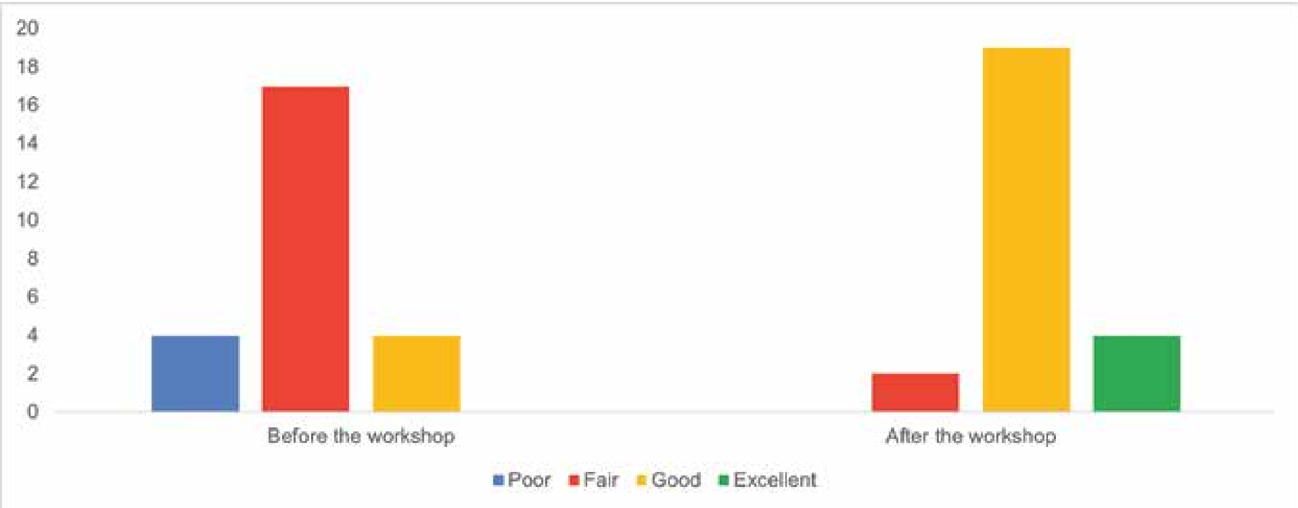


Figure 16.1: *Workshop participants were asked to evaluate their understanding of the science of wildlife monitoring both before and after the workshop.*

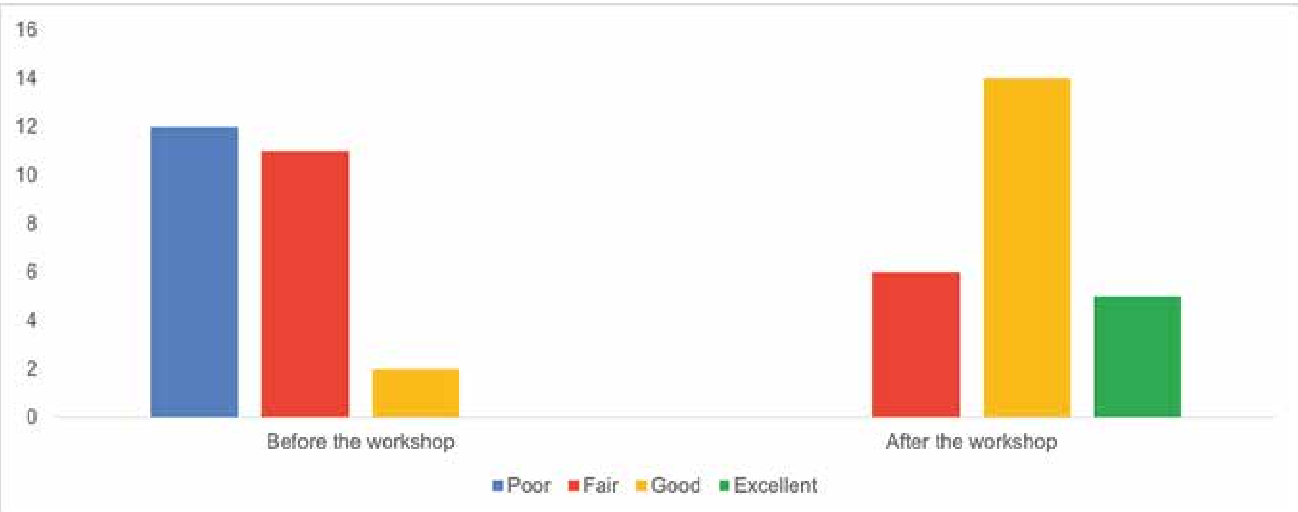


Figure 16.2: *Workshop participants were asked to evaluate their understanding of SECR theory both before and after the workshop.*

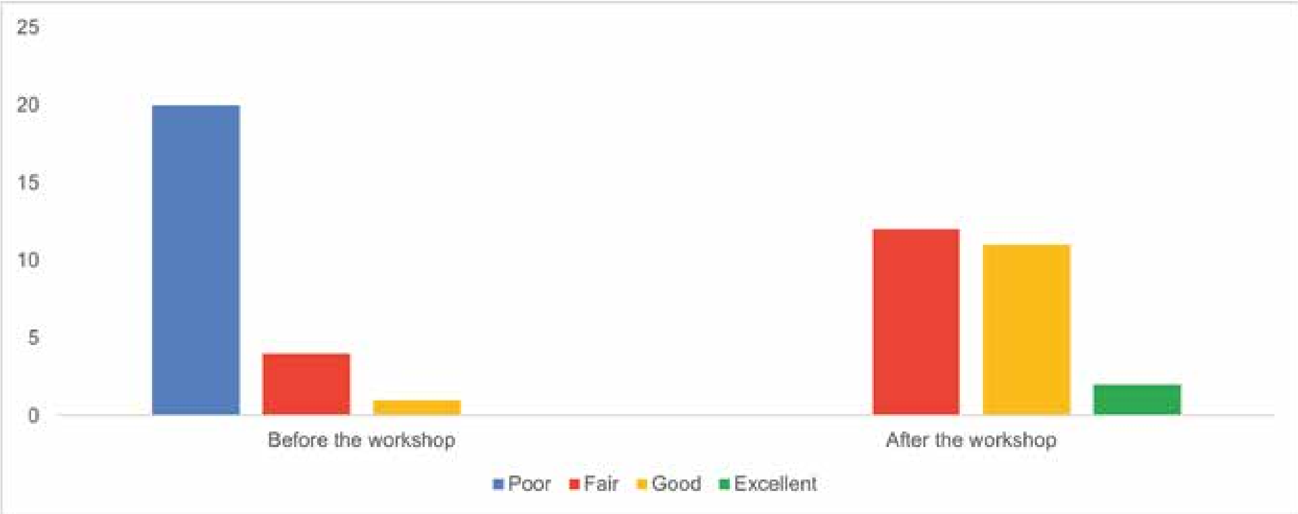


Figure 16.3: *Workshop participants were asked to evaluate their ability to design an SECR survey for lions both before and after the workshop.*

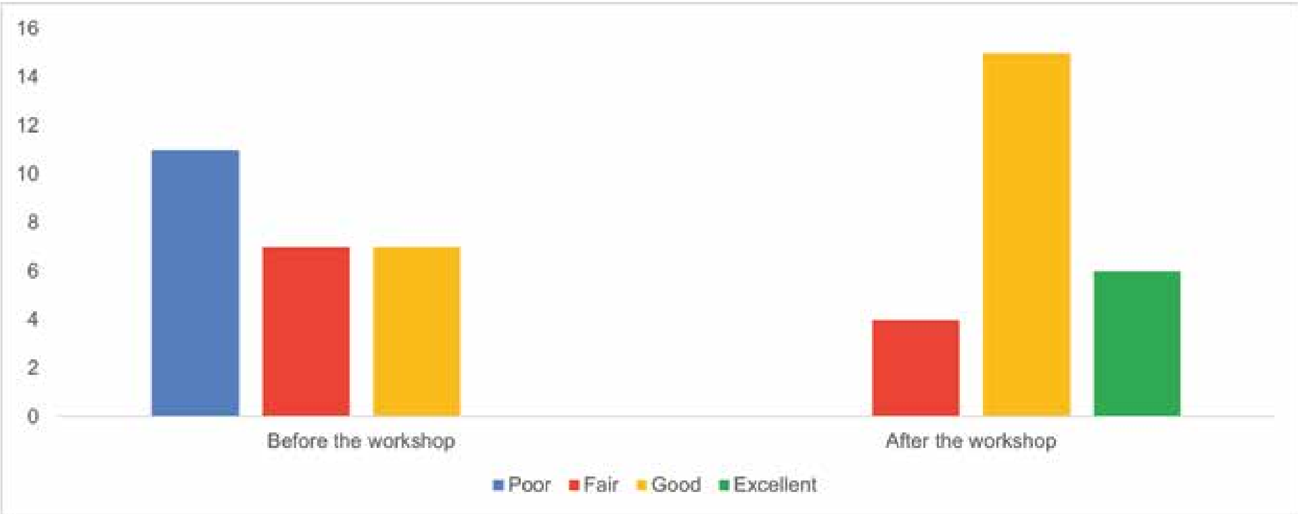


Figure 16.4: *Workshop participants were asked to evaluate their ability to manage the data for an SECR survey for lions both before and after the workshop.*

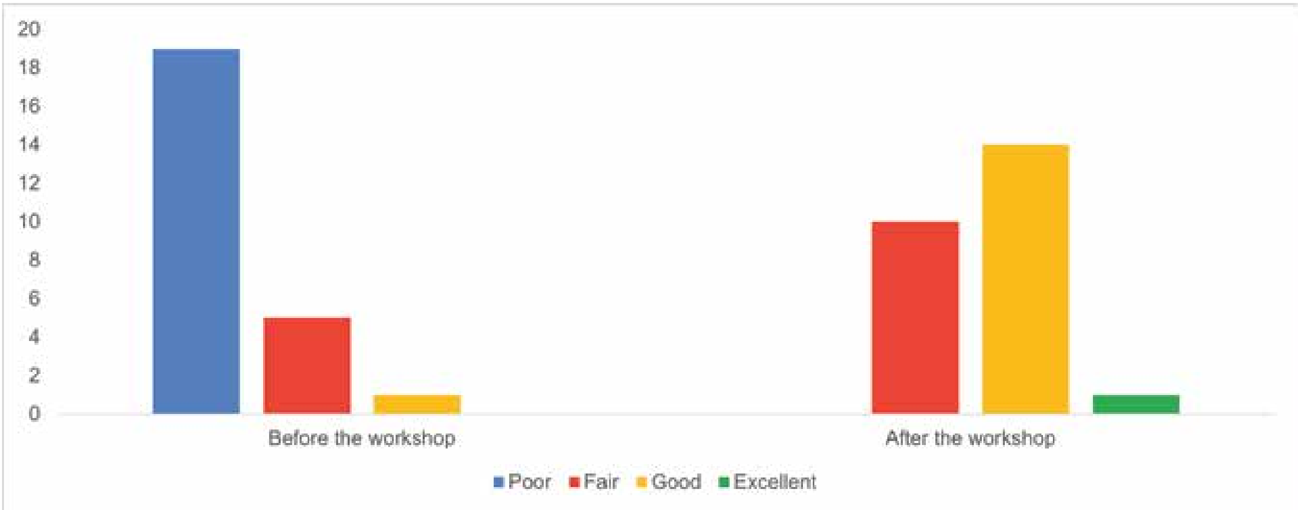


Figure 16.5: *Workshop participants were asked to evaluate their ability to analyse and interpret the outputs of an SECR survey both before and after the workshop.*

Acknowledgements

This initiative was a collaborative venture between the Kenya Wildlife Service and local and international non-governmental organisations. This multi-stakeholder approach was designed to be both transparent and inclusive, making full use of the skills and knowledge of local stakeholders while being supported by national and international bodies. We are grateful to the following for providing funding, field and logistical support. These surveys would not have been possible without the fieldwork of those people listed in the following pages, to whom we express our deepest thanks.

Funding support

This was a hugely ambitious project, and we are grateful to numerous organisations for supporting this initiative and seeing the value of this work. We thank the ICEA Lion Insurance Group for providing the initial funding to carrying out the critical standardisation workshop and pilot survey of Lake Nakuru National Park. Funding for the sightings-based and interview-based surveys were provided by the Wildlife Conservation Network's Lion Recovery Fund, Liz Claiborne Art Ortenberg Foundation and the National Geographic Society. WWF-Kenya provided some of the survey equipment and provided funding for the sightings-based surveys that were conducted in Southern Kenya. Additional funds were generously provided by the African Wildlife Foundation at a crucial time in the Tsavo survey which enabled us to continue the work and helped to ensure its success. The capacity building and analytical workshops that were held in 2019 and 2020 were funded by the Liz Claiborne Art Ortenberg Foundation, the Siemiatkowski Foundation, the National Geographic Explorer Community Fund and the African Wildlife Foundation kindly provided logistical support including a venue and catering. Femke Broekhuis would like to thank the Remembering Wildlife initiative for funding some of the cheetah-related work of this survey and Arjun Gopalaswamy thanks WCS for the partial funding and thanks WCS and Indian Statistical Institute, Bangalore Centre for the logistical support provided to be involved in the survey.

Logistical support

During the first phase of the survey, which was conducted in Southern Kenya, the Kenya Wildlife Service partnered with WWF-Kenya and the Kenya Wildlife Trust. The Kenya Wildlife Trust continued to be a partner throughout, assisting with fund raising and providing an institutional framework through which to receive and administer funds. We are also grateful for the use of the University of Oxford's Advanced Research Computing (ARC) facility (https://doi.org/10.5281/zenodo.22558). We acknowledge the use of CyberTracker (www.cybertracker.org)for all data collected during this survey - a testament to the versatility and reliability of this free software.

Local oversight

We are grateful to the Assistant Directors, Senior Wardens, Senior Research Scientists and research teams from both the Kenya Wildlife Service and local conservancies. Their support throughout the exercise both in terms of logistics, local knowledge and personnel was invaluable to this exercise.

Field support

For each survey, we aimed to collaborate with the various local stakeholders in all aspects of the survey. By assisting in data collection and participating in analysis workshops our intention is that this initiative evolves into long-term monitoring within all important lion populations. Indeed, much of the fieldwork outlined in this report was carried out by local stakeholders with the support of the technical team and with financial support of the partners listed above. In many cases, local partners provided their staff and vehicles throughout the exercise - these contributions cannot be overstated.

Sightings-based surveys

Nakuru National Park fieldwork was conducted by:
Alice Bett, Femke Broekhuis, Monica Chege, Catherine Combes, Edwyn, Jonah, Nadia de Souza, Nic Elliot, Julius Kabete, Anita Kiplagat, John Momanyi, George Obuya, Benard Olume, Christine Ong'iro, Kasaine Sankan, EverlineSilali, Rowena White

Maasai Mara Ecosystem fieldwork was conducted by:
KosiomKeiwua, Kelvin Koinet, Niels Mogensen, Kasaine Sankan, Eric Taki

Amboseli ecosystem fieldwork was conducted by:
Stephanie Dolrenry, Philip Briggs, Eric Ole Kesoi, Nadia de Souza, Jeremiah Purka and the Lion Guardians

South Rift fieldwork was conducted by:
Femke Broekhuis, Nic Elliot, Arjun Gopalaswamy, Peter Meiponyi, Benjamin Merumu, Patrick Nkele, Joshua Parsaloi, LoseremPukare, Steiner Sompete and Guy Western.

Nairobi National Park fieldwork was conducted by:
ElphasBitok, Agnes Oundo, Nic Elliot, Jackson Kingoo and Kasaine Sankan.

Tsavo ecosystem fieldwork was conducted by:
Team leaders: Bernard Amakobe, Philip Briggs, Femke Broekhuis, Nic Elliot, Denis Kibaara, David Kimutai, Phoebe Manyonge, Christine Mwende, Kenneth Onzere, Kasaine Sankan, Horris Wanyama, Moses Wakesa.
Additional field members: AbdrizakDahir, Yussuf Adow, Richard Akalo, Richard Akalo, Corporal Alex Kipoki Liaulo, Austin Ambani, Lilian Apollo, Yatani Bahati Mohammed, Baxton Biwott, Katana Bulushi, Monica Chege, Robert Chelanga, Viola Cherotech, Richard Cheruiyot, Kopgeno Cheruyiot, Abdirazak Dahir, Nadia De Souza, Nick De Souza, Shaban Duba, Shaban Duba, George Ekirapa, Bernard Ekitela, Regina Ewoi, Corporal Fredrick Nganga, Simon Gambia, James Gatimo, OC George Ekirapa, Arjun Gopalaswamy, Hussein Halkano, Keith Hellyer, Siyat Hirey, Fatuma Ibrahim, James Irungu, Ranger Irungu, James Irungu, Oliver Isalikho, Frank Kaburu, Francis Kamasiai, Mary Kamau, Kenneth Kamuyu, Joel Kapelinyang, Ben Kariankei, Linus Kariuki, Isaac Kashir, Msanzu Kazungu, Sergeant Kenneth Kamuyu, Eric Kesoi, Evans Kiagie, Zachariah kibet, Koech Kibet, Albert Kimama, Stephen Kimutai, Isack Kini, Isack Kini, Francis Kipainoi, Hiram Kiplimo, Cpl Kiprono, Hiyesa Kiribae, Samuel Kisaika, Vincent Koech, Francis Koome, Isaac Korir, Gilbert Kosgey, Joseph Kyalo, Chogo Lambarto, Jissari Lesiramba, Isaac Loki, Shadrack lolemtum, Emmanuel Lucky, Emmanuel Lucky, James Maina, Eric Maoga, Sammy Maya, Vincent Mecha, Dephence Mghoi, Geraldine Mjomba, Fred Muiruri, Kenneth Muriithi, John Musa, Stephen Musau, Peter Mutai, Stanley Muthaura, Daniel Mutie, Dickson Mutoro, Dickson Mwai, Bosco Mwandiki, John Mwangi, Charles Mwangi, Patrick Mwangi, Samuel Mwangi, Moses Mwangi, Samuel Mwangi, Mathis Mwasya, Suleiman Mwatembo, Emmanuel Mwawaza, Alex Mwazo, Polycarp Mwibi, Fridah Mwikamba, Jacob Mwololo, Francis Ngari, Shadrack Ngene, Ranger Ngigi, Peterson Njeru, James Njoka, Lawrence Njoroge, Francis Njoroge, Stephen Nyaga, Joseph Nyaga, Bernard Ochieng, Rashid Odhiambo, Jacob Oindo, Gilbert Oleel, Fredrick Ondieki, CollinceOnduto, Santos Opiyo, David Osoro, Ronny Otieno, Sergeant Peninah Kavingo, Parkesian Saitoti, Kheir Saud, Isaac Sekecha, Eli Shikanda, Simel Silim, illiam Solol, Simon Taurus, Ayub Vura, John Waiganjo, Jackson Waita, Wilfred Wanga, Enos, Eshihanda.

MCA fieldwork was conducted by:
Ali Abdi, Femke Broekhuis, Djurre Broekhuis, Geoffrey Bundotitch, Victor Cheruiyot, Nic Elliot, Anthony Ewesit, MurayaGithinji, Moses Gitonga, Peter Gitonga, Dorothy Jebet, Domiano Juan, Steven Kahindi, Peter Kariuki, Lead Kathure, Opit Kennedy, Kelvin Kibe, Viktor Kibet, Brian Kimani, David Kimathi, Shadrack Kimeu, Misheck Kirema, David Kiura, Alex Langat, Wilson Lemuli, Stephen Lepuyapui, Mercy Madrina, Emily Madsen, Peter Muchiri, Kennedy Mukiri, Mark Mukoyani, Eric Munene, Lewis Muritani, Philemon Mwangale, John Mwiti Mbiti, Caroline Ng'weno, Moses Nyagah, Eliphas Ogendi, Zechariah Onderi, Derrick Ruto, Parkesian Saitoti, Kasaine Sankan, Newton Simiyu, Lawrence Thuranira, Christine Tinyari and Simon Wachira.

Samburu-Isiolo fieldwork was conducted by:
Shivani Bhalla, Femke Broekhuis, LesiamitoEkale, Nic Elliot, Joseph Jisana, Evanson Kariuki, Ndume Lebacha, Ben Lejale, Jeneria Lekilelei, Francis Lendorop, Laikos Letupukwa, LetoiyeLmalasian, Samuel Lokitela, LealeLolkuroroi, Lenawasai Lpuresi, Thomas Mero, Toby Otieno, Steven Sanangi', Munteli Lalparasaroi, Yesalai Lemachokote, Jeremiah Letoole, Lekurana, Lempaghani, Mparasaroi Lemantaan, Reria Lolkidenye, Waibara, Lesara, Lemeen Lalampaa, John Lenakae, Kennedy, Solomon Lenasalia, Marco Lekapana, Lekurukki Rangers, Nasuulu Rangers, Il Ngwesi Rangers.

Laikipia fieldwork was conducted by:
Steven Ali, Wendy Andrews, Nicholas Apeot, Per Aronsson, Simon Awoakal, Paul Benson, Jackson Bithi, Philip Briggs, Femke Broekhuis, Djurre Broekhuis, Steve Carey, Alayne Cotterill, Tracey Crain, Amy Dickman, Omar Duba, John Ekiru, John Elain, Nic Elliot, Joseph Emathe, Joseph Emather, Hakan Forsmark, Jamie Gayner, Saibala Gilicho, Jennifer Githaiga, Bernard Gituku, David Gotlieb, Hassan Gro, Sveva Gullman, David Hewett, Samson Ituru, Francis Kamau, Francis Karanja, Paul Keiru, Peter Klink,

Mark Lawrence, Antonia Leckie, John Lekitagwa, Susan Lentaam, Simon Lerantilei, Stephen Leshoroni, Stephen Leshorono, Peter Lokadeli, Gidion Lokandangoi, Joseph Lokitol, Moses Lokoda, Nicholas Lomuria, Francis Long, Jackson Lopeyok, Joseph Loreng, George Lorinyo, Samuel Loroto, Boniface Lowoi, Thomas Majong, Yaro Manyas, Solomon Meshami, Daniel Metieki, Monica Mildh, Ellie Milmes, Eleanor Monbiot, Ann Mugie, Ceciliah Mumbi, Nason Murungi, Onesmus Mutua, Jackson Mwangi, Nicholas Nakua, Simon Njaramba, Robert Nyakwara, Lucy Nyambura, Hector Oriol, Josep Oriol, Paul Pussley, Kiloko Ramson, Jackson Reusi, Fern Roberts, Wilson Sabane, Francis Sadira, Parkesian Saitoti, Kasaine Sankan, Dennis Saruni, Charles Satim, Peter Sericho, Flora Strachan, Pauline Wairimu, Ann Wambui, Horris Wanjama, Toni Wild, James Yiangere, Boniface, Lang'at, Lomukonyo, Susan, Joseph (Kamogi), Simon (Lewa), Christopher (Ol Pejeta), Nixon (Ol Pejeta), Philip (Ol Pejeta).

Sibiloi fieldwork was conducted by:
Kipsaboi Cornelius, Nic Elliot, Thomas Kamweru, Erick Karani, Bernard Kuloba, Peter Lenguyayu, David Mucira, Parkesian Saitoti, Kasaine Sankan, Stephen Waigwa, Eric, Macharia and Nelson.

Interview-based survey

Interviews were conducted by the following enumerators:
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Additional assistance was provided by:
Somo Guyo, Anastasia Mwaura, Enrita Naanyu, Dedan Ngatia, Steiner Sempeta, Peter Tyrrell and Guy Western.

We would also like to thank all the respondents for volunteering their time and sharing their insights on carnivore presence and absence.

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ISBN 978-9914-40-516-3