DRAFT LION MONITORING HANDBOOK

GUIDELINES & PROTOCOLS FOR MONITORING KENYA'S SOURCE POPULATIONS

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Summary

The objective of this handbook is to provide principle investigators and field practitioners the tools they need to plan and execute a successful, long-term monitoring programme for lions within source populations. The emphasis is on the practical matters associated with every aspect of survey implementation, rather than data analysis. The first section provide the key concepts that need to be understood and internalised, so that a survey can be successfully implemented (the practicalities of which are the focus of the second and third section). The fourth section provides site-specific guidelines which draw on the outcomes of previous surveys, to detail the minimum data requirements and associated field effort, which will be useful for planning (in terms of budgeting, proposal writing and field logistics) and also for implementation (to ensure minimum data requirements are met). Throughout this handbook, the focus is on source populations which are defined as areas where lions are believed to be resident and breeding. All data collection protocols described here fit within a 'Search Encounter Spatially Explicit Capture Recapture' (SE-SECR) modelling framework. This framework was adopted by the Kenya Wildlife Service (KWS) and Wildlife Research Training Institute (WRTI) in 2017 as the official framework for lion monitoring within source populations. We present field-friendly standardised protocols for data collection, and describe the minimum requirements and equipment needed. When conducting these protocols, the emphasis is on two streams of data that must be collected: (1) careful records of the field effort invested, which in most cases will be limited to drive effort, but the protocols are flexible and have been extended to include walk effort and also playback protocols; (2) individual identification photographs obtained of lions detected during the survey.

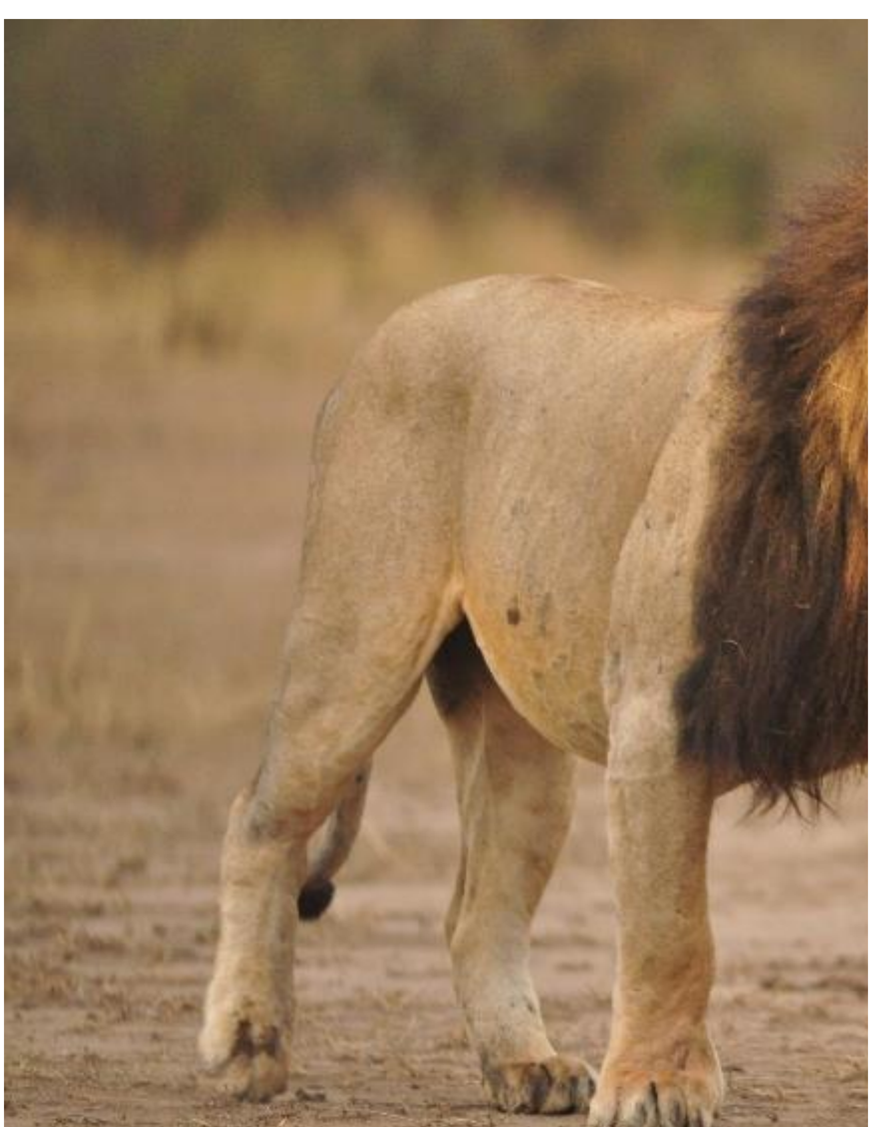
A well-designed monitoring programme coupled with rigorously collected field data and robust statistical analysis, provides a scientific basis for assessing the status of lions within source populations, and offers the opportunity to gain tremendous insights into lion ecology. An emphasis is placed on long-term monitoring, where data is collected at regular and short intervals, since this will optimise our understanding of population dynamics and trends. A key advantage of SECR methods compared to other methods, is that they make use of the idea that individuals are tracked over time. This provides two distinct advantages: (1) Identifying individuals increases information content in the data and thereby provides more robust estimates compared to the broad suite of unmarked methods; (2) This allows for the estimation of vital rates (recruitment, growth, mortality, movement).

Between 2017 and 2020, the Kenya Wildlife Service, together with a technical team, developed and successfully deployed these protocols within ten of Kenya's potential source populations of lions. In this first edition of the lion monitoring handbook, we incorporate the experience and learnings from those surveys to provide practical guidance for specific areas. We set the ambitious goal of source population monitoring on an annual basis, while acknowledging that this may not always be practical.

This handbook is accompanied by a suite of online tools that practitioners and principle investigators can download and use. These include:

- Mobile-phone based applications for data collection
- Templates for databases that can be used to store long-term data in a consistent manner
- Templates for creating lion catalogues
- R scripts to format the data ready for analysis
- R scripts to analyse the data
- R scripts to run model diagnostics

It is important to note that this handbook is not intended to provide an in-depth understanding of the theory or analytical procedures involved. For those readers who want to go deeper, we provide a list of key resources for further information. Rather, the intention here is to present a relatively non-technical handbook that will serve as a tool to ensure survey design, data collection and data management are meticulously carried out. The WRTI has a technical team that specializes in lion and large carnivore monitoring, and are on hand to assist and guide on all steps of the process.



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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.
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 100 km^2).
Detection	A detection is a positive identification of an individual on a particular day.
Detection probability	The probability of detecting an individual if it is present.
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.
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.

1. Key Concepts

1.1. A brief introduction to spatially-explicit capture-recapture

A comprehensive overview of spatially-explicit capture-recapture (SECR) theory and model formulation is beyond the scope of this handbook (refer to Royle et al. 2013 for a reference book that is dedicated entirely to this topic). However, it is important that the general concepts are grasped by field practitioners so that the protocols are better understood and followed.

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. 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 not detected. 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.

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. Furthermore, the SECR framework overcomes concerns related to direct estimation of density since it formally links individuals and space, and therefore defines abundance within an explicit spatial region, allowing for direct estimation of density with a measure of precision while accounting for individual heterogeneity in detection probability.

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. This field technique relies on vehicle-bound observers that systematically search a given study area, and when lions are found, take close-up photographs of each individual so that they can later be identified through their unique vibrissae spots.

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.

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, since investing more effort in a trap is likely to yield more detections. Paterson et al. (2019) 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.

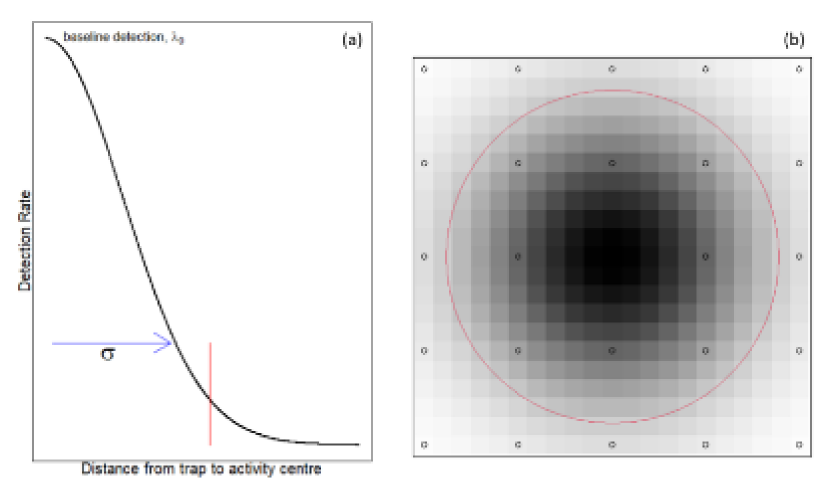


Figure 1. (a) A half-normal detection function was used for all lion SECR analyses. Basal detection rate (λ_0) represents the detection rate when an individual's activity centre (black dot) coincides with a trap location. The spatial scaling parameter (σ) describes how detection rate decreases with increasing 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=σ √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.

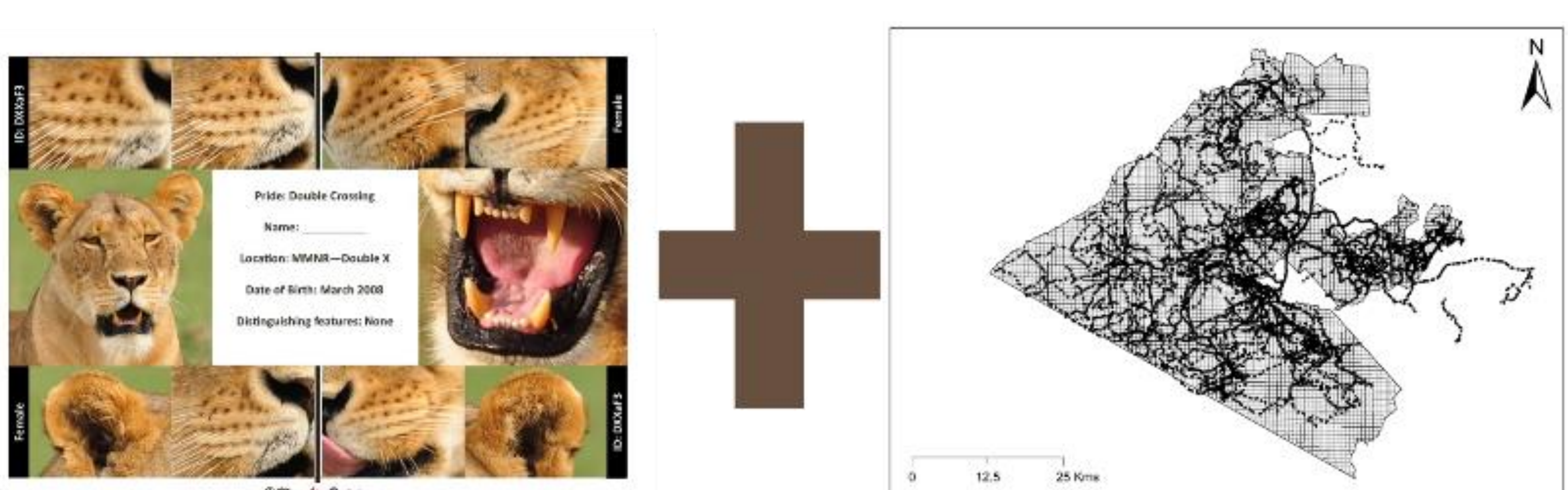


Figure 2.A variety of field protocols can be deployed. To date, four protocols have been developed and deployed in Kenya, and these are detailed within this handbook. Regardless of the protocol, two streams of data are always required: (1) the individual identity of lions together with associated metadata and (2) careful records of the effort invested to obtain the lion sighting.

1.2. Survey duration

A survey can be viewed as a 'snap-shot' of a population and the duration is often a compromise of being long enough that a robust dataset can be collected, yet not so long that assumptions of population 'closure' are violated. The term 'closure' refers to the assumption that a population does not change during the survey. For example, a survey that lasts one or two years, may well see a number of lions dying or being born, emigrating or immigrating. 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). One way to minimise violating closure is to keep the survey duration as short as possible. The shortest survey so far conducted in Kenya was in Nakuru National Park (22 days), while the longest was in Tsavo (105 days). The latter should be viewed as a maximum duration, with the duration usually scaling according to area size and number of teams available.

1.3. Lions under the age of 1 year

Lions under the age of one year typically suffer from high levels of mortality. Therefore including them in a survey, would likely violate demographic closure. This is especially the case in long-term, multi-year monitoring, since variable numbers of births or deaths of cubs due to various reasons (e.g. drought) could provide a confused picture as to population change and dynamics. We therefore suggest that while it is important to try and get ID photos of all cubs (which is often difficult, but useful for other reasons), individuals under one year should be excluded from analysis. It is however important to note this when interpreting and presenting results. Guideline to ageing lions is presented below.

1.4. 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 represent 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 to flawed inferences.

1.5. Data to collect

Two types of information need to be recorded: (1) Effort - following the survey design and protocols, keep a carefully detailed record of the field effort that was invested into finding lions (more on this in the protocols section) and (2) IDs - try to identify as many lions as possible, as many times as possible. Remember, the goal is not to find and identify or 'count' every single lion. This is usually impossible, even in small, fenced areas. Rather the goal is to sample the population and obtain repeat sightings of individuals. This information, together with the associated data on field effort allows us to estimate detection probability, and hence the number of individuals that were not seen.

1.6. The importance of field effort

As we will see later, the SECR framework is flexible and data collection protocols can be adapted to suit local field conditions. For example, in an area where lions are relatively easy to find, and are habituated to vehicles, the search encounter protocol can be employed. Whereas if lions are harder to find, playbacks may be used to help boost detections. Other studies have also made use of camera traps or genetics to acquire detections. The key here is that protocols must be defined during the design stage, then followed throughout the survey, while ensuring that detailed and careful accounts of the field effort are recorded. This information is used in estimating detection probability, an essential parameter in abundance estimation.

1.7. The importance of IDs

The protocols described in this handbook are geared towards obtaining individual identification photos of lions. While there are analytical tools that can be used to estimate populations from unidentified or partially identified individuals, these methods are less precise and more prone to bias. Identifying individuals increases information content in the data and thereby provides more robust estimates. Therefore, our goal is to identify as many individuals as possible, as many times as possible. Because much importance is placed on individual IDs, we adopt the cautionary approach of 'if in doubt, leave it out'. In other words, we must be certain of an ID at each detection to include that detection. Leaving out detections or individuals will decrease the precision of the estimates, but should not bias the estimates themselves (so long as we have a decent dataset). However, including individuals that have been incorrectly identified will lead to incorrect estimates.

1.8. Bias and precision

Ideally a survey will produce estimates that are unbiased (close to the true population size) and precise (a measure of how close an estimate is to the expected value). Longer surveys will likely provide larger sample sizes, which will increase precision, but may also violate assumptions of closure, which may introduce bias. During the first surveys of this kind conducted in Kenya, we did not know how much field effort would be required to obtain estimates that were unbiased and precise. Fortunately, we have now conducted many such surveys and have used the data collected during those, to run additional analyses and provide guidance for future surveys (see Section 4). By rarefying the data collected during each survey, we were able to assess the impacts of this on bias and precision of the estimates. For each source population, this has given a good indication of the amount of field effort required, which will be useful for budgeting and planning.

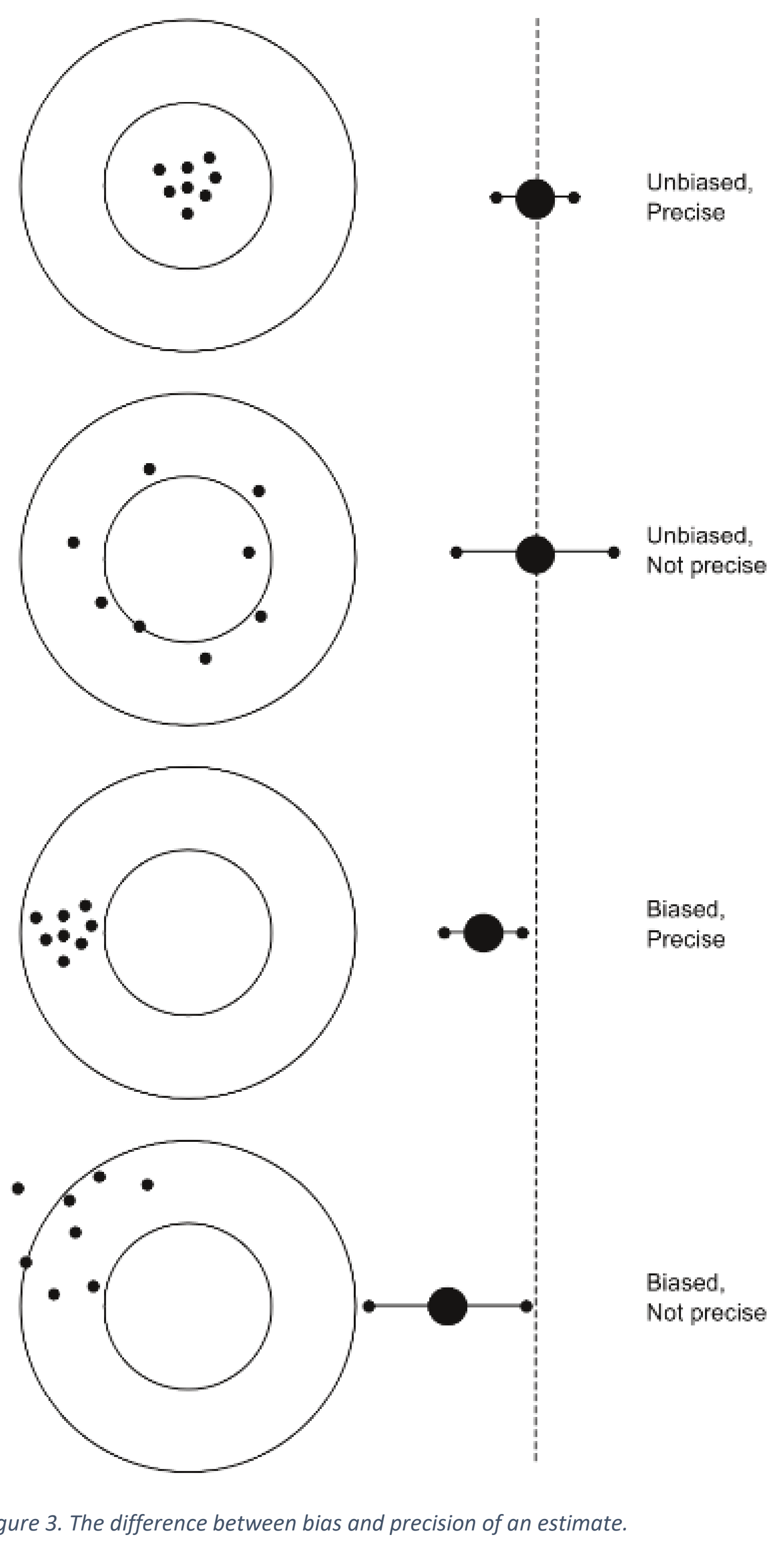


Figure 3. The difference between bias and precision of an estimate.

2. Conceptual Guide to Survey Implementation

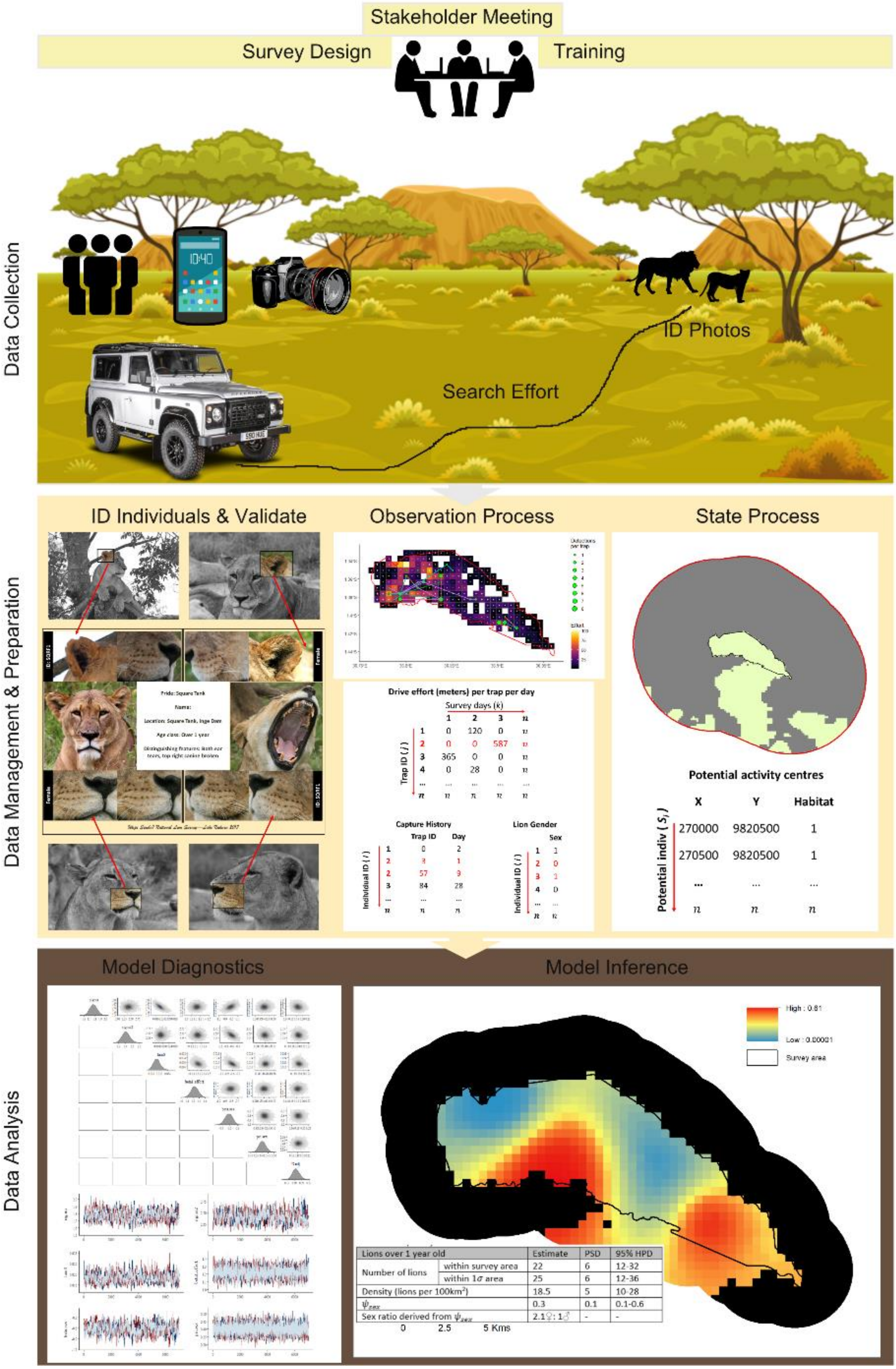


Figure 4. This figure details the steps (chronologically) that should be followed. Each of the steps is described in detail in the following section.

3. Survey Implementation

The following sections provide step-by-step guidance on the procedure of conducting a lion survey.

3.1. Study design

All monitoring programmes should be driven by sound scientific questions. Once such questions are defined, other aspects that need to be decided upon, such as when to conduct a survey, how frequently, the duration, over what spatial extent etc, will follow naturally. This will also help to ensure that any supplemental data is collected to answer additional questions. While this step is crucial, it is beyond the scope of this manual to define questions, as this will be area specific, and should ideally involve local stakeholders.

3.1.1. Survey timing

The timing of a survey is usually dictated by the question being asked. For example, if there is an interest in understanding potential changes between seasons, then surveys would need to be planned in both the wet and dry seasons. For example, see Broekhuis et al. (2022), who used search encounter SECR to answer questions relating to cheetah density and movement in the Maasai Mara during the wildebeest migration and outside of it.

Generally, the protocols described in this handbook are easier to implement in the dry season, since the vegetation is less thick (making it easier to find and photograph lions), and also sites are more accessible in the dry season, since the protocols require off-road driving. The timing of surveys should ideally be consistent over the years to allow for coherent population assessments over time.

3.1.2. Survey frequency

How often surveys are conducted is also usually informed by the question being asked. For source populations of lions, annual surveys are recommended. A great strength of SECR is that individual animals are tracked through time and this information is used to estimate vital rates (such as mortality and recruitment). If too much time passes between surveys, many individuals may have died or emigrated since the previous survey, thus rendering the overall dataset poorer. Furthermore, the ultimate goal of monitoring is to detect change over time, and if surveys are conducted very infrequently, detecting change or trends can be problematic.

3.1.3. Survey duration

As discussed above (see 1.8. Bias and precision), longer surveys will likely provide larger sample sizes, which will increase precision, but may violate assumptions of closure, which may introduce bias. The life history of a species is an important consideration when deciding on survey duration, since surveys of long-living species with low mortality are less likely to violate assumptions of closure, compared to short-living species with high mortality. This may also vary according to site. Although no studies have formally tested the ideal duration for lions, we recommend that surveys do not last longer than 90 days, and should ideally be shorter.

3.1.4. Survey area

SECR models estimate density and estimates of abundance are explicitly tied to the state-space and not to the traps. Therefore, the survey area can expand or contract between surveys . The amount of effort invested may be scaled accordingly. This will be taken into account during analysis and inference.

3.1.5. Survey effort

Precision of density estimates is optimized by maximizing the number of detected individuals (informative about density), and maximizing the number of recaptures and spatial recaptures (informative about spatial heterogeneity in detection). In search encounter designs we have little opportunity to adjust the location and spacing of traps, but can optimize the number of individuals detected and the number of recaptures by investing more search effort. Following the initial surveys conducted in Kenya (Elliot et al. 2021), various analyses have been conducted to guide practitioners as to the amount of effort to be invested per site (see section 4), with the goal of striking a balance between effort invested and the accuracy and precision of estimates.

3.2. Stakeholder meeting

Once a survey has been planned, and dates set, relevant stakeholders should be invited to a meeting to discuss the monitoring programme prior to commencement. The purpose is to brief stakeholders on the objective, protocols and duration of the activity. During this meeting the survey area should be defined. It is also an opportunity to discuss logistics and identify the teams who will assist with data collection.

3.3. Training

All primary data collectors must undertake a four-day training. The first day is concerned with ensuring that data collectors receive a foundational knowledge of the core principles of the study design and a solid grasp of the field protocols. This can be achieved via a series of PowerPoint presentations, followed by exercises and discussions. Most importantly it must be reiterated that search effort is recorded at all times, and that the teams should aim to find and identify (via photographs) as many lions as possible, as many times as possible. Data collectors must receive standardised training on field protocols, taking ID photos, sexing lions and ageing lions. Over the next three days a trainer or member of the technical team must join the data collector in the field to ensure they understand the protocols, are proficient at using the survey equipment, are correctly entering the data and able to reliably conduct the survey.

3.4. Data collection

Goal of fieldwork: The primary metric of sample size in the search-encounter based SECR approach is the area covered. Thus, a survey is as much about sampling the entire survey area (and investing uniform effort) as it is about finding lions. The other core goal is that the team should aim to identify as many individual lions as possible, as many times as possible.

To locate lions: Observers use local knowledge and field skills to find lions. A variety of different field protocols can be deployed. For each survey, a unique field sampling protocol is created that reflects the conditions of fieldwork in each area.

To identify lions: Observers should be patient, respectful of the lions and make every effort to take high-resolution photographs of whisker spots (both sides of the face) and any unique features for each individual present. ID photos must be taken even if the individual was previously photographed during the survey.

To record data: Observers must use customised applications installed onto GPS-enable smartphones. These applications are available from the technical team, and are determined by the protocol being followed. At a minimum, data recorded in the field must include:

- Detailed records of field effort
- The following metadata associated with each lion sighting
    - Date and time
    - GPS coordinates
    - Number of lions present
    - Age class and sex of each individual present
    - The individuals for which ID photos were taken

3.4.1 Field protocols

To date four field protocols have been used in Kenya's lion surveys, and these are detailed below. These protocols are not exclusive, and combinations of protocols can be used during a single survey. The technical team have developed a series of smartphone applications to record the required data for each protocol. These applications have been tried and tested and should be used to ensure consistent data collection and ease of data management. Additional field protocols can be implemented so long as (a) rigorous data collection protocols are designed and implemented, (b) data is meticulously recorded on field effort, (c) lions are identified to the individual level. For example, these protocols could be expanded to include camera traps or genetics. However, additional field protocols should not be considered without consulting the technical team. The protocols described below are most effectively implemented when field teams are able to:

- Drive off-road to take ID photos
- Work at night

3.4.1.1. Search-encounter protocol

Observation teams actively and systematically search the survey area while looking for lions. They need not stick to transects or roads but rather should use their knowledge of the area and their field skills to find lions. Drive effort is continuously recorded via the CyberTracker application which is customised to take a GPS point every 10 seconds, thus retaining a finely detailed account of search effort. Efforts must be made to cover the survey area in a uniform manner, and the technical team should regularly advise teams as to which areas should receive more attention. The observation teams should not simply focus on areas where they 'know' there are lions, and should invest equal effort throughout the study area. When sampling at night, a powerful spotlight must be used to scan the surroundings from an elevated position in the vehicle.

Central concepts:

- Use your knowledge of the area to find lions
- Use field signs (e.g. tracks, vultures etc) to find lions
- Be patient and try to get ID photos of all lions present
- Do not bias your effort to known areas of lion activity
- Cover the study area as uniformly as possible
- Go to places you don't normally see lions
- Get repeat sightings
- Use a spotlight at all times if sampling at night

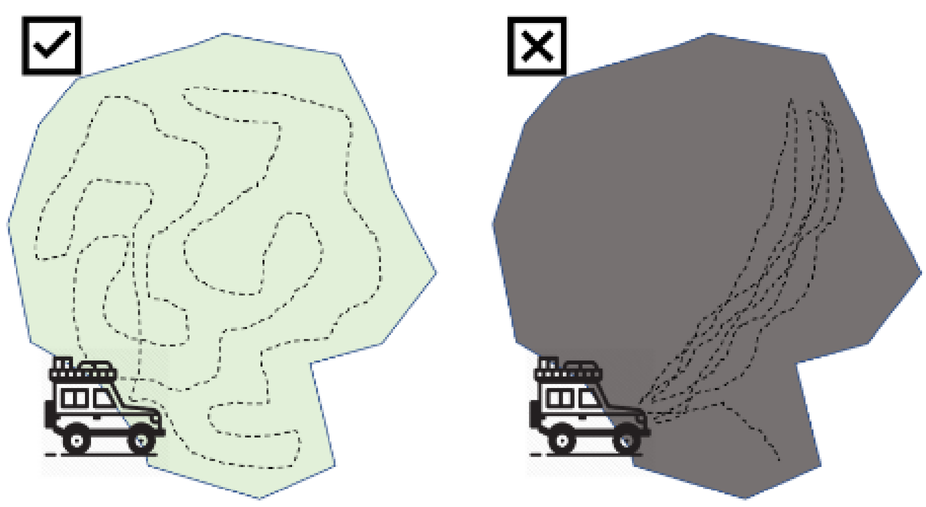


Figure 5. GPS tracks of search encounter drive effort is recorded via a smartphone. The area should be sampled uniformly (left panel) and field teams should not only sample one area (right panel).

Prior to departure:

- Ensure camera battery is charged
- Ensure camera has SD card inserted with sufficient memory
- Ensure phone battery is charged

Essential equipment:

Data to record:

- Drive effort (a track of where you have been)
- Photos of lions
- Metadata on lion sighting

Procedure:

- Open CyberTracker application
- Select names of all team members
- Go to *Start Monitoring* and click on the save icon .
- Start recording your effort before you begin your journey
- Keep the phone in a location where it can 'see' the sky
- Regularly check if you see the black triangle in the bottom left corner of your screen. This confirms that your field effort is being recorded. If you see the empty triangle , stop and wait until the phone has GPS signal. You may need to select *Start Monitoring* and save. Only proceed when you see the black triangle.
- Maintain a slow (<30km / h speed)
- So long as your effort is being recorded, you must be actively searching for lions, and be in a position to take ID photos if you find them (ie. you have enough time to do so, and you have a camera).
- When finished a sampling session, go to *Stop Monitoring* and click on the save icon .

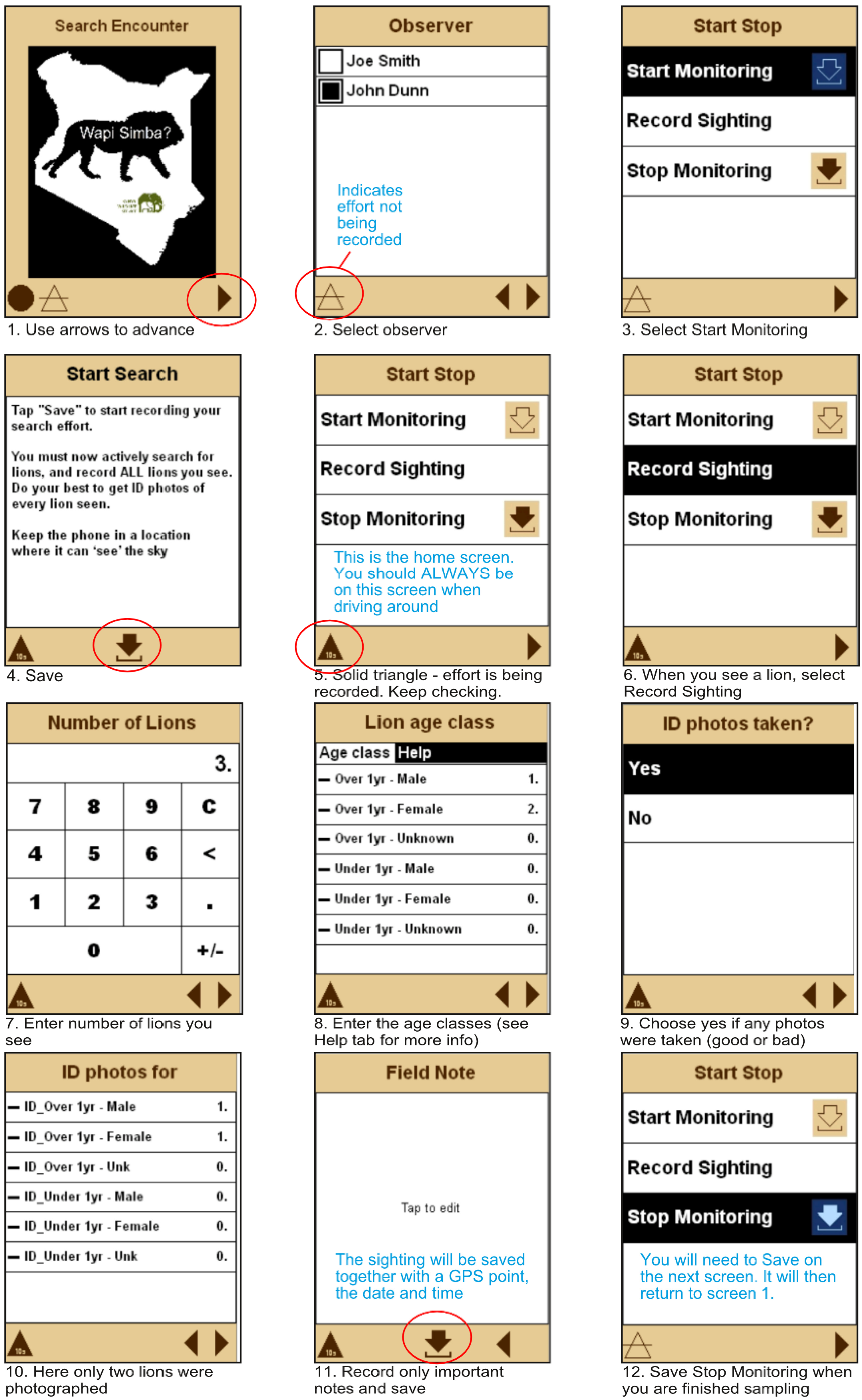


Figure 6. The procedure to follow when using CyberTracker for the Search Encounter Protocol.

3.4.1.2. Playback protocol

In areas where lions are more difficult to find or are more cryptic, playbacks can be used in conjunction with the unstructured search encounter protocol. Playback sites are not systematic or pre-determined but chosen either when fresh tracks have been found or may be used opportunistically, in an attempt to improve detection rates. Lions are attracted to the vehicle at night by means of playback sounds broadcast at a minimum of 95DB. Standard sounds that are known to attract lions should be used. Playbacks should be used with a bait, which serves two purposes: (1) if lions do approach, then the carcass provides an anchor and a distraction, (2) it is possible that lions who have responded to a playback and not been 'rewarded' will not respond again. This is important for recaptures.

Central concepts:

- Playbacks can be used to increase the chances of detecting lions
- They do not need to be conducted in a systematic manner (e.g. in a grid system)
- But the standardised protocol does need to be followed at each site
- The number of people in a team should be kept to a minimum. Usually playbacks are used to try and photograph skittish lions. Having too many people increases the chance of disturbance and failure
- Usually the search encounter protocol is used before and after the playback protocol. Ensure that this is the case on CyberTracker

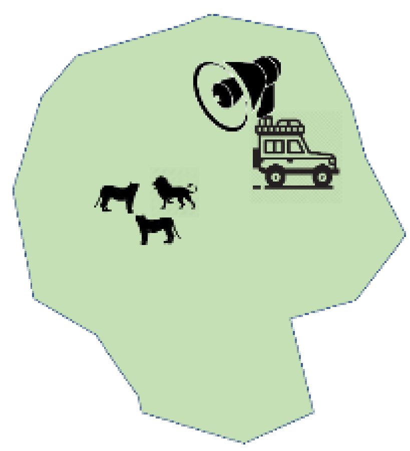


Figure 7. The playback protocol consists of broadcasting sounds via a loudspeaker to attract lions to a vehicle, where identification photographs are taken.

Prior to departure:

- Ensure camera battery is charged
- Ensure camera has SD card inserted with sufficient memory
- Ensure phone battery is charged
- Ensure spotlight is working
- Ensure speaker is working and charged (if battery powered)

Essential equipment:

Data to record:

- GPS point of the location the playback was conducted
- Photos of lions
- Metadata on lion sighting

Procedure:

- Keep disturbance to a minimum throughout
- Select a site
- Tie the bait (if present) to a tree of similar
- Position the vehicle in a relatively concealed place that allows for photography of the baited area
- Wait in silence for 10 minutes
- Change camera settings to optimize night-time photography
- On CyberTracker, go to *Start call-in* and click on the save icon .
- Broadcast for 5 minutes
- Wait in silence for 10 minutes
- Rotate the speaker 90°
- Repeat this until 4 broadcasts have been completed or lions have appeared
- A playback should not last more than 70 minutes
- If lions approach, turn on the spotlight before slowly focusing it on the lion and taking photographs with the camera flash
- Go to End *call-in*, enter additional data and click on the save icon .

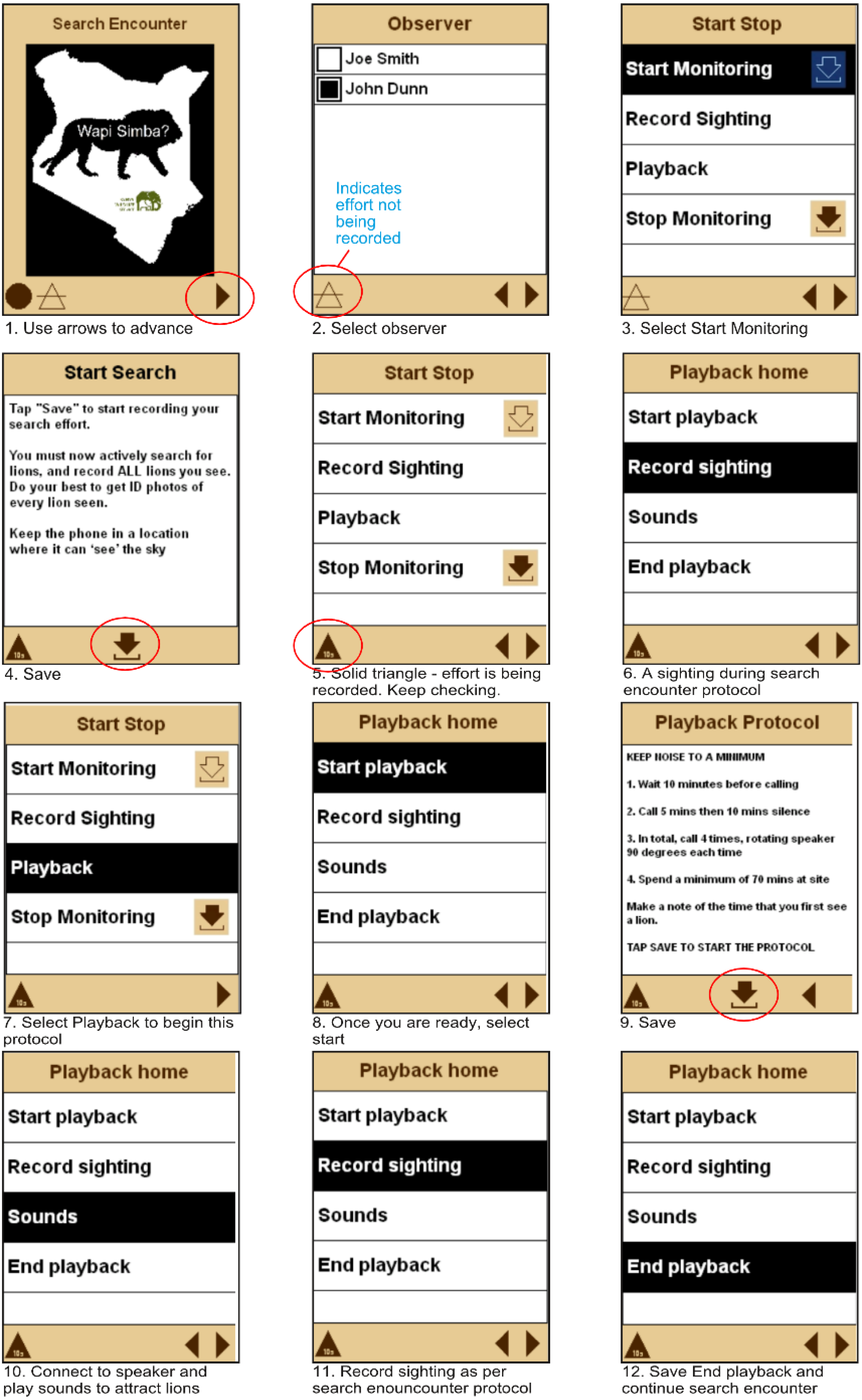


Figure 8. The playback protocol is frequently used in conjunction with the search encounter protocol. This is an example of the two protocols combined. The observation team drives around searching for lions, while recording their drive effort using the search encounter protocol. They then switch to the playback protocol to conduct a playback. Once this is finished, they continue with the search encounter protocol. Lion sightings are recorded in the same way regardless of the protocol (see Figure 6 for more details on entering a lion sighting).

3.4.1.3. Unstructured foot patrol protocol

This protocol is used in conjunction with the conditional drive effort protocol. It can be considered in areas where lions are more difficult to find, for example due to being very secretive, or occur at very low densities, or a poor road network exists. Similar to the playbacks, the idea here is to boost detection rates. Field teams (the more the better) are deployed on foot to search for fresh signs of lions. Taking ID photos of lions on foot is not possible, and therefore this is not the function of this protocol. Rather, when fresh signs are found, vehicle-based teams (which were on stand-by) are called in to the area to try and locate the lions, either by following their tracks, or by conducting playbacks. While this protocol can be combined with the search encounter and playback protocols, it must be combined with the conditional drive effort protocol detailed below.

3.4.1.4. Conditional drive effort protocol

This protocol is only used in conjunction with the unstructured foot patrol protocol. This protocol is used to record the drive effort that is invested between the location at which a tracker finds lion tracks and the eventual detection (or not) of a lion as the tracks were followed. Drive effort is continuously recorded via the CyberTracker application which is customised to take a GPS point every 10 seconds, thus retaining a finely detailed account of search effort.

Central concepts:

- Skilled trackers conduct foot patrols to search for signs of recent lion activity
- When signs are seen a vehicle is called in and will activate the conditional drive effort protocol on CyberTracker
- The vehicle-based team will then follow the tracks to the lions or use the playback protocol
- The protocol does need to be followed
- The number of people in a team should be kept to a minimum. Usually playbacks are used to try and photograph skittish lions. Having too many people increases the chance of disturbance and failure
- Usually the search encounter protocol is used before and after the playback protocol. Ensure that this is the case on CyberTracker

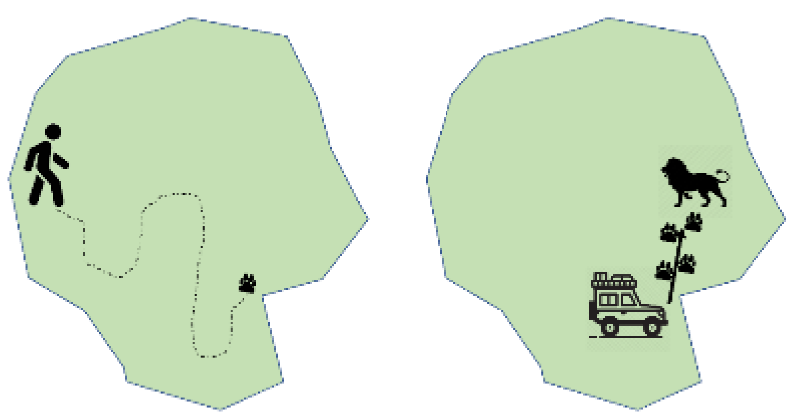


Figure 9. The unstructured foot patrol protocol (left panel) can be used to find fresh signs of lions. A vehicle is then called in (right panel) and begins the conditional drive effort protocol while following the tracks to find (or not) the lions.

Essential equipment:


Data to record:

- Walk effort (a track of where you have been)
- Conditional drive effort (a track of where you have been)
- GPS point of the location the playback was conducted (if used)
- Photos of lions
- Metadata on lion sighting

Procedure:

- The person conducting a foot patrol opens CyberTracker
- Go to *Start Foot Patrol* and click on the save icon .
- Start recording your effort before you begin your journey
- Keep the phone in a location where it can 'see' the sky
- Regularly check if you see the black triangle in the bottom left corner of your screen. This confirms that your field effort is being recorded. If you see the empty triangle , stop and wait until the phone has GPS signal. You may need to select *Start Monitoring* and save. Only proceed when you see the black triangle.
- So long as your effort is being recorded, you must be actively searching for lion signs
- When fresh sign of lion is located, a call is placed to the vehicle-based team
- The vehicle team meets the foot team and activates the conditional drive effort protocol on CyberTracker
- Go to *Start Conditional Drive* and click on the save icon .
- When finished a sampling session, go to *Stop Foot Patrol* and/or *Stop Conditional Drive* and click on the save icon .

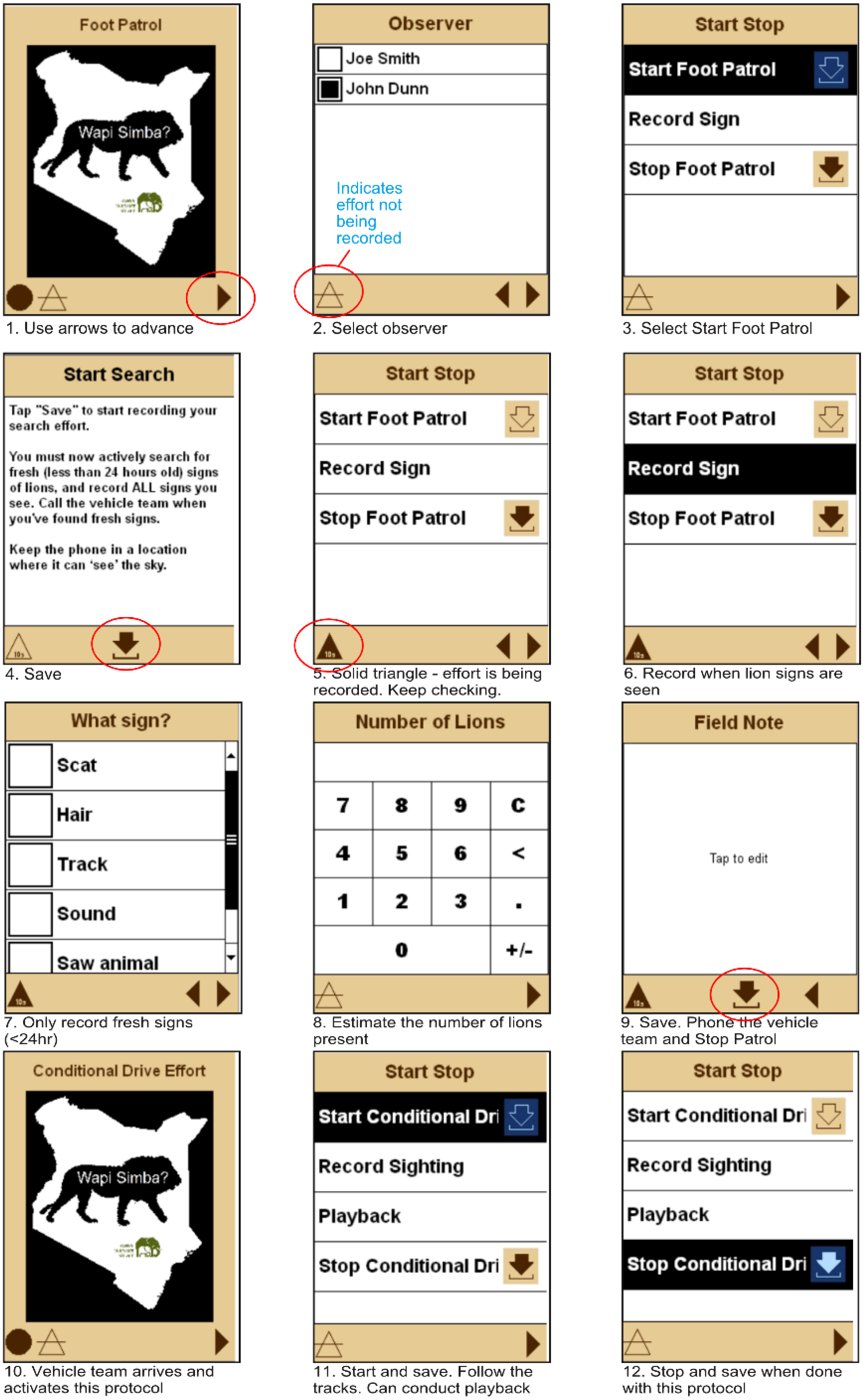


Figure 10. The foot patrol protocol is used in conjunction with the conditional drive effort protocol. This is an example of the two protocols combined. The foot team walks around searching for lions, while recording their effort using the foot patrol protocol. When they encounter fresh lion tracks they call in a vehicle-based team. When that team arrives, they switch on the conditional drive effort protocol. They then follow the tracks, or search for the lions. They can also conduct a playback protocol. Lion sightings are recorded in the same way regardless of the protocol (see Figure 6) for more details on entering a lion sighting.

3.4.2. Emerging and potential field protocols

Considering recent developments in both camera trapping and genetics, there are several field techniques that could be developed into protocols that fit within the same SECR framework. These could either become distinct, standalone protocols or used to supplement existing protocols.

3.4.2.1. Camera trapping

Although not yet used for lions in Kenya, camera traps are potentially a viable option. Indeed SECR methods were first developed with camera traps in mind (see Royle et al. 2013 and Karanth & Nichols 2017). There are two main hinderances to using camera traps for lions: (1) lions do not have large or very conspicuous pelage markings, and so a camera trap needs to take sharp enough images of a lion's whisker spots to enable individual identification, (2) camera traps are costly to purchase and maintain and may be prohibitively expensive if attempting a camera trap study across a vast ecosystem. The first point relates to IDs, the accuracy of which is paramount in SECR studies. A study in Tanzania demonstrated the potential of camera traps for gathering data on lions within an SECR framework (Strampelli et al. 2022), and noted the limitations of identifying individuals, especially for long-term studies, since identifications may be based on temporary rather than permanent features, and the financial implications of scaling-up. As technology improves, this is likely to be less of concern, but more work is needed to fully assess the utility of camera traps for long-term and large-scale studies. While camera traps are often preferred since they collect data on many different species, it should be remembered that the cameras themselves need to be set for species-specific needs – for example getting whisker spots of lions. For now, we envisage camera traps being a useful addition to the protocols described above, rather than having the potential to replace them in Kenya. For example, camera traps could be very useful in boosting detections in areas where lions are thought to be frequenting (perhaps tracks are being seen close to a river), but are difficult to manually photograph. In this manner, camera traps could be used in addition to the search encounter protocol, in much the same way that playbacks are used. Camera traps would not need to be placed in a grid, but the devices themselves must be high quality and (for now) white flash, to ensure the best possible pictures.

3.4.2.2. Genetics

Genetics have not yet been incorporated into lion monitoring in Kenya, or indeed for African lions anywhere. Genetic material (e.g. hair or scats) can be thought of in the same way as individual ID photos. The idea is to collect genetic material (again while keeping careful records of effort invested) and analyse this in laboratories to build individual capture histories. A survey can then consist entirely of genetic data (e.g. Russell et al. 2013) or a combination of genetic and photographic data (e.g. Gopalaswamy et al. 2012). Many studies rely on hair trapping to collect genetic data, but the utility of this for lions is questionable, since they have short coats. Perhaps holding more promise is the collection of scats, and for this to occur, a large labour force is required to walk through a landscape, searching for and collecting scats. Probably the most ambitious such study involved unstructured spatial sampling to collect faecal samples for brown bears, gray wolves, and wolverines across their known range in Sweden and Norway (Bischof et al. 2020). For lions we envisage that genetic data could be useful for specific applications, such as: in very large 'coexistence landscapes' where lions likely occur at very low density and are incredibly shy due to persecution; large landscapes where the road network is very poor, thus limiting the protocols described above. Like with camera traps, the cost implications of using genetics may be prohibitive, and the ability of laboratories to conduct the work needs to be explored in advance.

3.4.3. Applicability to other species

The protocols and methods described in this handbook can be applied to other carnivore species. For example, in the Maasai Mara, teams have been conducting search encounter based surveys using SECR models for both lions and cheetah simultaneously since 2014 (see Elliot et al. 2017 and Broekhuis et al. 2016 & 2021). However the inclusion of other species should not be treated lightly, since if teams set out to record data on multiple species they may spread themselves too thinly and not collect adequate data on any one species. Thus including multiple species is feasible but will usually require more resources. Furthermore, the inclusion of other species, especially those with large pelage patterns, might be more efficiently accomplished by making use of camera traps, or alternatively through genetic sampling.

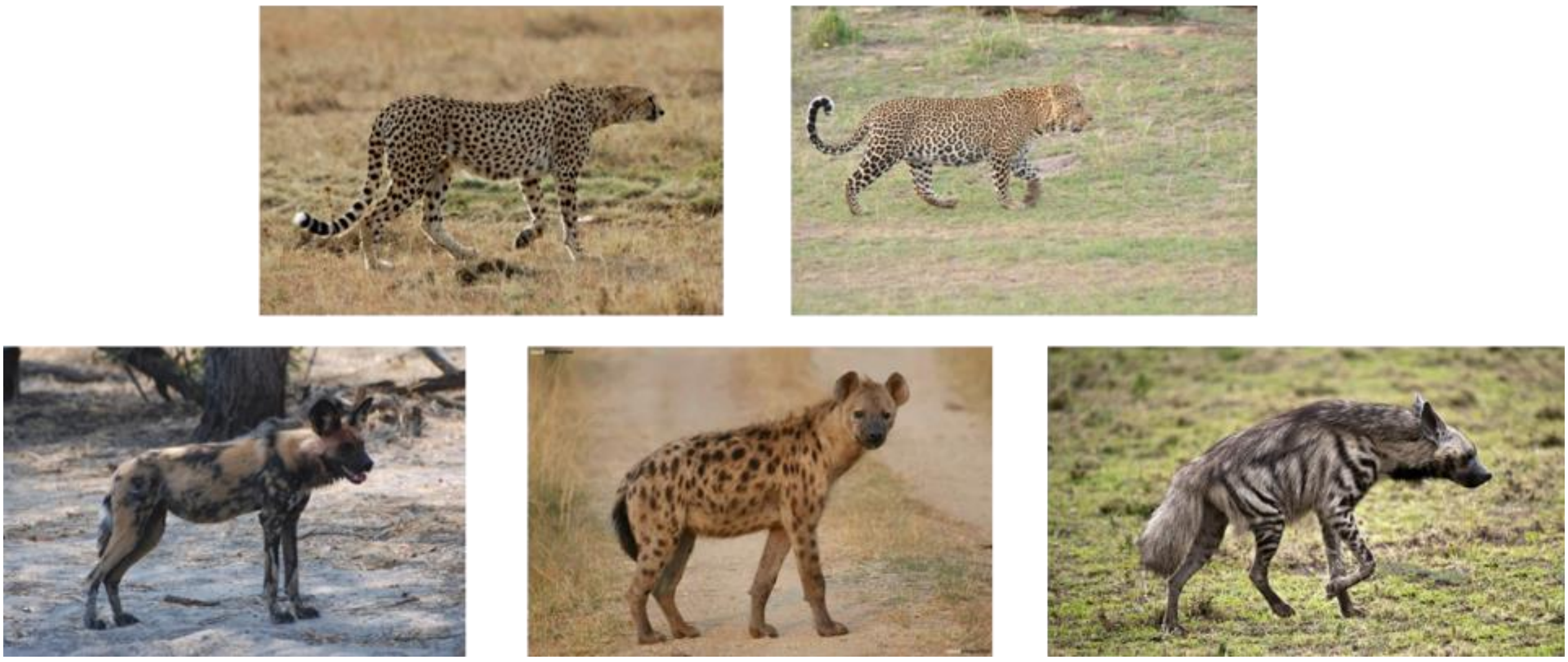


Figure 11. The protocols and methods described in this handbook can be applied to the other five large carnivores (and indeed smaller carnivores and even herbivores) found in Kenya. Once again, emphasis is placed on obtaining individual identities of animals, and keeping a careful record of the effort invested to obtain the identities. Cheetahs, leopards, wild dogs, and spotted and striped hyaenas all have unique coat patterns. Like a lion's whisker spots, these are unique to each individual and the left and right sides are different. Lions are a little more challenging than the carnivores shown here, since they do not have large or conspicuous markings. It is noted that species with large markings such as leopards are increasingly surveyed using camera traps combined with a SECR framework (e.g. Braczkowski et al. 2022)

3.4.4. Lion Data

3.4.4.1. Metadata

When a lion or group of lions is located, in addition to taking ID photos of all lions present, observers will need to record key metadata while sitting with the lions. At each sighting, the following information is entered into CyberTracker:

- Total number of lions seen
- The age class of each lion
- Whether or not photographs were taken
- Which lions were photographed
- The date and time (automatically captured)
- The GPS coordinates (automatically captured)

3.4.4.2. Taking individual ID photos

This is perhaps the most daunting part of the process for those who have not conducted a similar survey. Lions are often hard to find, shy, occur at low density, and within habitats that consist of thick vegetation. A detection in the context of SECR involves two things: (1) finding the lion(s), (2) taking ID pictures. The former involves field craft and skills, while the latter primarily involves patience and technical skills in operating a camera (often with extreme time pressure). Here we offer some general guidance on how to take ID photos and what constitutes an ID. A key point to remember is:

We don't have to ID every lion that we see
But, we do have to be certain of an ID to use it in the analysis

What this means is that our goal is not to find and 'count' every lion in an area. In most cases (if not all), this would be impossible. Similarly, once we find lions, it is OK not to get ID photos of every lion present (although we should aim to since this will improve the precision of the results). However an ID must be complete and unambiguous to be used in the analysis - we need to be certain of an ID, and to be certain, we need many good photographs. In summary, once lions are found, observers are encouraged to:

- Take LOTS of photos (even if they don't think it's an ID) – this can run into hundreds of photos at a single sighting
- Take close up photos of the left AND right side of the face – lions are identifiable via their whiskers spots, which are different on each side. Take photo from multiple angles

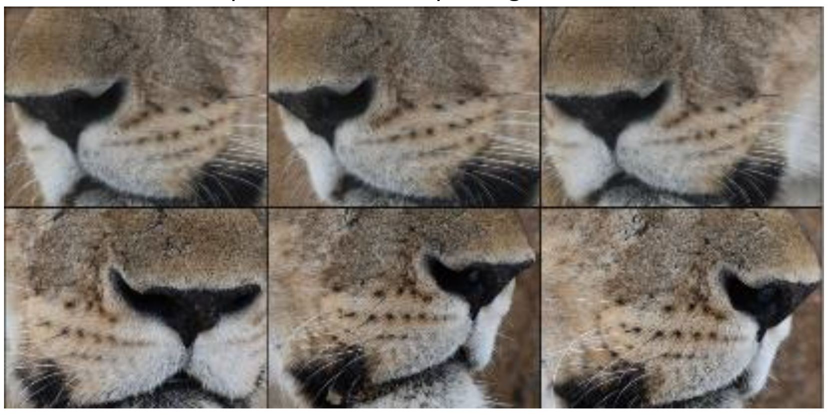


Figure 12. Every lion has a unique combination of whisker spots that allow for individual identification. Different angles will help with the identification process.

- Take profile photos and capture any distinct features, for example ears, teeth, scars, missing tail tufts

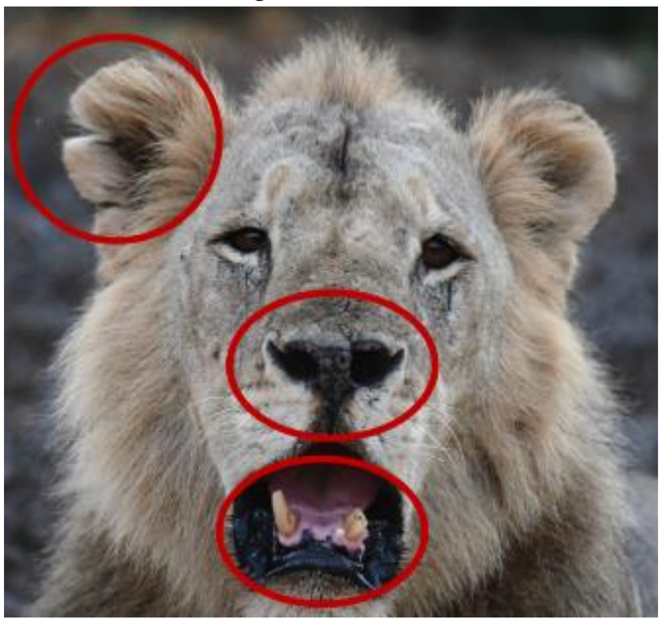


Figure 13. This lion has a large ear notch, and a cut in his nose. His bottom left canine is badly chipped, while the right one is slightly chipped. Five incisors are missing.

- Keep looking at the photos on the LCD of the camera while sitting with the lions. Zoom in and check that the whisker spots are visible.

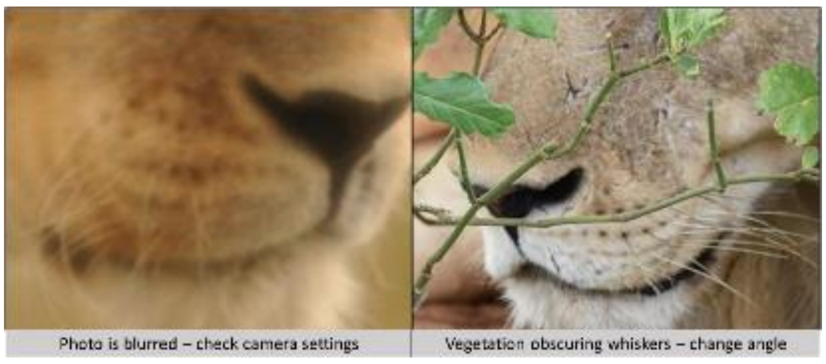


Figure 14. Camera settings need to be adjusted if the photos are blurred (left panel), while the vehicle may need to be moved (or wait for the lion to move) if vegetation is obscuring the whisker spots.

- When dealing with multiple individuals at a sighting, try to get left and right photos of one individual, then take a photo of the grass before taking photos of the next individual. This will make the office work of sorting photos much easier

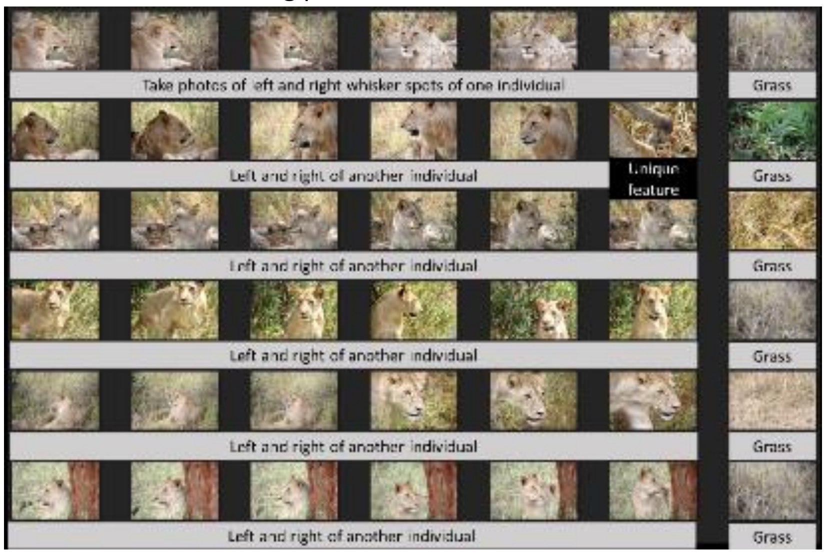


Figure 15. Taking photographs of grass act as a spacer, which indicate that the photos before and after the grass are two different individuals.

- Patience is critical – observers should be prepared to spend many hours waiting to take the ID photos. If lions are in a bush, sometimes you can get decent ID photos from the tightest angles.

Figure 16. Vegetation can be very troublesome in getting ID photos. Sometimes even a very small gap in the bushes can be enough to get a decent ID photo (right panel).

3.4.4.3. Sexing lions in the field

While lions generally display sexual dimorphism (males are bigger and (usually) have manes), it is frequently more challenging to sex younger individuals, and there are always exceptions. Take photos of sexual characteristics to be sure.

Figure 17. This young lioness has a little fluff around the neck, suggesting she might be a male. However, a photo taken as she walks away confirms she is female.

3.4.4.4. Ageing lions in the field

The aim is to differentiate between lions that are younger than one year, and lions that are older than one year. Under the age of one, a lion's nose is usually completely pink and it will be shorter than it's mother. Over the age of one there may be a few small spots on the nose and it will be almost as tall as the mother. See the Key Resources listed at the end of this document for several field guides.

3.4.5. Field team checklist

Successful implementation of these protocols requires trained and skilled personnel, in addition to some equipment. The table below itemizes the minimum requirements for data collection, which may vary depending on the location and the protocols being followed. This is not intended as a complete checklist of all items a team may need to go into the field (e.g. food, water, camping equipment).

Equipment Item	Notes	Minimum specifications
Vehicle	A reliable vehicle that can be driven off road in harsh terrains. Fully enclosed vehicles are not ideal. Roof hatches or pickups are preferable as the extra height and 360 view allows for better spotting of tracks & animals and also better photographs.	4 x 4 High clearance Spare tyre
Personnel	At least one person trained in the methodology must be present at all times. It is often easier (though not essential) to have an additional person in the car, either as a driver or spotter. When working at night, a second person is essential.	Team leader Driver/spotter
Smart Phone	Smart phone, with the CyberTracker software and application installed. This is required for all data collection. Samsung or iPhones are ideal, while lesser-used brands (e.g. Techno) should be avoided.	Android Must be GPS enabled
12V charger	Continuously running the phone's GPS drains the battery quickly. Having a 12V charger is ideal, but a powerbank can also suffice.	Ensure the in-vehicle socket is working
Digital camera	A good quality camera to take individual ID photos of lions. An SLR camera is ideal, but good quality compact cameras with a zoom equivalent of 300mm can be used.	24 mega pixels 300mm lens
SD cards	This will vary according to the camera	32GB
Inverter	This may be required if field teams are not readily able to charge devices (e.g. camera, speaker etc).	12 Volts 600 Watts
Binoculars	Magnification (first number) of 8 is more than enough. The diameter (second number e.g. 50) should be at least 40. Lower than this and you will really struggle to see anything in low light.	8 x 40 is ideal
Night work		
Spotlight	If working at night a spotlight is essential to first find and then photograph lions. A camera cannot focus in the dark so a spotlight is essential. A removable red filter is best so that observers can first locate animals with the red filter, although removing this will usually be necessary to take ID photos.	12V or rechargeable 500m beam Red filter
Speaker	If employing the playback protocol, a good speaker is needed to broadcast sounds (which can be done via the smartphone).	12V or rechargeable Minimum 95DB output

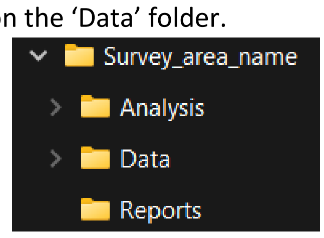
3.5. Data Management and Preparation

While the survey is ongoing it is imperative that the data is regularly checked and feedback is provided to data collectors. Not checking the data until after a survey is complete can be disastrous and lead to a wasted survey. Data collected via smartphones should be sent daily (if possible) to a centralized server (via mobile data). This serves two purposes: (1) it minimizes potential data loss if for example a phone is lost or damaged, (2) it allows the person leading the survey to check the data for inconsistencies and problems and give immediate feedback to the relevant team. The person leading the survey should:

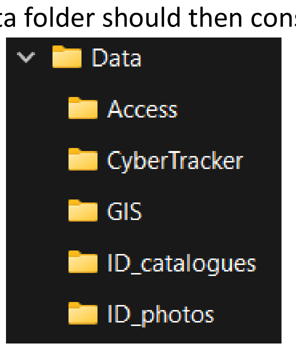
- Perform daily checks on the data collected via mobile phones, paying particular attention to
  - whether the field effort is being accurately recorded, which can be checked by ensuring the teams are 'starting' and 'stopping' their patrols, and also by visually inspecting the search effort in a map
  - whether the lion metadata is being accurately recorded
- Regularly visit the field teams to
  - collect and sort lion photographs
  - troubleshoot any challenges being experienced
- Provide regular feedback to the field teams to ensure data collection is consistently rigorous
- Provide guidance to the teams as to where to search for lions

3.4.2.3. Folder management

Data collected via smart phones, in addition to photographs, should be regularly downloaded onto a computer. The data will need to be well-managed and stored for easy access. The following workflow and folder structure is recommended. The rest of this section will focus on the 'Data' folder.



The Data folder should then consist of the following subfolders:



The folder above labelled 'Access' is used to house the database (a Microsoft Access database). An Access database already exists for each site where a survey has taken place , and should be built on over time. This database stores information relating to individual lions and the detections of those lions during the survey. Users should seek a tutorial from the technical team prior to initial use.

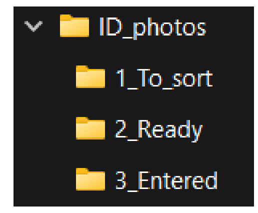
The CyberTracker folder houses the CyberTracker database and contains all the data collected in the field (apart from the photos). In time, the user will need to export the data from this database in order to clean it and create the necessary input files for analysis. Users should seek a tutorial from the technical team prior to initial use.

The GIS folder houses various GIS files relating to the survey, but not collected during the survey – for example, this can contain a polygon shapefile of the area being surveyed. Other shapefiles that are useful to obtain include road networks and water.

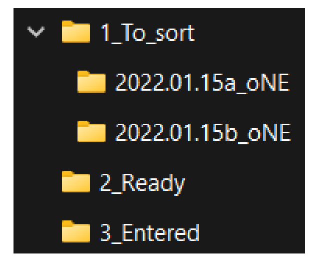
3.4.2.4. Sorting ID photos

The lion photos will need to be meticulously sorted. This can quickly become a mess and based on experience the following is recommended:

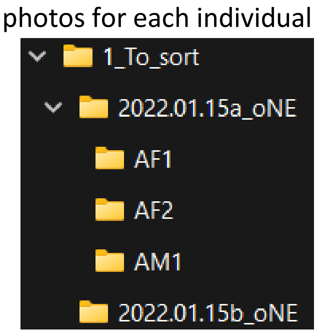
- Create three sub-folders within the ID_photos folder, labelled as



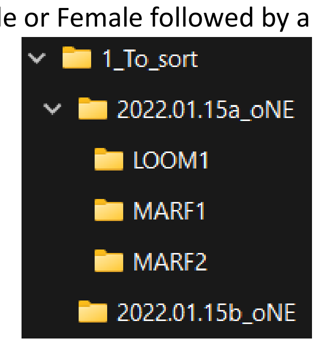
- Copy all photos into the To_sort folder
- Create subfolders for each sighting and name them with the format YYYY.MM.DDx_observer – so the folder with the first sighting by observer NE (_oNE) on 15th January 2022 would be labelled 2022.01.15a_oNE, and the second sighting on the same day would be labelled 2022.01.15b_oNE and so on



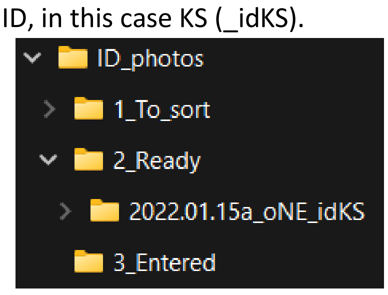
- Add photos to the relevant folders
- Within each sightings folder create subfolders for the different individuals (this is where the grass photos are very helpful). Add the photos for each individual to a separate folder.



- Next Identify the different individuals (in the above example, 2 adult females and 1 adult male were photographed. See below for details on identifying lions.
- Once identified, change the folder name to reflect the individual ID of that individual. Note that the last two characters represent Male or Female followed by a number.



- Cut and paste the sightings folder into the 'Ready' folder and add a suffix consisting of the initials of the person who performed the lion ID, in this case KS (_idKS).



- This sighting will then remain in the Ready folder until an independent person validates the identity of each individual (see 3.4.2.8 for this step). Once consensus has been reached on the identity of each lion, the sighting can be entered into the Access database. The folder should now be amended to include the initials of the person who validated the sighting, in this case FB (_vFB), and should be moved to the 'Entered' folder.

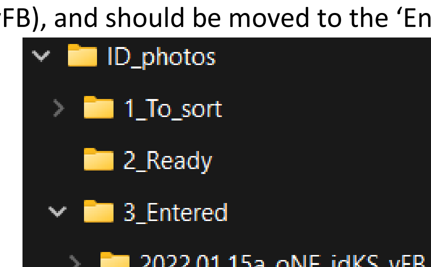


Figure 18. This shows that on 15/01/2022 the first sighting of the day was observed by NE, and the IDs were performed by KS and validated by FB. The data has been entered into the Access database.

3.4.2.5. Identifying individual lions from photographs

A lion's whisker spots are the primary feature used for identifying individual lions. For any lion detection to be included in the analysis it must be unambiguously identified. In other words, there should be certainty about it's identity as an individual. When individual lions are photographed, an ID card should be created (Figure 23). The lion identification protocol should then be followed for each sighting. As a general rule, the following guidelines should be adhered to:

- An individual must be fully identified during a single sighting at least once during the survey. This means that during at least one sighting, an observer should have taken photos of both the left and right side of the face, with the whisker spots clearly visible.
- A catalogue must be made of that individual.
- Subsequent sightings are then compared to existing catalogues and the whisker spots and unique features are visually inspected to decide whether this is a new individual or a recapture.
- If a subsequent detection only has one side of the face photographed, for this to be classed as a recapture, the whisker spots and at least one other unique feature must match an existing catalogue.
- If a detection cannot be identified to individual level, another observer should try to match it.
- Continue identifying individuals and creating ID catalogues until all the sightings folders have been shifted to the 'Ready' folder.

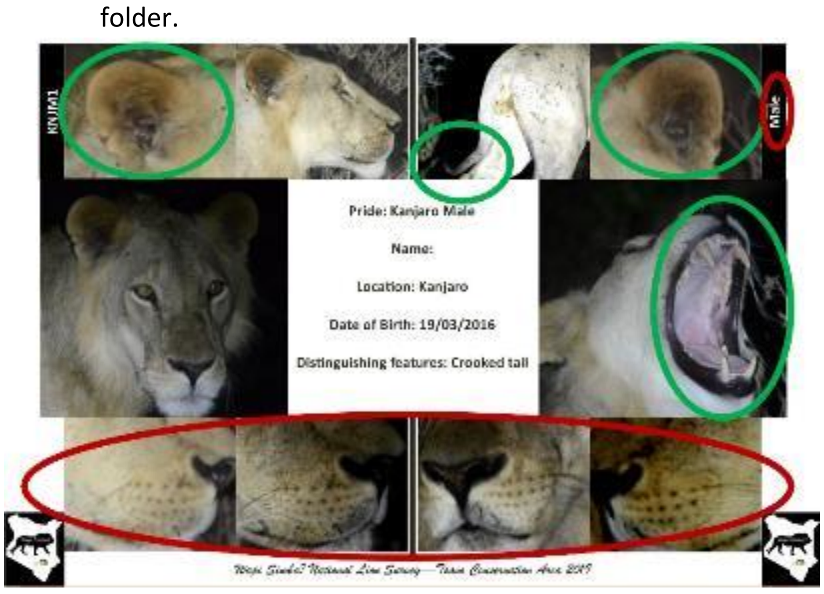


Figure 19. The whisker spots and sex of an animal are permanent features that will not change over time (shown within the red ovals), and are the primary aid to identification. Temporary unique features (shown within the green ovals) such as ears, teeth, tail kinks and scars, are useful secondary aids to identification of lions.

3.4.2.6. Sexing lions from photographs

Male lions tend to have larger home ranges that females. This, together with other factors may influence the probability of us detecting each sex. Ideally this will be accounted for in the analysis, but for this to occur we need to know the sex of each individual that has been identified. In most cases, adult lions display sexual dimorphism. Males are larger than females and usually grow manes. In low altitude conditions (e.g. Tsavo or the coast), the mane may be almost absent altogether. In any case, as much as possible, field teams should try to take photos that confirm the sex of an individual. If these photos are not present, then decisions should be made based on secondary sexual characteristics such as size and mane. The resources provided for ageing lions can be useful here. If the sex cannot be determined, or there is uncertainty, then observers should not apply guesswork and these individuals can simply be classified as unknown sex.

Figure 20. Observers should always look for a photo where sexual organs are present. This young lion is Nairobi National Park is actually a very hairy female!

3.4.2.7. Ageing lions from photographs

Field observers will have received training on how to age lions in the field, and for each lion, will have recorded whether they think it is over or under one year of age. Now in the office, an observer will corroborate the estimated age and assign a data of birth to each lion if this does not already exist. Lions will only be included in the analysis if their estimate age is one year or more as of the last day of the current survey. For further assistance see Whitman & Packer (2007), Miller et al. (2016), and for a website dedicated to ageing lions that includes training, tests and downloadable pocket guides see: http://www.agingtheafricanlion.com/)

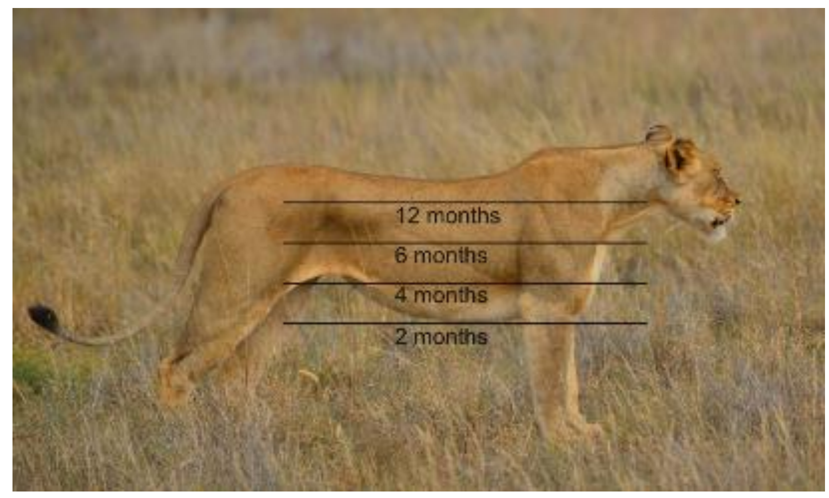


Figure 21. If a cub is as tall, or the same height as its mother, it is certainly at least one year old.

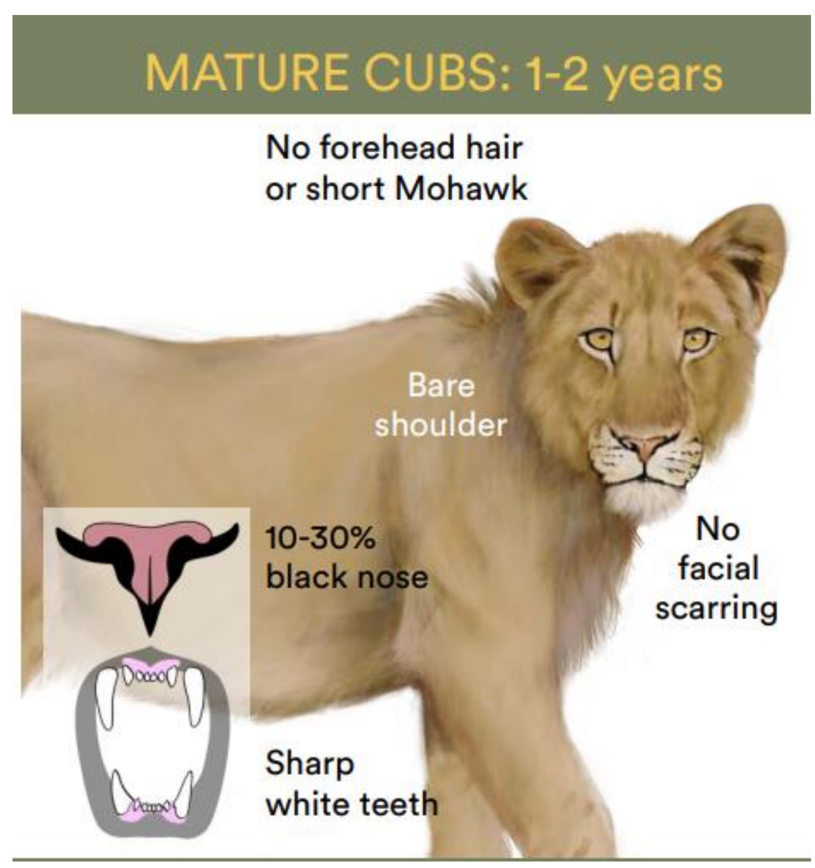


Figure 22. A lion that is older than one year will typically have some light spotting on the nose (10-30% for a lion between 1-2 years old). A male will usually have some main development. Image downloaded from http://www.agingtheafricanlion.com/

3.4.2.8. Data Validation

Once all the detections from a particular survey have been processed, they should all be in the Ready folder (see Sorting ID photos above). By this stage, all detections should have been assessed, and decisions made as to whether each is a new individual or a recapture. These decisions now need to be validated by an additional person. Every detection should now be validated. The validator(s) should work through the Ready folder and systematically check every detection to see whether they agree with the identity assigned to the individual. When the identity is confirmed, the folder should be renamed to include the initials of the validator as a suffix. The data should now be entered into the Access database and the photo folder should be moved to the Entered folder. If the validator does not agree with identities assigned to certain detections, they should discuss this with the person who performed the initial ID. If the two cannot reach consensus, a third observer can be sought. If there is not a unanimous decision as to the identity of the individual, the folder should be renamed to No_ID and moved to the Entered folder. This detection is still entered into the Access database, but as an unknown individual.

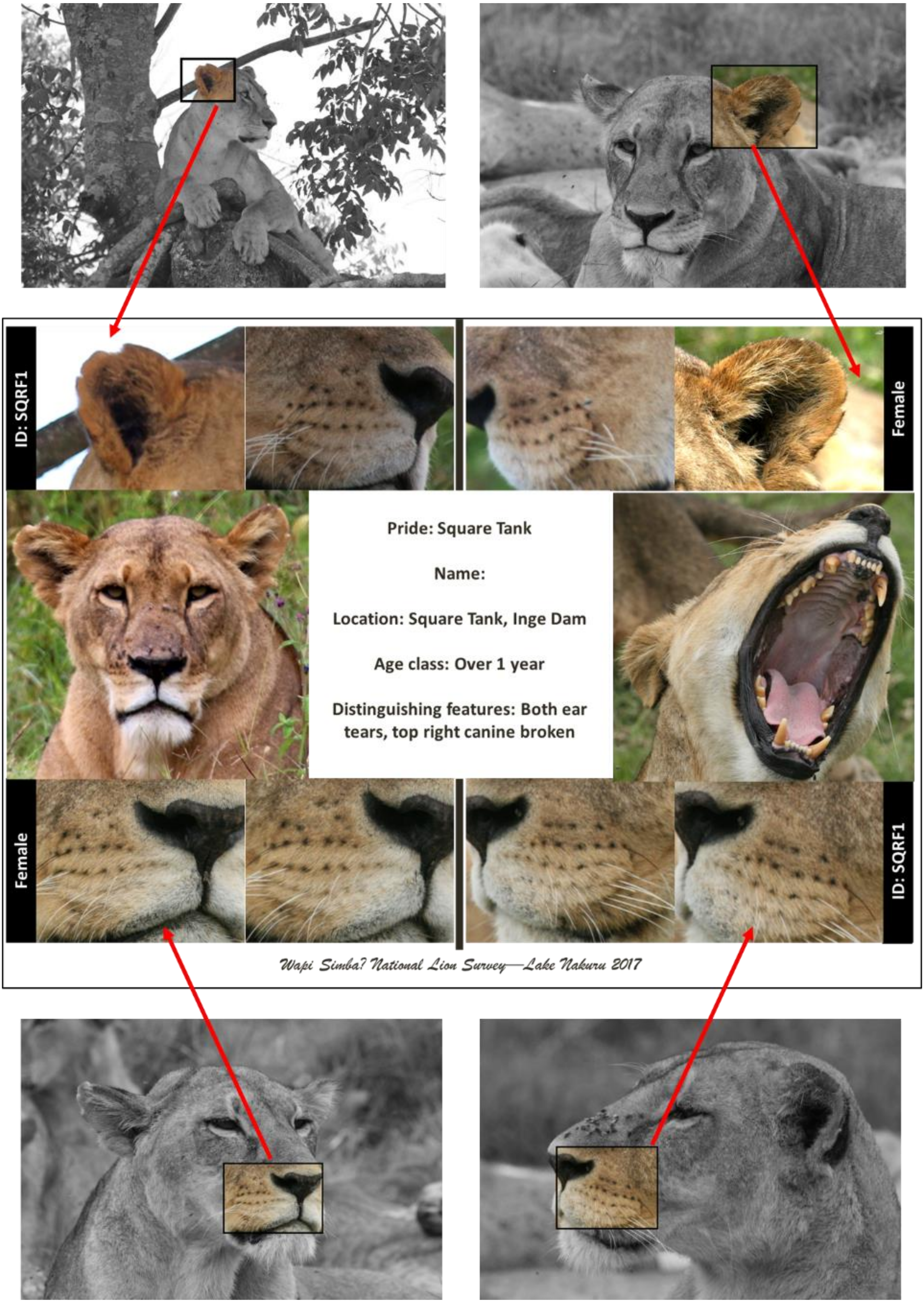


Figure 23. Whenever possible, multiple photographs are taken of each individual lion at each sighting (shown here in the black and white photos). These images are cropped to extract distinguishing features such as whisker vibrissae spots, ear tears and dental wear that can be used to distinguish individuals. Cropped images are then added to ID cards (as shown in the center of this figure) 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. 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.

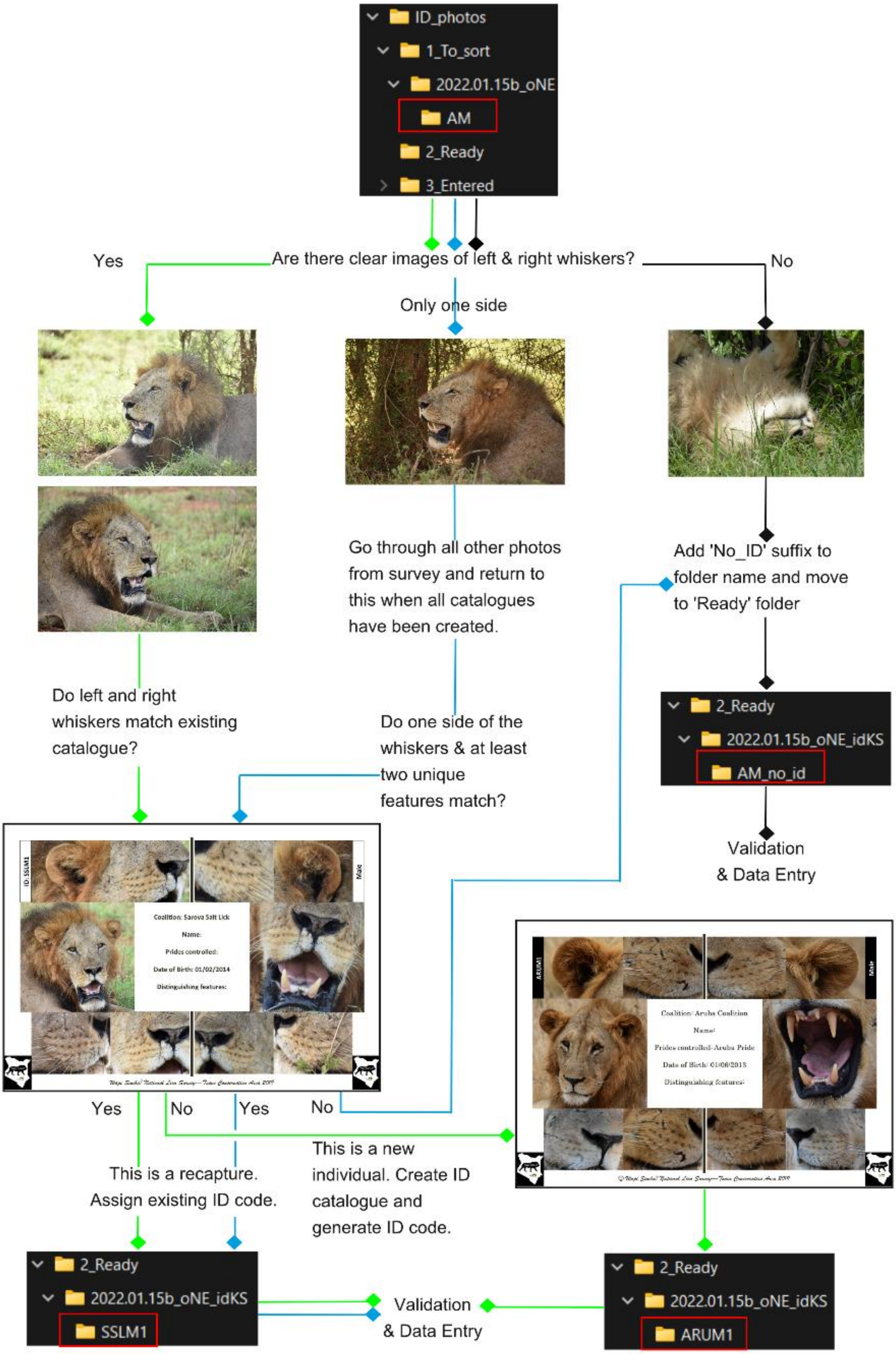


Figure 24. Each detection should be assessed to ascertain whether left and right whisker spot photos are available. Notice that if there are only photos of one side of the whisker spots at a single detection, this cannot be regarded as a new individual, and only as a recapture if there is a match in the whisker spots (of whichever side) and at least one other unique feature. Once the initial IDing has been conducted, a second person must validate all the detections. If there is disagreement on any detection, it should be discussed to see if consensus can be reached. The precautionary principle of 'if in doubt, leave it out' should be adopted.

3.6. Data Analysis

Data can be analysed within a variety of applications and packages using either maximum likelihood, or Bayesian approaches using Markov chain Monte Carlo (MCMC) methods. Under the likelihood approach, the programme DENSITY is available as are several packages within R including 'secr' and 'oSCR'. Under the Bayesian approach, models have been developed using WinBUGS, JAGS and Nimble. The programme SPACECAP 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 in Kenya (Elliot et al. 2021). 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 the individual activity centers which provide insights into spatial distribution; The entire posterior of each parameter is available and visually informative of parameter redundancy (or identifiability) as a result of model overfitting relative to sample size.

3.6.1. 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.

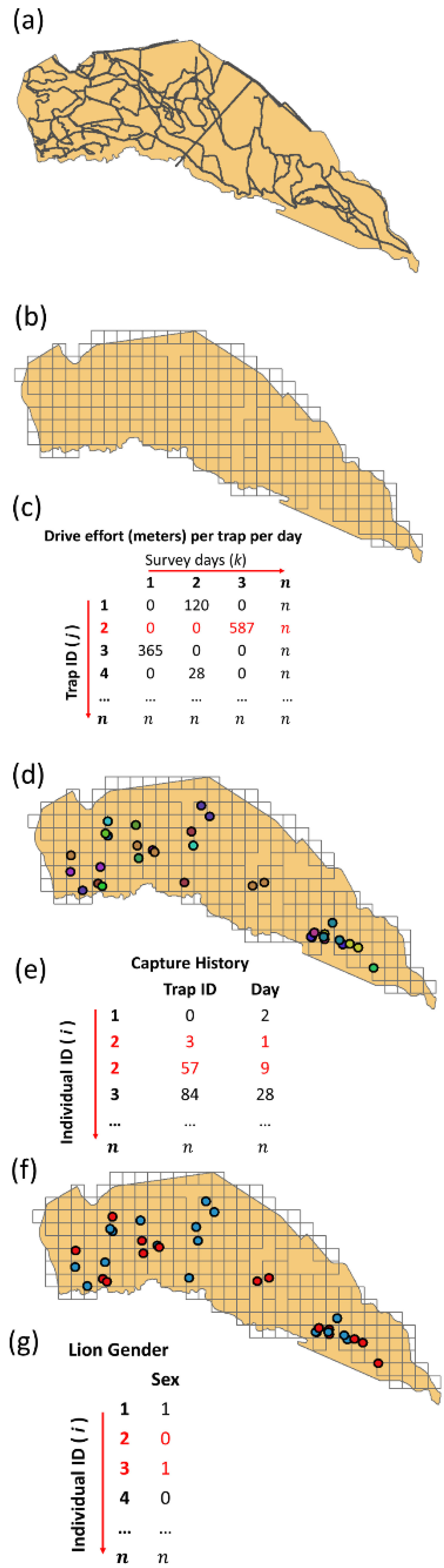


Figure 25. The observation process.

3.6.2. The State Process

Our goal is to determine the density and distribution of lions in any given landscape. To do this, we define a state process. 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.

(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.

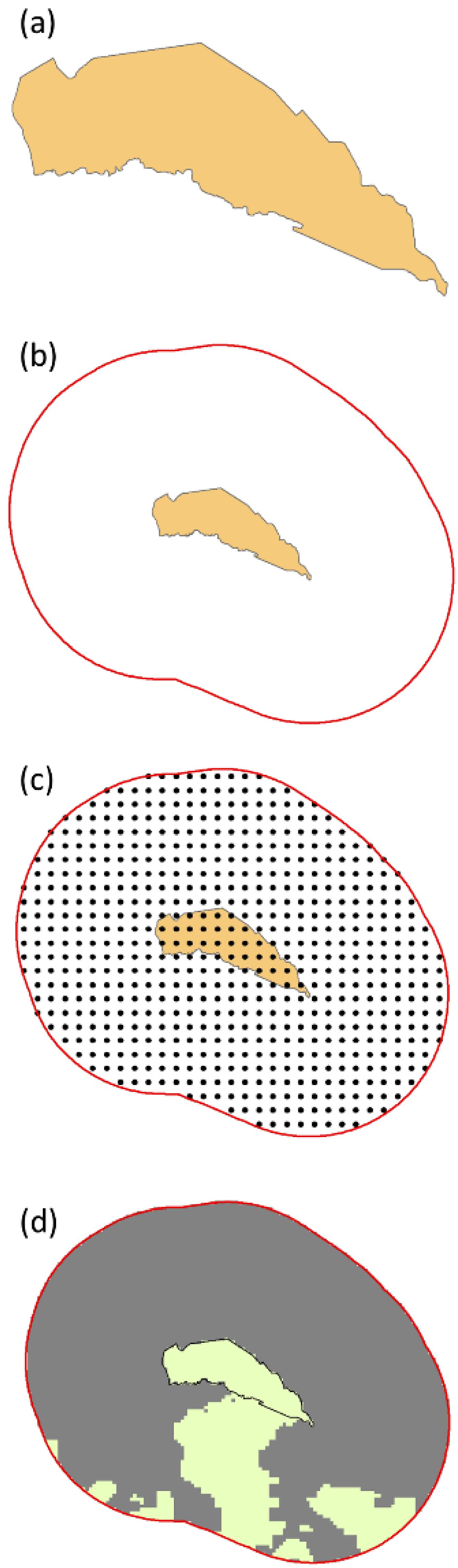
(e) This information is then tabulated, where each potential activity centre is given an X and a Y coordinate and is assigned a value of suitable habitat (1) or unsuitable habitat (0). So, we have R pixels of suitable habitat.

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

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

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

Figure 26. The state process.

4. Site Specific Guidelines

Obtaining accurate and precise estimates of population density is often resource intensive, and frequently there is a trade-off between expenditure of limited resources and obtaining reliable estimates. Between 2018 and 2020, surveys were conducted within 13 key source populations in Kenya that varied widely in terms of population size, density and detectability. To inform resource allocation and minimum data requirements for future surveys such that limited resources are maximized while obtaining robust estimates, an analytical framework was developed that made use of the existing data to evaluate how variation in sample size influences relative bias and precision of density estimates. This involved estimating density and associated precision from the full dataset and then randomly subsampling the search-encounter tracks, keeping entire tracks intact. The data were subsampled at 10% increments of the total drive effort (20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%), and 5 random repeats were taken from each increment. Only the lion detections obtained along the subsampled tracks were retained. In this manner, 40 subsampled datasets were created for each survey area, in addition to the complete dataset. Each dataset was analysed using the most simplified SECR model, $N(.), \lambda_0(effort), \sigma(.)$, and estimates of density and measures of precision were obtained.

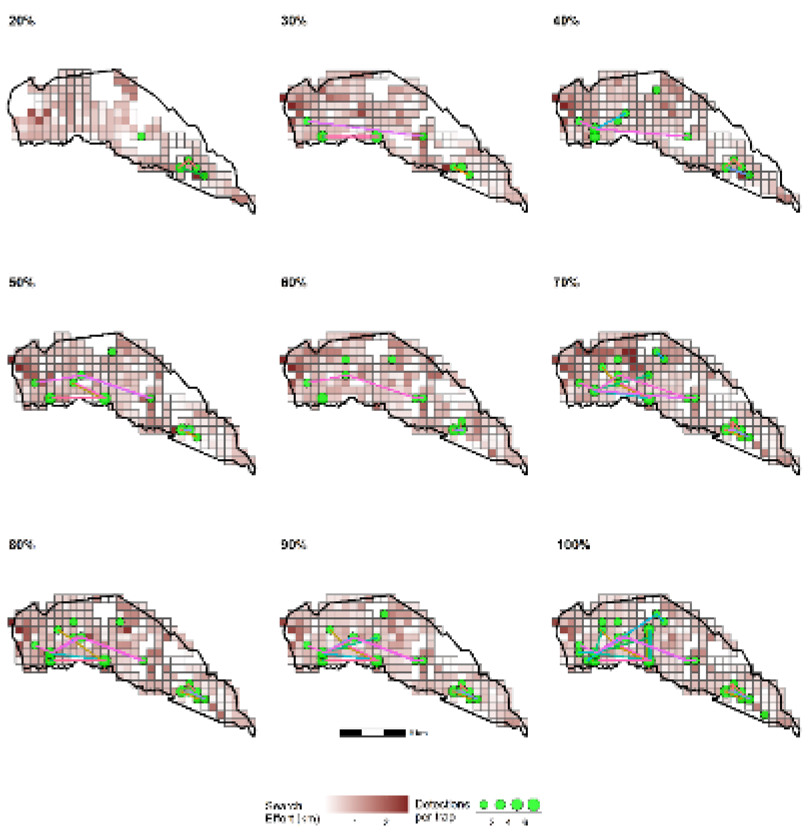


Figure 27. The full empirical dataset (bottom right 100%) was subsampled at 10% increments of the total search-encounter effort to rarefy the data. This resulted in incrementally 'weaker' datasets with fewer individuals and recaptures, and poorer spatial coverage. This figure illustrates one of five subsamples created for Nairobi National Park. The same procedure was followed for 13 survey sites.

The accuracy and precision of density estimates is influenced by sample size, with richer datasets providing more accurate and precise estimates than poorer datasets. SECR has a number of measures relevant to sample size, and the following are defined:

1. RSE_P: Calculated using $1/\sqrt{\min(n),(r)}$, this is a proxy for relative standard error where *n* is the number of unique individuals detected and *r* is the number of recaptures (Efford & Boulanger 2019). Here a recapture is any detection of an individual other than the first one.
2. Number of individuals detected at more than one trap. This refers to the number of different lions that have been detected in multiple traps (regardless of the number of detections).
3. Average spatial recaptures. The average number of traps within which each individual has been detected.
4. Proportion of traps. This is the proportion of active traps in the subset dataset relative to the full empirical dataset.

To assess relative bias, estimates from the reduced datasets were compared to those based on the full empirical dataset. Relative bias was calculated using $RB = (\widehat{D} - D)/D$, where D is the density estimate from the full empirical dataset and $\widehat{D}$ is the density estimate from a reduced dataset. Precision was measured by calculating the coefficient of variation using $CV = \frac{\widehat{SE}(\widehat{D})}{\widehat{D}}$. Estimates with CV < 20% and relative bias <15% were considered favorable outcomes.

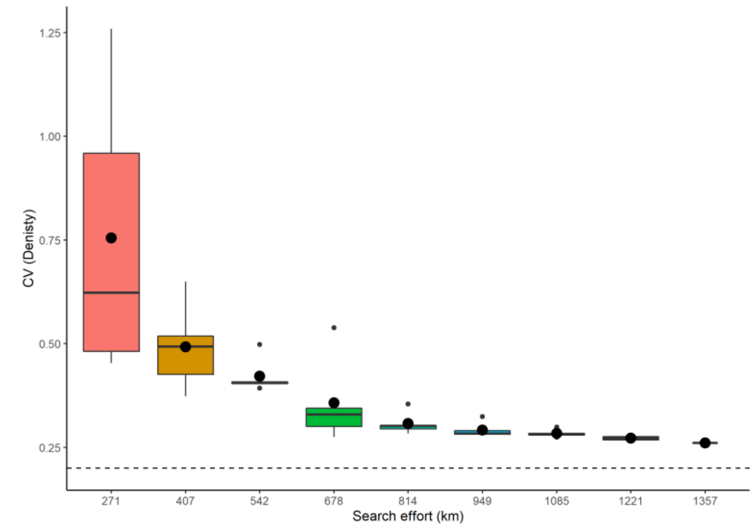


Figure 28. Reduced sampling intensity resulted in reduced precision, as measured by CV (blue dots indicate the mean). This was particularly the case for sites where the capture history data was relatively small.

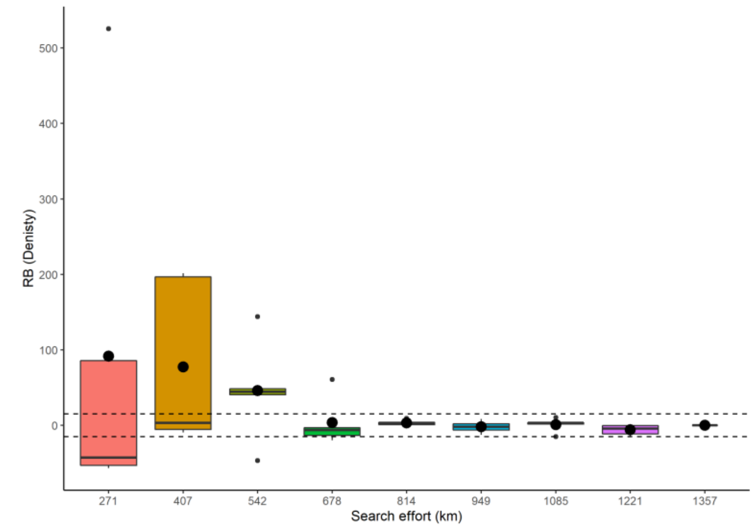


Figure 29. Reduced sampling intensity resulted in increased relative bias (RB). This was particularly the case for sites where the capture history data was relatively small.

To determine the relative influence of reduced sampling on precision and relative bias of density estimates, linear models were created using the sample size measures defined above as explanatory variables and CV and RB of density estimates as dependent variables. Predictions from these models were used to provide broad site-specific guidelines as to the minimum amount of field effort to invest and associated dataset characteristics aimed at maximizing precision (CV < 20%) and minimizing bias (RB < 15%) of density estimates. More ambitious targets were set for larger populations. Note that other data characteristics may be important when running more complex models, or when assessing other parameters (e.g. σ).

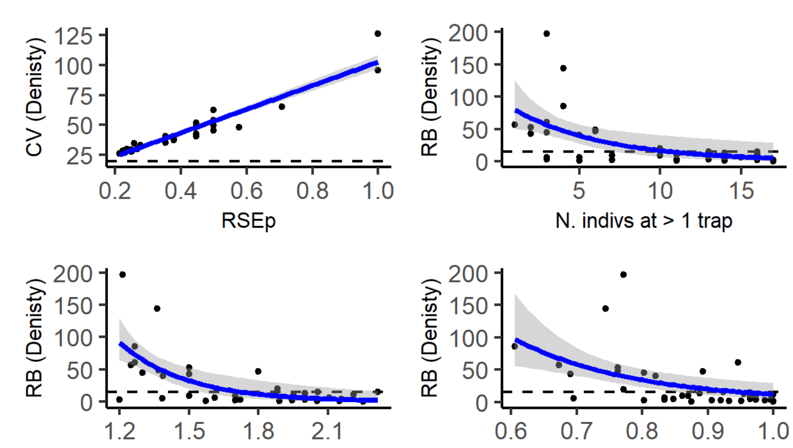


Figure 30. Continuing with the Nairobi National Park example, the top left figure shows the relationship between the CV of a density estimate and RSE_P calculated using $1/\sqrt{min(n),(r)}$. This suggests that as RSE_P decreases, precision will increase. Model predictions show that for Nairobi, to obtain a CV of less than 20%, the RSE_P will need to drop below 1.6, which translates to a minimum of 41 individuals and 41 recaptures, which is unlikely in Nairobi. The other three figures show the relationship between the RB of a density estimate and the remaining three sample size measures defined above. This suggests that to obtain accurate results, future surveys should aim to detect a minimum of seven individuals at more than one trap, with an average of 1.6 spatial recaptures, while sampling at least 82% of traps sampled during the 2018 survey. Future surveys that invest 1,500 km or more of search effort, will likely meet these minimum data requirements and therefore obtain accurate results. However, in small populations (less than ~40 individuals) it is likely that precision will always be reduced. However, because SECR methods track individuals over time, this allows for the estimation of population trend and vital rates (recruitment, growth, mortality, movement) even if the CV is high.

The following section repeats these methods for each site to provide practitioners with broad site-specific guidelines as to the minimum amount of field effort to invest and associated minimum dataset characteristics aimed at maximizing precision (CV < 20%) and minimizing bias (RB < 15%) of density estimates.

4.1. Amboseli Ecosystem

4.1.1. Field work recommendations

Areas to cover: At a minimum, Amboseli National Park and Olgulului, Eselenkei, and Mbirikani Group Ranches should be covered. In addition, the other sections illustrated in the map below should be included. It is not essential that Tsavo and Chyulu Hills National Parks be surveyed at the same time, but if opportunities arise, this would be ideal and offer tremendous insights.

Area size as of 2018 survey: 4,337 km^2.

Field protocols: Search-encounter (inside Amboseli National Park)
Foot patrols, conditional drive effort and playbacks within the Group Ranches

Best months: August-October

Fieldwork duration: 90 days

Frequency: Annual, or Biennial

Field partners: Lion Guardians
This field team pioneered the foot patrols and conditional drive effort protocols and are experts in finding and identifying shy, illusive and nocturnal lions. Their long history in this landscape has ensured they are uniquely placed to monitor these lions.

Opportunities: The Lion Guardians team continuously has people on foot looking for signs of lions. In their daily duties they record their search effort and any signs of lions. This provides an excellent opportunity to test and develop field methods relating to scat collection, and laboratory methods relating to individual identification. Across much of lion range it is very difficult to find and photograph lions, and scat collection represents a very real opportunity for monitoring lions across vast areas (e.g. Bischof et al. 2020). For example, in time a protocol could be developed to monitor lions across southern Kenya using this technique, but considerable development would need to occur first.

4.1.2. Sample size requirements

Minimum effort: 20,000 km

Minimum data goals to increase precision (CV < 15%):
Individuals detected: 42
Number of recaptures: 42

Minimum data goals to increase accuracy (RB < 10%):
Number of individuals detected at more than one trap: 34
Average spatial recaptures: 1.6
Proportion of traps: 79%, which equates to 2,230 traps

Summary data from 2018 as a reference
Search effort: 35,196 km of combined effort
Individuals detected: 107
Number of recaptures: 202
Number of individuals detected at more than one trap: 74
Average spatial recaptures: 2.52
Number of traps: 2,823 traps

4.1.1. Data analysis recommendations

Observation process
Trap size: 1 km^2

State process
Habitat pixel size: 0. 5 km^2
Buffer size: 20 km

Initial model specification
M = 1,000
Number of iterations: 11,000
Number of chains: 4

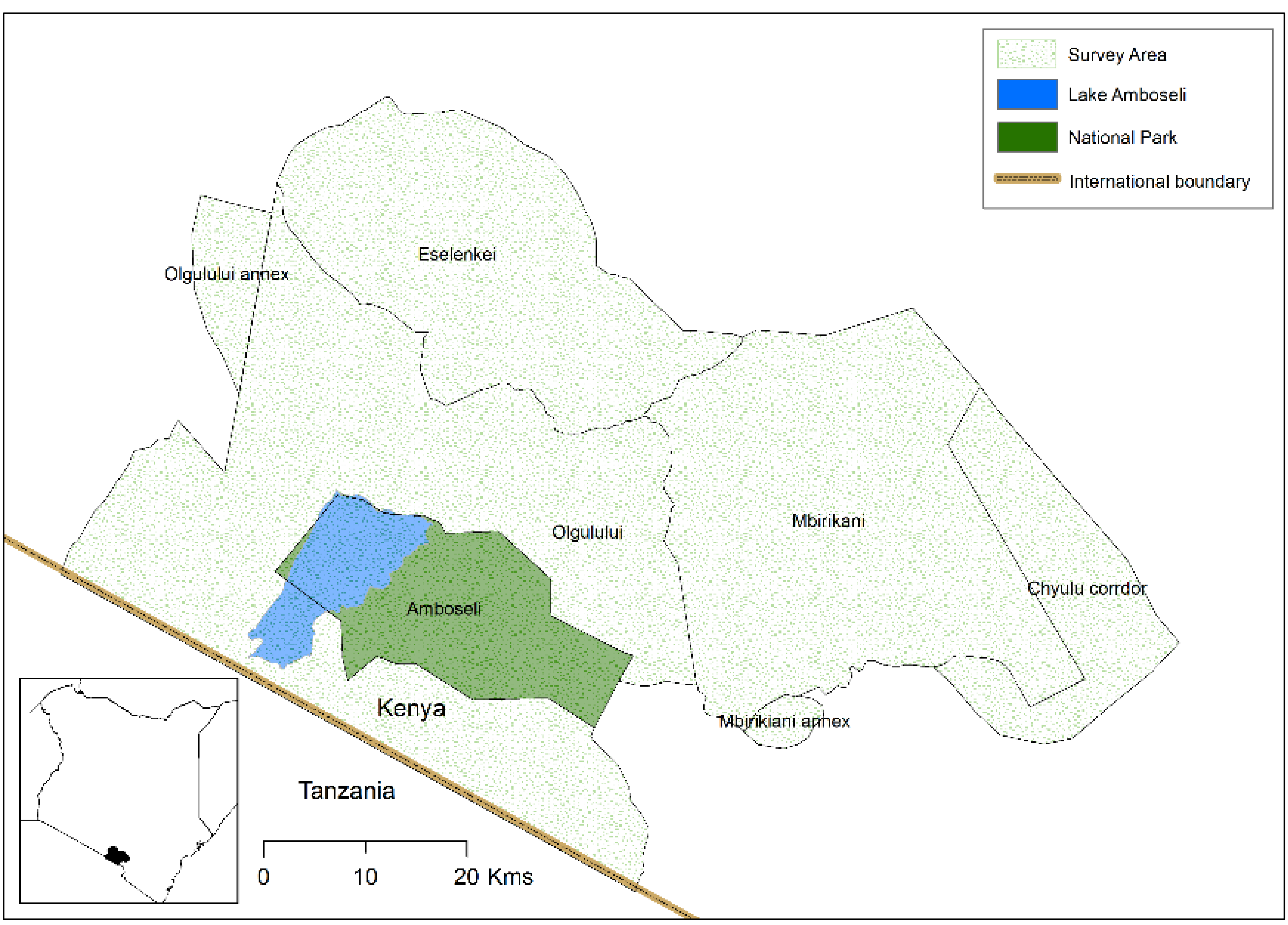


Figure 31. Amboseli National Park and Olgulului, Eselenkei, and Mbirikani Group Ranches should be covered.

4.2. Laikipia

4.2.1. Field work recommendations

Areas to cover: The following properties should be surveyed: Barkas, Borana, Brown, Chololo, El Karama, Enasoit, Jessel, Kamogi, Kihoto, Lewa, Loisaba, Loldaiga, Mathira, Mogwooni, Mpala, Mugie, Ngorare, Ol Doinyo Lemboro, Ol Jogi, Ol Maisor, Ol Malo, Ole Naishu, Segera, Soita Nyiro, Sosian and Suyian. In addition, Laikipia Nature Conservancy should be surveyed (this property was not previously surveyed). Future surveys should aim to survey the additional buffer areas surveyed in 2018 and illustrated in the map below.

Area size as of 2019 survey: 2,903 km^2.

Field protocols: Search-encounter. Playbacks can be used within certain ranches where deemed necessary.

Best months: August-October

Fieldwork duration: 90 days

Frequency: This is one of Kenya's key source populations and ideally should be monitored annually. Otherwise or biennially.

Field partners: Lion Landscapes and Ranch personnel
Many of the ranches have internal teams that may be able to participate. This is advantageous since they know the area and either already know, or will get to know, the resident lions. In this manner each of the ranches can be uniformly and thoroughly searched. The Lion Landscapes team is well positioned to provide oversight and coordination of the different teams.

Opportunities: A major advantage of using the search encounter protocol is that many people (for example guides, wildlife monitoring teams etc) are already going out and looking for lions on a daily basis and are essentially following the search encounter protocol already. With a little training and, in some cases, provision of equipment, multiple survey teams can be deployed. The Laikipia ranches provide a perfect example of this and during the 2019 survey, wildlife guides, monitoring teams, and rangers all participated in the fieldwork.

4.2.2. Sample size requirements

Minimum effort: 10,000 km

Minimum data goals to increase precision (CV < 10%):
Individuals detected: 116
Number of recaptures: 116

Minimum data goals to increase accuracy (RB < 5%):
Number of individuals detected at more than one trap: 72
Average spatial recaptures: 2.26
Proportion of traps: 83%, which equates to 1,824 traps

Summary data from 2019 as a reference
Search effort: 17,670 km
Individuals detected: 154
Number of recaptures: 202
Number of individuals detected at more than one trap: 74
Average spatial recaptures: 2.52
Number of traps: 2,823 traps

4.1.2. Data analysis recommendations

Observation process
Trap size: 1 km^2

State process
Habitat pixel size: 0. 5 km^2
Buffer size: 15 km

Initial model specification
M = 1,300
Number of iterations: 16,000
Number of chains: 4

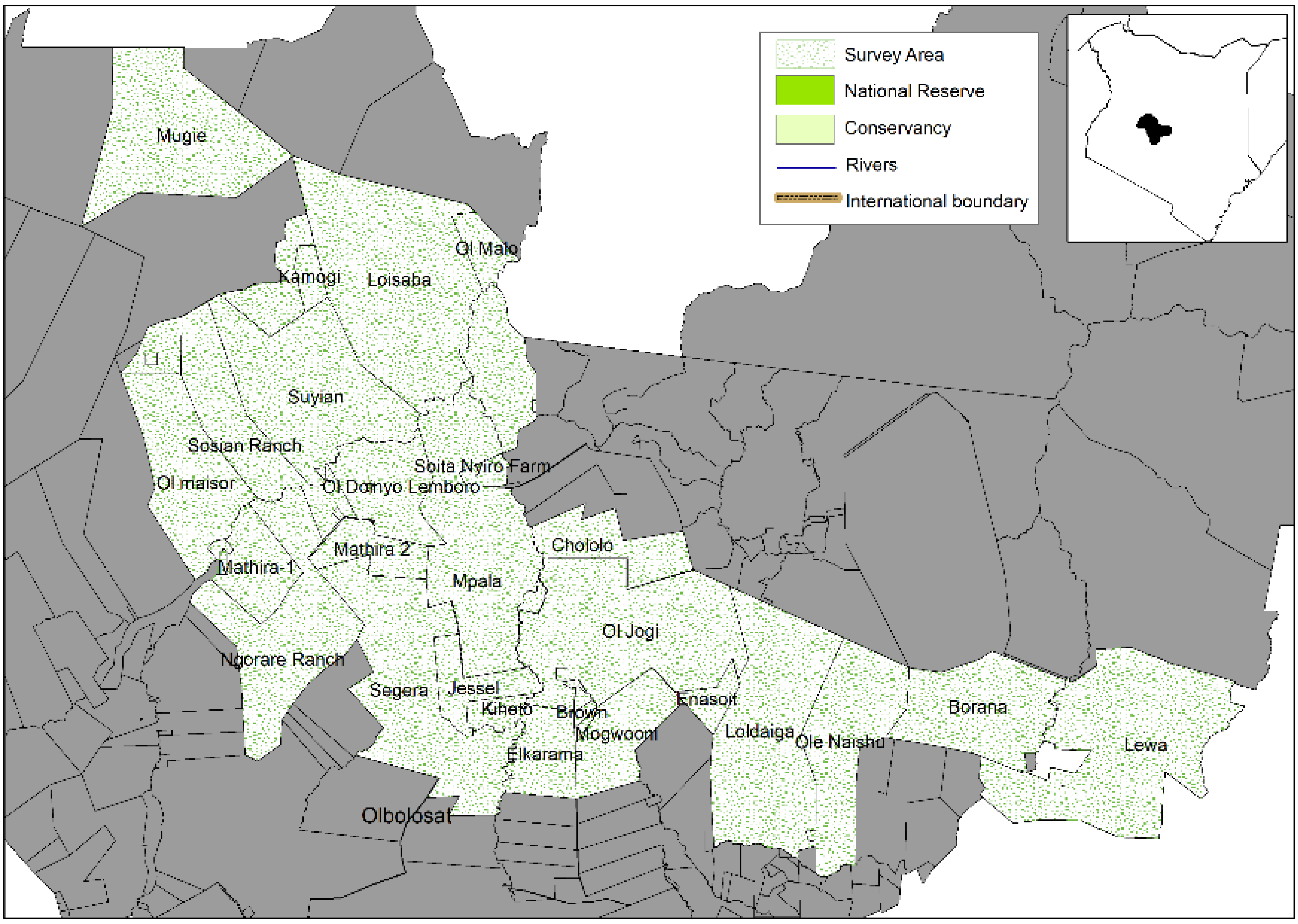


Figure 32. The properties shown here should be covered. Ol Pejeta and Solio can either be surveyed separately and independently or as part of this larger survey.

4.3. Maasai Mara

4.3.1. Field work recommendations

Areas to cover: At a minimum, the Maasai Mara National Reserve, Mara Triangle, and all conservancies should be covered. The survey area should expand to accommodate any emerging conservancies.

Area size as of 2018 survey: 2,541 km^2.

Field protocols: Search-encounter

Best months: August-October and February-April

Two sessions would be ideal for this ecosystem since it would capture population dynamics during the wildebeest migration and out-with the migration. The second session (February-April) is more difficult owing to the short rains and tall grass.

Fieldwork duration: 90 days

Frequency: This is Kenya's largest population and should be monitored annually, and ideally biannually.

Field teams: Kenya Wildlife Trust
This field team pioneered the search encounter protocol and has been conducting annual surveys since 2014.

Opportunities: Both lions and cheetahs have been monitored annually since 2014 using the search encounter protocol combined with SECR. This approach works well in the Maasai Mara due to the high density of largely habituated lions and cheetahs, good road network and support from the tourism industry. In principle, the data collection protocols could be extended to include other carnivores, but doing so would require expanded resources and should not come at the expense of robust lion monitoring. Camera trapping could be used to monitor other large carnivores. To extend inferences outside the wildlife areas, protocols that include scat sampling and or camera traps could be explored. Across greater scales, questionnaire-based or sign-based occupancy surveys could be conducted to assess species distribution and occupancy dynamics over time.

4.3.2. Sample size requirements

Minimum effort: 6,000 km

Minimum data goals to increase precision (CV < 10%):
Individuals detected: 81
Number of recaptures: 81

Minimum data goals to increase accuracy (RB < 5%):
Number of individuals detected at more than one trap: 94
Average spatial recaptures: 1.5
Proportion of traps: 83%, which equates to 1,875 traps

Summary data from 2018 as a reference
Search effort: 9,684 km
Individuals detected: 361
Number of recaptures: 352
Number of individuals detected at more than one trap: 190
Average spatial recaptures: 1.79
Number of traps: 2,286 traps

4.1.3. Data analysis recommendations

Observation process
Trap size: 1 km^2

State process
Habitat pixel size: 0.25 km^2
Buffer size: 15 km

Initial model specification
M = 2,000
Number of iterations: 11,000
Number of chains: 4

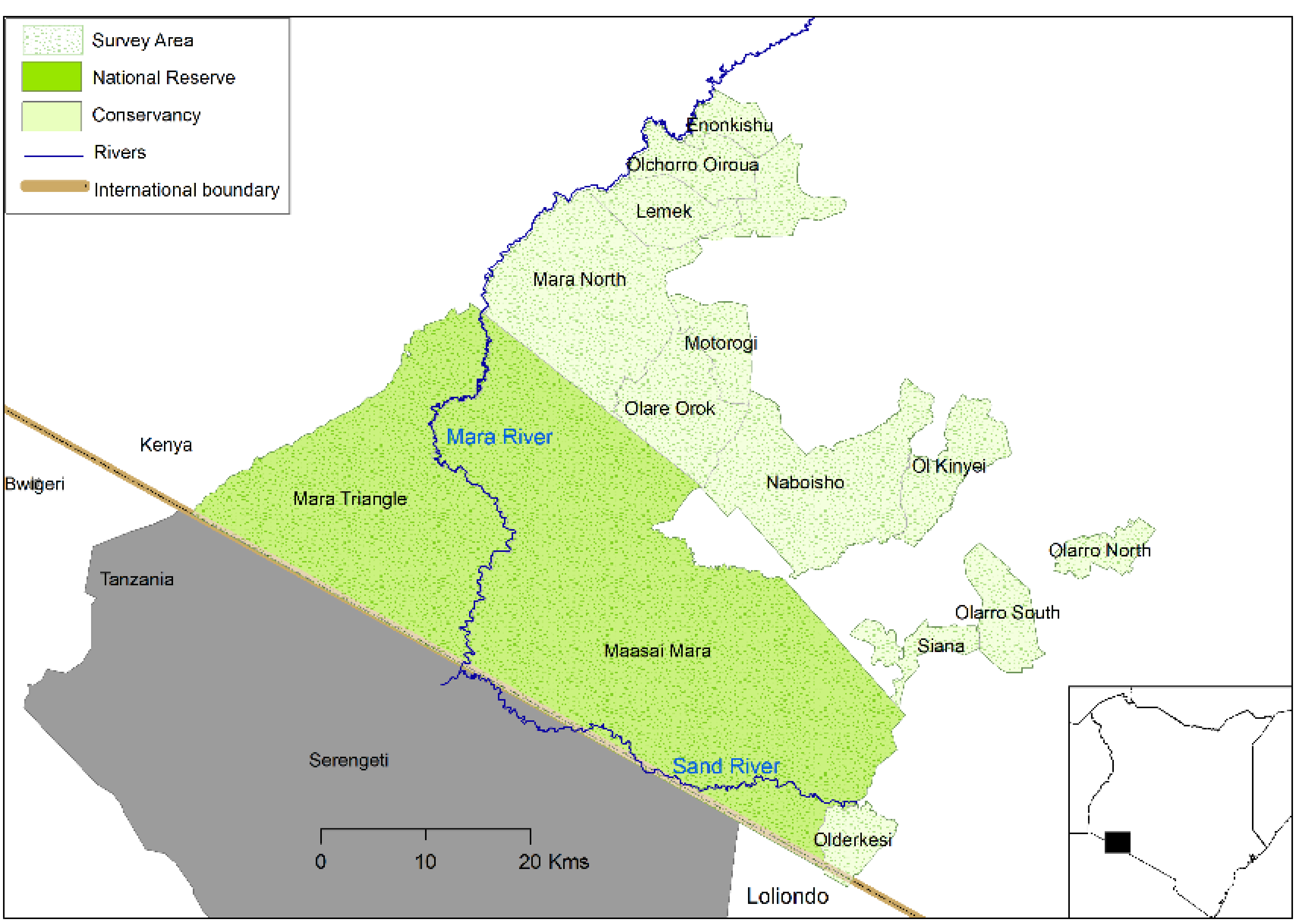


Figure 33. The Maasai Mara National Reserve, Mara Triangle, and all conservancies should be covered. The survey area should expand to accommodate any emerging conservancies.

4.4. Meru Conservation Area

4.4.1. Field work recommendations

Areas to cover: Meru and Kora National Parks, and Bisanadi and Mwingi National Reserves should be covered. During the 2019 survey, no sign of lions was found anywhere other than Meru National Park. However, the other three areas (and potentially also Rahole National Reserve) should still be covered as the situation may change.

Area size as of 2019 survey: Meru (877 km) MCA (3,810 km^2).

Field protocols: Search-encounter and playbacks

Best months: August-October

Fieldwork duration: 90 days

Frequency: Annual (Meru NP), Biennial (Meru Conservation Area)

Field partners: Born Free
This team already monitors lions on a consistent basis, and so are well placed to engage in an annual survey.

Opportunities:
Apart from Meru National Park, the road network is poor, and the vegetation is thick. This reduces the chances of detecting lions (if present) in these areas. Other protocols that involve camera traps could be explored. Alternatively (or in combination) foot based protocols to search for scats could be deployed.

Since no lions were found outside Meru, the 2019 analysis consisted only of effort in Meru, and so the following data requirements are based solely on Meru, and additional effort will need to be deployed for the other areas.

4.4.2. Sample size requirements (for Meru NP)

Minimum effort: 10,000 km

Minimum data goals to increase precision (CV < 20%):
Individuals detected: 31
Number of recaptures: 31

Minimum data goals to increase accuracy (RB < 15%):
Number of individuals detected at more than one trap: 13
Average spatial recaptures: 2.3
Proportion of traps: 85%, which equates to 595 traps

Summary data from 2019 as a reference
Search effort: 9,875 km
Individuals detected: 30
Number of recaptures: 86
Number of individuals detected at more than one trap: 18
Average spatial recaptures: 3.1
Number of traps: 700 traps

4.1.4. Data analysis recommendations

Observation process
Trap size: 1 km^2

State process
Habitat pixel size: 0.5 km^2
Buffer size: 15 km

Initial model specification
M = 300
Number of iterations: 51,000
Number of chains: 4

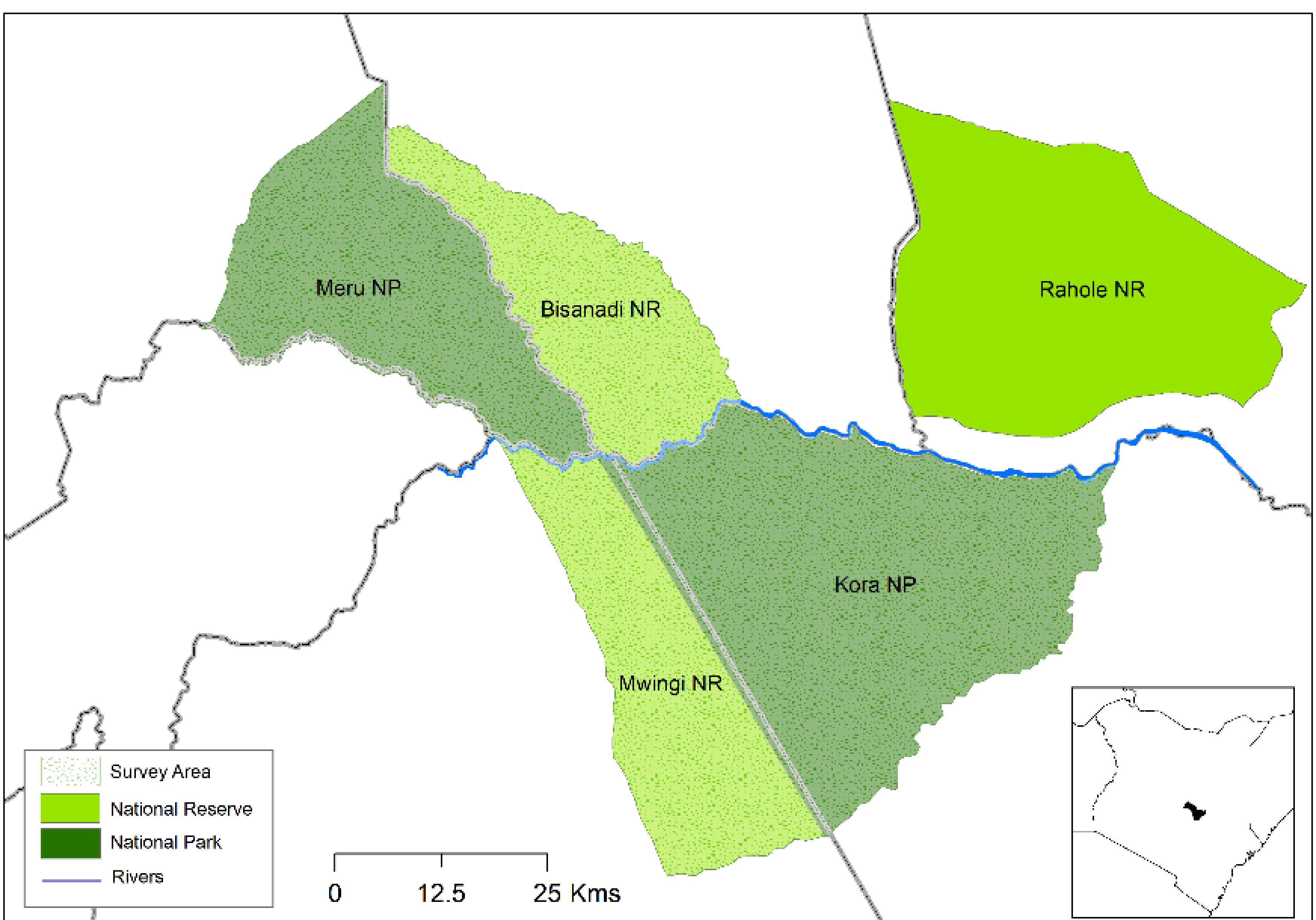


Figure 34. Meru (annually) and Kora National Parks, and Bisanadi and Mwingi National Reserves (Biennially) should be covered. Rahole National Reserve could be included if lions move into the area.

4.5. Nairobi National Park

4.5.1. Field work recommendations

Areas to cover: Nairobi National Park should be covered. The survey area could expand to accommodate the areas south of the park.

Area size as of 2018 survey: 117 km^2.

Field protocols: Search-encounter

Best months: October/November

Two sessions would be ideal for this ecosystem since it would capture population dynamics during the wet and dry seasons when wildlife move out of the park and back into the park.

Fieldwork duration: 10-30 days

Frequency: Annual, ideally biannual

Field partners: NGOs, FONAP members
This area can be surveyed by a dedicated team, citizen scientists or as part of a workshop.

Opportunities: Nairobi National Park was surveyed using search encounter SECR in 2018, 2021 and 2022. The first survey consisted of one dedicated team, the second involved citizen scientists and the third was conducted as part of a science-based workshop where participants were engaged in every step of an SECR survey. The workshop model has tremendous potential and provides an opportunity to (a) train participants in rigorous carnivore monitoring and (b) conduct regular and robust monitoring of lions in Nairobi National Park. This is a truly unique opportunity, and the workshop could be repeated annually over ten days.

If the survey area were to be expanded outside of the park, additional field protocols would need to be developed and deployed.

4.5.2. Sample size requirements

Minimum effort: 1,500 km

Minimum data goals to increase precision (CV < 20%):
Individuals detected: 41
Number of recaptures: 41

Minimum data goals to increase accuracy (RB < 5%):
Number of individuals detected at more than one trap: 14
Average spatial recaptures: 2.01
Proportion of traps: 95%, which equates to 212 traps

Lion abundance in Nairobi National Park is relatively low, meaning that precision of estimates will generally be poor, but accuracy can be high as shown by the data requirements for RB < 5%.

Summary data from 2018 as a reference
Search effort: 1,377 km
Individuals detected: 22
Number of recaptures: 41
Number of individuals detected at more than one trap: 18
Average spatial recaptures: 2.6
Number of traps: 223 traps

4.1.5. Data analysis recommendations

Observation process
Trap size: 0.5 km^2

State process
Habitat pixel size: 0.25 km^2
Buffer size: 20 km

Initial model specification
M = 300
Number of iterations: 151,000
Number of chains: 4

Figure 35. The entire National Park should be uniformly and systematically covered.

4.6. Nakuru National Park

4.6.1. Field work recommendations

Areas to cover: The confines of Nakuru National Park should be covered. The survey area should expand to include Soysambu Conservancy if sufficient resident lions are present.

Area size as of 2018 survey: 137 km^2.

Field protocols: Search-encounter

Best months: September/October

The dry season will make it easier to find and photograph lions.

Fieldwork duration: 21 days

Frequency: Annual

Field partners: There are currently no resident partners in this landscape.

Opportunities: Similar to Nairobi National Park, Nakuru National Park is relatively small and confined, meaning that it can be surveyed in a relatively short period of time and likely only with one team. Regular surveys conducted here would provide important insights into population dynamics of a small, fenced population of lions. Lions from Nakuru National Park have settled in Soysambu Conservancy, although the population in Soysambu is generally very small (< 5 individuals), so any attempts at surveying Soysambu, should be done concurrently with Nakuru National Park, otherwise the capture history data is likely to be very sparse, further compromising precision of the estimates.

4.6.2. Sample size requirements

Minimum effort: 6,000 km

Minimum data goals to increase precision (CV < 20%):
Individuals detected: 25
Number of recaptures: 25

Minimum data goals to increase accuracy (RB < 10%):
Number of individuals detected at more than one trap: 5
Average spatial recaptures: 2.4
Proportion of traps: 87%, which equates to 416 traps

Lion abundance in Nakuru National Park is relatively low, meaning that precision of estimates will generally be poor, but accuracy can be high as shown by the data requirements for RB < 10%.

Summary data from 2017 as a reference
Search effort: 2,579 km
Individuals detected: 10
Number of recaptures: 44
Number of individuals detected at more than one trap: 6
Average spatial recaptures: 3.7
Number of traps: 478 traps

4.1.6. Data analysis recommendations

Observation process
Trap size: 0.25 km^2

State process
Habitat pixel size: 0.25 km^2
Buffer size: 0 km (due to the fenced nature)

Initial model specification
M = 90
Number of iterations: 151,000
Number of chains: 4

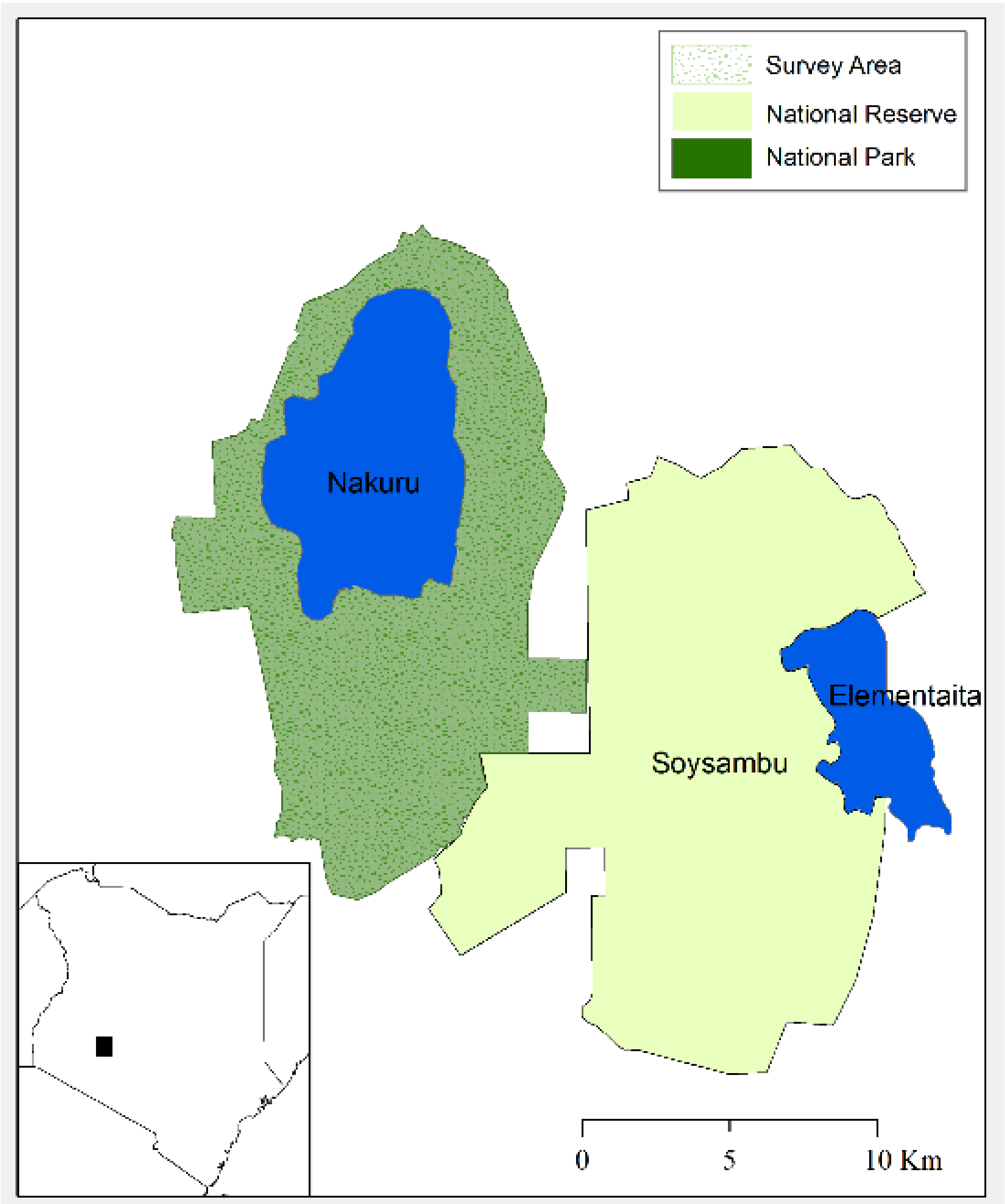


Figure 36. Nakuru National Park should be covered and the survey area could expand to include Soysambu Conservancy (the two must be done concurrently) otherwise sample sizes will be very small.

4.7. Ol Pejeta

4.7.1. Field work recommendations

Areas to cover: The entire ranch. This area can be done concurrently with the rest of Laikipia, or separately.

Area size as of 2018 survey: 302 km^2.

Field protocols: Search-encounter

Best months: August-October

Fieldwork duration: 45 days

Frequency: Annual

Field partners: Ol Pejeta monitoring team
This field team regularly monitors the lion population and keeps records of unique individuals.

Opportunities: This ranch is relatively small and contained and from the perspective of planning and running a search encounter based survey, is quite manageable. In addition, the resident field and monitoring teams already monitor individual lions by taking whisker spot photographs and also through GPS collaring of selected individuals. This team is therefore well placed to provide regular and robust monitoring of the lion population, and provide valuable insights into population dynamics of lions in a semi-fenced wildlife area.

The 2019 survey in Ol Pejeta yielded a relatively poor dataset – indeed there were no recaptures of male lions. This is partly because many sightings of lions did not result in individual identification photos being taken. As a result, only the most simple model was applicable to this dataset. In future, field practitioners should aim to acquire a richer dataset as per the recommendations, especially by increasing the number of recaptures.

4.7.2. Sample size requirements

Minimum effort: 3,000 km

Minimum data goals to increase precision (CV < 20%):
Individuals detected: 26
Number of recaptures: 26

Minimum data goals to increase accuracy (RB < 10%):
Number of individuals detected at more than one trap: 10
Average spatial recaptures: 1.8
Proportion of traps: 100%, which equates to 295 traps

Summary data from 2019 as a reference
Search effort: 2,782 km
Individuals detected: 23
Number of recaptures: 19
Number of individuals detected at more than one trap: 11
Average spatial recaptures: 1.7
Number of traps: 295 traps

4.1.7. Data analysis recommendations

Observation process
Trap size: 1 km^2

State process
Habitat pixel size: 0. 5 km^2
Buffer size: 15 km

Initial model specification
M = 350
Number of iterations: 51,000
Number of chains: 4

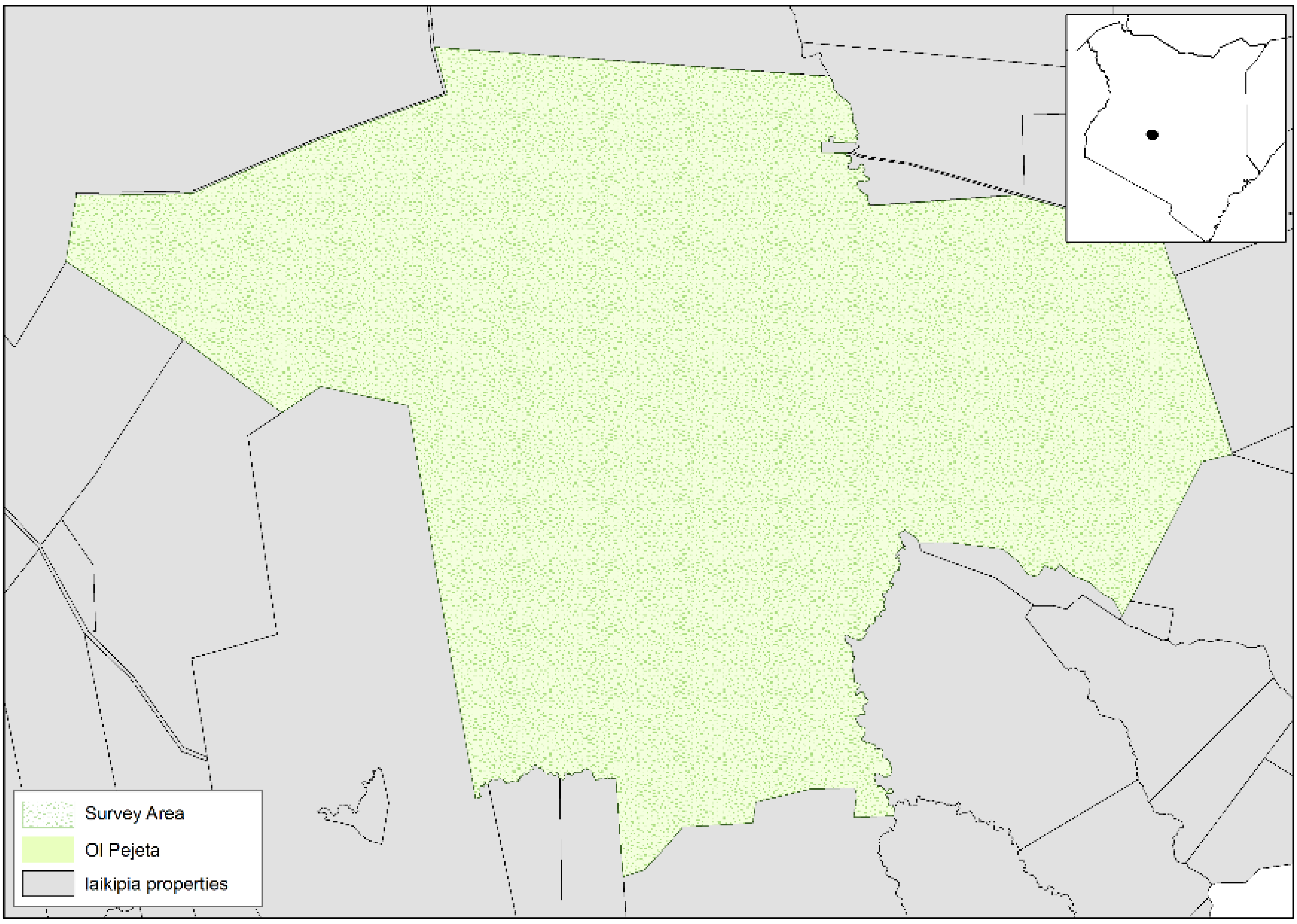


Figure 37. The entire ranch should be uniformly and systematically covered. This area can be done concurrently with the rest of Laikipia, or separately.

4.8. Samburu, Isiolo And Laikipia Counties

4.8.1. Field work recommendations

Areas to cover: The following National Reserves should be covered: Samburu, Buffalo Springs, Shaba. The following Community Conservancies should be covered: West Gate, Kalama, Nakuprat Gotu, Nasuulu, Leparua, Nanapisho, Naapo, Lekurruki, Il Ngwesi. If feasible and lions are resident, the following areas could also be included: Namunyak (both Sarara and Milgis areas), Biliqo Bulesa, Sera and Melako.

Area size as of 2018 survey: 3,093 km^2.

Field protocols: Search-encounter and playbacks

Best months: August - October

While the dry season is preferable in terms of fieldwork, this is also the time that security in the area can become problematic.

Fieldwork duration: 90 days

Frequency: Biennial

Field partners: Ewaso Lions, Northern Rangelands Trust
This area is vast and requires multiple teams to cover it adequately.

Opportunities: Lions within the National Reserve are habituated and relatively straight forward to photograph. Outside of the Reserves, lions are more nocturnal and elusive. In addition, they occur at very low densities, meaning that large amounts of effort are required to obtain a decent sample size. It is likely that the addition of the foot patrol and conditional drive effort protocols would increase the detection rates considerably. In addition, an expanded monitoring programme could be considered, where protocols that include scat sampling and or camera traps could be explored. Across greater scales, sign-based occupancy surveys could be conducted to assess species distribution and occupancy dynamics over time.

4.8.2. Sample size requirements (for areas covered in 2019 survey)

Minimum effort: 4,000 km

Minimum data goals to increase precision (CV < 20%):
Individuals detected: 37
Number of recaptures: 37

Minimum data goals to increase accuracy (RB < 15%):
Number of individuals detected at more than one trap: 9
Average spatial recaptures: 3.5
Proportion of traps: 95%, which equates to 1,475 traps

Lion abundance is relatively low in this area, meaning that precision of estimates will generally be poor, but accuracy can be high as shown by the data requirements for RB < 15%.

Summary data from 2019 as a reference
Search effort: 11,503 km
Individuals detected: 13
Number of recaptures: 94
Number of individuals detected at more than one trap: 10
Average spatial recaptures: 5.2
Number of traps: 1,553 traps

4.1.8. Data analysis recommendations

Observation process
Trap size: 1 km^2

State process
Habitat pixel size: 0.5 km^2
Buffer size: 15 km

Initial model specification
M = 300
Number of iterations: 51,000
Number of chains: 4

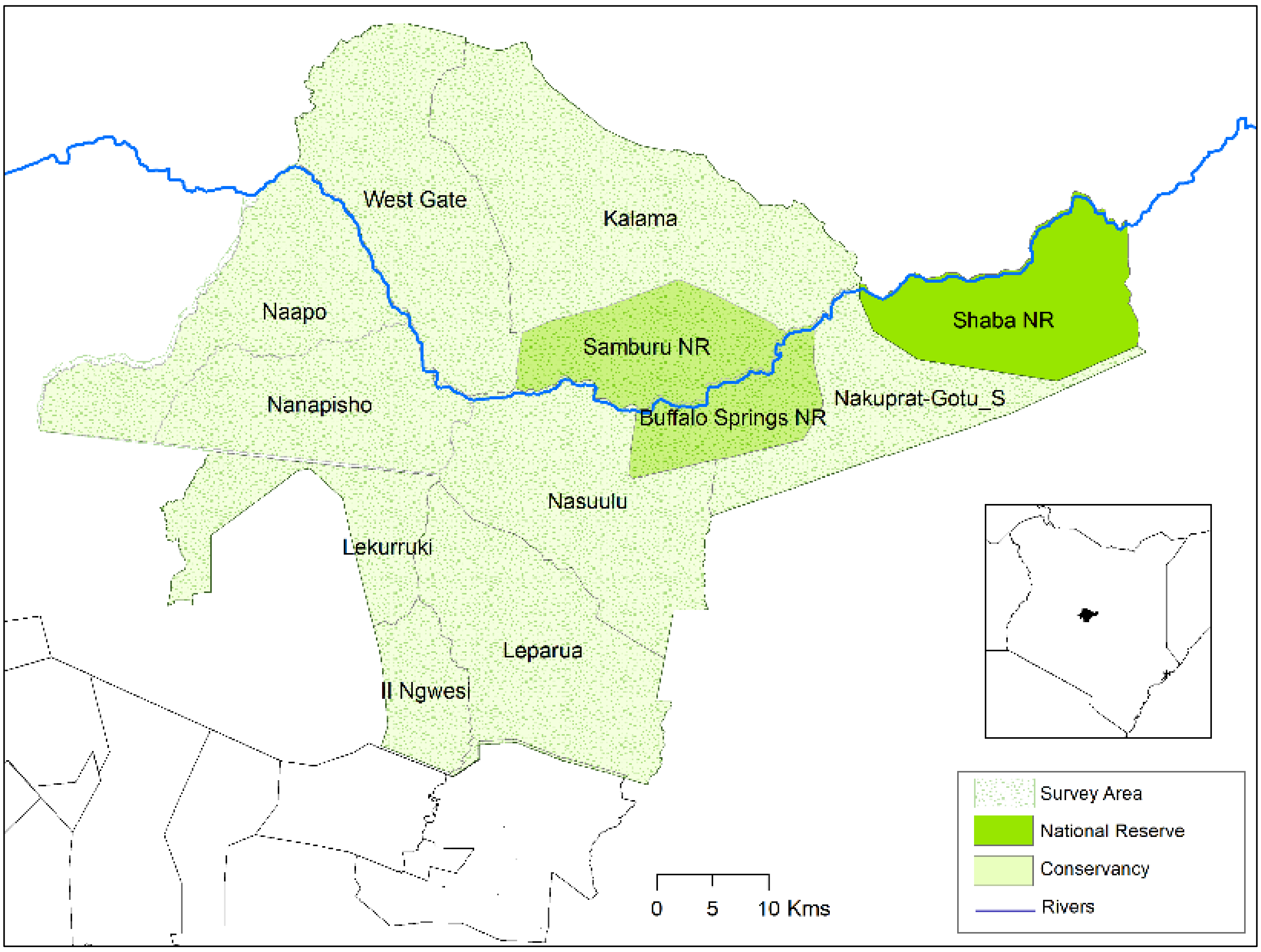


Figure 38. At a minimum, the following National Reserves should be covered: Samburu, Buffalo Springs, Shaba. The following Community Conservancies should be covered: West Gate, Kalama, Nakuprat Gotu, Nasuulu, Leparua, Nanapisho, Naapo, Lekurruki, Il Ngwesi.

4.9. Shompole and Ol Kiramatian

4.9.1. Field work recommendations

Areas to cover: At a minimum, the conservation areas within Olkiramatian and Shompole group ranches should be covered. The survey area should expand to accommodate any emerging conservancies.

Area size as of 2018 survey: 358 km^2.

Field protocols: Search-encounter and playbacks

Best months: September-November

While the dry season is preferable in terms of fieldwork, the lions tend to be more active in the wet season and emerge from the swamps more, making them easier to find.

Fieldwork duration: 90 days

Frequency: Annual

Field partners: SORALO
In addition to the 2018 survey, this team has conducted another survey in 2021 (February-April).

Opportunities: Lions here are elusive and nocturnal. The playback protocol is not particularly efficient here and it is likely that the addition of the foot patrol and conditional drive effort protocols would increase the detection rates considerably. This area is more than 100 km from the nearest protected area and is likely a key stepping stone in the wildlife connectivity of southern Kenya. As such, an expanded monitoring programme could be considered, where protocols that include scat sampling and or camera traps could be explored. Across greater scales, sign-based occupancy surveys could be conducted to assess species distribution and occupancy dynamics over time.

4.9.2. Sample size requirements

Minimum effort: 4,000 km

Minimum data goals to increase precision (CV < 20%):
Individuals detected: 28
Number of recaptures: 28

Minimum data goals to increase accuracy (RB < 15%):
Number of individuals detected at more than one trap: 19
Average spatial recaptures: 2.95
Proportion of traps: 95%, which equates to 244 traps

Summary data from 2018 as a reference
Search effort: 2,701 km
Individuals detected: 19
Number of recaptures: 65
Number of individuals detected at more than one trap: 17
Average spatial recaptures: 3.05
Number of traps: 257 traps

4.1.9. Data analysis recommendations

Observation process
Trap size: 1 km^2

State process
Habitat pixel size: 0.5 km^2
Buffer size: 15 km

Initial model specification
M = 250
Number of iterations: 51,000
Number of chains: 4

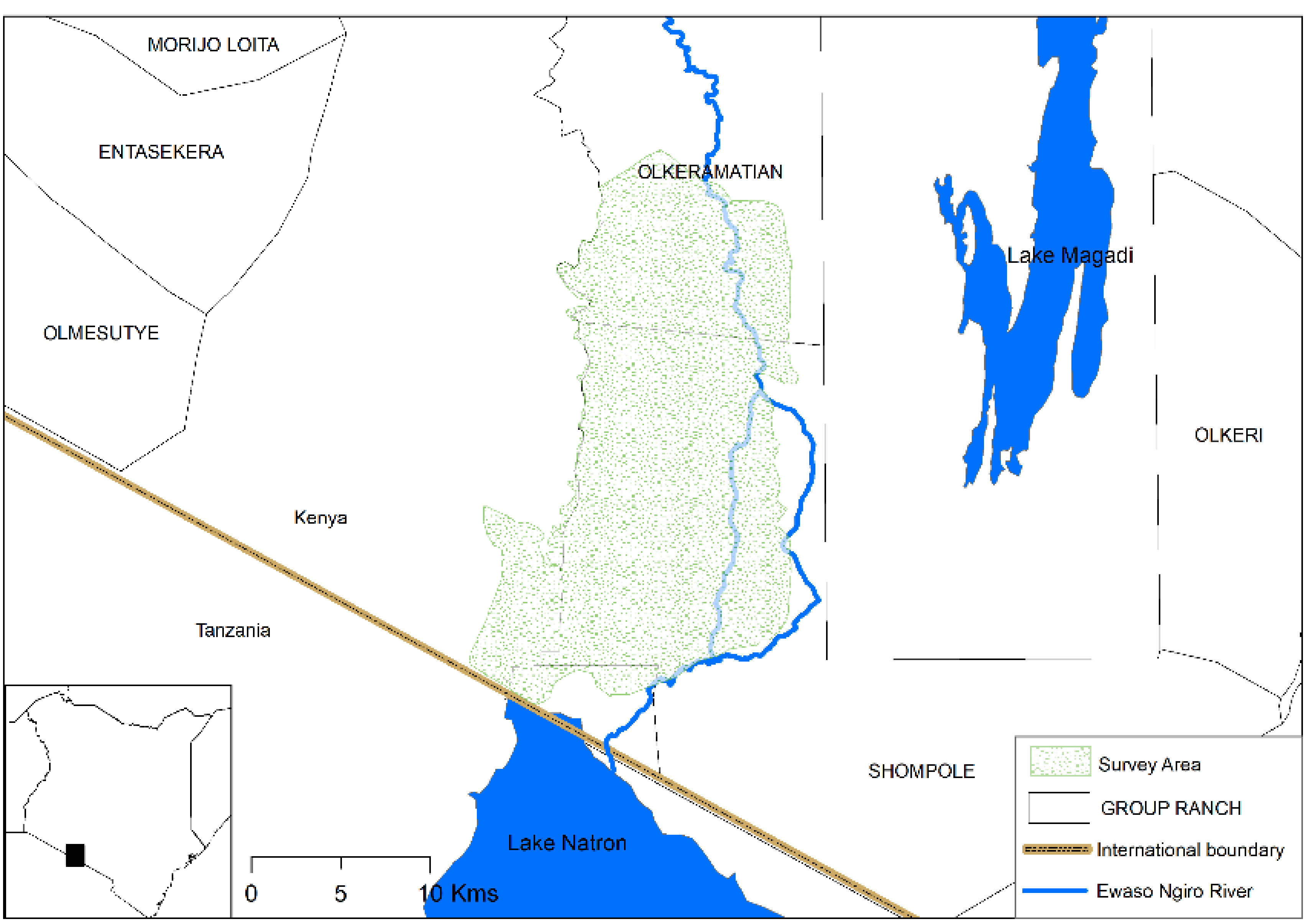


Figure 39. The conservation areas within Olkiramatian and Shompole group ranches should be covered

4.10. Solio Ranch

4.10.1. Field work recommendations

Areas to cover: The entire ranch. This area can be done concurrently with the rest of Laikipia, or separately.

Area size as of 2018 survey: 161 km^2.

Field protocols: Search-encounter and playbacks

Best months: September-November

Fieldwork duration: 30 days

Frequency: Annual

Field partners: Solio monitoring team
This field team regularly monitors the lion population and keeps records of unique individuals.

Opportunities: This ranch is relatively small and contained and from the perspective of planning and running a search encounter based survey, is quite manageable. The lion population tends to occur at high density meaning that in a very short period of time, a rich dataset can be gathered. Small, fenced populations tend to grow rapidly and require active management, which is best informed by regular and robust monitoring. The 2019 survey demonstrated that this is feasible and not very resource intensive. Furthermore, the resident field and monitoring teams already monitor individual lions by taking whisker spot photographs. This team is therefore well placed to provide regular monitoring of the lion population, which will provide valuable insights into population dynamics of lions in a fenced wildlife area.

4.10.2. Sample size requirements

Minimum effort: 4,000 km

Minimum data goals to increase precision (CV < 20%):
Individuals detected: 28
Number of recaptures: 28

Minimum data goals to increase accuracy (RB < 5%):
Number of individuals detected at more than one trap: 21
Average spatial recaptures: 1.6
Proportion of traps: 94%, which equates to 135 traps

Summary data from 2019 as a reference
Search effort: 1,018 km
Individuals detected: 44
Number of recaptures: 55
Number of individuals detected at more than one trap: 31
Average spatial recaptures: 1.9
Number of traps: 144 traps

4.1.10. Data analysis recommendations

Observation process
Trap size: 1 km^2

State process
Habitat pixel size: 0.5 km^2
Buffer size: 0 km (due to the fenced nature)

Initial model specification
M = 300
Number of iterations: 51,000
Number of chains: 4

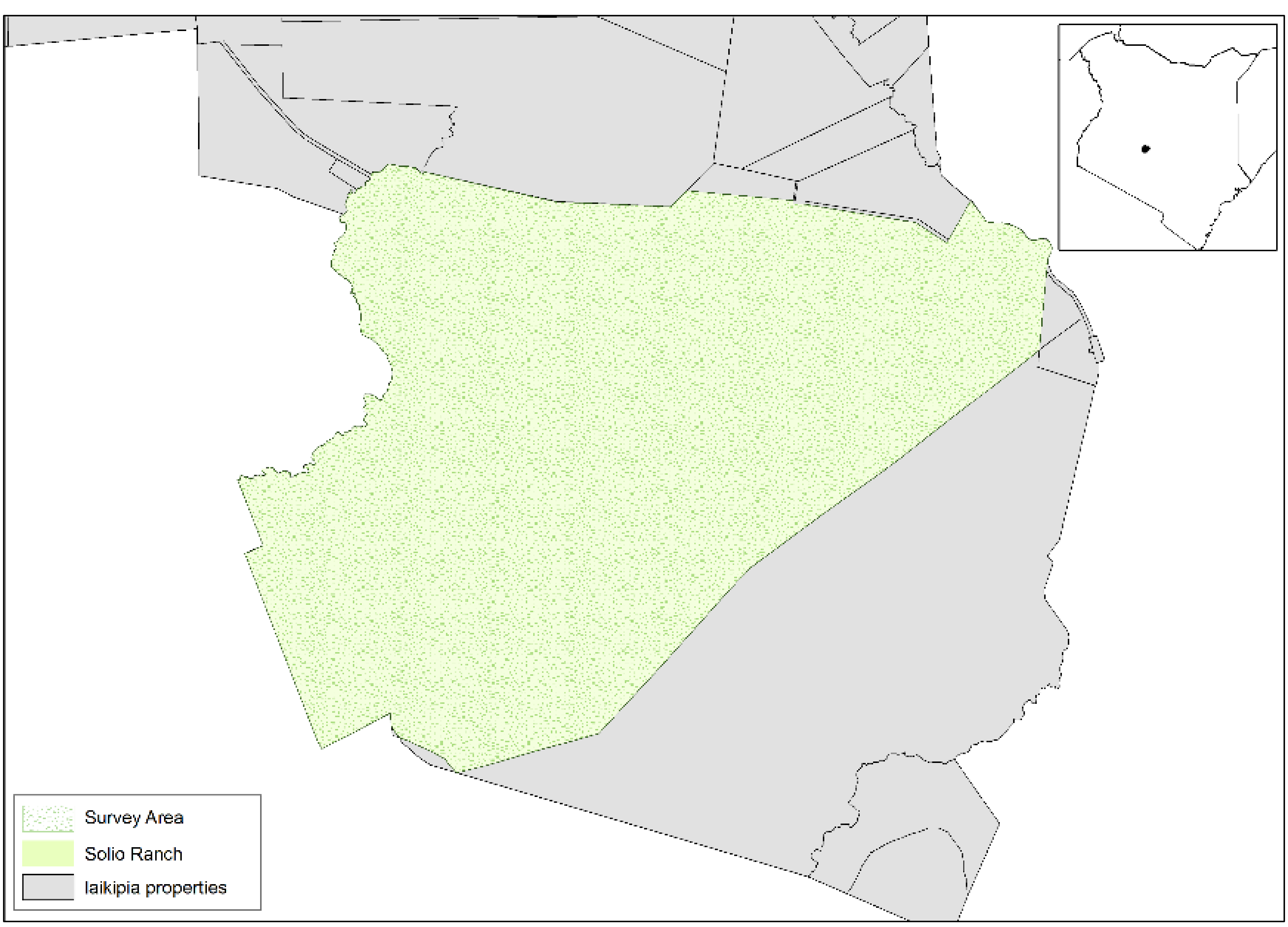


Figure 40. The entire ranch should be uniformly and systematically covered. This area can be done concurrently with the rest of Laikipia, or separately.

4.11. Tsavo Conservation Area

4.11.1. Field work recommendations

Areas to cover: The following National Parks should be covered: Tsavo East, Tsavo West, Chyulu Hills. The following private and community ranches and conservancies should be covered: 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 the initial survey based on consultations with local stakeholders who indicated absence of resident lions. If this situation changes, the National Reserves should also be included.

Area size as of 2018 survey: 23,902 km^2.

Field protocols: Search-encounter and playbacks

Best months: August-October or January-March

This area should be surveyed in the dry season when the vegetation is not as thick and wildlife (including lions) are more concentrated around waterholes, making them easier to find. The dry season also makes logistics much easier.

Fieldwork duration: 90 days

Frequency: This is Kenya's second largest population (largest if Amboseli is included) and ideally would be monitored annually. Alternatively, the small sigma area (Figure 41) could be monitored annually and the remaining areas every two to three years.

Field partners: Tsavo Trust, Wildlife Works, ZSL
The 2019 survey consisted of ten teams.

Opportunities: The 2019 survey revealed that lions in this ecosystem occur at very different densities and have variable detection rates and movement patterns. South of the Galana River (Tsavo East) and in several of the Taita Ranches, lions occur at relatively high density, within small home ranges and are relatively habituated and easy to detect (this is the 'small sigma' area illustrated in Figure 41). In the medium sigma area (essentially Tsavo West and Chyulu Hills National Parks), lions are at lower density, with larger home ranges and detection rates are lower. In the large sigma area (Tsavo East, north of the Galana), lions occur at very low density, have massive home ranges and are very difficult to detect. As such, the medium and large sigma areas require significant field effort and highly skilled teams to locate and photograph lions, which are often skittish. The small sigma area contains 70% of the area's lions and could be surveyed annually by two teams, which would be relatively straightforward logistically. The medium sigma (24%) and large sigma (6%) areas contain far fewer lions and could be surveyed less frequently (biennially) with specialized field teams. Additional field protocols (such as camera traps and scat collection) could also be explored.

4.11.2. Sample size requirements

Minimum effort (km):

	SS	MS	LS
Minimum effort	13,000	20,000	7,500

Minimum data goals to increase precision (CV < 20%):

	SS	MS	LS
Individuals detected	61	27	51
Number of recaptures	61	27	51

Minimum data goals to increase accuracy:

	SS (RB < 10%)	MS (RB < 15%)	LS (RB < 10%)
Inds at > 1 trap*	46	27	9
Average spatial recaps	1.8	1.8	2.2
Proportion of traps	98%	86%	92%

*Number of individuals detected at more than one trap

Summary data from 2018 as a reference

	SS	MS	LS
Search effort	17,551 km	14,671 km	6,593 km
Individuals detected	138	36	18
Number of recaptures	302	17	19
Inds at > 1 trap*	102	10	10
Average spatial recaps	2.2	1.4	2.1
Number of traps	1,619	1,148	367

4.1.11. Data analysis recommendations

Observation process

	SS	MS	LS
Trap size	2 km^2	4 km^2	8 km^2

Trap size: 1 km^2

State process

	SS	MS	LS
Habitat pixel size	0.5 km^2	1 km^2	2 km^2
Buffer size	15 km	25 km	55 km

Initial model specification

	SS	MS	LS
M	1,500	1,000	1,000
Number of iterations	15,000	31,000	71,000
Number of chains	4	4	4

Lion abundance is relatively low in the medium and large sigma areas, meaning that precision of estimates will generally be poor, regardless of the amount of effort, but accuracy can be high as shown by the data requirements for RB. However, this requires a vast amount of field effort (km driven) and highly skilled data collectors.

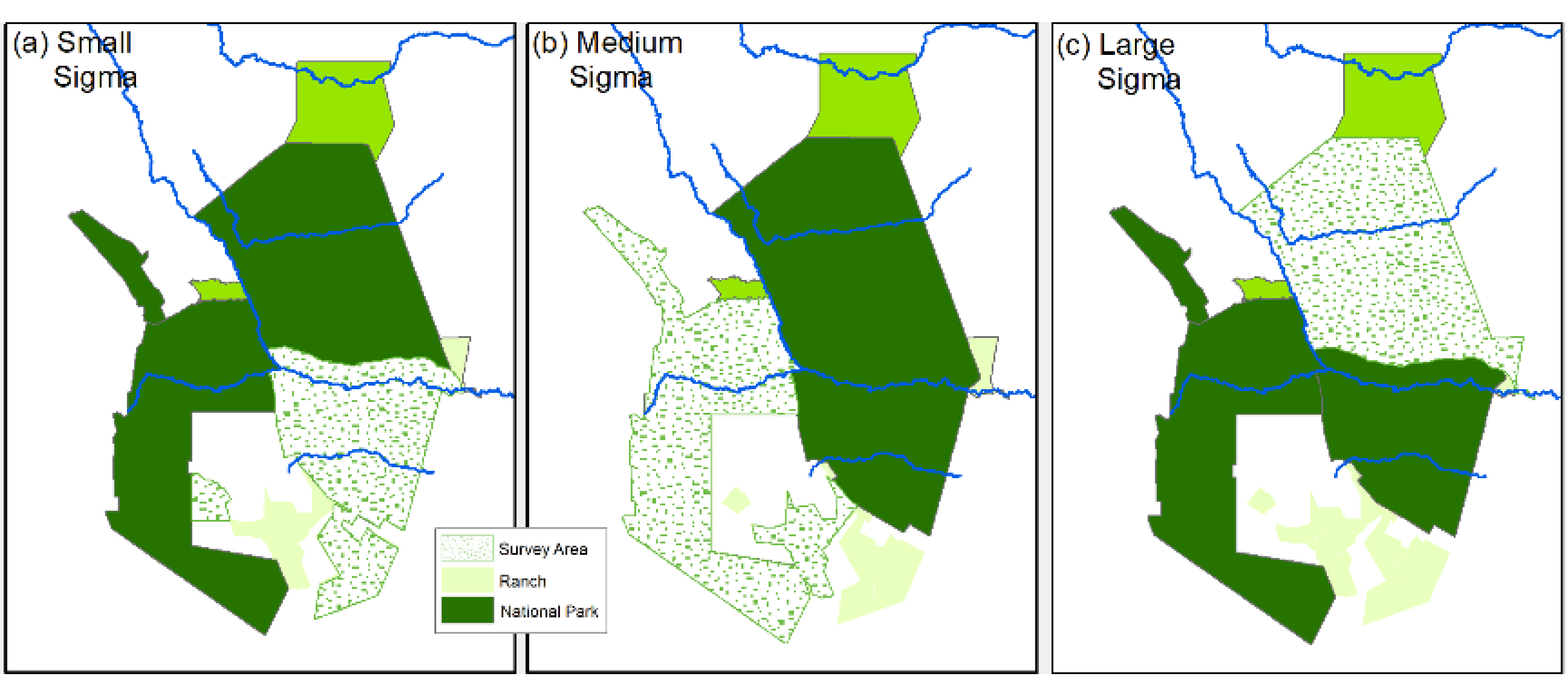


Figure 41. Tsavo can be surveyed all together, but is likely preferable to analyse the different sections as per this figure, owing to vast differences in density and movement of lions. The small sigma could be surveyed separately and this area contains the majority of the lions in this ecosystem. The medium sigma (Tsavo West and Chyulu Hills National Parks) could also be surveyed separately but sample size may be limited, as will almost certainly be the case with the large sigma area.

5. Notes on Site-Specific Guidelines

The guidelines provided above for minimum field effort and sample size are meant as a broad standards that field coordinators and practitioners should aim to meet. This will be particularly helpful when planning a survey, both in terms of budgets and also logistics. Typically, 100 km of drive effort is the absolute maximum a single team can cope with in one day, and the total number of field days required can be planned by scaling drive effort with the number of field teams available. For example, if a survey of Nairobi National Park is being planned, a total search effort of 1,500 km can be budgeted. To meet this requirement, a minimum of 15 days of fieldwork would be required. One team could conduct this fieldwork over 15 field days by driving 100 km per day or over 30 days by driving 50 km per day. An additional team would half the workload of the original team, but the total field days would remain the same.

It should be noted that the effort specified carries an assumption that detections will follow in a similar manner to that of the 2018 and 2019 surveys. This may not be the case as detection probability can increase or decrease depending on any number of factors, for example abundance could have decreased markedly since the previous survey, vegetation could have changed, observers may be more or less skilled. For this reason, it is important to also consider the sample size guidelines (with respect to individuals detected, number of recaptures, number of individuals detected at more than one trap, average spatial recaptures and proportion of traps). If these are lower that the specified guidelines, it is likely that data collection will need to continue, even if the minimum effort has been exhausted. There are two primary means of minimising the risk of this occurring: (1) field personnel should be adequately trained and have experience in finding and photographing lions, (2) surveys should be planned during periods where data collection can be optimised, for example by avoiding the rainy seasons.

6. Surveying 'new' source populations

It is acknowledged that several potential source populations of lions were not surveyed during the initial 2018 – 2019 surveys. Specific areas had been identified, but surveys were not able to take place due to insecurity and/or Covid-19. This included the following areas: Kuku Ranch, Shaba National Reserve, Biliqo Conservancy, Mathew's Range, Namunyak Conservancy, Milgis area and several coast properties. These areas should be surveyed as a priority to estimate lion numbers within these potential sources. In addition, the 'National recovery and action plan for lion and spotted hyena in Kenya (2020-2030)' obtained guess estimates from local stakeholders in different localities throughout the country. These figures motivate future assessments of lion populations within those areas while noting that many may contain lions at a density too low for reliable survey estimates. However, site visits should be carried out to assess feasibility of surveys within the areas listed. When planning these surveys, it is not very difficult to estimate the amount of field effort that will need to be invested, since this will vary considerably depending on detection rates of lions. As a very broad rule of thumb, surveys in novel landscapes can budget for a drive effort of 3-4 times the area size, and more for areas where detection rates are likely to be very low. For example, if a survey is planned in a novel landscape of 3,000 km^2, a total field effort of 12,000 km could be budgeted, and this can be adjusted in future surveys using the methods described in the site-specific guidelines. .

7. Future Directions: An Inclusive Monitoring Framework

In this science-based approach to monitoring, it is important that there is a goal of constant improvement. The field of wildlife monitoring is a fully-fledged science in it's own right, and will continue to evolve. As such, the aim should not be to institutionalise certain methods and techniques, but rather to continuously improve them. Scientific collaborations are an excellent way of ensuring that Kenya stays at the cutting edge of large carnivore monitoring and the approach of the 2018-2019 surveys holds as an excellent example of inclusive monitoring. During those surveys, a multi-agency technical team was assembled to oversee the surveys, and over 400 people from more than 40 organisations participated. The approach was bottom-up, where key local stakeholders were identified and subsequently involved in every step of the scientific process. This helped ensure local uptake of the methods and results and will hopefully result in support of the subsequent conservation recommendations. This approach of including local stakeholders holds tremendous promise in ensuring that monitoring is regular and rigorous and serves as a template to follow going forwards (see Ngene et al. 2022).

Key Resources for Further Information

Reference	Notes	Topic
Royle JA, Chandler RB, Sollmann R, Gardner B 2013. Spatial capture-recapture. Academic Press, Amsterdam. https://doi.org/10.1016/C2012-0-01222-7.	A definitive textbook that should be a part of any field/office library.	General SECR
Karanth KU, Nichols JD 2017. Methods For Monitoring Tiger And Prey Populations. Springer. https://doi.org/10.1007/978-981-10-5436-5.	A comprehensive book that should be a part of any field/office library.	SECR + Occupancy
Russell RE, Royle JA, Desimone R, Schwartz MK, Edwards VL, Pilgrim KP, Mckelvey KS. 2012. Estimating abundance of mountain lions from unstructured spatial sampling. The Journal of Wildlife Management 76:1551-1561. https://doi.org/10.1002/jwmg.412.	First application of unstructured spatial sampling (search encounter) used within an SECR framework.	SECR
Pennycuick CJ, Rudnai J. 1970. A method of identifying individual lions (*Panthera leo*), with an analysis of reliability of identification. Journal of Zoology **160**:497-508. https://doi.org/10.1111/j.1469-7998.1970.tb03093.x	The first study to formalize a procedure for identifying individual lions using their whisker spots	Individual lion Identification
Elliot NB, Gopalaswamy AM. 2017. Towards accurate and precise estimates of lion density. Conservation Biology 31:934-943. http://doi.org/10.1111/cobi.12878.	First application of search encounter-based SECR with African lions.	SECR + lions
Broekhuis F, Gopalaswamy AM. 2016. Counting Cats: Spatially Explicit Population Estimates of Cheetah (Acinonyx jubatus) Using Unstructured Sampling Data. PLoS ONE 11. : http://doi.org/10.1371/journal.pone.0153875.	First application of search encounter-based SECR with cheetahs.	SECR + cheetahs
Elliot NB, Bett A, Chege M, Sankan K, de Souza N, Kariuki L, Broekhuis F, Omondi P, Ngene S, Gopalaswamy AM. 2020. The importance of reliable monitoring methods for the management of small, isolated populations. Conservation Science and Practice 2:e217. http://doi.org/10.1111/csp2.217.	A pilot study in Nakuru NP that resulted in the adoption of SECR for lion monitoring in Kenya.	SECR + lions
Western G, Elliot NB, Sompeta SL, Broekhuis F, Ngene S, Gopalaswamy AM. 2022. Lions in a coexistence landscape: Repurposing a traditional field technique to monitor an elusive carnivore. Ecology and Evolution 12:e8662. https://doi.org/10.1002/ece3.8662.	First application of search-encounter methods combined with playbacks to monitor lions.	SECR + lions
Elliot, N. B., F. Broekhuis, P. Omondi, S. Ngene, L. Kariuki, K. Sankan, M. Chege, Y. Wato, I. Amoke, S. Dolrenry, and A. M. Gopalaswamy. 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. ISBN: 978-9914-40-516-3. Available at https://bit.ly/lion-large-carnivore-survey	Final report detailing the outcomes of 10 SECR surveys conducted within source populations, and large carnivore occupancy and distribution across Kenya.	SECR + lions
Broekhuis F, Elliot NB, Keiwua K, Koinet K, Macdonald DW, Mogensen N, Thuo D, Gopalaswamy AM. 2021. Resource pulses influence the spatio-temporal dynamics of a large carnivore population. Ecography 44:358-369. https://doi.org/10.1111/ecog.05154.	A study of spatio-temporal dynamics of cheetahs using SECR.	SECR + cheetahs
Paterson JT, Proffitt K, Jimenez B, Rotella J, Garrott R. 2019. Simulation-based validation of spatial capture-recapture models: A case study using mountain lions. PLOS ONE **14**:e0215458. http://doi.org/10.1371/journal.pone.0215458.	A study exploring best practices when collecting search encounter data for SECR studies	Search encounter SECR
Strampelli P, Searle CE, Smit JB, Henschel P, Mkuburo L, Ikanda D, Macdonald DW, Dickman AJ. 2022. Camera trapping and spatially explicit capture–recapture for the monitoring and conservation management of lions: Insights from a globally important population in Tanzania. Ecological Solutions and Evidence 3:e12129. https://doi.org/10.1002/2688-8319.12129	A study using camera traps to obtain individual identities on lions and analyse these data with SECR models	SECR + lions + camera traps
Gopalaswamy AM, Royle JA, Delampady M, Nichols JD, Karanth KU, Macdonald DW. 2012. Density estimation in tiger populations: combining information for strong inference. Ecology 93:1741-1751. http://doi.org/10.1890/11-2110.1.	A study on tigers that demonstrates the power of combining different data sources using SECR models	Genetic + photographic data
Braczkowski, A., R. Schenk, D. Samarasinghe, D. Biggs, A. Richardson, N. Swanson, M. Swanson, A. Dheer, and J. Fattebert. 2022. Leopard and spotted hyena densities in the Lake Mburo National Park, southwestern Uganda. PeerJ 10:e12307. https://doi.org/10.7717/peerj.12307	An example of using paired camera trap stations to estimate leopard density using Bayesian SECR methods	Camera traps + SECR
Bischof R, et al. 2020. Estimating and forecasting spatial population dynamics of apex predators using transnational genetic monitoring. Proceedings of the National Academy of Sciences. https://doi.org/10.1073/pnas.2011383117	An example of using search encounter field protocols for scat collection at very large spatial scales	SECR and genetics (scats)
Efford MG, Boulanger J. 2019. Fast evaluation of study designs for spatially explicit capture–recapture. Methods in Ecology and Evolution 10:1529-1535. https://doi.org/10.1111/2041-210X.13239	Evaluation of different study designs	SECR
Dupont G, Royle JA, Nawaz MA, Sutherland C. 2021. Optimal sampling design for spatial capture–recapture. Ecology **102**: e03262. https://doi.org/10.1002/ecy.3262.	Evaluation of different study designs	SECR
Ngene S, Broekhuis F, Elliot NB, Mukeka J, Chege M, Muteti D, Ngoru B, Lala F, Mwiu S, Amoke I, Western G, Wato Y, Dolrenry S, Gopalaswamy AM. The emergence of a robust and inclusive framework for a nationwide assessment of African lions. Conservation Science and Practice. https://doi.org/10.1111/csp2.12871	Discussion of the conservation impact of the science-based monitoring conducted in Kenya.	SECR
Whitman KL, Packer C. 2007. A Hunter's Guide to Aging Lions in Eastern and Southern Africa. Safari Press, Long Beach, CA. Available at http://www.cbs.umn.edu/sites/default/files/public/downloads/Lion_Aging_Guide-1.pdf	A useful field guide for aging lions based on mane development, nose pigmentation and teeth.	Aging lions
Miller JR, Balme G, Lindsey PA, Loveridge AJ, Becker MS, Begg C, Brink H, Dolrenry S, Hunt JE, Jansson I. 2016. Aging traits and sustainable trophy hunting of African lions. Biological Conservation 201:160-168. https://doi.org/10.1016/j.biocon.2016.07.003	Expanded study on aging lions in different areas	Aging lions
http://www.agingtheafricanlion.com/	A website that accompanies Miller et al. (2016) and provides trainings	Aging lions