FINAL

AERIAL SURVEY STANDARDS

CITES MIKE PROGRAMME

Version 3.0

CITES MIKE Programme
c/o UNEP/DELC
P. O. Box 30552
Nairobi 00100
KENYA

www.citesmike.org

MONITORING THE ILLEGAL KILLING OF ELEPHANTS

Funded by the European Union

Citation: CITES MIKE Programme. 2020 *Monitoring the Illegal Killing of Elephants: Aerial Survey Standards for the MIKE Programme. Version 3.0*. CITES MIKE Programme, Nairobi, Kenya.

This document has been produced with financial assistance from the European Union. The European Union's support for the production of this publication does not constitute an endorsement of the contents, which reflect views only of the authors, and the European Union cannot be held responsible for any use which may be made of the information contained therein.

Contents

1 Introduction

1.1 Background

The system for Monitoring of Illegal Killing of Elephants (MIKE) was established in 1997 through Resolution Conf. 10.10 and is implemented under the supervision of the CITES Standing Committee. The Resolution has been amended at subsequent meetings of the Conference of the Parties (E-Res-10-10-R18). Although the MIKE Programme's initial main objective was to measure levels of and trends in the illegal killing of elephants in Africa and Asia (E-CoP11-31-2, presented at the 11th Conference of the Parties), the mandate has been expanded since. The overall aim of MIKE is according to Resolution Conf. 10.10 (Rev. CoP18) to provide information needed for elephant range States and the Parties to CITES to make appropriate management and enforcement decisions, and to build institutional capacity within the range States for the long-term management of their elephant populations by improving their ability to monitor elephant populations, detect changes in levels of illegal killing, use this information to provide more effective law enforcement and strengthen any regulatory measures required to support such enforcement.

In the beginning, part of the monitoring under the MIKE initiative included aerial surveys of selected savanna sites to obtain estimates of numbers of elephants and elephant carcasses. Such surveys repeated over time could provide a means of detecting changes (trends) in elephant numbers and mortality at the selected sites. In order that this could be done as effectively as possible, it was necessary to use methods which were efficient in producing accurate and precise results which were comparable over all sites and which remained comparable over time within sites. Arising from this was a need for standards to be set as a means of maintaining the uniformity and comparability of surveys. The MIKE aerial survey standards were developed by the MIKE programme to address this need. The standards were revised in 2012 and again during 2019. MIKE no longer funds aerial surveys, but the standards have been widely adopted for surveys of savannah elephants at MIKE sites as well as sites which are not MIKE sites (Thouless *et al*. 2016).

The original MIKE standards were intended for aerial surveys which had the objective of obtaining estimates of the numbers of elephants and elephant carcasses using methods which were efficient in producing accurate and precise results, and repeatable over time and between sites. The requirement that the population estimates included a measure of precision favoured the use of sampling methods, especially transect surveys (see below for a discussion of different aerial survey methods and their advantages and disadvantages).

The widespread adoption of the standards for many surveys of African savannah elephants means that the standards may now be used for surveys for which the primary objective is not to obtain population estimates. For example, the primary objective of a survey may be to determine the spatial distribution of elephants during the rainy season. If the survey is conducted using systematically arranged transects, the results will include not only the wet-season spatial distribution, but also estimates of numbers. Although the estimates are likely to be less accurate (than for a dry-season survey), because of the greater woody plant cover and hence reduced visibility of animals during the rainy season, these estimates still provide an indices of abundance.

1.2 This Document

The purpose of this document is to provide a statement of the standards for each aspect of aerial surveys of elephants (section 3). It is assumed that the reader has some knowledge and experience of aerial survey techniques.

It is not the purpose of this document to tell the reader whether it is appropriate to conduct an aerial survey of elephants in his or her study area. Nor is the purpose of this document to provide a manual of survey methods - suitable texts already exist (see Norton-Griffiths 1978, Gasaway *et al*. 1986, Douglas-Hamilton 1996, Mbugua 1996, Jachmann 2001). However, where this is felt necessary to illuminate the needs for particular standards, additional notes and references have been provided (section 4), but these are not part of the standards. A glossary is provided, as are appendices on optimising of sampling effort among strata and sites; and specimen datasheets.

The data collected during an aerial survey should include information which, while not necessarily required to meet current survey objectives, may be needed for future analyses for validation of data from a series of surveys.

1.3 Survey Objective

The objective of an aerial survey must be determined before survey design and planning commence.

The *primary* objective of a survey is likely to fall into one of three categories:

a) to estimate the number of elephants in the survey area as accurately and precisely as reasonably possible;
b) to estimate the number of elephants in the survey area in order to compare that estimate with the results of previous surveys in the same area (a trend analysis); or
c) to determine the spatial distribution of elephants within the survey area at the time of the survey.

The standards in this document can be followed regardless of the survey objective, with any departures from the standards and the reasons for these noted in the survey report. Some standards are crucial for all surveys (e.g. having an adequate search effort, completing the survey within a short time during a single, clearly-defined season).

Most of the standards are intended to improve the accuracy of an elephant population estimate by reducing counting bias during the survey. Accuracy and precision are independent. The precision of a population estimate is dependent on the design of the survey (e.g. overall sampling intensity, stratification of the survey area, optimal allocation of sampling effort between strata, type of sample survey, transect orientation) [a]. Hence, for example, changing the sampling intensity of a sample survey will affect the precision of the population estimate, but not its accuracy. Close adherence to the survey standards, including those for survey design, is required to produce an elephant population estimate that is reasonably accurate and precise - objective (a) above.

For a trend analysis - objective (b) above - using the same techniques as utilized during the previous surveys of the study area is of prime importance, even if the previous survey standards do not meet the current ones. It is more important to keep the counting bias approximately constant between surveys than to minimise it during the latest survey. A trend analysis requires precise population estimates and so an efficient survey design is essential. A trend analysis is facilitated by conducting surveys as often as possible.

To determine spatial distribution - objective (c) above - the choice of survey type and, if a sample survey is chosen, the type, number and spatial distribution of the sampling units are of prime importance. The population estimate derived from such a survey may not be accurate or precise, and it does not need to be. But if the survey standards are followed, the survey can produce - in addition to the distribution map – a population estimate that is reasonably accurate and precise.

---

[a] The precision is also dependent on factors beyond the control of a survey designer, specifically the density of elephants in the survey area and the sizes of their herds (Jachmann 2001).

1.4 Abbreviations / Acronyms

AED	African Elephant Database (http://africanelephantdatabase.org/)
agl	above ground level (usually with reference to flying height)
FSO	Front Seat Observer (often called the Recorder)
ft	feet (aircraft flying heights are commonly measured in feet)
GPS	Global Positioning System
gpx	GPS exchange format. A common file format for GPS data, which allows data to be interchanged between GPS devices, and between GPS devices and computers.
kph	kilometres per hour
PRP	Percentage Relative Precision (also referred to as the Relative Margin of Error)
RME	Relative Margin of Error
RSO	Rear Seat Observer (if the FSO is a Recorder, a RSO is often called simply an Observer)

2 Aerial Survey Methods

As there are a few options for the aerial survey method to use, standards depend on the method to be used. The choice of method affects accuracy, precision and efficiency. However, differing circumstances may demand different choices and one survey may even be made up of areas that need to be surveyed by different methods. There are four different approaches, classified as follows:

- Complete census:
  - *Total count*
- Sample survey*:*
  - Fixed sample methods:
    - *Transect survey*
    - *Block survey*
  - Variable sample methods:
    - *Distance survey*

A brief outline of each survey method is provided as a background to this document but the methods are described in detail elsewhere (Norton-Griffiths 1978, Gasaway *et al.*1986, Craig 1993, Mbugua 1996, Douglas-Hamilton 1996, Jachmann 2001, Frederick *et al*. 2010) except for aerial distance counts, which are covered in general terms by Buckland *et al*. (2001) and in more detail by Griffin *et al*. (2006) and Kruger *et al*. (2008). Distance surveys require more equipment, preparation and analysis than a transect survey, and while they are intended to improve both precision and accuracy, in practice there are often significant drawbacks when using fixed-wing aircraft[1]. Recently, distance surveys of large herbivores including elephants have been executed more successfully with a helicopter (Goodman & Mbise 2018, Goodman & Worth 2018), but the expense of such aircraft will undoubtedly discourage the wider use of that technique, especially in large survey areas.

2.1 Transect survey

Transect surveys are carried out by flying at a fixed height above ground level along transects spaced apart as required for the selected sampling intensity. Pairs of rods are attached to the aircraft struts at a fixed distance apart according to the required "strip width". Observers count animals seen between these rods. Analysis of the information provides estimates of densities within each stratum which can be combined to provide an overall estimate for the survey area.

2.1.1 Advantages

Transect surveys:

- provide a statistical measure of precision for the population estimate;
- produce results that are often more accurate than those from a total count, because sample surveys usually have a greater search effort (time spent searching per unit area)[2];
- are cheaper than total counts for large survey areas;
- provide useful data on spatial distribution if the transects are arranged systematically and not spaced far apart; and
- are more efficient than block surveys, being superior in terms of cost, navigation, boundary effects, sample error and crew fatigue (Norton-Griffiths 1978).

2.1.2 Disadvantages

Transect surveys:

- must be flown at a constant height above ground level, which is maintained as accurately as possible using special equipment such as a radar or laser altimeter; and
- cannot be flown over ground which is mountainous.

2.2 Block survey

Block surveys are conducted by dividing the survey area into small “blocks” (usually ≤20 km^2)[b]. A number of blocks are selected randomly or systematically according to the required sampling intensity and these blocks are searched until all animals within them have been counted. If blocks are arranged systematically, they will usually need to be of uniform area and shape, often square or rectangular.

2.2.1 Advantages

Block surveys:

- permit a sample survey to be flown in mountainous areas (the sampling units (blocks) can be searched as convenient for flying the terrain, i.e. not necessarily in straight lines).
- do not require flying height to be kept constant and hence need no special altimeter;
- can therefore be flown where-ever transect surveys can, when the special altimeter necessary to fly transects is not available;
- can provide useful distribution data if the blocks are uniform in area (usually square or rectangular) and the remaining blocks are systematically arranged after the position of the first block is determined randomly;
- provide a statistical measure of precision for the population estimate;
- produce results which are often more accurate than those from a total count, because sample surveys usually have a greater search effort (time spent searching per unit area); and
- are cheaper than total counts for large survey areas.

2.2.2 Disadvantages

Block surveys:

- often produce population estimates that are less precise at the same level of effort (in terms of both sampling intensity and flying hours) than transect surveys, and so the latter are carried out in preference, when possible, to maximise cost-effectiveness; and
- produce poor data on spatial distribution unless the blocks are arranged regularly, e.g. aligned with a map or similar grid, and blocks for searching are arranged systematically.

2.3 Total count

Total counts are intended to count every single animal in the designated area. They are conducted by flying along flight lines that are extremely close together (e.g. over the woody savannas of southern Africa adjacent flight lines would be no further apart than approximately 500 m). These flight lines may not necessarily be straight lines and depend on the terrain, the shape of the area and on the known distribution of elephants.

2.3.1 Advantages

A total count:

- avoids many of the difficulties of sampling (calibration and height recording for transects, design and analysis) and hence greatly simplifies the surveyor’s task (related to this, no radar altimeter or laser rangefinder is needed for the aircraft); and
- provides detailed data on spatial distribution.

---

[b] A *block* is a *sampling unit* which may be square or rectangular, or irregularly shaped and demarcated on the ground by physical features such as roads. Blocks are the sampling units in a block survey. The entire area of a stratum intended for block sampling must be divided into non-overlapping blocks and the boundaries of all blocks defined before blocks are selected for sampling. A block should not be confused with a *counting block*, which is a discrete subdivision of the study area during a total count. A *counting block* is usually of a size that can be covered by one aircraft during one flying day and is also often demarcated by roads, rivers and terrain. During a sample survey, such a subdivision of the study area is called a *stratum*. See the Glossary for more details.

2.3.2 Disadvantages

While, in principle, total counts are the most precise technique and can produce results as accurate as those from sample surveys if search effort standards are achieved (section 3.5.7), there are potential shortcomings that should be borne in mind:

- The "dead" zone below the aircraft may be inadequately covered from adjacent flight lines, causing animals to be missed;
- Navigation along closely spaced flight lines has to be extremely accurate throughout the survey to ensure all the ground is covered;
- When the search effort is great enough to ensure that no animals are missed, some may be counted twice because of the close spacing of flight lines (although this problem can be reduced by counting groups and mapping their locations simultaneously);
- The resources to carry out the hours of flying required for total counts are seldom available or justifiable;
- A total count is generally not practical for a large area unless it can be divided into smaller counting blocks (strata) that can be counted simultaneously using several aircraft;
- A population estimate derived from a total count lacks a statistical measure of precision; and
- A total count at best can provide only a minimum estimate of number present.

2.3.3 When to use a total count

Total counts may be considered:

- when there is a requirement that dictates a complete census (for example when the past counts have used this method and there is a need for comparability; or when the population to be surveyed is highly-clumped, with a relatively few big groups representing a large proportion of the population (GEC 2014)); or
- when a stratum of a survey requires a high coverage within the overall survey design, or
- when the survey area or stratum area is smaller than 100 km^2.

This last criterion is recommended because such a small area can be covered at a sufficiently high search effort within one flight, and it is feasible to identify all groups seen so that none are counted twice.

Norton-Griffiths (1978) recommended that, if a total count is conducted, a large survey area should be divided into smaller counting blocks; counting should extend into neighbouring blocks to address potential double-counting; large groups of animals should be photographed; and flight lines and animal locations should be mapped (nowadays with a GPS unit and displayed, alongside the block boundaries, on the moving map display of a GPS unit during the flight). Some experimental work can be conducted to test the observers' efficiency during a total count. For example, where bias, i.e. undercounting due to an inadequate search effort, is suspected, some strata should be repeated at a greater search effort to obtain an estimate of bias. Or, when many counting blocks within a survey area are, of necessity, not surveyed simultaneously, movement of animals during the survey constitutes a source of variation not reflected in the absolute precision assumed for a total census - this variability could be measured by counting some blocks a second time and comparing the two counts.

3 Standards for Aerial Surveys

Superscripts within this section of the document refer to notes (section 4) which elaborate points as necessary.

3.1 Selection of Aerial Survey Method

Where previous surveys have been done, it may be preferable to repeat the methods in the interests of obtaining a comparable result, rather than to use the strictly applicable methods given below.

The criteria about which survey method to use, described in section 2, are embodied in the following key, which comprises a simple repeatable protocol for the selection of the method. When starting a new series of surveys, the key should be followed.

Key for Selection of Survey Method (from Craig 2012)

1	a	Sampling effort required to meet survey objective (or, in the case of a stratum, sampling effort required to obtain optimum allocation among strata) is more than 70 %	…………...…………. **2**
	b	Required sampling effort < 70 %	…………...…………. **4**
2	a	Area to be counted smaller than 100 km^2	**Total Count**
	b	Area to be counted 100 km^2 or larger	……….……….….. **3**
3	a	Resources available are sufficient to cover all strata (counting blocks), nearly simultaneously, at a search effort of more than 0.67 minutes per km^2	**Total Count**
	b	Resources described in 3a are not available	…………………..…. **4**
4	a	More than 20 % of the survey area has escarpments or hills with slopes of more than 30 % for a height exceeding 200 m (i.e. the survey area is mountainous)	**Block Survey**
	b	Survey area not as described in 4a	…………………..…. **5**
5	a	Equipment (radar or laser altimeter, etc.) necessary for Transect Survey is available	**Transect Survey**
	b	Equipment necessary for Transect Survey is not available	**Block Survey**

3.2 Survey Plan

This section deals with the standardisation of approaches involved in the planning and design of aerial surveys.

3.2.1 Survey objective

The objective of the survey should be determined at the outset and stated in the report. The survey objective/s may be to obtain a population estimate or trend, in which case visibility is a critical factor; or to obtain an understanding of the spatial distribution of elephants, which can be affected by seasonal factors.

3.2.2 Boundaries

The limits of the survey area should be clearly defined at the outset, with GIS files created and stored digitally.

3.2.3 Sample survey

3.2.3.1 Sampling intensity

The overall effort to be expended will depend on the precision required by the objective of the survey [3] and therefore the survey design should maximise the precision of the population estimate within the available resources [4]. If the objective of the survey is to detect a change in elephant number, the overall sampling effort sufficient to detect a change of the required magnitude (Steidl *et al.* 1997) should be determined in advance.

3.2.3.2 Stratification

The survey area is usually divided into a number of subdivisions (strata); if possible, based on known populations. If there is no previous information on elephant populations and distribution, a pre-survey systematic reconnaissance flight (a recce flight) may be necessary to define the strata [5]. To maximise precision of the final estimate of elephant number, the sampling units within a stratum should contain similar densities of elephant. It is acceptable to change stratum boundaries from a previous survey to accommodate changes in population distributions or other requirements. However, the use of identical stratum boundaries facilitates trend analyses: should changes be needed in response to changes in density distributions, previous strata can be subdivided appropriately. It is highly recommended that the overall survey area boundary is not changed between surveys.

Ideally, strata are:

- each of uniform topography and ecology [6]; and
- contain homogeneous densities of animals [7].

Clearly establishing the stratum boundaries is usually the first requirement of a survey plan. A series of boundary coordinates provides a concise and repeatable description. The boundary of each stratum should be defined digitally. Each stratum should be allocated a unique code for identification.

In the case of an area of special interest (e.g. a MIKE site) which does not conform to a stratum or several strata, then the survey data must be collected in a manner that allows the data for the area of special interest to be extracted as a geographic subdivision.

3.2.3.3 Sampling units

For sample surveys, a representative sample of the study area will be selected. The sampling units can be transects or blocks.

3.2.3.3.1 Transects

- Transects must be oriented across the grain of the country rather than along it (Caughley & Sinclair 1994). Hence, transects should cross a river rather than run parallel to it; they should go up a slope rather than follow the contour. Each transect should sample as much as possible of the variation within the stratum, so that the variation between transects is minimised.

- The number of transects should be maximised by also orientating them approximately perpendicular to the long axis of the survey area or stratum.
- Transects should also be oriented to avoid flying directly into the sun in early morning or late afternoon.
- Transects should be arranged systematically [8] from a randomly selected starting point on a baseline which is at right angles to the transect orientation and runs the entire length of the stratum.

Each transect should be described by the location (i.e. latitude and longitude) of its start and end points. These should be in an electronic format suitable for loading into a GPS receiver.

If subunits will be used to record the locations of sightings, the transects will likely be orientated north-south, or east-west. A map of the grid squares which define the subunits should be prepared as a GIS vector file and points along the transects which mark a boundary between adjacent subunits should be loaded into the GPS receiver as waypoints.

3.2.3.3.2 Blocks

- Blocks may be rectangular quadrats or, in rugged landscapes, irregularly–shaped areas defined by features recognisable on the ground (e.g. roads, rivers, watersheds).
- The survey area (or stratum) should be divided into blocks each no larger than 20 km^2.
- Rectangular blocks should be selected randomly or systematically from a map covering the entire stratum.
- Irregularly–shaped blocks should be selected randomly from a map covering the entire stratum. If block size within a stratum varies, blocks should be selected with a probability proportional to their area, e.g. by using random numbers as map co-ordinates and selecting for searching those blocks in which the random points fall [9].
- Blocks of uniform shape and size can be randomly selected if each block is given a unique ID number. Or those to be searched can be arranged systematically in relation to the random location of the first selected block.

A rectangular block (quadrat) should be described as a vector of the corner points. An irregularly-shaped block should be described by a series of boundary coordinates. Block boundaries should be stored electronically in a format suitable for uploading to a GPS.

3.3 Equipment

3.3.1 Aircraft

Safety is crucial and it is important that a suitable aircraft is used. All standard flying safety procedures must be adhered to (e.g. quality of fuel, volume of fuel, flying conditions including temperature and terrain, etc.).

The quality of the Perspex forming the aircraft windows, particularly those of the observers, should be high in order to ensure that visibility is good. Perspex quality is especially important if photographs will be taken through the Perspex.

When possible, the same type of aircraft should be used for all surveys in a given area. If a different aircraft is used, it should be possible to fly safely at the same speeds as in the previous aircraft. Also, the aircraft should be similar in terms of altitude control, noise, comfort, seating configuration; visibility for the observers, and communication between crew members.

3.3.1.1 Total count

While helicopters are ideal for total counts, they are expensive. Fixed-wing aircraft are recommended and high wings are essential. These aircraft may be four-seaters, usually Cessna aircraft (170, 180, 182, 185, 206), or tandem two-seaters such as the Piper Super Cub or Christen Husky [10].

3.3.1.2 Transect survey

The Cessna 180, 182, 185 or 206, or Partenavia are commonly used, but others may also meet requirements [11]. The aircraft must be high winged. The Cessna 208 (Caravan) is not recommended [12].

3.3.1.3 Block survey

Those aircraft not considered useful for transect surveys, such as Piper Super Cub, Christen Husky, Kit Fox, Bellanca Scout or helicopter, can be used for block surveys. Other aircraft such as small Cessnas or microlights may also be feasible, but low speeds in mountainous terrain can be dangerous and must be well within the aircraft's power and performance capability.

3.3.2 Navigation equipment

A printed map of the area should be carried in the aircraft. For all surveys the following are needed for navigation:

Two GPS units are essential, one for the pilot and one for the recorder/FSO [13]. The GPS units must possess the following facilities:

- a moving map display;
- the ability for position information (waypoints, routes and track logs) to be uploaded and downloaded; and
- the ability to record position continuously (track log function).

For all survey types and for all flights, the GPS units should be set to record the track of the aircraft (flight path) at intervals of 1-4 seconds using the GPS track log facility.

For transect surveys, the intended flight path along transects should be entered into the GPS units to show the route. The responsibilities of the recorder/FSO include using his/her GPS unit to monitor ground speed and cross-track error. If the subunit system is used to record observations, the FSO is responsible for calling changes in subunit along a transect to the observers (RSOs).

3.3.3 Intercom

The aircraft must be fitted with an intercom system and a headset for each crew member to allow easy communication among the crew. The system should have a cut-out switch to enable the pilot to use the radio while the other crew members remain in contact over the intercom.

3.3.4 Digital voice recorder

If the call-out system is used to record observations, a digital voice recorder should be linked to the intercom system, to provide a back-up record of the sightings made by the observers and called to the recorder. This is particularly important for multi-species surveys. If the subunit system is used to record observations, each observer (RSO) should use a digital voice recorder to record observations by subunit.

3.3.5 Equipment for transect survey

3.3.5.1 Altimeter

- For maintaining and recording height, the aircraft must be fitted with a laser altimeter (rangefinder) or radar altimeter.
- The laser altimeter must be able to measure accurately distances up to at least 400 ft.
- The radar altimeter must be calibrated prior to and occasionally (if the survey is over a long period) during the survey. This can be done by comparing the reading of the radar altimeter with that of the pressure altimeter (set to zero on the ground) while flying over the point where it was zeroed. [14]
- A laser altimeter can be tested in a similar way.

3.3.5.2 Strip markers

There must be two markers on each side of the aircraft to mark the inner and outer sides of the search strips. These markers should be stiff rods securely clamped to the wing struts of the aircraft [15]. The rods must be long enough to cover the full view of an observer. The rods are arranged to demarcate, on each side of the aircraft, a search strip close to 150 m wide (and no wider than 200 m) when the aircraft is flying at the target height (see Calibration of search strips for transect survey).

3.3.5.3 Photographic equipment

Photography can be used to reduce counting bias by the observers (Norton-Griffiths 1974). Therefore, each observer should be equipped with a digital SLR camera which should be:

- used to take an oblique photograph of each group of 10 or more animals seen by the observer inside the strip;
- not handheld;
- mounted on the window frame (if the window can be opened or removed when the aircraft is in flight), or attached to the window with a large suction mount;
- fitted with a wide-angle (e.g. 24 to 28 mm focal length) lens with manual focus capability and the focus point taped at infinity;
- set to record images of the highest quality and greatest resolution;
- positioned so as to replicate the observer's angle of view and to include the two rods demarcating the strip, as well as the decision point, in each photograph;
- capable of taking photographs with a resolution ≥18 megapixels; and
- capable of being fired with an electronic cable release.

Furthermore:

- The quality and cleanliness of the Perspex forming the observers' windows is of central concern when it is planned to take photographs through the Perspex.
- The date/time setting of each camera should be synchronised with the date/time displayed by a GPS unit immediately prior to the start of a survey.

3.4 Crew

The standard crew in a four or six-seater aircraft for a transect survey, or a total count in non-mountainous terrain, is a pilot, a recorder (or front-seat observer), a left observer and a right observer (left and right rear-seat observers) [16].

For a block survey, or a total count in mountainous terrain, a two-seater aircraft can be used, with the pilot and a recorder/observer seated side by side, or one behind the other. The pilot then has a secondary role as an observer, when it is safe for him/her to do this.

3.4.1 Pilot

- Commercial pilot or suitably qualified pilot;
- Recommended minimum of 1000 hours flying experience; and
- Experience of bush flying (e.g. flying low level at relatively low speeds, landing and taking-off on dirt, often short, airstrips).

3.4.2 Recorder / Front seat observer

This should be someone, preferably a wildlife biologist, with:

- demonstrated experience of aerial surveys;
- the ability to take recordings (sightings and positions) rapidly and accurately;
- the ability to make decisions during the course of the flight; and
- the ability to supervise all in-flight survey procedures.

In-flight survey procedures include: monitoring adherence to the required flying height, ground speed and route, and advising the pilot to correct any significant deviations; and interacting with and supervising the observers.

3.4.3 Observers

Observers should have adequate experience and training [17]. They must:

- have good visual acuity;
- be physically capable of carrying out air surveys (e.g. not suffer from air sickness);
- be able to identify correctly and count accurately species and carcasses;
- be able to estimate correctly animal numbers in large groups; and
- be able to use the mounted camera reliably to photograph groups of 10 or more animals.

For transect surveys, the observers must also:

- be able to generate a consistent calibration (see section Calibration of search strips for transect survey); and
- be able to determine correctly whether observations are in or out of the search strip.

For operation of two-seater aircraft during a block survey or total count, both the pilot and observer/recorder must have experience of aerial observation, species identification and estimation of group sizes.

3.5 Survey Implementation

3.5.1 Comparability of Surveys: Season / Times

For the best estimates of population number, surveys should be carried out at the best time of year for visibility, usually when most trees and shrubs have few leaves.

Wet season surveys may not provide accurate population estimates because of differences in vegetation cover and therefore visibility, and differences in elephant movements and densities, but will provide information on elephant spatial distribution during that season and population estimates that can be used as indices of abundance.

Flights should be at the best time of day for observation, depending on local conditions including cloud cover. Flights in the middle of the day are usually not useful as animals tend to rest under trees and are then easily missed. But flights soon after sunrise or shortly before sunset should also be avoided because long shadows hinder the observers' ability to see animals.

3.5.2 Survey period

Surveys must cover the entire survey area within as short a time as possible. This is particularly important during transboundary surveys of elephant which are known to move rapidly in response to environmental conditions (rainfall, disturbance, etc.). It is not acceptable to allow long periods to pass between surveys of adjacent strata, nor to conduct part of the survey during one season and continue the remainder during another.

3.5.3 Ground speed

Transect surveys and total counts should be flown at a ground speed of approximately 90 knots (170 kph) and ground speed should not exceed 100 knots (185 kph) Block surveys should be flown at 70 knots or less (≤130 kph).

3.5.4 Navigation

A printed map showing the blocks, transects, or counting blocks should be carried [18]. Tracks of all flights (the track logs) must be recorded on a GPS unit and down-loaded to a computer after each flight.

3.5.4.1 Total count

Total-count strata (counting blocks) are covered using parallel flight-lines flown by reference to the map display of the pilot's GPS unit, with the spacing between the lines being appropriate to vegetation cover. In East African savannahs, where there is often <25 % woody cover, adjacent flight lines may be 1 km apart; in more dense woodlands of southern Africa, adjacent flight lines may be as close as 500 m. If the results of total counts are intended to be comparable to those from transect surveys, the line spacing should be 500 m (in order to achieve a comparable search effort).

3.5.4.2 Transect survey

Transects are flown by reference to the GPS. The pilot should aim to keep the aircraft within 50 m of the transect line. The maximum unplanned deviation from that line should be 100 m [19].

3.5.4.3 Block survey

Blocks are also covered by flying on flight lines spaced at about 500 m or less. If necessary, lines may be curved and orientated as required by terrain.

3.5.5 Height above ground level

3.5.5.1 Transect survey

The flying height should be the same for successive surveys of an area (i.e. it should not be changed from 300 ft on one survey and to, say, 350 ft for the next survey). In southern Africa, the flying height should be maintained close to 300 feet agl (the historical norm) when flying transects and ideally recorded every 30 seconds. Where previous surveys have used a different height standard, it is preferable to maintain that standard: in eastern Africa, surveys have been conducted at 350 or 400 feet.

Common models of laser altimeter may not properly record flying heights greater than 400 ft.

A laser altimeter can be connected to a flightlogger to provide a detailed record of flying heights during a flight.

3.5.5.2 Block survey or total count

During a block survey or a total count, flying height is at the discretion of the crew and takes into consideration the optimal height for sighting animals as well as safety [20].

3.5.6 Calibration of search strips for transect survey

- Calibration [21] must be done before the survey by flying at the ground speed to be used during the survey across numbered markers clearly marked at 10 m intervals on the ground.
- A marker (a small piece of tape) on the window at the eye level of each observer helps ensure consistency of viewing angle if the observer aligns his/her eye with the marker and the outer rod. If the tape is moved during calibration, the calibration process must restart. After calibration, the tape must not be moved and it must remain in place throughout the survey.
- Tape markers on the rods provide a *decision point* at which to determine if a group of animals is inside the strip, and the point at which the calibration numbers are read.
- Although separate left and right values are obtained, calibration must be carried out for *pairs* of observers (i.e. if one observer fails to see the calibration numbers, then that pass is omitted from the calibration series).
- Height agl is recorded on each pass overhead the markers
- Height should be varied between at least 50 ft below and 50 ft above the planned survey flying height, but the range of flying heights during calibration should be as wide as practical.
- At least 20 replicate passes should be performed per calibration
- The actual strip width during calibration should be positively and linearly correlated with the flying height. A linear regression of actual strip width against flying height agl should have an intercept on the y-axis that is close to zero.
- Standard error of the mean calibrated strip width should be less than 5 % of the mean calibrated strip width
- Strip width should be no more than 400 m in total (200 m per side) at 300 ft agl (or at survey target height if different from 300 ft). But strip widths close to 150 m per side at survey target height are preferred.
- Calibrated strip widths are specific to the individual observers. If one or both observers change partway through a survey, or even if the observers switch between the left and right seats, the strip widths must be re-calibrated for those observers/positions.

3.5.7 Search Effort / Search Rate

The search effort is expressed in minutes per km^2 and the search rate is the same measure expressed in reverse, in km^2 per minute [22]. (The former units are preferred because, all other things being equal, a survey with a high search effort would be better than a survey with a low search effort.)

The following are commonly acceptable search efforts (Craig 2012):

Survey Type	Search Effort (minutes per km^2)	Search Rate (km^2 per minute)
Transect or block survey	0.67 - 1.0	1 - 1.5 (≡ 60 – 90 km^2 / hour)
Block survey with crew of 2	1	<1
Total count	0.67 - 1.0	1 - 1.5

The search effort should never be less than 0.67 minutes (40 seconds) per km^2 (exceed 1.5 km^2 per minute).

The survey plan should aim to achieve a search effort of 1 minute per km^2 (1 km^2 per minute).

3.5.8 Commuting, positioning and counting

The ratio of commuting/ferry time to counting time should be minimised [23]. Records of flying times spent on searching/counting, positioning between sampling units and commuting should be kept.

3.5.9 Fatigue

The primary objective is to minimise observer fatigue. To achieve this, it is recommended that:

- Maximum counting (searching) time per transect is 20-25 minutes
- Total counting time is a maximum of 3 (-3.5 [24]) hours per flight and 5 hours per day.
- Total flight time (time between take-off and landing) is a maximum of 5 hours.

Observer fatigue may also be reduced by limiting survey flights to one flight per day and ensuring that survey crews have frequent rest days. If practical in terms of survey planning and logistics, survey flights should take place only during the morning (and not the afternoon), and survey crews should have a rest day (or a non-fly day with only light duties) after four consecutive days of intensive survey flights.

Low-level flying is tiring for pilots and thus regular rest days for pilots are an important safety as well as legal requirement.

3.5.10 Observing - general

Observers should restrict their attention to the species of interest - in this case elephants and elephant carcasses [25]. Depending on the survey objectives, other observations should be secondary and discretionary.

During a total count, the observer(s) should concentrate on searching close to the aircraft. Avoiding double-counting (counting the same elephant group twice) within a counting block requires the crew to use group size, composition and location to determine if a group was seen previously whilst flying the previous flight line.

During a transect survey, the observers' search pattern should concentrate within the strip, with attention on the inside marker [26]; i.e. the search should start on the inside marker moving out to the outer marker, flip back to the inside marker and then moving out to the outer marker again. Confirmation that a sighting is within the strip should be made for each sighting by reference to the strip markers. Numbers of animals in and out of the strip for groups that are partially out of the strip should be determined [27]. Groups of 10 or more animals should be photographed to check the real-time estimate.

During a block survey, whether an observation is in or out of the sampling unit is determined by reference to the moving map display of the GPS unit.

3.5.11 Observations to be recorded

If the call-out system is used during a transect survey, the observations by the observers should be called to the recorder and recorded manually by the recorder directly onto datasheets, with a digital voice recorder providing a back-up record of all conversations in the cockpit. The recorder should mark a waypoint and record the waypoint number on the datasheet.

If the subunit system is used during a SRF transect survey, the observations by the RSOs should be dictated into individual digital voice recorders, which should also record changes in transect and subunit numbers, as called by the FSO to the RSOs.

3.5.11.1 Each flight [28]

- Aircraft registration
- Crew names and roles
- Survey name
- Date
- Weather at start of flight
- Time of take-off
- Time of landing
- Track log [29]

3.5.11.2 Each sampling unit [30]

- Survey name
- Stratum name
- Sampling unit name / number
- Time of start
- Time of finish
- Location of start (in decimal degrees) [31]
- Location of end (in decimal degrees)
- Height in feet above ground level every 30 seconds [32]
- Any changes in weather / visibility
- Filename for waypoints [33]

3.5.11.3 Each sighting

- Species/observation
- Number seen
- In or out of strip
- Left or right of aircraft
- Location (in decimal degrees) [34]
- Subunit number (if subunits used)
- Optional notes (e.g. fire, water, poachers, poaching camps, dogs)

3.5.11.4 Species/observations that must be recorded [35]

- Elephants in family group
- Elephants in bull group
- Elephant carcasses
  - category 1
  - category 2
  - category 3
  - category 4
  - (Remark when tusks seen in carcass; or when lower jaw seen hanging in nearby tree; or when carcass is covered with vegetation)
- Other species, depending on local requirements

Codes used to record species/observations on the datasheets should be clear and consistent [36].

3.5.12 Post-flight protocol

Photographic imagery should be downloaded promptly after each flight and cross-checked with observers so that an image is matched with the observation record.

The track log (= actual flight path), route (= intended flight path) and waypoints (= sighting locations) should be downloaded from the recorder's GPS unit promptly after each flight and saved as a gpx file. If a flightlogger was used, the flying heights agl should be downloaded. The aircraft's / pilot's GPS unit provides a second track log and that should also be downloaded. Track logs include a record of ground speed throughout a flight.

Sound files from digital voice recorders should be downloaded promptly after each flight. The voice records of observations by RSOs should be transcribed promptly to datasheets.

3.5.13 Data security during and immediately after the survey

Care should be taken to prevent the corruption or loss of data during survey implementation and during the transport of data to home base [37].

3.6 Data Analysis

3.6.1 Total count

For total counts, the minimum number of elephants in the survey area is calculated simply as the sum of the numbers counted in the separate counting blocks (after elimination of any groups which were believed to have been double-counted accidentally).

3.6.2 Transect survey

3.6.2.1 Population estimate and variance

When the transects within one stratum have unequal areas (which is usually the case, even if the transect lengths are identical, because the mean flying heights and thus transect widths likely differ), Jolly's (1969) method 2 should be used to calculate, for each stratum and each species, the population estimate, its variance and its confidence limits, as below. Jolly's method 2 is a ratio estimator which is a method of estimation widely used in wildlife surveys. Each transect is formed of two search strips, the left one and the right one, and so, prior to the analysis, for each transect the sightings by the left and right observers are combined. Then:

$$R = \frac{\sum y}{\sum z}$$

$$\hat{Y} = Z.R$$

$$Var_{\hat{Y}} = \frac{N(N-n)}{n} \,.\, (s_y^2 - 2.R.s_{xy} + R^2.s_z^2)$$

where:

$\hat{Y}$ = estimate of number of animals in stratum

y = number of animals counted in sampling unit

Z = total area of stratum

z = area of sampling unit

R = mean density of animals in sampling units

n = number of sampling units in stratum

N = number of possible sampling units in stratum (N = length of stratum baseline / mean actual width of transects flown in stratum)

s_y^2 = variance between numbers of animals counted in sampling units

s_z^2 = variance between areas of sampling units

s_{xy} = covariance between animals counted and areas of sampling units

$Var_{\hat{Y}}$ = population variance of stratum; the standard error ($SE_{\hat{Y}}$) is the square root of this

The baseline is a straight line orientated at right angles to the transects and running the full length of the stratum (see Norton-Griffiths (1978, his figure 3). The 95 % confidence interval is calculated from the standard error × *t* (where *t* is Student's *t* for p = 0.95 (α = 0.05 and *n*-1 degrees of freedom), which is approximately 2 for large *n*). The 95 % confidence limits are the estimated number of animals ± the confidence interval. When the lower confidence limit is less than the actual number of animals seen in the stratum, the actual number seen can be taken as the lower limit. The Percentage Relative Precision or Relative Margin of Error is calculated as the 95 % confidence interval expressed as a percentage of the population estimate:

$$PRP = RME = \frac{SE_{\hat{Y}}}{\hat{Y}} \, .t.100$$

3.6.2.2 Mean flying height

The mean flying height and its standard deviation should be calculated for the survey and reported.

3.6.2.3 Comparison of left and right observers (left and right RSOs)

For each species, the number of groups seen by the left and right observers (RSOs) should be compared using a chi-square test, with the expected numbers calculated on the basis of the observers' individual strip widths [38].

For each species, the number of animals in the groups seen by the left and right observers should be compared using a Mann-Whitney *U*-test to determine if any differences are statistically significant [39].

3.6.3 Block survey

3.6.3.1 Population estimate and variance

For block surveys with blocks that are identical or nearly so in size; and with all blocks having equal probability of being selected for searching, or the selected blocks being arranged systematically, Jolly's (1969) method 2 should be used to calculate, for each stratum and each species, the population estimate, its variance and its confidence limits, as above. (Jolly's method 1 is appropriate if all blocks are identical in area, but method 1 is a special case of Method 2 (Caughley & Sinclair 1994)).

For block surveys in which blocks for searching are selected in proportion to their area (e.g. using random map co-ordinates), blocks can be selected with or without replacement (Caughley 1977b). Sampling with replacement means that a sampling unit is returned to the pool of sampling units available for selection even after it has already been selected. In practice, this means that "if one [sampling] unit happens to contains, say, two or three [random] points, this unit is counted two or three times in the subsequent calculations; it need, of course, be [searched] only once" (Jolly 1969).

If blocks for searching are selected in proportion to their area, Jolly's (1969) method 3 should be used to calculate, for each stratum and each species, the population estimate, its variance and its confidence limits, as below.

$$\hat{Y} = Z.\bar{d}$$

$$Var_{\hat{Y}} = \frac{Z^2}{n} . s_d^2$$

$$s_d^2 = \frac{1}{n-1} . (\sum d^2 - \frac{(\sum d)^2}{n})$$

where:

$\hat{Y}$	=	estimate of number of animals in stratum
y	=	number of animals counted in sampling unit
Z	=	total area of stratum
z	=	area of sampling unit
n	=	number of sampling units in stratum
d	=	density of animals in sampling unit ($d = y / z$)
$\bar{d}$	=	mean density of animals in sampling units
s_d^2	=	variance between density in sampling units
$Var_{\hat{Y}}$	=	population variance of stratum; the standard error ($SE_{\hat{Y}}$) is the square root of this

The 95 % confidence interval is calculated from the standard error × *t* (where *t* is Student's *t* for p = 0.95 (α = 0.05 and *n*-1 degrees of freedom), which is approximately 2 for large *n*). The 95 % confidence limits are the estimated number of animals ± the confidence interval. When the lower confidence limit is less than the actual number of animals seen in the stratum, the actual number seen can be taken as the lower limit. The Percentage Relative Precision or Relative Margin of Error is calculated as the 95 % confidence interval expressed as a percentage of the population estimate:

$$PRP = RME = \frac{SE_{\hat{Y}}}{\hat{Y}} . t. 100$$

3.6.4 Carcass ratio

For all surveys, the carcass ratio (Douglas-Hamilton & Burrill 1991) should be calculated as:

$$100 . \frac{Number\ of\ carcasses}{Number\ of\ carcasses + Number\ of\ live\ elephants}$$

Although called a ratio, the figure is actually a percentage and reported as such. It is based on all elephant carcasses and provides an index of mortality during the several years preceding the survey.

An index of the most recent mortality is provided by the 1+2 carcass ratio, which is calculated as:

$$100 . \frac{Number\ of\ category\ 1\ carcasses + Number\ of\ category\ 2\ carcasses}{Number\ of\ category\ 1\ carcasses + Number\ of\ category\ 2\ carcasses + Number\ of\ live\ elephants}$$

3.7 Reporting

3.7.1 Narrative report

This should contain the following elements:

3.7.1.1 Summary

The summary should be understandable without reference to other sections of the report.

3.7.1.2 Background

- location of survey area, dates, area description
- previous information (e.g. past surveys)
- survey objective
- survey design, stratification, sampling
- power of design [40]

3.7.1.3 Results

3.7.1.3.1 Narrative

There should be a narrative with any other notable results, e.g. remarks on carcasses seen, large increases or decreases in population estimates since previous surveys.

3.7.1.3.2 Tables

For sample surveys, the tables of results should include results for each stratum, for combined strata and for the entire survey area.

For a total count, the tables of results should include results for each counting block (stratum) and for the entire survey area.

There should be separate tables for:

- All elephants
- Elephants in family groups
- Elephants in bull groups
- Elephant carcasses
  - category 1
  - category 2
  - category 3
  - category 4
  - carcass ratios [41]

For a sample survey, each species table should report, for each stratum, for combined strata and for the entire survey area:

- estimated number of animals
- number of animals seen in the sample
- additional animals seen [42]
- variance of estimate [43]
- 95 % confidence interval
- PRP (Percentage Relative Precision), also known as RME (Relative Margin of Error)
- density

For a total count, each species table should report, for each counting block (stratum) and for the entire survey area:

- number of animals seen in the counting block
- density

3.7.1.3.3 Correction factors

All the numbers in the above results tables must be reported without the use of any correction factors. If correction factors are used for any reason, this must be clearly stated and the correction factors must be given. Then additional tables derived after the application of correction factors may be included. But these must be additional tables and not replacements for the above required tables.

3.7.1.3.4 Maps

There should be maps showing:

- track logs of the flights along transects, in blocks, or in counting blocks; and
- for each species/attribute, the stratum or counting block boundaries and the sighting locations; or a grid map if the survey was undertaken using a subunit method.

3.7.1.4 Discussion

The discussion should avoid speculation. It should comment on at least the following:

- difference in numbers and precision compared with previous comparable surveys, preferably illustrated in a table;
- implications of changes in estimated numbers;
- implications of carcasses seen;
- comments and any problems encountered; and
- any deviations from the MIKE survey standards.

3.7.1.5 Literature cited

Sources of information about the survey area or previous surveys should be given.

Sources for methods or design unique to the survey should be given.

3.7.1.6 Appendices

The following information should be included in the report. It may be in the body of the report, but, if it is not, it must be placed in appendices.

For all surveys, the following information should be included:

- details of methods (including aircraft type,
- crew details
- flight information: dates and times for sampling flying, positioning and commuting flying
- map of strata or counting blocks, with tracks actually flown
- equipment list including makes and models of GPS units, altimeter and cameras, and details of the software versions in these units [44]
- mean ground speed and search effort for each stratum or counting block
- description of file names and formats for digital data archived

For a sample survey, the following information should also be included:

- sampling information: strata, sampling design, areas, the actual sampling intensities for the strata (as opposed to the planned sampling intensities); number of sampling units
- map of strata and sampling units

And for a transect survey, the following additional information should also be included:

- calibration data, including variance estimate
- mean height flown for the survey and its standard deviation
- comparison of left and right observers

3.7.1.7 Additional information

The above sections detail the minimum information which should be in the report. The report may include any additional information which the author considers relevant or important.

3.7.2 Distribution of report

CITES Parties, which include all African Elephant range States, have agreed that data on elephant populations will be maintained in databases established by the IUCN Species Survival Commission's African Elephant Specialist Group (CITES Resolution Conf. 10.10 (Rev. CoP18) – 1). Hence, with the permission of the contracting authority, a copy of the survey report and the GIS vector files should be submitted to the African Elephant Database, along with guidance on their further use or distribution.

3.8 Data Archive and Data Security

After the survey, the data should be archived and secured safely so that it is readily available for possible review or audit.

3.8.1 Data security

There should be a clear, systematic protocol for the safe storage and retrieval of the survey data. For example, the digital data should be stored on several servers and in more than one location and certainly not on a single laptop [45].

3.8.2 Information to be included in archive

3.8.2.1 Original datasheets

The original datasheets without transcription, or scans or photographs of them.

The original calibration datasheets without transcription, or scans or photographs of them.

3.8.2.2 Digital copies of data

The following information should be archived electronically:

- Stratum / counting block boundaries (GIS vector files)
- Track logs (actual records of tracks flown, in gpx format)
- List of strata / counting blocks with names, areas (and sampling intensities)
- List of species/observations giving alphabetic code (used as identifier in digital records of sightings) numeric code and description

For sample surveys:

- Sampling unit descriptions consisting of 1 record for each unit. For transect surveys, the records should have the following fields:

    stratum name;
    transect number;
    date;
    time of start;
    time of end
    longitude/latitude of start;
    longitude/latitude of end;
    mean flying height agl; and
    mean width of strip.

  For block surveys, the records should have the following fields:

    stratum name;
    block number;
    date;
    time of start;
    time of end;
    area; and
    file name for GIS vector file with block boundaries.

- Description of each sighting consisting of 1 record for each sighting with the following fields:

  stratum / counting block name/number;
  sampling unit number;
  date;
  time;
  species alphabetic code;
  species numeric code;
  number seen;
  number counted on photograph (if taken);
  file name/number of photograph (if taken); and
  longitude/latitude (decimal degrees).

  For transect surveys, there should be these additional fields:

  subunit number (if subunit method used);
  in/out (of search strip); and
  left/right (observer).

- The photographs taken of groups of 10 or more animals should be included in the archive with, for each, details of the location and count data (both photo and visual)
- Maps of all subunits and blocks (if used)
- GIS files defining each stratum and sampling unit, or each counting block
- GIS file defining each subunit (if subunits used)
- For transect surveys, a comparison of left and right observers
- For sample surveys, files illustrating the calculations involved in the analyses to determine the population estimate and variance using Jolly's (1969) methods

3.8.3 Distribution of survey data

CITES Parties, which include all African Elephant range States, have agreed that data on elephant populations will be maintained in databases established by the IUCN Species Survival Commission's African Elephant Specialist Group (CITES Resolution Conf. 10.10 (Rev. CoP18) – 1). Hence, with the permission of the contracting authority, a copy of the survey's GIS vector files should be submitted to the African Elephant Database.

3.9 Improved Equipment and Methods

The above standards are intended to be the minimum necessary to meet the data requirements. However, no standards can ensure a perfect result and so there will always be room for improvement in equipment and methods. Where new methods can be shown to give an improved result, these can be adopted. However, when that is done, the comparability of previous results for the area with the improved results must be ensured.

4 Notes and Advice

The notes in this section do not form part of the survey standards, but are intended to illuminate the needs for particular standards, when this is considered necessary; or to provide advice to those wishing to implement the standards, when this is considered useful.

---

[1] Problems with aerial distance surveys using fixed-wing aircraft include violation of critical assumptions of the method, including that: all animals on the transect line are detected; animals are detected in their original locations; and perpendicular distances from the transect are measured accurately. In practice: the observers cannot see the transect line, which is ahead of and then under the aircraft; animals may move away from the transect in response to the aircraft flying overhead; and animals may be inaccurately assigned to a distance interval owing to aircraft's rolling movements, as well as the difficulty of determining when animals are perpendicular to aircraft. Griffin *et al*. (2006) found that the estimate of elephant number in Kruger NP determined using distance sampling was substantially less than that obtained from transect sampling, or from a total count undertaken using a helicopter.

Helicopters have been more successful for conducting distance surveys, because they can travel slower and because the pilot and recorder/observer in the co-pilot's seat can easily see forward and observe animals that are on or near the transect line before they move. Goodman & Worth (2018) used an aerial distance survey flown with a 5-seater AS350 B-2 Squirrel helicopter to estimate elephant number in Karingani GR, Mozambique. With flight lines 1 km apart (in effect, a total count), 707 elephants were counted in 127 groups. The same dataset subjected to distance analysis gave a population estimate of 835 (with 90 % confidence limits 576 and 1210), a (non-significant) increase of 18 %. For a similar survey in Ikorongo and Grumeti GRs, Tanzania, distance analysis gave a mean population estimate that was (a non-significant) 5 % greater than the total count number (Goodman & Mbise 2018).

[2] For example, a total count of elephants in the Tsavo ecosystem, Kenya, during February 2014 returned a population number of 11217 (Kyale *et al*. 2014). The following month, a transect survey returned a population estimate of 14087 (+/- 95 % confidence interval of 2929) (Chase *et al*. 2014).

[3] As an example, the target of aerial surveys at MIKE sites was to be able to detect a real decrease of 40 % between surveys, given β (the probability of making a type II error) of 0.2 and α (the probability of a type I error) of 0.05. This could be achieved if the PRP/RME was 20 % or less (Craig 2012).

[4] There is no standard on the sampling intensity to use for a survey, but the following notes are relevant.

Survey objective If the primary survey objective is to determine the spatial distribution of elephants in the survey area, then the sampling intensity to be used during the survey will be determined by the required spatial resolution of elephant sightings. A sampling intensity of 20 % (with a planned transect width of 300 m) will be met with systematically arranged transects, 1.5 km apart, over the entire survey area; while a sampling intensity of 5 % will require transects 6 km apart.

It is more likely that the primary objective of the survey will require a precise estimate of elephant number in the overall survey area.

Relationship between precision of population estimate and sampling intensity In a stratum or unstratified survey area, the precision of a population estimate increases (i.e. the variance decreases) with increasing sampling intensity, but the relationship is not simple. Initially the variance declines rapidly as the sampling intensity increases, but then further increases in sampling intensity reduce the variance relatively little (e.g. Jachmann 2001, his Figure 6.7). Hence, the point at which the curve starts to flatten out represents the best compromise between maximising the precision and minimising the flying time. While the general shape of the curve is similar for different areas, the actual shape depends on s_y^2, the variance in the number of elephants seen between sampling units. If this is small, then initially the precision of the population estimate increases rapidly as sampling intensity increases, but then the increase in precision falls off rapidly as sampling intensity increases further (e.g. Jachmann 2001, his Figure 6.7). But if s_y^2 is large, then the increase in precision is less marked and there is a less marked fall off (e.g. Norton-Griffiths 1978, his Figure 6). s_y^2 increases with both the density of elephants in the survey area or stratum, and with their herd size.

Relationship between precision of population estimate and elephant number and range Barnes (2002) used data from a wide range of aerial surveys to illustrate how the precision of the population estimate increased both with the estimated number of elephants and with the area of their range. Precision initially increased rapidly as number or range area increased, but then declined much more slowly as number or range area continued to increase. Barnes did not consider the effect of sampling intensity, other than to consider only those surveys with an intensity >5 %.

Cost Flying time is a major component of survey cost and the number of flying hours needed to undertake a survey is directly proportional to the sampling intensity. Hence, both the precision of the population estimate and the cost of survey increase as sampling intensity increases. But beyond a certain sampling intensity, the law of diminishing returns applies - survey costs continue to increase in proportion to sampling intensity, but with little increase in precision. Unfortunately, that certain sampling intensity varies between areas as elephant density and herd size vary. It can even differ within a survey area over time, if, for example, poaching reduces the density of elephants but the disturbance caused by poaching prompts the surviving elephants to form large herds.

Increasing number of sample units without increasing sampling intensity The survey plan should optimise the number of sampling units for any given sampling intensity. For a transect survey, this means ensuring that transects are perpendicular to the long axis of a survey area or stratum, which increases the number of transects within that area or stratum with only a small increase in flying time (specifically, in the time spent flying between transects).

For a block survey, searching many small blocks would be better from a statistical viewpoint than searching a few large blocks. But this strategy would increase the proportion of the flying time that was spent flying *between* blocks rather than searching *within* blocks, which is not an efficient use of flying time. The survey planner must strike a compromise between block size and number searched. An advantage of the random selection of blocks to be searched during a block survey is that the sample size does not have to be determined in advance of the survey. If a minimum sample size is set at, say, 5, then the first five selected blocks can be searched in whatever order is most efficient in terms of flying time. If, after searching those five blocks, the variance of the population estimate is too judged to be too great, then the sixth selected block can be searched and a new variance calculated. Additional blocks can be added to the sample until the surveyor is content with the variance for the population estimate. But those additional blocks must be added to the sample in the same order as they were randomly selected. However, this approach does require flexibility in the survey logistics.

Increasing precision of population estimate without increasing sampling intensity The precision of the overall population estimate for a survey area can be increased (without increasing sampling intensity and thus costs) by: (a) efficient stratification of the survey area; (b) orientating transects across the grain of the landscape; and (c) the optimal allocation of sampling effort to different strata on the basis of predicted densities (Appendix 1). Actions (a) and (b) reduce s_y^2, which, for any given number of sampling units, should increase the precision of the population estimate. Action (c) varies the number of sampling units in the different strata, placing more sampling units in strata where s_y^2, is expected to be greater.

Logistics Finance and statistics are not the only factors influencing survey planning – sometimes practicalities will overrule both. For example, aircraft used for surveys usually require a 'check' (equivalent to a vehicle service) every 50 or 100 flying hours. Unless the pilot is also qualified to conduct that check, the aircraft will probably have to fly to a major airport specifically for that check. These positioning flights count towards the between-check flying hours (and have to be paid for). Hence, it is a good idea to design a survey so that the number of flying hours required to complete that survey falls within the between-check interval and is not slightly greater.

Planning a survey From the above, it is clear that it is easier to design an aerial survey with the primary objective of obtaining a precise estimate of population number if a comprehensive report from a recent previous survey of the same area is available, or if detailed data (particularly the s_y^2 values) from that survey are available. The report and data should be used to determine if there is scope for improving the stratification (with a preference, if possible, for subdividing old strata rather than making a new subdivisions of the survey area if revisions are considered necessary), or changing the transect orientations. Planning should always consider if elephant density, the spatial distribution of herds, or the herd sizes may have changed since the last survey, either for environmental reasons (e.g. changes in the spatial distribution of surface water), or because of disturbance (e.g. poaching). Optimal allocation of sampling effort between the strata (Appendix 1) should be based on the new, predicted densities.

Gasaway *et al*. (1986) advise on the planning of surveys to detect specified population changes, explaining how to estimate the required precision (variance) of a second population estimate when the first survey has been completed; or how to estimate the required precision before making the first of two surveys. But again these require information from previous surveys of the same area.

Sometimes there will have been no previous survey in the planned survey area. Or the previous survey was long ago and major changes in elephant density or distribution are known or believed to have occurred since that survey. Caughley & Sinclair (1994) offer practical advice on dealing with sampling effort allocation in this situation. First, guess the expected density in each stratum (using knowledge from similar survey areas and/or observations from anyone working on the ground in the planned survey area); then guess the expected number of elephants in each stratum (= guessed density x stratum area). The number of sampling units allocated to each stratum should be directly proportional to the number of elephants expected in the stratum. As Caughley & Sinclair (1994) explain, it does not matter too much if the guessed densities are wrong, even badly wrong.

In strata where very few or even no elephants are predicted to occur, the number of sampling units could be as low as five; but in strata where numerous elephants are predicted to be, the number of sampling units could be 30 or more.

Sampling intensity should be greater in small survey areas with relatively few elephants, than in large areas with large populations of elephants. With two search strips each 150 m wide, transects will be 1.5 km apart for a sampling intensity of 20 %. Attempting to increase sampling intensity beyond 20 % by reducing transect spacing is inadvisable, because of the possibility that any animals disturbed by the aircraft on one transect may move into the adjacent transect. But a greater sampling intensity can be achieved by surveying a survey area twice during a short period, each time at, say, 20 % sampling intensity, and then merging the results of the two surveys (Gasaway *et al*. 1986) to provide a population estimate effectively based on a 40 % sample.

The following table suggests sampling intensities that are commonly used in survey areas of various sizes. But in practice, the sampling intensity used for any aerial survey is often dependent on a combination of statistics, costs and logistics.

Survey Area (km^2)	Approximate Sampling Intensity (%)
*c.*1000	≥20
*c.*1000 – 5000	20
5000 – 10000	15 - 20
10000 - 20000	10 - 15
>20000	5 - 10

[5] Management staff or safari operators may be able to provide current information about an area (e.g. the spatial distributions of elephants and other wildlife and of surface water, recent or planned disturbances (e.g. capture operations)), which can inform the survey design, particularly stratification, and the choice of sampling intensity and its allocation between strata.

[6] Stratification Survey areas are divided into strata:

- to permit different methods appropriate to the terrain to be carried out in different parts of the area (e.g. Gasaway *et al.* 1986);
- to improve precision, given a constant effort, by dividing into areas of differing densities (Jolly 1969, Caughley 1977), where these are approximately known; and
- to create areas that are easier to cover in a short time (Norton Griffiths 1978).

[7] Number of sampling units Caughley (1977) recommends at least 30 sampling units. Norton Griffiths (1978), who had considerable survey experience, suggests that in areas for which no prior information is available, then a general rule of thumb is to avoid very small samples (< 10) and very large samples (> 50).

If a very low density of elephants is expected in a stratum, one approach is to fly that stratum with a very small number of transects: but, if the density estimate and therefore likely also the variance are greater than expected, to fly a second and maybe third survey of the same stratum using different sets of transects. Afterwards, results from the several surveys can be combined to provide a mean estimate for the stratum (Gasaway *et al.* 1986). Gibson & Craig (2015a, b) provide examples of this approach. Its advantage is that it avoids flying a large number of transects in a stratum with very few elephants and thus it helps to optimise the use of expensive flying time. The disadvantage is that it demands a more flexible approach to survey implementation.

[8] For strict statistical validity, there should be a random selection of sampling units within a stratum, and where distribution information is not a high priority, sampling units should be selected at random (Caughley 1977, Norton Griffiths 1978).

For transect surveys however, systematically spaced transects should be used because they: are in regular use in existing survey protocols for savannah elephants; improve survey repeatability; give better information on spatial distribution; and offer stream-lined design opportunities such as returning to the same units on successive surveys.

[9] Sampling can be with or without replacement (e.g. Caughley & Sinclair 1994). In sampling with replacement, if two or more random points fall in one block, then that block is included in the calculations as many times as there are random points in the block, but that block needs to be searched just once during the survey. In sampling without replacement, each selected block is included just once in the calculations regardless of how many random points fall within that block.

[10] For total counts (and block surveys) many types of aircraft will suffice, but, where safety permits, slower flying types are preferable. Helicopters are sometimes necessary for mountainous terrain.

[11] The aircraft type is based on a requirement for a four (or more) seated high-wing aircraft with wing struts to which strip markers may be attached. The aircraft's performance must allow safe operation at low speeds and have sufficient power to operate safely with full fuel tanks and the required passenger load under a range of conditions, including at high air temperatures and at altitude. Those types in common use are listed, but others may fit the requirement. Some aircraft can be fitted with a STOL (Short Take-Off and Landing) kit which increases the aircraft's ability to land safely at reduced speeds and on shorter airstrips. The Cessna 172 may be suitable for transect surveys if it is an extra performance version using a larger engine than standard, and a constant speed propeller. Aircraft to be avoided include those for which flying at low power settings and in hot weather is not advised, e.g. Cessna 206 turbo.

[12] The Cessna 208 (Caravan) is sometimes used but is likely to show dissimilar flight characteristics to the other Cessnas (and the Partenavia). It has other disadvantages such as running cost, weight, refuelling practicalities and safety at slow speeds. Analyses of the differences between this and previously used aircraft would be needed, and this may be beyond the financial resources of the project.

[13] For the recorder/FSO, GPS units such as the Garmin GPSMAP 64 series are ideal, but other makes and models may be equally good (the features required of the GPS units are described below). For the pilot, the make and model of GPS unit to be used will often depend on availability and personal preference.

A moving map display will allow the GPS unit to display transects or blocks in relation to aircraft position during the flight. The GPS will be used to follow transects and to navigate between them and, during block surveys, to determine whether sightings are within the block. It will also record the track of the aircraft at intervals of 1-4 seconds in the track log and be used to store sighting positions as waypoints.

During transect surveys, the recorder's GPS unit should, if possible, be set to display alongside the moving map, fields showing the ground speed, the cross-track error (the distance between the transect and the actual flight path) and the time and distance to the next waypoint (e.g. the end point of the current transect, or the start of the next). After a flight, the GPS track log should be downloaded and used to confirm that the entire survey was completed, the transects were flown accurately and there were no undue deviations from the required track.

[14] During calibration calculations, the regression of flying height agl (recorded from the radar altimeter) and the height recorded from a pressure altimeter should have an intercept of the airstrip elevation (or zero if the pressure altimeter is set to zero before take-off) and a slope of 0.95-1.07. A slope outside this range suggests that the radar altimeter may be faulty (GEC 2014), but if the slope is seen to change between sessions (by >5 %) this is a clear sign that the radar altimeter has problems and must not be used (Howard Frederick, pers. comm.).

[15] Stiff rods provide a rigid frame of reference within which to count. However, the rod-clamp design must be extremely secure so that the rod position cannot move during the survey and so that the rods are aligned correctly to the line of flight.

[16] For all survey types, it may be advantageous to include in the survey team a "data manager", who is ground-based and can provide ground support including driving, entering the data from datasheets into a computer, and assisting with downloading files from electronic equipment after flights, maintaining that equipment and ensuring all devices have fully-charged batteries.

[17] Observers should be trained before a survey, not during a survey. A pre-survey schedule for observer testing and training in Tanzania is provided by Frederick & Norton-Griffith (2013) and the following advice is based on their text.

- *Lab. testing* Trainees tested for eyesight and basic species recognition skills:
  - Resolution: using a standard eye chart (English letter recognition), trainees tested for resolving power and focus. A pass is given for normal (6/6, or 20/20) or better vision, with trainees allowed to use corrective lenses.

  - Colour blindness: using a digital version of the Ishihara eye test on a laptop with a sRGB colour-corrected screen, trainees screened for colour blindness, and a pass given for a negative result.
  - Species recognition: trainees asked to identify common large mammal species from a PowerPoint presentation, given 5 seconds to identify, and afterwards asked to think out loud about how they were identifying the more difficult slides.

- *Flight Testing*
  - Trainee participated in 3 hour survey flight as rear seat observer in a four-seater Cessna
  - Minimum of 1.5-2 hours of transects were flown.
  - Rods affixed in approximate positions for a survey (but no calibration if time is limited).
  - Observers instructed to call out, loudly, all observations of large mammals.
  - The pilot and recorder (ideally, both experienced wildlife surveyors and familiar with the landscape and wildlife species) work with trainees by confirming identifications as they are called out, watch for missed observations or misidentifications and check estimates of the number of animals in large groups.
  - Cameras affixed to the windows of the aircraft at the eye height and angle of view of the observer and fitted with cable releases; observers instructed to photograph all observations.
  - Post-flight briefing conducted with the observers, reviewing identification and detection performance, and examining photographs taken. The pilot and recorder independently review the observer from their side of the aircraft and score according to performance.

- *Flight Training*
  - Each observer to have at least 3 training flights (> 5 hours in total), confirming reliability with species identification, fatigue issues, and correct camera operation; and that they do not suffer from air sickness.

[18] For transect surveys, the waypoints defining the start and end of the transects can be entered in the GPS unit as a route (or flight plan), with the transects in the order in which it is intended to fly them.

For total counts with parallel flight lines, the correct track can be maintained by following virtual transects on the moving map display of the GPS.

For block surveys, waypoints defining key points on the boundaries of each selected block can be entered in the GPS unit. Virtual blocks can be created in the GPS unit by making the waypoints for the boundary of each block (in the correct order) into a gps 'route'. Then each selected block can be located by flying to the virtual block on the GPS and searched by flying lines within the block which are traced on the GPS's moving map display by the track log function. These lines are visually kept about 500 m apart and the tracks displayed in real time are used to ensure complete coverage of the block.

[19] In survey areas with inselbergs, the flight plan may require the aircraft to fly around an inselberg and thus deviate >100 m from the transect line.

[20] Flying height should usually be <700 feet agl.

[21] Calibration methods are described by Norton-Griffiths (1978). The aircraft is flown at a range of heights at right angles to a runway alongside which large-sized numbers are painted. These numbers should be at least 1 m high and spaced at 10 m intervals. Inner and outer numbers within the strip markers are read by observers as they pass abeam. The calibration datasheet in Appendix II illustrates what is recorded and how this is processed.

It is easier for an observer to read the minimum and maximum numbers within their search strip than to count un-numbered markers in a line across the strip. Numbered markers are essential if calibration includes comparing the search strip seen by an observer with that photographed with a camera. Only with numbered markers is it possible to be sure that the observer and the camera are seeing the same search strip.

For each observer, the actual strip width during calibration should be positively correlated with the flying height. If the actual strip width is plotted against the flying height agl, the regression line should be linear and the intercept of the regression line with the y-axis should be close to zero (Frederick *et al*. (2010) recommend that the intercept should be between +20 and -20).

[22] The probability that animals will be seen is strongly affected by height, speed and strip width (Caughley 1974; Caughley *et al.* 1976). Surveys flown at different speeds and strip widths are therefore not comparable. A height of 300 ft agl is a standard for many surveys of elephants. As a measure of comparability, it has become common to characterise surveys in terms of search rate, which integrates strip width and speed and which is expressed in area searched per unit time (e.g. Said *et al.* 1995), or search effort, which is expressed in time to search unit area (e.g. Gasaway *et al.* 1986). Search time

per unit area is often the preferred measure because if two otherwise similar surveys are compared, the better survey is the one with the greater search time per unit area. Search times are on a per aircraft basis, not on per observer basis.

Most series of sample surveys for elephants have, by trial and error, converged on a search effort of approximately 1 minute per km^2 (Craig 2012) Total counts seldom achieve this rate, which is not too much of a problem, provided that a total count and a sample survey of an area are not compared. (For comparability with previous total counts in areas of good visibility, it may be necessary to use search rates of < 0.2 minutes per km^2 (up to 5 km^2 per minute)). However, common standards should enable the broadest possible comparability - there is no reason why a total count may not be considered equivalent to a 100 % sample survey provided that search rates are similar and therefore no reason why a stratified sample survey should not include some strata which are totally counted.

In block surveys, where each selected block is flown as a total count would be, it is important that the search rate is comparable with other sample surveys.

Where there is a two-man aircraft and there is, in effect, only one observer per side, search efforts should be >1 minute per km^2 (<1 km^2 per minute).

[23] The following advice is relevant to survey planning and budgeting. Much of the flying on a survey is "dead time" - time not spent counting but commuting from base to the survey area, positioning between sampling units on a sample count, or turning outside the stratum onto the next flight line in a total count. It is not possible to set standards for the proportion of time to be spent counting, but records should be kept. This is facilitated by the times recorded on datasheets (times of take-off and landing and start and end times for transects, blocks and flight-lines - see Appendix II). The survey coordinator should also keep records of flights with no survey component, e.g. commuting and calibration flights, for accounting purposes. The track log facility of a GPS unit can provide a complete record of flight times if it is always on from before take-off until after landing.

[24] Generally, the maximum counting (searching) time per flight should be 3 hours, but *occasionally* it may be extended to 3.5 hours.

[25] The species for which the observer develops a search image will tend to be seen preferentially. It is therefore essential to ensure that the observers have a search image dominated by the species of primary interest. In the present case this is elephants.

[26] The way the strip is searched affects the potential for undercounting bias: too much time spent searching the far side of the strip or beyond may result in nearby animals, which should be the easiest to see, being missed. This would result in more of an undercount than missing difficult-to-see animals. The observers' attention should, therefore, be on the inside edge of the counting strip, sweeping the field of vision out to the far edge every few seconds. This is known as "guarding the line" in distance sampling (Buckland *et al.* 2001) and although the surveys will not be distance surveys, it is nevertheless a useful detail to borrow from that method. Observers should search forward and continually scan in order to avoid being hypnotized and staring but not searching.

[27] During a transect survey, the *decision point* on the strip marker (i.e. on the rod) should be marked with tape and should be the same point at which calibration sightings were made (i.e. the point abeam the observer (RSO)). As the aircraft moves forward, each observed group of elephants crosses an imaginary line stretching from the eye of the seated observer, to the window marker, to the decision point and beyond. It is as a group is aligned with the decision point that the observer decides if the group is inside or outside the search strip (or, if some animals in the herd are inside while others are outside, how many animals are inside the search strip and how many are outside). During calibration flights, it is as the line of numbered markers on the ground is aligned with the decision point that the observer calls the smallest and largest numbers between the rods.

During a block survey, in/out decisions are made with reference to the GPS unit which shows the position of the aircraft in relation to the block boundaries, shown as a virtual block on the GPS moving map display.

[28] Only the top sheet need be filled in for some information, but date, times (at least am or pm) and aircraft registration (if two or more aircraft are used) must appear on all sheets - examples of datasheets are given in Appendix II.

[29] The track log facility (which keeps a continuous record of position) of the GPS should be set to record while the survey is being carried out. The recording frequency should be set to 4 seconds or less. After each flight, the track log should be downloaded and saved as a gpx file. A gpx file of a track log includes all the information recorded by the GPS unit, including the speed information which is lost if the track log is saved as a shapefile.

[30] With transects, a separate datasheet should be used for each, as some information (mean height, start and end information) will be different for each transect. With blocks (and transects with little information) this wastes paper - several can be put on each sheet, but each block must be ruled off at the start and end and the start and end times for each recorded on the line (see example datasheets in Appendix II).

[31] Position of the start of the transect should be the read from the GPS as the transect is begun (similarly for the end of the transect). However, this should be the same as the position being used to display the transect on the GPS, so it is strictly not necessary to record again, although writing it down provides the redundancy necessary to check that the correct transect was flown. Where mistakes are unlikely, the names of the transect start and end points (e.g. 21A and 21B) can be written here, but this must be checked on the GPS display. Position need not be recorded for a block, but the block ID should be read from the GPS, as blocks are often flown out of numerical sequence.

[32] Height is recorded by the recorder / FSO at regular intervals to obtain a good measure of the average height on the transect in order to correct the strip width when doing the analysis. This is done from the radar altimeter or laser rangefinder to the nearest 5 feet. Note that it is not recorded for each sighting but independently and preferably every 30 seconds. Height is not recorded during a block survey or a total count. During a transect survey, the recorder is responsible for ensuring that the pilot adheres to the planned flying height (as safety concerns permit).

[33] Location data recorded during the flight in the GPS will be downloaded into files after the flight. Sightings for all transects covered during that flight will go into one file although there will be a different file for each flight. The file name must therefore appear on all datasheets so that there can be no doubt where the data for any transect are. This is not applicable if the GPS has enough memory for the entire survey, although downloads after each flight are highly recommended.

[34] Locations of animal sightings should be recorded on the datasheet from a location read from the GPS. The location may also be recorded by marking it with the GPS and then entering the waypoint number allocated by the GPS on the datasheet. Such waypoints should be downloaded after the flight into a file whose name is recorded on all the datasheets for the flight. Approximate locations can be recorded using a subunit number, called by the FSO and recorded initially on the digital voice recorders by the RSOs.

[35] The following information on animal sightings must be recorded:

- *elephant family groups*. These are defined as herds in which females and young are present. Any bulls in the group count as part of the family group.
- *elephant bull groups*. These are single animals, or male-only groups which contain no females or juveniles.

Bull and family groups are recorded separately mainly because illegal hunting may impact the two categories differently.

- *elephant carcass*. There are four carcass categories (Douglas-Hamilton & Hillman 1981, Douglas-Hamilton 1996) representing various stages of decomposition:
  - *Category 1*: Fresh. Still has flesh giving the body a rounded appearance. Vultures probably present and ground still moist from body fluids.
  - *Category 2*: Recent. Rot patch and skin still present. Skeleton not scattered.
  - *Category 3*: Old. Clean bones, skin usually absent, vegetation regrown in rot patch.
  - *Category 4*: Very old. Bones scattered and turning grey.

In some areas, management staff hang the lower jaw from an elephant carcass in a nearby tree to indicate to colleagues that the carcass has been recorded. In other areas, carcasses may be marked with paint. A carcass covered in branches may indicate that the animal was killed illegally.

The importance of recording carcasses and reporting carcass estimates and carcass ratios cannot be over-emphasised. While a survey may fail to detect an elephant population decline of, say, less than 40 %, a loss of a proportion of the live population will result in a several-fold increase in the number of carcasses. This makes the number of carcasses by far the more sensitive indicator of population change.

[36] Standard codes should be adopted in the electronic dataset, e.g.:

LaF = Elephant family group
LaM = Elephant bull group
LaC1 = Elephant carcass category 1
LaC2 = Elephant carcass category 2
etc.

But these may be difficult to use when recording sightings on the datasheets as they are counter intuitive; personal shorthand in the recorder's language is much easier to use (e.g. EleB for elephant bull). Whatever codes are used, they should be consistent within a survey and the meanings of the codes must be clearly stated in notes accompanying the datasheets. In the case of carcasses, care must be taken not to confuse the number seen with the number describing the decomposition category.

[37] More than one copy of all digital data should be maintained during the survey. After the flying is complete, the paper datasheets and the backup digital voice records should travel in different vehicles back to home base, or the site where the data will be analysed. Both vehicles should carry copies of all digital data. The temporary digital archive which accumulates during survey implementation is easier to maintain if there are at least two dedicated external hard drives with data backups which are updated daily. When the flying is concluded, one disk can be left temporarily at a secure location at the study site, to provide a backup for the data being transported to the site for analysis and write-up.

[38] Chi-square test for goodness of fit, single classification, with frequencies divided into two classes (left and right) and expected frequencies based on a hypothesis extrinsic to the data. In theory, for each species, the left and right observers – if they are equally efficient at spotting elephants - should see a similar number of groups. But it is likely that the observers' individual strip widths are not identical and hence the expected numbers of groups in the chi-square test should be calculated based on the individual strip widths determined during the calibration flights.

The numbers of groups recorded for the left and right observers may vary - even if the two observers are equally efficient and have identical strip widths - if the two observers applied different criteria to define a 'group', e.g. if the individuals within an elephant herd were well spaced out along a transect.

[39] Mann-Whitney *U*-test for two samples (left and right), ranked observations, not paired. This test is the non-parametric equivalent of the *t*-test for comparing two samples. For each species, a sample consists of the numbers of individual animals in the groups seen by the observer. The Mann-Whitney *U*-test can be performed in Excel using the free Real Statistics add-in (see http://www.real-statistics.com).

[40] The power of the design required to detect population changes of an agreed magnitude should have been calculated prior to the survey (Steidl *et al.* 1997), although it is rare that this is done.

[41] Douglas-Hamilton & Burrill (1991, their Appendix 2) suggest that for a transect survey a carcass ratio of ≤8 % is indicative of an increasing or constant population number; a carcass ratio of >8 % may be indicative of a worrying level of mortality. But the situation is not always simple: the carcass ratio can be high – and not of concern - if elephants occupy the survey area only seasonally and not during the season of the survey. The temporal trend in carcass ratio may be a more useful indicator than the absolute value.

[42] Additional animals seen are those observed outside the sampling units, but within the stratum.

[43] The variance and not only the standard error (SE) should be given in the report. It is easy to calculate SE as the square root of the variance; but if, during later use of the survey data, variance has to be calculated as $(SE)^2$, the answer is often slightly inaccurate because of a rounding error. The variance is required when separate survey estimates are pooled to calculate an overall estimate and its error (Norton-Griffiths 1978); for this, the individual survey variances are essential.

[44] GPS units have been shown to have differences in the way they record, for example, altitude information: information which appears unimportant now may be important during a future re-analysis of the data.

[45] Laptops, portable hard drives, memory sticks, etc. are not long-term safe storage facilities. Secure, dedicated servers should be set up for the safe-keeping and archiving of digital survey data and maps. (Remember LOCKSS – Lots Of Copies Keeps Stuff Safe)

5 Acknowledgements

To be developed…

6 References

Barnes, R.F.W. 2002. The problem of precision and trend detection posed by small elephant populations in West Africa. *African Journal of Ecology* 40: 179-185.

Barnes, R.F.W., Craig, G.C., Dublin, H.T., Overton, G., Simons W. & Thouless, C.R. 1999. African Elephant Database 1998. *Occasional Paper of the Species Survival Commission. Produced by IUCN in collaboration with UNEP*. Gland, Switzerland. 249 pp.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.I., Borchers, D.L. & Thomas, L. 2001. *Introduction to Distance Sampling. Estimating abundance of biological populations*. Oxford University Press, Oxford, UK. 432 pp.

Caughley, G. 1974. Bias in aerial survey. *Journal of Wildlife Management* 38(4): 921–933.

Caughley, G. 1977. Sampling in aerial survey. *Journal of Wildlife Management* 41(4): 605-615.

Caughley, G. 1977b. *Analysis of Vertebrate Populations*. John Wiley & Sons, New York, USA. 234 pp.

Caughley, G. & Sinclair, A.R.E. 1994. *Wildlife Ecology and Management*. Blackwell Scientific Publications, Boston, USA. 334 pp.

Caughley, G., Sinclair, R. & Scott, D. 1976. Experiments in aerial survey. *Journal of Wildlife Management* 40(2): 290 - 300.

Chase, M., Frederick, H., Mukeka, J. & Ngene, S. 2014. *Dry season fixed-wing aerial survey of elephants and other large mammals in the Tsavo and Amboseli Ecosystems*, *Kenya*. Report. Elephants Without Borders, Kasane, Botswana, and Kenya Wildlife Service, Nairobi, Kenya.

Cochran, W.G. 1977. *Sampling Techniques.* Third Edition. Wiley, New York, USA. 428 pp.

Craig, G.C. 1993. Options for aerial surveys of elephants. *Pachyderm* 16: 15-20.

Craig, G.C. 2012. *Monitoring the Illegal Killing of Elephants: Aerial Survey Standards for the MIKE Programme. Version 2*. CITES MIKE Programme, Nairobi, Kenya. 25 pp.

Douglas-Hamilton, I. 1996. Counting elephants from the air - total counts. In: *Studying Elephants*. pp 28-37. Ed. K. Kangwana. AWF Technical Handbook series. African Wildlife Foundation, Nairobi, Kenya.

Douglas-Hamilton, I. & Burrill, A. 1991. Using carcass ratios to determine population trends. In: *Proceedings of the International Symposium. African Wildlife: Research and Management.* Eds F.I.B. Kayanja & E.L. Edroma. pp. 98-105. ICSU, Paris, France.

Douglas-Hamilton, I. & Hillman, A.K.K. 1981. Elephant carcasses and skeletons as indicators of population trends. In: *Low Level Aerial Survey Techniques. Report of an International Workshop, 6-11 November 1981, Nairobi*. pp. 113-129. ILCA Monograph 4. International Livestock Centre for Africa, Addis Ababa, Ethiopia.

Frederick, H., Kohi, E., Lorenzo, J., Coyote, M., Schmitt, T. & Larsen, K. 2015. *Improving Flight Accuracy for Aerial Wildlife Surveys in Sub-Saharan Africa.* ACM DEV 2015, December 1–2, 2015, London, United Kingdom. ACM 978-1-4503-3490-7/15/11. DOI: http://dx.doi.org/10.1145/2830629.2835221 .

Frederick, H., Moyer, D. & Plumptre, A.J. 2010. *Aerial Procedures Manual, version 1.0*. Wildlife Conservation Society.

Frederick, H. & Norton-Griffiths, M. 2013. *Discussion Paper for Aerial Survey Standards for the Proposed Aerial Census of Elephants in the Selous Game Reserve*. TAWIRI, Arusha, Tanzania. 12 pp.

Gasaway, W.C., DuBois, S.D., Reed, D.J. & Harbo, S.J. 1986. Estimating moose population parameters from aerial surveys. *Biological Papers of the University of Alaska* No. 22. 108 pp.

Gibson, D.St.C. & Craig, G.C. 2015. *Aerial Survey of Elephants and Other Wildlife in Zambezi Region September/October 2015*. WWF, Windhoek, Namibia. WWF, Windhoek, Namibia. 62 pp.

Gibson, D.St.C. & Craig, G.C. 2015. *Aerial Survey of Elephants and Other Wildlife in Khaudum National Park and Neighbouring Conservancies October 2015*. WWF, Windhoek, Namibia. 52 pp.

Goodman, P.S. & Mbise, N.L. 2018. *Large herbivore population estimates for the Ikorongo and Grumeti Game Reserves and associated concessions.* Singita Grumeti Fund, Sasakwa, Serengeti District, Tanzania. 14 pp.

Goodman, P.S. & Worth, E.S. 2018. *Karingani Game Reserve: Large mammal population survey – November 2018*. Karingani Game Reserve, Mozambique. 18 pp.

Great Elephant Census. 2014. *Aerial Survey Standards and Guidelines for the Pan-African Elephant Aerial Survey 2014*. Appendix to: Chase *et al*. (2016) Continent-wide survey reveals massive decline in African savannah elephants. PeerJ 4:e2354; DOI 10.7717/peerj.2354.

Greenwood, J.J.D. & Robinson, R.A. 2006. Principles of sampling. In: *Ecological Census Techniques. A Handbook*. Second edition. pp. 11-86. Ed. W.J. Sutherland. Cambridge University Press, Cambridge, UK.

Griffin, C.R., Chase, M., Cushman, S. & Whyte, I. 2006. *Is there a better way to count elephants? Assessment of DISTANCE Sampling and Strip Transect Methods in Aerial Surveys*. Report to US Fish & Wildlife Service. Office of Internal Affairs, Washington DC, USA. 18 pp.

IUCN. 1998. *Proposal for establishing a long term system for monitoring the illegal killing of elephants (MIKE)*. 87 pp.

Jachmann, H. 2001. *Estimating Abundance of African Wildlife: an Aid to Adaptive Management*. Kluwer Academic Publishers. Norwell, MS, USA. 285 pp.

Jolly, G.M. 1969. Sampling methods for aerial censuses of wildlife populations. *East African Agricultural and Forestry Journal* 34 (sup1): 46-49.

Kruger, J.M., Reilly, B.K. & Whyte, I.J. 2008. Application of distance sampling to estimate population densities of large herbivores in Kruger National Park. *Wildlife Research* 35(4): 371–376.

Kyale, D.M., Mukeka, J.M., Kimitei, K.K., Munyao, M.N. & Lala, F.O. 2014*. Tsavo-Mkomazi Total Aerial Census for Elephants and Large Animals*. A technical Report for Kenya Wildlife Service, Nairobi, Kenya. 84 pp.

Mbugua, S. 1996. Counting elephants from the air - sample counts. In: *Studying Elephants*. pp. 21-27. Ed. K. Kangwana. AWF Technical Handbook series. African Wildlife Foundation, Nairobi, Kenya.

Norton-Griffiths, M. 1974. Reducing counting bias in aerial censuses by photography. *East African Wildlife Journal* 12: 245-248.

Norton-Griffiths, M. 1978. *Counting Animals*. AWF Technical Handbooks series, No. 1. Ed. J.J.R. Grimsdell. African Wildlife Foundation, Nairobi, Kenya.

Said, M.Y., Chunge, R.N., Craig, G.C., Thouless, C.R., Barnes, R.F.W. & Dublin, H.T. 1995. African Elephant Database 1995. *Occasional Paper of the Species Survival Commission. Produced by IUCN in collaboration with UNEP*. Gland, Switzerland. 225 pp.

Steidl, R.J., Hayes, J.P. & Schauber, E. 1997. Statistical power analysis in wildlife research. *Journal of Wildlife Management* 61(2): 270-279.

Thouless, C.R., Dublin, H.T., Blanc, J.J., Skinner, D.P., Daniel, T.E., Taylor, R.D., Maisels, F., Frederick, H.L. & Bouché, P. 2016. African Elephant Status Report 2016: an update from the African Elephant Database. *Occasional Paper Series of the IUCN Species Survival Commission, No. 60.* IUCN/SSC African Elephant Specialist Group. IUCN, Gland, Switzerland. vi + 309 pp.

7 Glossary

Accuracy is a measure of bias error, i.e. how close a population estimate is to the true number. If the estimate is close to the true number, the estimate is described as accurate. Not the same as *precision*.

Baseline – For a *transect survey*, the baseline is a line at right angles to the orientation of the *transects* and running the full length of a *stratum*. *Transects* are arranged systematically along the baseline, with the position of the first *transect* determinedly randomly.

Block – A block is a *sampling unit* which may be square or rectangular, or irregularly shaped and demarcated on the ground by physical features such as roads or watersheds. Blocks are the sampling units in a *block survey* (called aerial block sampling by Norton-Griffiths (1978)). The entire area of a stratum intended for block sampling must be divided into non-overlapping blocks and the boundaries of all blocks should be defined before blocks are selected for sampling. The selected blocks are searched until all animals within them have been counted (Mbugua 1996, Jachmann 2001). A block should not be confused with a *counting block*.

Block Survey – A block survey is a form of *sample survey* in which the *sampling units* are *blocks*. The *blocks* may be square or rectangular, or irregularly shaped and demarcated on the ground by physical features such as roads or watersheds.

Call-Out Method – The technique whereby details of sightings by the observers in a *transect survey* are called by the observer to the recorder who immediately writes those details on a datasheet and marks a GPS *waypoint* to record the location of each sighting.

Counting Block – A counting block is a discrete subdivision of the study area during a total count. It is usually of a size (500 - 1500 km^2) that can be covered by one aircraft during one flying day (Douglas-Hamilton 1996). During a sample survey, such a subdivision of the study area is called a *stratum*.

Cross-Track Error A term used during navigation to describe the shortest distance between current location and the intended (planned) *route* or flight path.

Decision Point During a transect survey, the decision point is a mark (often a piece of tape) on the outer strip marker (rod) abeam the observer (RSO). As the aircraft moves forward, each observed group of elephants crosses an imaginary line stretching from the observer's eye, to the window marker, to the decision point and beyond. It is as a group is aligned with the decision point that the observer decides if the group is inside or outside the search strip (or, if some animals in the herd are inside while others are outside, how many animals are inside the search strip and how many are outside). During calibration flights, it is as the line of numbered markers on the ground is aligned with the decision point that the observer calls the smallest and largest numbers between the rods.

Distance Survey is a special type of *transect survey*, in which the data collected during the survey (which includes the perpendicular distance from the centre line of the transect for each observed group) is used, in effect, to calculate a correction factor for the animals missed by the observers. Various problems (see Note 1) have prevented the widespread adoption of aerial distance surveys to survey elephants.

Efficiency of aerial surveys can be considered in terms of the number of flying hours, or the financial cost, required to achieve the survey objective. An efficient survey is one that achieves the survey objective at minimal expense.

Flightlogger – A mobile application that provides visual real-time feedback of flying height and course to assist aircraft crews conducting aerial surveys. The system is based on a 7" Android tablet, which acquires altitude readings from a laser altimeter mounted externally on the survey aircraft and which uses its own GPS receiver. The tablet can be mounted above the aircraft dashboard using a small light case containing a 3D-printed tablet mount, an extra battery for long flights, and a serial to USB converter which interfaces with the USB port on the tablet. Or it can be mounted temporarily in front of the aircraft dashboard for the duration of a flight. See Frederick *et al*. (2015) for details.

Knot – A unit of speed, often used with reference to aircraft. 1 knot = 1 nautical mile per hour = 1.852 kilometres per hour.

Percentage Relative Precision (PRP) is the difference between the estimated population number and its 95 % confidence limits, expressed as a percentage of the population estimate (Greenwood & Robinson 2006). The PRP is also known as the Relative Margin of Error.

Precision is a measure of sampling error. If a set of estimates has little scatter or variability, then the estimates are described as precise. Not the same as *accuracy*. Precision can be increased by good *stratification*, efficient orientation of *transects* during a *transect survey*, and greater *sampling intensity* (i.e. an increased number of *sampling units*).

Recce Flight – A recce flight is an informal, usually low-level and relatively slow, flight over the area of interest in any aircraft that can safely fly low level (e.g. 500 ft agl) and slow with a crew of, usually, one pilot and one or more observers. Usually, the objective of a recce flight is to determine if elephants are present and, if so, the size and location of the groups and their relative density. Hence, the flight path has no set pattern but would usually be close to features where elephants are thought more likely to be present, e.g. during the dry season, in riverine vegetation or near waterpoints. A flight with another main purpose, e.g. as a ferry flight, can also serve a secondary purpose as a recce flight if the flight path and usual flying height can be adapted temporarily to those suitable for a recce flight. Information from a recce flight can be useful for stratifying a survey area. In the absence of a formal survey, the number of elephants seen during a recce flight (assuming that no groups were counted twice) would provide a minimum estimate of the population number in the area. The term 'recce flight' is shorthand for reconnaissance flight. A recce flight should not be confused with a *Systematic Reconnaissance Flight*.

Relative Margin of Error (RME) is the difference between the estimated population number and its 95 % confidence limits, expressed as a percentage of the population estimate. The RME is also known as the *Percentage Relative Precision*.

Route – In a GPS unit, a route is a sequence of *waypoints* which form the path which the user intends to follow. In aviation models of GPS units, a track will be called a flight plan.

Sample Area is the sum of the areas of the sampling units (transects or blocks) searched during a sample survey.

Sample Survey – A sample survey is a survey during which only part of the study area is searched. That part should be selected randomly, or in an unbiased manner. Both transect surveys and block surveys are types of sample surveys.

Sampling Effort is an alternative term for *Sampling Intensity*.

Sampling Intensity is the proportion of a *survey area* (or *stratum*) that is actually searched for elephants during a *sample survey*. After a survey, the sampling intensity can be calculated as the sum of the areas of all the *sampling units*, divided by the area of the *survey area* (or *stratum*). Sampling intensity is usually expressed as a percentage.

Sampling Unit – During a sample survey, the study area is divided in sampling units (which may be transects or blocks) which cover the entire area and do not overlap each other. A random or unbiased subset of sampling units is drawn from the complete set. During an aerial sample survey, the sampling units in this subset are then searched for elephants.

Search Effort is the mean time spent searching per unit area during an aerial survey. Often expressed in minutes per square kilometre. See also *Search Rate*.

Search Rate is the mean area searched per unit of time during an aerial survey. Often expressed in square kilometres per minute. See also *Search Effort*.

Standard Error ($SE_{\hat{Y}}$) of the population estimate is the square root of the population *variance*. It is one measure of the *precision* of the population estimate.

Stratification is the process by which the *survey area* subject to a *sample survey* is divided into subareas (strata) so that, within each stratum, elephant density within the *sampling units* will be relatively uniform. Well-planned stratification can increase the precision of the estimated number of elephants in the study area.

Stratum (plural **Strata**) is a subdivision of the *survey area*, with the boundaries of the stratum drawn during the process of *stratification* so that, in the stratum, elephant density within the *sampling units* will be relatively uniform.

Subunit – A subunit (often 5 km long) is a section of a longer transect. The use of subunits is one means of recording the location of sightings and was more common before GPS units became available. The use of subunits requires that the transects were uniformly spaced, and orientated either north-south or east-west. During a *Systematic Reconnaissance Flight*, the locations of wildlife sightings are recorded by reference to a subunit.

Survey Area is the same as the study area. It is the entire area which will be surveyed for elephants and is often subdivided into counting blocks (for a total count), or strata (for a sample survey).

Systematic Reconnaissance Flight – For a Systematic Reconnaissance Flight (SRF), the *survey area* is a framework of map grid squares (Norton-Griffiths 1978). North-south or east-west *transects* are arranged systematically across the *survey area* so that a *transect* runs down the centre of each row of squares. Each square forms a *subunit*. During the survey, the person in the co-pilot's seat (the FSO) records environmental data to supplement the wildlife observations by the rear-seat observers. A SRF survey is one form of *transect survey*. Repeat SRF surveys of an area may re-fly the same transects on each survey.

Total Count – A total count is a survey during which the entire *survey area* (or *stratum*) is searched, with the intention that all elephants in the *survey area* (or *stratum*) are seen and counted.

Track Log – A track log is a record (of latitude, longitude, elevation, date and time) maintained by a GPS unit of points along the path being followed by the user. The interval between points (in terms of distance or time) can be set by the user. A real-time track log can be seen on a moving map display as a breadcrumb trail. A track log can be saved to provide a permanent record of locations, dates and times, and speed, and in a GPS unit this record will be called a track.

Transect – A transect is a sampling unit which is long, straight and relatively narrow. During sample surveys, transects within one stratum are parallel to each other.

Transect Survey – A transect survey is a form of *sample survey* in which the *sampling units* are *transects*. These transects are straight and relatively long and narrow, usually evenly spaced and parallel to each other.

Variance – The *sample variance* (s_y^2) is a measure of how much the number of elephants counted in each sampling unit varies. The *population variance* ($Var_{\hat{Y}}$) is a measure of how much the population estimate would vary if independent population estimates were derived from the elephant density observed in each *sampling unit*.

Waypoint – A waypoint is a record (stored in a GPS unit) of latitude, longitude, elevation, date and time for a point location.

8 Appendices

8.1 Appendix I: Optimal Allocation of Survey Effort

Whatever the overall sampling intensity, sampling each stratum at the same sampling intensity will not usually give the most precise estimate of the number of elephants in the entire survey area. The precision of the survey estimate can be maximised by optimising the distribution of the sampling effort among strata using prior information on variance, i.e. the variability of elephant density within the strata.

Cochran (1977) suggested that, for the optimum allocation of sampling effort, the number of transects (n_i) in stratum i should be proportional to $(N_i\, s_i)$ / $\sqrt{c_i}$

where

> N_i is the potential number of sampling units in stratum *i*
>
> s_i is the square root of the variance in number seen between sampling units in stratum i (i.e. $\sqrt{s_y^2}$, which is not the same as the standard error of the estimate ($SE_{\hat{Y}}$); and
>
> c_i is the cost of sampling per unit in stratum i.

In words, this formula indicates that the number of transects in a stratum should be greater when stratum size (N_i) is large, the variability in elephant density within the stratum (s_i) is high, and when the unit cost of surveying in the stratum is low.

For most elephant surveys, the cost of survey per sampling unit does not vary much between strata and so it can be assumed that c_i is constant. If c_i = 1 for all strata, then $\sqrt{c_i}$ also equals 1 and the cost component of the formula can be ignored. Thus, the relative sample size in each stratum can be expressed as $(N_i\; s_i)/\sum(N_i\; s_i)$.

Also for most elephant surveys, the area of sampling units varies between strata. Hence, it is preferable to determine initially the sampling intensity in each stratum that would maximise the precision of the overall population estimate. Within any stratum, the number of sampling units will be proportional to the sampling intensity (assuming that transect orientation or mean block size is unchanged). Hence, Craig (2012) modified the formula slightly. He noted that the calculation is easier to follow in an example and demonstrated the allocation of sampling effort between strata based on his real data (Table A1.1).

Table A1.1: Calculation of allocation of sampling effort between strata

column	2	3	4	5	6	7	8	9	10	11	12	13
				Sample				Weight		New sample		
Stratum	Estimate	s_i	Area (A_i)	area (a_i)	%	n_i	N_i	$N_i\, s_i$	Rel.	area	p_i (%)	n
1	921	2.63	16118	1669	10.36	104	1004.4	2641.5	0.1175	508.3	3.15	32
2	697	4.106	2699	278.9	10.33	26	251.6	1033.1	0.0460	198.8	7.37	19
3	1509	7.468	3709	381	10.27	34	331.0	2471.8	0.1099	475.6	12.82	42
4	895	17.028	1466	152.4	10.4	15	144.3	2457.0	0.1093	472.8	32.25	47
5	886	7.322	2337	240	10.27	19	185.0	1354.7	0.0603	260.7	11.15	21
6	1284	11.223	2662	275.8	10.36	20	193.0	2166.5	0.0964	416.9	15.66	30
7	590	6.907	2245	232.3	10.35	20	193.3	1335.0	0.0594	256.9	11.44	22
8	470	5.566	1818	185.8	10.22	17	166.3	925.8	0.0412	178.1	9.80	16
9	736	4.873	2296	236.9	10.32	26	252.0	1227.9	0.0546	236.3	10.29	26
10	1864	9.645	4371	450	10.3	51	495.4	4777.9	0.2125	919.4	21.03	104
11	1993	14.61	2135	223.8	10.48	15	143.1	2090.7	0.0930	402.3	18.84	27
Total				4325.9				22481.9	1.0000	4325.9		

In the table, columns 2 to 8 are from a previous survey. s_i is the square root of the variance in number seen between sampling units (i.e. $\sqrt{s_y^2}$) and is not the same as the standard error of the estimate ($SE_{\hat{Y}}$).

n_i is the number of sampling units and N_i is the maximum possible number of sampling units (i.e. N = column 7 × column 4 ÷ column 5). The weight, $N_i s_i$, is column 3 × column 8, while the relative weight (column 10) is column 9 ÷ sum of column 9. The new area of the sample for each stratum (column 11) is the total sample area (4325.9) multiplied by the relative weight (column 10). Column 12 expresses the new sample area as a percentage. Column 13 (= column 8 × column 12 ÷ 100) gives the number of transects in the new sample.

In terms of a formula, the sampling intensity is allocated as:

$$p_i = 100 \left(\frac{N_i s_i}{\sum(N_i s_i)}\right)\left(\frac{\sum a_i}{A_i}\right)$$

where

N_i is the maximum possible number of sampling units in stratum i (e.g. 193.3 in stratum 7);

s_i is the square root of the sampling variance in stratum i (e.g. 6.907 in stratum 7);

$\Sigma(N_i s_i)$ is the sum of the products N_i s_i over all strata;

Σa_i is the target total sample area to be divided among all strata (4325.9 in the example);

A_i is the area of stratum i (e.g. 2245 for stratum 7); and

p_i is the percent sample to be taken (e.g. 11.44 % in the case of stratum 7).

The original design in the example (which had uniform sampling) gave a percentage relative precision (or relative margin of error) of 22 %. The predicted improvement would bring this to 18 %.

If, for any reason, a different sampling intensity is desired in a stratum (e.g. when the required sampling intensity is too small to give a reliable result), this can be substituted and only the overall precision will be affected. Another approach is to consolidate several low-density strata into a single stratum large enough for sufficient sampling units (stratum 1 in the example is a consolidation of 5 original strata). There can also be occasions where the procedure returns a sampling intensity of greater than 100 % for a stratum. In such cases the sampling intensity should be set to 100 % for that stratum (i.e. a total count can be carried out in it), and the remainder of the available sampling effort should be reallocated among the remaining sites according to the above protocol. Where the assumptions of a total count cannot be met (e.g. when the stratum is too big, or a suitable aircraft is not available), it would be more straightforward to carry out five 20 % surveys and combine the results.

It can be impractical to meet the assumptions of a sample survey for high sampling intensities. In such cases, the necessary coverage can be obtained by conducting two or more independent sample surveys of the same survey area (or stratum) at a lower sampling intensity. For example, two surveys of the same area at, say, 20 % sampling intensity will be equivalent to a single survey at 40 % sampling intensity.

If N and s for a previous survey are not directly known (they are often not reported), but the standard error of the estimate ($SE_{\hat{Y}}$) and the sampling intensity (p) for strata are known, ($SE_{\hat{Y}}\sqrt{p}\,\sqrt{A}$) is a good approximation to $N\,s$.

When only estimated densities are available, $A\,\sqrt{d}$ (where A is the stratum area and d is the animal density) has been used as the stratum weight (Craig 1993), .i.e. substituted for $N\,s$ in column 9 of the above table. But this makes the simplifying assumption that the number of elephants seen in a stratum is proportional to its variance, which is true when groups are randomly spaced but which often does not hold over a wide range of densities, owing to clumping. It is better to use actual variances when these are known.

A remaining source of error is that, while empirical variances are used, the prediction of a new variance for a different sample size still depends on the assumption that $s_y^2 \propto \bar{y}$ (groups are randomly distributed), whereas clumping causes $s_y^2 \propto \bar{y}^x$ (in this example x = 1.3) which implies a different exponent should be used to calculate the weights for sample allocation. However, in the absence of good information about the variation of x over populations and time, the assumption of random distribution is used as a default.

The above protocol could also be applied at a regional level to optimise a regional population estimate, given previous survey results for areas within the region.

Although the unit cost of survey in different strata (c_i) was assumed to vary little, c_i can also be used to indicate the 'importance' of the different strata: strata considered, by the survey designer, to be 'important' can be allocated a lower 'cost' than 'unimportant' strata.

8.2 Appendix II: Examples of Aerial Survey Datasheets

The following examples of datasheets are included as an additional illustration of the recording of observations, as required in the standards. As survey areas may have different data needs, and new requirements may be added as methods improve, it is difficult and perhaps counter-productive, to set a standard for datasheets. However, while the use of the examples is not a standard in itself, the same information as required on these sheets should be recorded, regardless of sheet design. These examples have been found from the extensive experience of Colin Craig and Howard Frederick to facilitate the recording of data.

The first datasheet is used for strip width calibration, and, in addition to in-flight recording, can be used to complete the calculations of calibrated strip width.

Then, three types of in-flight data recording sheet are shown, for transect surveys, block surveys and total counts respectively. In each case it is intended that the data columns continue on the back of the sheet. When few observations are being made per unit, several units can be recorded on the same sheet, provided that the sheet is ruled off between each unit and that the time and position of start and end, as well as the unit identification code, are written in below the ruling. This economises on sheets and assists in their movement and storage – not a minor consideration when there are several hundred sampling units.

Lastly, there is the datasheet for in-flight recording by the FSO of a SRF transect survey, with the instructions for completing this datasheet, followed by the datasheet for post-flight completion by a RSO as he/she examines the photographs that he/she took during a SRF transect survey.

FINAL

CALIBRATION SHEET

Survey . . . . Location . . . . Date . . . .

Aircraft . . . . Pilot . . . . Recorder . . . .

Left Observer . . . . Right Observer . . . .

	Left		Right		W = 10 x (out-in+1)		Corr. = W x 300/ht		Corr.
Height	In	Out	In	Out	L	R	L	R	L + R

Mean ________

SE ________

FINAL

AERIAL SURVEY DATA SHEET (TRANSECT)

SURVEY .... **STRATUM** .... **Aircraft** .... **DATE** .... **am / pm**

Complete once per flight

PILOT .... TAKE OFF TIME ....

RECORDER .... LANDING TIME ....

LEFT OBSERVER .... STRIP WIDTH: LEFT ....

RIGHT OBSERVER .... STRIP WIDTH: RIGHT ....

TRANSECT No. .... Transect spacing ....

Start time .... **Start Waypoint** .... S .... E

End time .... **End Waypoint** .... S .... E

Mean height ....

Waypt. file: ....

Waypt. No.	SIGHTINGS (Species, Number seen) LEFT IN STRIP	LEFT OUT	RIGHT IN STRIP	RIGHT OUT	NOTES

Height
Record every 30 secs

PTO /

FINAL

AERIAL SURVEY DATA SHEET (BLOCK COUNT)

SURVEY.................................. **Aircraft** .... **DATE**...................... **am / pm**

STRATUM ....

Complete once per flight

TIME: **Take off** .... **Landing** ....

Pilot... **Recorder**...

Observers..

Waypoint file: ....

Block No.	Wpt. No.	Sightings (Species, Number seen) In	Out	Notes/ Times: start / end

Rule off between blocks

FINAL

AERIAL SURVEY DATA SHEET (TOTAL COUNT)

SURVEY.................................... Aircraft .... DATE....................... am / pm

Complete once per flight

TIME: Take off .... Landing ....

Pilot.. Recorder..

Observers..

Stratum .... Time: Start........................ End.......................

Waypoint file: ....

Rule off between flightlines

Line No.	Wpt. No.	Sightings (Species, Number seen) In	Out	Notes /times

Aerial Survey Datasheet (SRF Transect - FSO Data Sheet)

Survey:	Date:	Transect:
Aircraft:		GPS Start:
FSO:	RSO_Rt:	Time Start:
Pilot:	RSO_Lft:	GPS End:
		Time End:

SU	AGL	GS	Water / Other	SU	AGL	GS	Water / Other
1				21			
2				22			
3				23			
4				24			
5				25			
6				26			
7				27			
8				28			
9				29			
10				30			
11				31			
12				32			
13				33			
14				34			
15				35			
16				36			
17				37			
18				38			
19				39			
20				40			

FINAL

Aerial Survey Datasheet (SRF Transect - FSO Data Sheet - Instructions)

Instructions for FSO

Survey	Survey code – 4 characters, e.g. SL27
Date	Flight date, day-month-year, e.g. 23-09-2017
Airplane	Registration – e.g. 5H-CFA
FSO	Name of FSO
RSO_	Names of right and left RSOs
Pilot	Name of Pilot
Transect	Transect ID as given by coordinator – including stratum/counting block and number, e.g. C01, or F23, or SE05.
GPS Start	Waypoint where you ACTUALLY STARTED the transect. This is pre-planned – a subunit name, usually like C01-E. If you start at a different subunit, cross out or erase anything written here before, and write <u>the new</u> name, OR take a GPS waypoint and write number here.
Time start	Exact time when you call “Subunit One”, to the nearest second, e.g. 10:03:23 . If you miss the exact time, write just the hour and minutes and then put a ‘?’, so the exact time can be checked from the track log later.
GPS End	Waypoint where you actually finished – as per start, make sure you record the actual waypoint where you stopped.
Time end	Exact time of calling “end of transect”
SU	The subunit that you announce along the transect, starting at “one” – if you start at the correct point on the transect. This should be the same as what you see on the GPS. If you start at a different point (“GPS Start”), then the GPS points will no longer align, but you ALWAYS starting announcing and writing down at “one”, no matter what you see on the FSO GPS – otherwise you confuse the RSOs. In that case, it’s usually helpful to write the GPS waypoints next to the subunit number to help you remember / correlate the two.
AGL	The flying height above ground (in feet) recorded from radar altimeter or laser altimeter. When you announce the subunit, look at the altimeter display and write down the first number you see.
GS	Ground speed recorded from FSO GPS immediately after recording AGL. Can be in kph or knots, but be consistent
Water	Waterholes or swamps with <u>visible open water</u> present in the whole subunit (including beyond strip marker rods). Put a hollow circle for each waterhole, and an S for each swampy area.

Other	Any other important observations, such as:
	• **Elephant carcass** spotted by you or pilot. Write GPS waypoint number, carcass stage, number of carcasses, whether left or right, and location, e.g:
	  o **001** EC3/x2/L/400m (waypoint 001, carcass stage 3, 2 carcasses, left side, 400m out [outside rods]).
	• **Active fire (flames or smoke visible):** GPS waypoint, F for fire, whether left or right, distance from aircraft
	  o **003** F/R/500m
	• **Any other observations** you think worthwhile – poachers’ camps, predators,

FINAL

Aerial Survey Datasheet (SRF Transect - RSO Data Sheet)

Survey:	Aircraft:	Date:
Transect:	RSO Name:	RSO Left or Right:

Subunit	**Species Code**	**COUNT**		**PHOTOS**			**Remarks**
		In Strip	**Out**	**No. taken**	**File Nos**	**Count**	