

Using sample aerial surveys to estimate the abundance of the endangered Grevy's zebra in northern Kenya

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Abstract

The effective management of endangered mammals requires reliable estimates of population size. This is challenging for species such as Grevy's zebra (*Equus grevyi*) that are distributed over large areas at low densities. Less than 2500 Grevy's zebra remain in the wild, scattered across 85,000 km² of savannah in northern Kenya and Ethiopia. An efficient, accurate and repeatable survey method is required to guide conservation planning for the species. Currently, total aerial counts are used to census endangered species within Kenya, but are costly in terms of resources. In this study, we evaluated the suitability of sample survey methods for Grevy's zebra. We estimated population size using sample aerial counts for a known population of Grevy's zebra in Lewa Wildlife Conservancy (LWC), providing the opportunity to test the accuracy of sample methods, while comparing resource costs with total count methods. We sampled one-third of LWC using parallel 500-m strip transects at 1500-m intervals. The population estimate was comparable to the known population size and was less than half as expensive as the equivalent total count survey. Our results suggest sample aerial surveys provide an accurate and cost-effective means of monitoring Grevy's zebra and other endangered species in open habitats.

Key words: aerial survey, Africa, endangered species, Grevy's zebra, large mammals, sample survey

Résumé

La gestion efficace de mammifères en danger exige des estimations fiables de la taille des populations. Ceci est un

vrai défi pour des espèces telles que le zèbre de Grévy (*Equus grevyi*) qui sont distribuées en faible densité sur de vastes étendues. Il reste moins de 2500 zèbres de Grévy dans la nature, éparpillés sur quelque 85.000 km² de savane, dans le nord du Kenya et en Ethiopie. Il faut une méthode d'étude efficace, exacte et reproductible pour guider la planification de la conservation de cette espèce. Actuellement, on a recours à des comptages aériens totaux pour recenser les espèces menacées au Kenya, mais c'est une méthode coûteuse. Dans cette étude, nous avons évalué l'opportunité de méthodes par échantillons pour le zèbre de Grévy. Nous avons estimé la taille de la population en utilisant des comptages échantillons d'une population de zèbres de Grévy connue dans la *Lewa Wildlife Conservancy* (LWC), ce qui nous a donné l'occasion de tester l'exactitude de méthodes par échantillons tout en comparant les coûts avec les méthodes de comptage complet. Nous avons échantillonné un tiers de LWC en traçant des transects parallèles de 500 m de large à intervalles de 1500 m. L'estimation de la population était comparable à sa taille connue, et elle a coûté moins de la moitié du dénombrement total équivalent. Nos résultats suggèrent que des recherches aériennes par échantillons sont un moyen précis et économique de suivre le zèbre de Grévy et d'autres espèces en danger dans des habitats ouverts.

Introduction

The effective conservation and management of endangered species requires a reliable estimate of population size and density (Ogutu *et al.*, 1996; Williams, Nichols & Conroy, 2002). However, the inherent rarity of such species makes obtaining accurate estimates challenging (Thompson, 2004). Many endangered large mammals are distributed

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over large areas and at low densities. In such cases, and given the limited resources available for monitoring wildlife populations on this scale, there is a need for both effective and cost-efficient survey methods.

The Grevy's zebra is a prime example of a species for which it has been a challenge to effectively monitor the population's status at regular intervals. The Grevy's zebra is a unique arid-adapted equid and is found in habitats that would be inhospitable for the more abundant plains zebra (*Equus burchelli*). In recent years Grevy's zebra have undergone a catastrophic decline in both numbers and range, from approximately 15,000 in the late 1970s (Grunblatt, Said & Wargute, 1996; Klingel, 1980) to recent estimates of around 2400 individuals within Kenya (Low *et al.*, 2009) living in small, isolated populations. Similarly, the range of the Grevy's zebra has been greatly reduced. Once distributed widely over Somalia, Kenya, Ethiopia, Djibouti and Eritrea, this species is now restricted to northern Kenya, where the majority of remaining Grevy's zebra occur, and isolated areas of southern Ethiopia (Low *et al.*, 2009).

Although the evidence for this decline is indisputable, it is reliant on episodic surveys which have employed a variety of methods (see Nelson & Williams, 2002; Woodfine *et al.*, 2009). A more consistent and regular approach to monitoring the now perilously low numbers of Grevy's zebra that remain is needed to measure the impact of conservation initiatives (KWS, 2008) and stochastic events such as anthrax.

Aerial surveys are considered the most practicable means of estimating numbers of large animals inhabiting a large area (Caughley, 1977; Pennycuik *et al.*, 1977). However, to be accurate, aerial surveys must adhere to strict operating parameters, including altitude, speed and strip width (Jachmann, 2001). Another key concern is the detectability of target animals, as influenced by habitat type, group size, movement, body size and colour (Graham & Bell, 1989; Jachmann, 2002), with lower detection leading to an underestimate of population size. Nevertheless, aerial surveys are considered to be suitable for conspicuous grazers such as buffalo and zebra in open habitat (Jachmann, 2002).

Two main approaches to aerial surveys exist: total counts and sample counts. In a total count, surveyors scan the entire study area and count all individuals observed, with the assumption that every individual is detected (Cook & Jacobson, 1979; Norton-Griffiths, 1978) and none are counted twice. The total count is popular for large and conspicuous mammals such as elephants (Craig, 2004)

and is the standard methodology for large mammalian species in Kenya. However, the assumption that all animals are detected is rarely tested, despite the fact that errors can arise from undercounting for all the reasons outlined above. Total counts also have no estimate of precision associated with them.

In a sample count, only a fraction of the entire study area is surveyed. Usually, a series of samples are taken (Jolly, 1969; Norton-Griffiths, 1978) using a standardized sampling design. Population size is estimated from sample count data, and confidence limits provide a measure of precision. It is still assumed that all individuals are counted within each sample area and animals are not counted twice. However, the fact that sample blocks are small means that it is more likely that this assumption is met.

The cost of carrying out sample surveys is typically much lower than the cost for total counts, because the area surveyed is smaller, requiring fewer aircraft, vehicles and personnel. For this reason, it is seldom feasible to conduct a total count over very large areas, and sample counts are considered instead (Jolly, 1969; Norton-Griffiths, 1978).

We tested sample surveys on Grevy's zebra at Lewa Wildlife Conservancy (LWC) in northern Kenya. LWC was considered ideal for testing new survey methods because it has reliable quantitative data for Grevy's zebra, where total aerial counts have been conducted annually since 1977 (Nelson & Williams, 2003), intensive monitoring of births, deaths and movements occur on a monthly basis (Chege, Kisio & Mwololo, 2007), and there is a photo ID database of adult zebra. Given the multiple sources of data, the authors consider the information on the Lewa Grevy's zebra population to be near-perfect. Thus, it serves as a reliable benchmark against which to verify population estimation methods, an important consideration when trialing new techniques (White *et al.*, 1989; Otto & Pollock, 1990).

In this study, we trial sample survey methods for Grevy's zebra on a known population within LWC, first by testing the accuracy of a sample survey and second by comparing the cost of a sample survey with that of a total count. We use these results to make recommendations for the future monitoring of Grevy's zebra and other endangered species within Kenya.

Materials and methods

Our study took place at LWC, a 209-km² fenced private wildlife conservancy located on the northern foothills of

Mount Kenya (centre point: 0°06'N, 37°21'E). Primary habitats include open grassland, bushed acacia grassland and riverine woodland.

Sample aerial survey transects were flown in a Piper Super Cub at 90 m (300 feet) above ground level and at a constant ground speed of approx. 90 mph. Markers on the wing struts were calibrated to represent a survey strip width of 500 m on both sides of the aircraft when flying at 90 m.

The aircraft flew twelve transects at 1.5-km intervals east–west across LWC (Fig. 1), which equated to one-third of the possible transects, or 33% survey effort. Each transect was oriented east–west to standardize flight paths: LWC has high ground to its northern and southern boundaries and flying E-W enables each transect to be flown at a constant altitude. Grevy's zebra were counted on the left side of the aircraft when flying transects in a westward direction and on the right side of the aircraft when flying eastwards. This ensured maximum separation between the survey strips and reduced the risk of double counting. The position of the first transect was selected using a random number corresponding to UTM coordinates along a base line running north–south across LWC.

A single observer seated behind the pilot counted Grevy's zebra on one side of the aircraft and marked their position with a Global Positioning System (GPS) and on a large-scale map at their approximate position to reduce the chance of double counting. Within the 500-m strip width, it was assumed that all zebras were detected (detection

probability equals one), based upon the calculated detection rate of 0.99 for plains and Grevy's zebra in Laikipia and Samburu (Kinnaird, M. & O'Brien, T., unpublished data). Only Grevy's zebra falling within the markers were counted by the observer, who recorded the size of each herd and its GPS location on a map. Where groups straddled the boundary of the survey strip, only those individuals falling within the survey area were counted.

For the sample survey, we estimated total population abundance and 95% confidence limits using a simple ratio estimator (Williams, Nichols & Conroy, 2002). This estimator accounted for the both variance in counts among transects, and variation among transects in length, and consequently area. To use the ratio estimator, counts from each transect must be proportional to the area of that transect (Cochran, 1977). We examined whether this was the case using a linear regression of counts and areas.

To examine how the precision of the population estimate varied with survey effort, we subsampled our data using 16.5%, 11% and 8.25% survey effort, which corresponded to 6, 4 and 3 transects. Here again, we used a ratio estimator to compute population size and its variance. We also computed the expected coefficient of variation (CV) corresponding to different sample sizes using the observed mean and variance from our sample count.

Total counts are carried out annually using standard Lewa methodology. Transects were spaced at 500-m interval and flown at 90 m (300 feet) above the ground level in a Piper Super Cub, with a single rear seat observer



Fig 1 Map showing Lewa Wildlife Conservancy (LWC) as a solid grey polygon, with total count transects as a dashed line and sample survey transects as a solid line. Insert shows LWC's position within Kenya within the box and the approximate range of the Grevy's zebra as a dark grey polygon

Table 1 Population estimate, coefficient of variation and precision for Grevy's zebra at different sampling efforts

Interval	Number of transects	Estimated population size	Standard deviation	Coefficient of variation	95% CI (lower–upper)
1.5 km	12	344	54.8	0.16	(237–451)
3 km	6	430	90.5	0.21	(252–607)
4.5 km	4	409	141.4	0.35	(132–687)
6 km	3	413	202.4	0.49	(16–810)

recording observations with a GPS and on a large-scale map. Lewa's Grevy's zebra population size for any 1 year is determined from a combination of annual total count figures, mortality and birth data and photo ID patrols.

Resource calculations were relatively straightforward for both survey methodologies, given that the same aircraft and operating parameters were used. Aircraft costs were charged at US \$180 per hour flown, and each survey was carefully timed. LWC provided the pilot and observer free of charge and so personnel costs were not incorporated into this calculation.

Results

The sample aerial survey was carried out on the 8th March 2008, under overcast conditions with light rain. The survey began at 08:30 h and finished at 11:50 h. The first 30 min were used to calibrate the strip width, and the survey was stopped for 40 min mid way through the survey because of the rain. The total flying time for the survey was 2 h 10 min.

Twelve transects were flown east to west across LWC at a total length of 134.8 km. Individual transect lengths ranged between 2.3 and 17.3 km, with a mean length of 9.63 km. A total of 21 groups of Grevy's zebra were observed, with group size ranging from 1 to 17, and a mean group size of 9.2. All groups that were observed occurred wholly within the sampling strip.

Our data confirmed that counts from sample units were linearly related to unit area ($F_{1,11} = 34.1$, $P < 0.0001$, $r^2 = 0.46$). Using the ratio estimator, we estimate that LWC had 344 (SD = 54.8) Grevy's zebra at 33% survey effort. We found the CV was 16% and the 95% confidence intervals for the estimate were 237–451.

We subsampled our sample survey data to simulate carrying out 6, 4 and 3 transects, which revealed higher estimates with much lower precision (Table 1). Accuracy declined substantially (344 to >400) as the survey effort was halved but then stabilized as survey effort was further

reduced. Precision declined steadily as sampling effort declined, as indicated by the high CV and widening confidence intervals.

We calculated the expected CV for a range of survey effort, from 0 to 36 transects (Fig. 2). The expected CV is computed using the observed mean and variance among sampling units (Williams, Nichols & Conroy, 2002). As expected, the CV decreased as the sample effort increased. We found that obtaining an estimate with a CV of 10% would require carrying out 25 transects, or approximately 68% survey effort (Fig. 2).

The total count for 2008 was carried out on 27th March under cloudy conditions but with good visibility. The survey began at 07:30 and finished at 13:00, a total time of 5 h 30 min. Thirty-three transects were flown across LWC at a total length of 402 km. Transect lengths ranged between 3.2 and 17.7 km, with a mean length of 12.2 km. On the basis of the total aerial count and ground surveys, the Grevy's zebra population of Lewa for 2008 was determined to be 322.

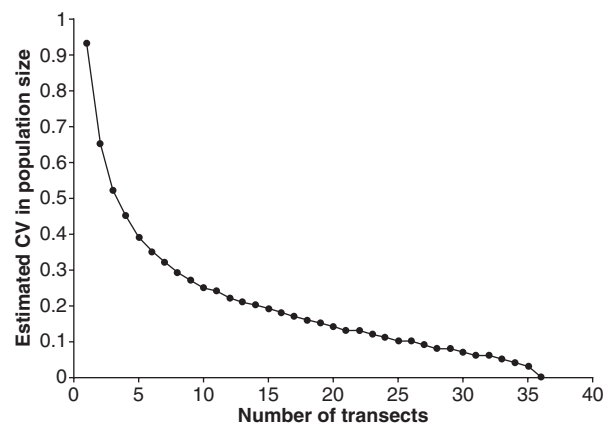


Fig 2 Estimated coefficient of variation in population size for an increasing number of transects, based upon observed mean and variance among transects during the sample survey

The sample count at 33% survey effort of 344 (CI 237–451) compared favourably with the official population size of 322, which fell comfortably within the confidence intervals.

In terms of costs, the sample survey at 33% survey effort covered twelve transects over 2 h 10 min at \$180 per hour, at a total cost of \$390. In contrast, the annual total count covered 33 transects over 5 h 30 min at a cost of \$180 per hour, for a total of \$990.

Discussion

Estimating the population size of endangered species can be difficult because they tend to be widely dispersed and at low density. The challenge is to develop survey methods that return accurate results and that are efficient. In this paper, we calculated a Grevy's zebra population estimate using sample survey methods and compared these to a known population within a fenced reserve. We found that the sample count produced an estimate of zebra population size that was accurate. Further, the sample count required a much smaller investment of resources.

The population estimate produced by our trial sample survey at 33% effort was comparable to LWC's published population figures, whose value fell within the confidence intervals of our estimate. Therefore, we believe that the sample survey has produced an accurate estimate of Grevy's zebra within LWC and shows potential for being more widely applicable across Grevy's zebra range in the future.

When managing endangered species, it is essential to be able to monitor changes in population size. In providing a measure of precision, in the form of confidence intervals, the sample survey method provides wildlife managers with the means to determine population trends over time. Inferential statistics can be used, which determine the significance of population changes between surveys, and thus accurately assess the effect of management interventions and threats upon the population (Williams, Nichols & Conroy, 2002).

Our sample aerial survey with 33% survey effort was less than half as expensive as the annual total count conducted at LWC. Considering that Grevy's zebra range across 85,000 km² within Kenya, sample surveys could dramatically reduce national survey costs. The high investment of resources and manpower makes it challenging to carry out regular monitoring, but by reducing costs, sample surveys could make regular monitoring more plausible. Further, such an approach would free up

resources which could be redirected to monitor fine grained parameters, such as foal survival, disease outbreaks or competition with livestock for resources, the understanding of which will help to conserve this valuable species.

The majority of Grevy's zebra are found on land owned or managed by local pastoralist communities across northern Kenya (Low *et al.*, 2009), where Grevy's zebra are a flagship species for community-based conservation conservancies. These conservancies would benefit from regular estimates of Grevy's zebra populations to assess their management actions. Needless to say, an efficient and simple population survey method would be of great value, both for conservancies, and at the wider habitat scale.

The favoured habitat of Grevy's zebra in northern Kenya is short grass open savannah (Low *et al.*, 2009), which has excellent visibility and where a detection rate close to one is likely to be met (Kinnaid and O'Brien, unpublished data). However, across the entire Grevy's zebra range, we expect that Grevy's zebra will utilize a range of habitat types including bushland, and may be more dispersed, both of which will be influenced by resource availability and season (Williams, 1998).

In such conditions, it is widely recognized that negative bias, or undercount, is a major issue with aerial surveys (Jachmann, 2002; Ogutu *et al.*, 1996) because of the failure to detect all animals. For these conditions, we suggest that surveys which explicitly estimate detectability are implemented. For example, the double-observer methodology (Cook & Jacobson, 1979; Jachmann, 2001) generates a global detection correction factor for different habitat types and thus allows more robust population estimation.

We recommend that sample aerial surveys be experimentally applied in the more diverse habitats of northern Kenya using appropriate means of measuring, and correcting for, detectability. Such trials will also allow us to determine the level of survey effort required to return an accurate population estimate in this more challenging environment.

This study indicates that sample surveys are an effective and efficient method of surveying Grevy's zebra in open habitats. We derived a precise and accurate estimate of population size at less than half the cost of those from an equivalent total count method. In conclusion, we recommend the wider testing of sample survey methods for Grevy's zebra across their range, with a view to considering this approach for future surveys.

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