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Reliable monitoring of elephant populations in the forests of India: Analytical and practical considerations

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ABSTRACT

Reliable estimation of elephant population abundance and density assumes great importance in the context of massive threats from illegal hunting and habitat loss. However, available estimates of elephant populations, particularly in Asia, are often unreliable and misleading. We evaluate sources of bias and imprecision in commonly used estimation approaches, and demonstrate that if correctly applied, line transect sampling based on visual detections of elephant clusters can address these issues. We compare our own early transect surveys on foot that relied on purposive line placement, to subsequent surveys in 2011, which employed rigorous survey designs. Estimated elephant density ($\widehat{D}(95\%\widehat{CI}(\widehat{D}))$ in our study sites in India, ranged between 0.25(0.12–0.53) and 3.29(1.74–6.21) elephants/km^2 in the earlier surveys and between 0.32(0.14–0.75) and 2.24(1.41–3.56) elephants/km^2 in the 2011 survey. Although coefficients of variation of estimated detection probability ($\hat{p}$) and cluster size ($\widehat{E}(S)$) were higher at low sample sizes, they dropped to <15% with $n > 40$ detections. Variance of encounter rate (n/l) was the largest contributor to the variance of density estimates. We recommend that rigorous line transect surveys must ensure: random transect placement with systematic and sufficient spatial replication to ensure adequate spatial coverage; coverage of sufficiently large areas in a short duration to ensure population closure; and investment of adequate effort to ensure reasonable number of detections. Field and analytical protocols presented here can enable reliable estimation of density and abundance of other wildlife species that can be visually detected in forests. They can lead to improved animal monitoring programs that are central to rigorously evaluating the effectiveness of widely employed, expensive conservation interventions meant to counter massive anthropogenic threats facing elephants and other large, diurnal species.

1. Introduction

Growing trade in illegally acquired parts of wild animals has been driving massive population and range declines in several endangered species (Bennett, 2015). Elephants are amongst the worst hit, with recent estimates suggesting as many as 35,000 individuals being killed annually in Africa to feed an illegal ivory market (Wittemyer et al., 2014). Elephant conservation in the face of such pressures is a formidable challenge that requires law enforcement to control ivory poaching, in addition to reducing demand for ivory in the long run (Bennett, 2015). Concurrently, elephants––particularly those in the densely-populated regions of Asia––are severely threatened by conflict with humans, as well as habitat loss and degradation (Blake and Hedges, 2004; Goswami et al., 2014). It is therefore imperative that elephant populations are reliably monitored to permit assessments of their dynamics, and for the prioritization of protection and conflict mitigation efforts at important conservation sites across their range.

Abundance is a key state variable. It strongly influences various ecological and behavioral attributes, and consequently the potential viability of animal populations (Williams et al., 2002). Reliable population monitoring can therefore allow the detection of departures of a given system from its desired state, and help evaluate the influence of perturbations such as anthropogenic threats, as well as the effectiveness of management interventions (Sukumar, 1989; Williams et al., 2002). The development and

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application of methods that can provide accurate population estimates in forested habitats is particularly important given that elephants in such habitats have suffered some of the severest onslaughts of poaching (Blake et al., 2007; Maisels et al., 2013). However, while there has been a long history of estimating the abundance of elephant populations in the African savannahs, efforts directed towards populations in the forests of Asia and Africa are weaker and more recent. For example, wildlife managers regularly attempt a massive, countrywide 'Synchronised Elephant Census' (SEC) covering the entire elephant range in India (Bist, 2003; Rangarajan et al., 2010), but the reliability of the elephant population sizes thus obtained is questionable. Blake and Hedges (2004) argue that the lack of consistency and reliability make these frequently cited regional 'elephant numbers', at best, educated guesses. They conclude that "uncritical acceptance of poor-quality data (such as the current estimates of Asian elephant populations) impedes [...] effective elephant conservation" (Blake and Hedges, 2004).

Population estimation efforts for elephants in the forests of Asia have been dogged by the same fundamental problems of survey design and sampling previously pointed out for other flagship species such as the tiger *Panthera tigris* (Karanth et al., 2003). India's nationally-conducted SEC includes methods such as 'waterhole' and 'block' counts that are not based on modern animal sampling and estimation theory (Rangarajan et al., 2010). Thus, while the focus is on assessing elephant population size across the country (an area > 3 million km^2), methods employed by managers for achieving this ambitious goal are highly inadequate.

On the other hand, many wildlife researchers in India (e.g. Dekker et al., 1991; Kumaraguru et al., 2010; Ramakrishnan et al., 1998), elsewhere in Asia (e.g. Dawson, 1992; de Silva, 2001), and in Africa (e.g. Barnes et al., 1995; Olivier et al., 2009), favor indirect methods of surveying population through sign surveys over visual counts of animals. In this approach, the density of elephant dung is first estimated using standard line transect sampling (Buckland et al., 2001). This estimate is thereafter converted to elephant density using estimated rates of defecation and dung decay (Barnes, 1993, 2001) that are seldom estimated specifically for the survey area. Instead, defecation and dung decay rates are typically borrowed from other studies due to logistical difficulties. Importantly, we note that using borrowed estimates of these two critical parameters or failing to fully capture their inherently high spatial and temporal variation, can result in substantially biased estimates of elephant density and abundance (see Hedges, 2012a for details). A few investigators (Baskaran et al., 2010; Karanth and Sunquist, 1992; Varman and Sukumar, 1995) have carried out 'direct' line transect surveys of elephant groups to estimate ecological densities.

Keeping in view current animal sampling theory (Williams et al., 2002), reliable estimation of elephant population parameters requires serious consideration of two factors that confound the relationship between observations (data) and reality (true numbers/density): (1) spatial sampling, which permits spatial extrapolation from what was sampled to areas not sampled, through randomization and replication of samples(Thompson, 2002; Williams et al., 2002); and (2) imperfect detection, which represents the inability of observers to detect every elephant within the area surveyed (Nichols and Karanth, 2002; Pollock et al., 2002; Williams et al., 2002).

In this study we compare sources of bias and uncertainty in approaches typically used to estimate elephant density and abundance within forests (block and waterhole counts, and indirect, dung-based estimation) with direct distance sampling of elephant groups, within the framework of current population estimation theory. We then demonstrate the use of line transect sampling (Buckland et al., 2001; Strindberg, 2012) for estimating elephant densities from visual detections. This approach addresses both imperfect detectability and spatial sampling issues, while also avoiding statistical and practical complexities involved in converting dung densities into elephant densities. Based on our estimates at multiple forested sites, we elucidate common mistakes in the conduct of line transect surveys by contrasting our own pre-2000 efforts with a recent survey that addressed necessary design considerations. Finally, we discuss the critical relevance of spatial scale of survey methods to estimated parameters, and generate practical and analytical recommendations for population monitoring of elephants and other visually detectable animal species.

2. Methods

2.1. Comparison of density estimation methods

We reviewed the literature for detailed methodological protocols and field implementation of waterhole and block counts, and dung-based density estimation. We compiled the major sources of bias and uncertainty in these methods. We then used existing theory to compare how these sources of bias and uncertainty affect waterhole and block counts, and dung density–based estimates, as well as how line transect surveys that we conducted (pre-2000 and in 2011) account for, or are affected by these factors.

2.2. Study sites

We surveyed elephants in several sites, spanning a range of rainfall, habitat types, topography and human disturbance within India (Fig. 1, Appendix A Table A1). Our field surveys were conducted between November and May each year. Prior to the year 2000 we surveyed six sites, with study area sizes ranging from 52 km^2 to 166 km^2. In 2011, we surveyed four sites of 359 km^2 to 572 km^2, encompassing the majority of our earlier sites. Among our pre-2000 sites, Nalkeri, Sunkadakatte and Arikeri are located within Nagarahole Tiger Reserve, the Bhadra-1998 site within the Bhadra-2011 study area, and the Bandipur-2011 site encompasses the Bandipur-1999 study area. All fieldwork was carried out under field research permits issued by the Karnataka and Assam Forest Departments.

2.3. Design of field surveys

In each pre-2000 field sites, we purposively placed 3–6 straight-line transects considering adequate geographical coverage of the study area and proportional representation of the different habitat types on an *ad hoc* basis, without the recommended formal study design (Buckland et al., 2001; Strindberg et al., 2004). In 2011 we used a systematic survey design with a random start, using 23–56 replicates, with a square (rather than straight line) geometry (Fig. 1). The survey design we employed in 2011 eliminated backtracking (or returning) along the line to return to the start, increased efficiency, provided testably adequate spatial coverage of the study area and captured fine-scale spatial variation in elephant density and detectability. These survey designs were implemented using the design module in Distance software (Strindberg et al., 2004; Thomas et al., 2010).

2.4. Field data collection methods

Data were collected by two trained observers walking along transect lines between 0615 and 0830 h, and between 1600 and 1815 h. In the tall grasslands of Kaziranga, surveys were conducted from platforms on trained riding elephants. On detecting elephant(s), observers recorded group size, sighting distance, and