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Spatial analysis of aerial survey data reveals correlates of elephant carcasses within a heavily poached ecosystem

Colin M. Beale[a,*], Severin Hauenstein[b], Simon Mduma[c], Howard Frederick[d], Trevor Jones[e], Claire Bracebridge[f], Honori Maliti[c], Hamza Kija[c], Edward M. Kohi[c,g]

[a] *Department of Biology, University of York, YO19 5PR, UK*
[b] *Department of Biometry and Environmental System Analysis, University of Freiburg, 79106 Freiburg, Germany*
[c] *Tanzania Wildlife Research Institute, Box 661, Arusha, Tanzania*
[d] *Independent consultant, Box 1890, Cortaro, AZ, USA*
[e] *Southern Tanzania Elephant Program, Box 2494, Iringa, Tanzania*
[f] *Wildlife Conservation Society, Box 1654, Iringa, Tanzania*
[g] *Mahale-Gombe Wildlife Research Centre, Box 1053, Kigoma, Tanzania*

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A B S T R A C T

Growth of the illegal wildlife trade is a key driver of biodiversity loss, with considerable research focussing on trafficking and trade, but rather less focussed on supply. Elephant poaching for ivory has driven a recent population decline in African elephants and is a typical example of illegal wildlife trade. Some of the heaviest poaching has been in Southern Tanzania's Ruaha-Rungwa ecosystem. Using data from three successive aerial surveys and modern spatial analysis techniques we identify the correlates of elephant carcasses within the ecosystem, from which important information about how poachers operate can be gleaned. Carcass density was highest close to wet-season (but not dry season) waterholes, at higher altitudes and at intermediate travel cost from villages. We found no evidence for an ecosystem-wide impact of ranger patrol locations on carcass abundance, but found strong evidence that different ranger posts showed contrasting patterns in relation to carcasses, some being significantly associated with clusters of carcasses, others showing the expected negative correlation and most showing no pattern at all. Despite a spatial change in elephant carcass locations between years, we find little evidence to suggest poachers have changed their behaviour in relation to key modelled covariates. Our maps of poaching activity can feed directly into anti-poaching control measures, but also provide general insights into how illegal harvest of high value wildlife products occurs in the field, and our spatio-temporal analysis provides a valuable analysis framework for aerial survey data from protected areas globally.

1. Introduction

Despite global commitments to halt biodiversity loss, the populations of many species continue to decline (Pimm et al., 2014). Although protecting land in national parks and nature reserves remains a cornerstone of conservation practice, for many species and in many areas, wildlife populations within protected areas are also dwindling (Laurance et al., 2012). A primary cause of ongoing wildlife decline in protected areas is illegal harvesting, with inadequate law enforcement driven by insufficient resourcing and under-motivated staff, exacerbated by corruption of those charged with enforcing laws (Moreto et al., 2015). For some high-value wildlife products such as pangolin scales, rosewood, rhinoceros horn or elephant ivory a thriving international trade has developed that simultaneously endangers the harvested animal and plant populations (Challender et al., 2015–2017) and provides financial support to criminal gangs that can destabilise local institutions (Bennett, 2015). An apparent increase in elephant poaching over recent years has received significant publicity, with evidence that poaching rates of African elephant *Loxodonta africana* are again driving continental scale population declines (Chase et al., 2016; Wittemyer et al., 2014). This is a particular concern because elephants are ecosystem engineers, facilitating numerous other species in the savannah (Kohi et al., 2011), but their large size and the consequent ease of finding evidence of illegal activity in the form of carcasses also offers opportunities to study usually cryptic patterns of illegal harvest of high-value wildlife commodities.

East Africa is home to several of the largest populations of African elephant: in 2013 the IUCN African elephant specialist group estimated

* Corresponding author.
E-mail address: colin.beale@york.ac.uk (C.M. Beale).

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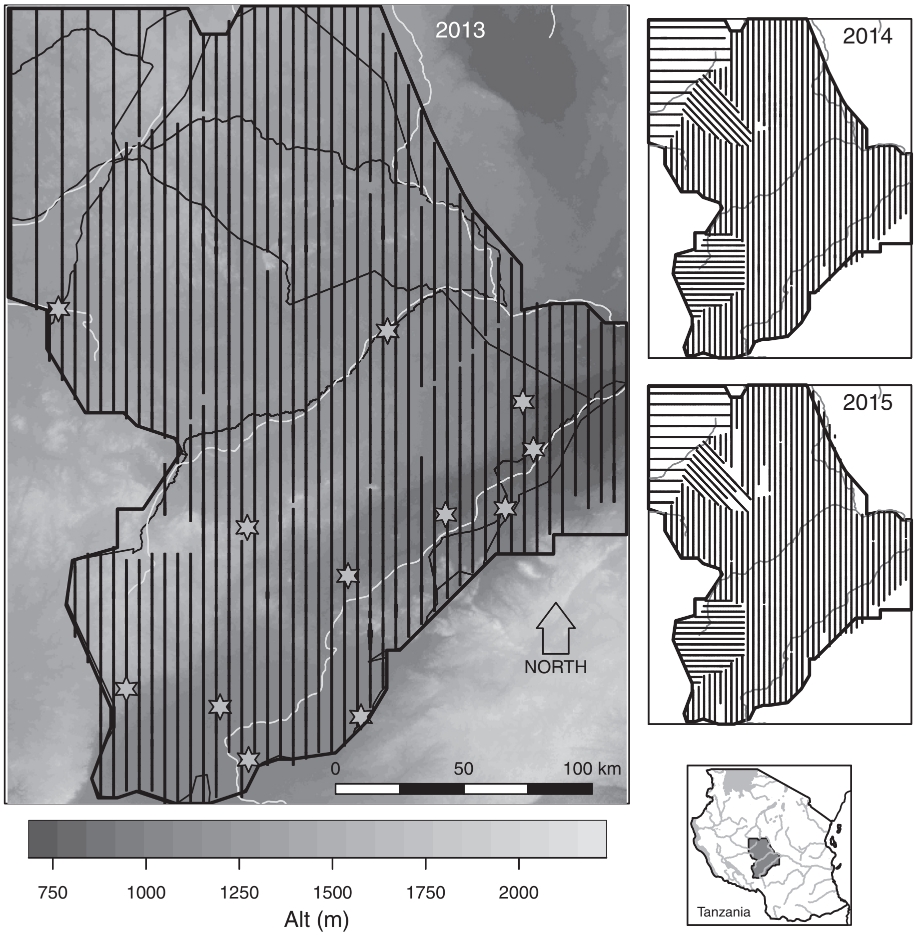

Fig. 1. Flightlines for the Ruaha/Rungwa surveys 2013–2015, with map of Tanzania showing detailed region. Background shows altitude. Note changes in alignment in 2014 and minor differences in 2015, main protected areas and rivers and presented with the positions of permanent ranger posts indicated by pale stars in the main panel.

that there were around 400,000 elephants in Africa (IUCN, 2013). In 2009 Tanzania's elephant population within the Ruaha-Rungwa ecosystem was the third largest in Africa, holding nearly 10% of the global population, ranging over 40,000 km^2 of strictly protected National Park, Game Reserve and Wildlife Management Areas. Recently, however, several lines of evidence suggest this population is in rapid decline due to poaching,with a large majority of elephant carcasses encountered by monitoring teams between 2013 and 2015 resulting from illegal killings (CITES, 2016). Genetic identification of source populations for ivory seized from international smugglers has identified an increase in the harvest coming from southern, then south-western Tanzania (Wasser et al., 2015). Since the largest population of elephants (estimated at 30,500–38,800 individuals in 2006) in south-western Tanzania is found in the Ruaha-Rungwa ecosystem, it is logical to conclude many are from this population. Simultaneously, aerial surveys tell a story of rapid decline (TAWIRI, 2013, 2014, 2015): a 56% decline between 2009 and 2013, with a further decline of 22–59% to 11,100–20,600 individuals in 2015. (A 2014 survey estimated only 6600–9900 individuals, with at least some of the low numbers in 2014 likely due to the lack of large herds inflating both estimate and confidence intervals: TAWIRI, 2015). These data are strongly suggestive that poaching is having a dramatic effect on the elephant population in the ecosystem, an inference further supported by demographic change in the Ruaha elephant population over the same period (Jones et al., in press). In addition to counting live elephants, the aerial surveys also count carcasses. Carcass counts can be corrected by a standard decay rate to generate a plausibility check of observed declines (Chase et al., 2016; Wells, 1989). These data indicate that the declines between 2009 and 2013 were in agreement with the estimated number of carcasses, whilst the continued decline between 2013 and 2014 was not matched by the estimated carcass ratio and the apparent population increase to 2015 was accompanied by a further increase in carcasses (TAWIRI, 2013, 2014, 2015). Moreover, at several thousand elephants per year, the implied poaching rate suggests elephant poaching on a near industrial scale, despite active ranger units throughout the ecosystem. The size of this decline and the poaching pressure exerted across Africa suggests that review and redirection of protection effort would be timely.

Aerial surveys are commonly used to survey both terrestrial (e.g. Ogutu et al., 2016) and marine species (Andriolo et al., 2006). Analysis of aerial survey of elephants typically focuses on estimating the number of animals (and carcasses) that are seen across the ecosystem as a whole, and the richness of information contained within the spatial pattern of observed live and dead animals is usually ignored (Booth and Dunham, 2016; e.g. Chase et al., 2016). Since Geographical Positioning System (GPS) technology has become widely available, aerial surveys usually record the location of every animal seen within known observation windows in order to present spatial distribution maps of observation as well as density estimates (e.g. Chase et al., 2016). The presence of spatial information on live and dead elephants in combination with widely available spatial datasets including important covariates makes it possible to use spatial analysis to identify both the correlates of animal and carcass distribution at fine scales (Ndaimani et al., 2016) and to assess how these correlates may change over time. Such spatial analyses can provide insight into the ways poachers are operating within a landscape and have recently been used to identify priority areas for ranger patrols, with potential for dramatic improvement with relatively little investment (Critchlow et al., 2016).

Here, we use Bayesian spatially explicit generalised additive models fitted by integrated nested Laplace approximation (INLA: (Rue et al.,