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Robust estimation of snare prevalence within a tropical forest context using N-mixture models

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ABSTRACT

Hunting with snares is indiscriminate and wasteful, and this practice is currently one of the gravest threats to terrestrial vertebrates in the tropics. However, as snares are difficult to detect and often dispersed widely across large, inaccessible areas it is problematic to reliably estimate their prevalence and no standard survey methods exist. Conservation managers need reliable, timely, information on the spatio-temporal patterns of hunting and on responses to interventions, and we present an innovative sampling and analysis framework that allows for the rigorous estimation of snare detectability and 'abundance', but which can be feasibly implemented in challenging field contexts. This new approach was used to undertake a large-scale systematic snare survey in Keo Seima Wildlife Sanctuary, in Eastern Cambodia, and the resulting data were analysed using a novel application of N-mixture models. A range of environmental and management factors were examined as potential determinants of snare abundance and detectability, and proximity to the Vietnamese border was shown to be overwhelmingly the most influential factor. Snares were more common in the wet season rather than the dry season, and the detection probability of snares was shown to be low (~ 0.33), as predicted. No clear relationships between snaring levels, anti-poaching patrol effort and ungulate densities were evident from these data. There was clear evidence that certain factors, such as the percentage of dense forest cover, will exert confounding effects on both detectability and abundance, highlighting the critical need to take account of the imperfect detection when designing threat monitoring systems.

1. Introduction

Illegal hunting, be it for local subsistence or to supply ever-expanding markets with meat, pets, trophies and other body parts, arguably constitutes the greatest current threat facing wild vertebrates in tropical Asia and Africa (Corlett, 2007; Fa and Brown, 2009; Harrison et al., 2016). Unsustainable hunting can have dire consequences not just in terms of causing species extirpations and degrading the ecological integrity of forest systems, but also through its impact on the livelihoods of the rural, often marginalised, people who depend on these resources (Milner-Gulland and Bennett, 2003; Fa et al., 2016).

Traditional approaches to monitoring poaching and other forms of illegal resource use (i.e. interview-based techniques, self-reporting, direct observation) all have methodological challenges associated with them (Gavin et al., 2010). This is largely due to the fact that offenders typically have strong incentives to conceal the true nature of their activities from investigators, potentially leading to severe and unquantifiable bias in estimates of the prevalence of illegal resource-use (Keane et al., 2008; Gavin et al., 2010). With the global roll-out of standardised law enforcement monitoring systems such as SMART, there has been a growing interest in threat data collected during routine patrols (i.e. encounters of infractions; e.g. Jachmann, 2008; Linkie et al., 2015), and the use of such cheap and readily available data will undoubtedly continue to increase. However, as essentially a by-product of efforts to deter illegal activities, these data typically also contain severe biases which can limit their utility for threat monitoring purposes (Gavin et al., 2010; Keane et al., 2011).

Any attempt to estimate the prevalence of a given threat can be affected by the same two sources of bias which affect all ecological surveys, imperfect detection and unrepresentative spatial sampling (Williams et al., 2002). The importance of considering these potential biases when designing ecological monitoring programs has been repeatedly highlighted (Yoccoz et al., 2001; Legg and Nagy, 2006; Nichols and Williams, 2006) but these issues are equally applicable to the monitoring of threats such as hunting. Employing a probabilistic sampling strategy and investing in sufficient survey effort can ensure

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representativeness (Brashares and Sam, 2005), but accounting for detection error can be more challenging. The problem of imperfect detection is of particular relevance to illegal hunting, not only because it precludes reliable monitoring of this threat, but also because a key factor in successful poaching deterrence is a high rate of detection (Leader-Williams and Milner-Gulland, 1993; Hilborn et al., 2006). And yet, to our knowledge, there are no published studies which attempt to estimate the extent or impact of illegal hunting using systematic surveys which account for imperfect detection.

The development of flexible hierarchical models has greatly improved researchers' ability to simultaneously account for variation which is related to spatial or temporal variation in an underlying ecological process of interest (i.e. occurrence or abundance) and variation which is due to the imperfect observation of this process (i.e. detectability Royle and Dorazio, 2008; Kéry and Royle, 2016). One class of hierarchical models includes multinomial and binomial mixture models of Royle (2004a, 2004b), which to date have been most frequently used in the analysis of avian point count data, although they have also been employed in the study of mammal and amphibian populations (Mazerolle et al., 2007; Zellweger-Fischer et al., 2011). A natural extension of these methods is to adapt them for modelling observations of hunting rather than of wildlife.

We present a case study in which binomial mixture models, or 'N' mixture models, are used to generate a robust estimate of snaring prevalence in a protected area in Eastern Cambodia. As elsewhere in the tropics, wire snares are a common method of hunting in this region, as the equipment involved is affordable and easily accessible, and the technique is effective for a wide range of vertebrate species (Noss, 1998; Becker et al., 2013). This form of hunting is particularly detrimental because in practice it is often indiscriminate and wasteful (Lindsey et al., 2011; Gray et al., 2017), and the use of snares is therefore illegal in Cambodia. However, the covert nature of this activity means that it is extremely difficult to detect perpetrators or snares, and consequently the enforcement of snaring prohibitions is challenging (Noss, 1998). Although some surveys have been undertaken in Africa (i.e. Wato et al., 2006; Lindsey et al., 2011; Becker et al., 2013) none of them address the detection issue, and almost no studies have been carried out in Southeast Asia (but see Linkie et al., 2015). This is despite the fact that hunting with snares represents one of the gravest threats to terrestrial biodiversity in the region (Gray et al., 2017). Without accurate measurement of such threats, managers cannot easily evaluate the success of conservation actions designed to reduce snaring levels, or design more effective interventions as a result (Hockings et al., 2000).

The aim of this study was to develop an approach which could reliably estimate the abundance and detectability of snares, but that could be implemented within a typically challenging tropical forest context. Our objectives were both methodological and relevant to management, and related both to the field component and the subsequent modelling process:

Objective 1. Develop an appropriate sampling design for a snare survey to produce data suitable for analysis within a hierarchical modelling framework.
Objective 2. Analyse the resultant snare survey data using N-mixture models to generate a detectability-corrected spatially explicit index of snare abundance.
Objective 3. Within this modelling framework, investigate a priori hypothesised relationships between a range of potential covariates and both snare detectability and snare abundance.

2. Methods

2.1. Methodological framework

Any application of N-mixture models requires both spatial and temporal replication within the data (Royle, 2004a, 2004b; Kéry et al., 2005), hence a sampling design was required which incorporated both multiple sites and repeated surveys of each site. In practical terms, although relatively numerous, snares are extremely difficult to detect (O'Kelly et al., 2017). They also tend to be aggregated in space at one scale (i.e. where one hunter operates) whilst also dispersed across a large survey area (i.e. the entirety of the protected area). Therefore, the sampling design necessarily involved a balance between maximising the efficiency of data collection and adhering to best practice in terms of scientific rigour.

N-mixture models are extensions of the Poisson generalized linear model (GLM) or generalized linear mixed model (GLMM), but they include an additional stochastic component that explicitly models the observation process (Kéry and Royle, 2010, 2016). These models can produce estimates of abundance without the need for the identification of individuals, and they are particularly appropriate for scenarios where data are relatively sparse (Royle, 2004a, 2004b). These models are also useful for investigating how both the abundance and detection processes vary as a function of both ecological and management factors (i.e. Chandler et al., 2009; Chandler and King, 2011).

Our modelling approach incorporated two stages, the first of which examined covariates for which we had some clear a priori hypothesis regarding their relationship to abundance and/or detectability. The second phase involved including additional covariates in order to explore the relationship between threats (e.g. snaring rates), interventions (e.g. patrol effort) and impacts (i.e. wildlife densities). Whilst the relationships and potential causal linkages of the second stage are of fundamental interest to conservation managers, they are difficult to predict *a priori* or to interpret with any certainty.

2.2. Study site

The Keo Seima Wildlife Sanctuary (KSWS) covers a 292,690 ha mosaic of evergreen, semi-evergreen forest and deciduous forest in eastern Cambodia. Biodiversity values within KSWS are high, as it holds globally or regionally significant populations of elephants and wild cattle, and multiple species of primates, carnivores and large birds (Evans et al., 2012; O'Kelly et al., 2012).

The 20,000 people living near or within KSWS comprise both indigenous ethnic minorities and ethnic Khmer, the latter having arrived during a more recent wave of in-migration. Agriculture is the dominant livelihood activity but residents are also heavily forest dependent and a critical source of income for many families is tapping of liquid resin from *Dipterocarpus* trees, which takes place widely throughout the reserve (Evans et al., 2012). The most significant threat to key wildlife species in KSWS is over-hunting and several large mammal species have been extirpated from the area (O'Kelly et al., 2012). Populations of many other taxa have been drastically reduced by hunting with guns and, more commonly, snares, both of which are prohibited.

2.3. Sampling design and field protocols

Sampling took place across the 187,983 ha core area of KSWS in 37 clusters of 12 × 1km^2 "sites". Clustered sites formed a circuit around a set of permanent line transects used for long-term wildlife monitoring and positioned using a systematic design with a random starting point (O'Kelly et al., 2012). The cluster design maximised sampling efficiency but at the cost of inducing potential non-independence of sites within a cluster.

However, each cluster of sites was assumed to be spatially independent with respect to both hunter and prey movement during the study period. The distance between clusters was c.7 km which is greater than the ranging distances of any of the target species and likely to be much further than the distances typically covered by hunters in this terrain (patches of < 1 km^2, HJOK pers obs).

Between February 2011 and February 2012, each of the 37 clusters