

Conservation decision-making under uncertainty: Identifying when to reintroduce tiger *Panthera tigris* to Cambodia

Thomas N. E. Gray¹  | Matthew J. Grainger² | Romica Grosu³

¹Wildlife Alliance, New York, New York

²Norwegian Institute for Nature Research, Trondheim, Norway

³Wildlife Alliance, Phnom Penh, Cambodia

Correspondence

Romica Grosu, Wildlife Alliance, No. 86, Street 123, Toultompong I Precinct, Chamcamon District, Phnom Penh, Cambodia.
Email: romicagrosu@gmail.com

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Abstract

Conservationists need to present biological monitoring data to decision makers in a way which clearly represents uncertainty. Providing results in terms of the probability of a hypothesis being true may have greater utility for decision-making than traditionally used frequentist statistical approaches. Here, we demonstrate such an approach with regard to assessing the suitability of the Cardamom Rainforest Landscape, Cambodia for *Panthera tigris* (tiger) reintroduction. We estimated the density of tiger prey in the core of the landscape using the Random Encounter Model from camera-trap data and used Monte Carlo simulation to prorogate uncertainty around our model parameter estimates. This suggests there is currently a low probability that the core area of the landscape supports sufficient prey for a population of 25 adult tigers and that significant prey recovery is thus required prior to any reintroduction into the landscape. The Random Encounter Model contains a number of assumptions and we stress our main purpose is to illustrate an approach to incorporating uncertainty into conservation decision-making rather than providing robust estimation of current tiger prey densities in the Cardamom Rainforest Landscape. Our approach has wide utility for conveying species monitoring information to conservation planners in a simple to understand fashion.

KEYWORDS

Asia, Bayesian, camera-trap, carnivore, management, protected area, restoration, rewilding

1 | INTRODUCTION

Conservation managers often need to make important decisions based on uncertain and imperfect information. Biological monitoring data, which form the basis of planning and operational decision-making for many protected area managers, are inherently uncertain with

observational uncertainty impacting most estimates of species' abundance (Milner-Gulland & Shea, 2017). How to intuitively and transparently represent such uncertainty and account for it in conservation decision-making, particularly when decision makers are not scientists, is an important issue. Observational uncertainty is particularly prevalent when dealing with rare

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or threatened species as monitoring estimates are often bounded by wide confidence intervals (Gray, Prum, Pin, & Phan, 2012).

Large carnivore reintroductions are increasingly advocated as a tool to “rewild” landscapes and to support the conservation of threatened carnivores (Pettorelli, Durant, & du Toit, 2019). Successful carnivore reintroductions have demonstrated ecological and species conservation benefits (Hayward & Somers, 2009; Sarkar et al., 2016). As such, reintroduction has been identified as a key component of the global strategy to recover *Panthera tigris* Linnaeus, 1758 (tiger), populations in areas where the species has been extirpated including central Asia and Indochina (Chestin, Paltsyn, Pereladova, Iegorova, & Gibbs, 2017; Lynam, 2010). In Cambodia, tiger were extirpated in 2007 and ambitious plans for reintroduction have been developed for two conservation landscapes: the Cardamom Rainforest and Eastern Plains (Gray, Baltzer, Gopal, & Seng, 2017a). A critical factor determining a site's tiger carrying capacity, and hence suitability for reintroduction, is the density of prey (Karanth, Nichols, Kumar, Link, & Hines, 2004), with a recent study suggesting sufficient prey for 25 adult tigers as a necessary prerequisite for reintroduction (Gray, Crouthers, et al., 2017b). However, estimates of tiger prey densities will be uncertain. How should such data be interpreted by conservation decision makers? And how can the probability that prey densities reach certain thresholds be quantified?

A Bayesian statistical framework can assist with such decision-making through highlighting clear probabilities surrounding outcomes (Wade, 2000). Bayesian results are given in terms of the probability of a hypothesis (e.g., prey densities are sufficient to support a certain number of tigers) being true, and thus may have much greater utility for decision-making than the more traditionally used frequentist statistical approaches and associated 95% confidence intervals (Gray, Nguyen, & Nguyen, 2014). We demonstrate the use of such a non-frequentist analytical framework for conservation decision-making by presenting uncertainty around estimates of the density of tiger prey in the Cardamom Rainforest Landscape. We estimated combined ungulate and primate tiger prey density using a Random Encounter Model (Rowcliffe, Field, Turvey, & Carbone, 2008) on camera-trap data from the Cardamom Rainforest Landscape and use Monte Carlo simulation to propagate uncertainty around our model parameter estimates. We subsequently estimate the probability that prey density is sufficient to support various sized tiger populations—critical information for planning, implementing, and reintroduction in the landscape.

2 | METHODS

2.1 | Study area

The study was conducted within the core of Southern Cardamom National Park (SCNP), Koh Kong province, Cambodia (~11°47'N 103°20'E). SCNP was identified as one of two possible tiger reintroduction sites in the 2016 Cambodia Tiger Action Plan developed by the Royal Government of Cambodia under the Global Tiger Recovery Program (Gray, Baltzer, et al., 2017a). As a result of historic hunting the largest carnivores, tiger and *Panthera pardus* Linnaeus, 1758 (leopard), have been extirpated from the landscape, but smaller carnivores including *Cuon alpinus* Pallas, 1811 (dhole), *Neofelis nebulosa* Griffith, 1821 (mainland clouded leopard), and *Helarctos malayanus* Raffles, 1821 (sun bear) remain widespread (Gray, Billingsley, et al., 2017c).

2.2 | Estimating uncertainty in prey density

We estimated the density of potential tiger prey species in SCNP by applying the Random Encounter Model (Rowcliffe et al., 2008) to data from 65 automatic camera-traps (Bushnell Trophy Camera Model 119537) set within a 200-km² grid in the core of SCNP. We used the R package “propagate” (Spiess, 2014) to propagate the uncertainty around the estimates of parameters within the Random Encounter Model. This package uses first-/second-order Taylor approximation and Monte Carlo simulation to calculate uncertainty propagation. We ran 500 simulations using the mean and standard deviations obtained from our data. For each simulation, the density of tiger prey was estimated. See Supporting Information and Gray (2018) for more details of the camera-trap methodology and modeling.

2.3 | Estimating tiger carrying capacity

Consistent relationships exist between prey and carnivore abundance allowing the calculation of carnivore carrying capacity based on prey densities (Carbone & Gittleman, 2002). The following formula has been used to estimate tiger carrying capacity for assessing site suitability for tiger reintroduction in central Asia (Chestin et al., 2017) and Cambodia (Gray, Crouthers, et al., 2017b):

$$K = N_{\text{prey}}/450 \quad (1)$$

where K is the site-specific carrying capacity for tigers, N_{prey} is the abundance of all prey species in the site, and

450 represents the mean number of ungulate of different body mass required to support one tiger (Karanth et al., 2004; Miller et al., 2014). Under this model, a population of 25 tigers requires at least 11,250 prey items. We used Equation (1) to estimate the densities of tiger prey required to support various sized tiger population within 1,500 km² of the core of SCNP—a hypothetical tiger reintroduction site (Table 1). R was then used to estimate the proportion of density simulations sufficient to support various tiger populations.

3 | RESULTS

A total of 65 camera-trap stations were operational for 8,236 trap-nights and generated 601 detections of five tiger prey species: *Sus scrofa* Linnaeus, 1758 (wild pig), *Rusa unicolor* Kerr, 1792 (sambar), *Capricornis milneedwardsii* David, 1869 (Chinese serow), *Muntiacus vaginalis* Boddaert, 1785 (northern red muntjac), and *Macaca leonina* Blyth, 1863 (northern pig-tailed macaque). Across 500 simulations, the median tiger prey density was 4.2 individuals per km² with a mode of 3.3 individuals per km². In 82% of simulations, the 1,500-km² landscape was able to support 5 tigers and in 24% of simulations there was sufficient prey for 25 adult tigers (Table 1; Figure 1).

4 | DISCUSSION

Biological monitoring data are inherently uncertain with observational uncertainty often obscuring the “true” status of conservation targets. Non-frequentist approaches to presenting data variability may make it simpler for conservation decision makers to interpret the uncertainty surrounding species monitoring data and, as such, more easily assess the risks and rewards associated with their

decisions (Gray et al., 2014). We demonstrate the value of such an approach with regard to estimating tiger prey density, and thus current landscape tiger carrying capacity, in SCNP, southwest Cambodia—a putative tiger reintroduction site (Gray, Baltzer, et al., 2017a). We used Monte Carlo simulation to propagate uncertainty around our density estimates and illustrate how such information could be presented to conservation decision makers. We showed that there is currently a low probability (<25%) that the 1,500-km² core area of SCNP supports sufficient prey for a tiger population of at least 25 adult tigers (Gray, Crouthers, et al., 2017b). There is a much higher probability (>80%) that the landscape could currently support a founder population of five tigers (Figure 1).

However, even when presented with such information, decision makers need to assess, and define, their own levels of risk and tolerance. A draft Operational Plan for tiger reintroduction into Cambodia, developed by the Ministry of Environment and the World Wide Fund for Nature, suggested that evidence of greater than 70% probability of tiger prey levels exceeding 5 individuals per km² (sufficient for 17 tigers in 1,500-km²) was a prerequisite for supporting reintroduction. Assessing such targets is best achieved through statistical approaches such as we have used. And our analysis suggests that there is, currently, a 36.6% chance that prey densities exceed five individuals per km² in our study area. As such further tiger prey recovery is needed and currently the risk of insufficient prey to support a viable tiger population is too high for decision makers to endorse tiger reintroduction. It may also be important to identify which sources of uncertainty have the largest effect on the choices available to conservation managers. Is scientific (e.g., observational uncertainty and uncertainty in the model parameters as we address in this paper) or management (e.g., budget, support of local communities, etc.) uncertainty more important in determining the choices of management action? Which uncertainties need to be prioritized to ensure a successful conservation outcome? Formal methods such as the Value of Information can be used to address these types of questions (Bolam et al., 2019).

Estimating animal density using the Random Encounter Model from camera-trap data relies on a number of assumptions and we acknowledge significant caveats regarding using this approach to estimate tiger prey density (Foster & Harmsen, 2012; Rowcliffe et al., 2008). However, our main purpose is to illustrate an approach to incorporating uncertainty into conservation decision-making rather than providing robust estimation of current tiger prey densities in SCNP per se. In our Random Encounter Model, we borrowed animal movement parameters from the literature (see Supporting Information). Recently developed methods for calculating this

TABLE 1 Probability that tiger prey abundance within 1,500-km² of the Cardamom Rainforest Landscape is sufficient to support various sized tiger populations based on 500 simulations propagating uncertainty surrounding prey density estimates from Random Encounter Modeling of camera-trap data

Tiger population size	Minimum required prey density	Probability prey density exceeds minimum
5	1.5 per km ²	0.816
10	3.0 per km ²	0.582
15	4.5 per km ²	0.424
20	6.0 per km ²	0.308
25	7.5 per km ²	0.236

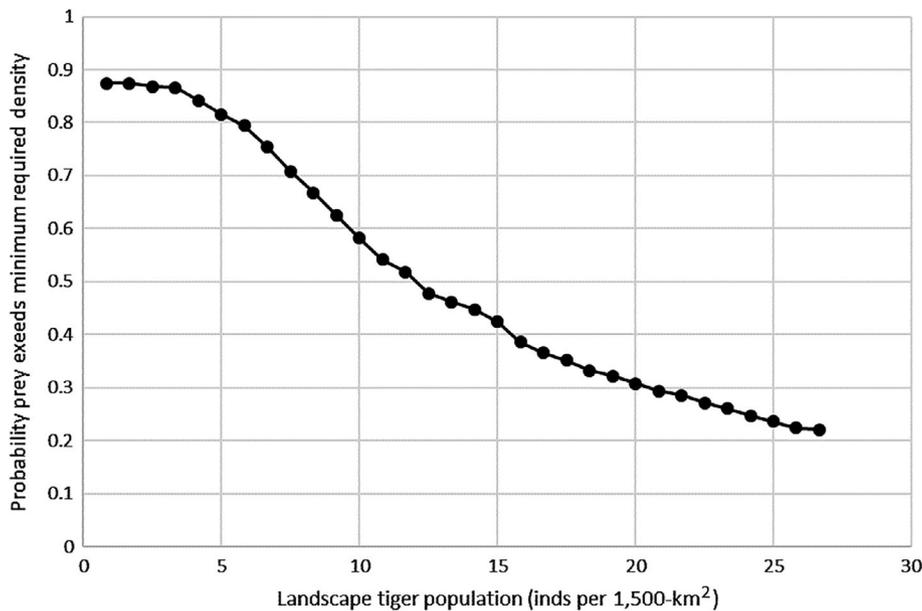


FIGURE 1 Probability of 1,500-km² core of the Cardamom Rainforest Landscape supporting sufficient prey to support various sized tiger populations based on propagating uncertainty around estimates in prey density

model parameter from camera-trap data are available (Palencia et al., 2019; Rowcliffe, Jansen, Kays, Kranstauber, & Carbone, 2016) and we recommend their use in similar studies. Unfortunately, the camera-trap data we used were not amenable to such approaches.

Our tiger prey community comprised four ungulate species and one primate—the highly terrestrial *Macaca leonina*. There have been few studies on tiger diet in South East Asian evergreen forests but it seems likely that all of these species are key components of tiger diets in the region. There is evidence of primates in tiger diets throughout Asia (Hart, 2007; Sankar & Johnsingh, 2002). Despite the exploratory nature of our analysis, our estimates of tiger prey densities appear to make ecological sense. There are limited estimates of ungulate densities in Asian evergreen rainforest, particularly those such as SCNP which have been impacted by historic hunting. But our estimated densities (i.e., mean and mode of between 3 and 4 individuals per km² from our 500 simulations) are very similar to those from Keo Seima Wildlife Sanctuary, eastern Cambodia (O’Kelly et al., 2012) and, logically, lower than in less intensively hunted south Indian evergreen forests which still support tigers (Ramesh et al., 2012).

It is important for conservationists to present biological monitoring data to decision makers in a way which clearly represents uncertainty. We demonstrate how conservationists can present uncertainty around monitoring estimates in a simple way and apply this to answer a real conservation question—what is the probability that the Cardamom Rainforest Landscape is currently ready for tiger reintroduction? We believe this approach has wide utility for conveying species monitoring information to conservation planners in a simple to understand fashion.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

AUTHOR CONTRIBUTIONS

T.N.E.G.: planned study; T.N.E.G., M.J.G.: wrote manuscript; R.G.: collected data; T.N.E.G., M.J.G.: analyzed data.

ETHICS STATEMENT

This study met all relevant ethical guidelines and was performed with full permission and in accordance with the laws of the Kingdom of Cambodia.

DATA ACCESSIBILITY STATEMENT

All data are available from the lead author.

ORCID

Thomas N. E. Gray  <https://orcid.org/0000-0002-3642-4724>

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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