**Finding the sweet spot in camera trapping: a review of camera trap papers to test for reported sampling effort in population estimates.**

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**Keywords**

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**Introduction**

Camera traps provide a means to survey wildlife and its interactions with the surrounding environment with relatively little human interference. These survey devices normally record animal presence via a triggered passive, infrared motion sensor (Marcus Rowcliffe et al. 2011). They are one of the most popular survey tools in current wildlife research, particularly in the domain of terrestrial vertebrate biology (P. Meek et al. 2014), used to record activity patterns and determine parameters such as occupancy, abundance, and diversity (Karanth et al. 2004; Kelly et al. 2008). Besides their use in wildlife research, camera traps have been used in studies that focus on nest ecology, detection of rare species, estimation of population size and species richness, behavioural studies, habitat use, and occupation of human-built structures (Cutler and Swann 1999; O’Connell et al. 2011 ). Thus, camera traps are a versatile method for collecting data on the functioning of many systems that can be used for a variety of management and conservation practices. Knowing their popularity in abundance and diversity research, herein we examine the sampling effort of this tool to predict animal abundances and diversity for a system.

Various crucial aspects can influence the number of species detected by camera traps, as well as the trapping rate (ratio of photographs to camera trapping time (Rovero and Marshall 2009)). These include trigger speed, detection zone, recovery time, night detection, and battery consumption that can impact the collected data (Hughson and Darby 2010). Limitations of this method can also arise from camera models, placement and orientation, temperature differentials, and species behavioural responses (P. D. Meek, Ballard, and Fleming 2015). The factors can be summarized as trapping effort and trapping design and can affect estimates of abundance and diversity (Yasuda 2004; Wegge, Pokheral, and Jnawali 2004).

Trapping rate is a useful index for abundance and diversity estimates (Rovero and Marshall 2009; J. Marcus Rowcliffe et al. 2008; Silveira, Jácomo, and Diniz-Filho 2003). Minimum trapping effort (MTE) is another important factor for population estimates. MTE refers to the number of camera trap days required to record species of interest in an area (Si, Kays, and Ding 2014) and varies extensively across studies. The number of camera traps used in a study is directly related to both trapping design and effort because a small number of cameras can result in low detection probabilities and affect the strength of population estimates (Foster and Harmsen 2012). The interplay amongst these elements provides us with an excellent opportunity to explore the relationship between trapping time, number of cameras, and richness estimates across the literature.

In the present study, we conducted a systematic review of camera trap literature to test for sampling effort as a predictor of animal diversity. We tested the threshold for sampling and provided an overview of the relationship between trapping rate and richness, and tested if ecosystem affects this relationship. Given that camera traps are increasingly being used in wildlife estimations, our study can provide some insight into the ‘sweet spot’ in sampling in different systems. This is valuable considering the connectedness of this tool for data acquisition and the implementation of conservation and management practices.

**Methods**

***Systematic review***

We conducted a systematic review using the terms Camera Trap\* AND Richness\*, Camera\* Trap\* AND Diversity\*, and Camera Trap\* AND Rarefaction\* Curve\* in ISI Web of Science (WoS). This search was done in January 2019. Search results were exported as a CSV file and are available publicly alongside the dataset (Figshare citation). Additionally, we conducted supplemental searches in book chapters and Google Scholar to validate the publication coverage of WoS. Searches resulted in a total of 397 publications once duplicates were removed. PRISMA diagram from Moher et al. (2009) demonstrates selection and review procedure (SA, Figure 1). We screened the abstracts and excluded papers based on relevance, whether they were a review, opinion, or idea paper, and if they focused on one species and were not quantitative. Moreover, only English language research papers were further examined. Full-text articles if they included: 1) a measure of richness or diversity; 2) the number of records; 3) duration of camera trapping (days). Additional variables such as the number of cameras and sites, as well the system were also recorded. The system of study was simplified into ecosystem, including coniferous, deciduous, desert, grassland, tropical, and mixed. In total, we screened 252 full-text articles.

***Statistical analyses***

All meta-statistical analyses were performed in R version 4.0.4 (R Development Core Team 2021). Codes are published openly on Zenodo (Citation). Species richness and the number of captures were independent event count variables and treated as raw incidence rates using the number of cameras in effect size calculations (PT Higgins, Li, and Deeks 2021). Effects sizes were calculated using the function *escalc* from the *metafor* package (Viechtbauer 2010). Random-effects models (*rma)* were applied to analyze estimate values and stand error where the number of cameras (sampling effort) served as independent variables and the number of captures or species richness served as the dependent variable. Heterogeneity in models was examined to ensure that variance does not rise from grouping similar measures in random-effect models (Langan et al. 2019). Forest plots were constructed using the function *ggplot* from the package *ggplot2* (Wickham 2009) where the dashed vertical line represents no effect and studies that do not cross this line significantly differ from the null effect (Verhagen and Ferreira 2014).

**Results**

A total of 119 articles were included in this study. Residual funnel plots were asymmetrically-skewed, indicating systematic heterogeneity (SA, Figures 2 and 3). Mixed-effect models were used to model the number of cameras as sampling effort by the number of captures and the estimate was significantly positive (132.9475 ± 35.6037, p<0.0001, Figure 1). There was significant heterogeneity between groups (Q = 299612.31, p<0.0001). We tested the same model with the variable ‘ecosystem’ and found it to be a significant moderator (F = 5.6266, p-Value = 0.0002). The relationship remained positive in all systems but was only significant in deserts and grasslands (Table 1 and Figure 2). Significant heterogeneity between groups was observed (Q = 237835.99, p = 0.0002). Additionally, the number of camera trap days was not a significant moderator in this model.

Subsequently, we modeled the effect between the number of cameras and richness found a smaller effect size than the above model, though still significantly positive (0.7878 ± 0.1064, p<0.0001, Figure 1). Heterogeneity between groups was significant (Q = 94675.90, p<0.0001). Ecosystem was a significant moderator in this model (F = 16.15, p<0.0001) and animal richness significantly increased with the number of cameras in all ecosystems except coniferous forest (Table 2 and Figure 2). The number of days was also not significant as a moderator in this model. Both the capture rate and richness rate were different from the null effect in all systems (SA, Figures 3 and 4, forest plots).

**Discussion**

Our results demonstrate the utility of camera traps as a tool in population estimate studies. In the last 20 years, camera traps have not only become more readily available as a tool but have also become more affordable (J. M. Rowcliffe and Carbone 2008), which is good news for conservation, ecology, wildlife, and species inventory studies. Their popularity in richness estimate studies (Tobler et al. 2008b; 2008a) provides us with the opportunity to explore aspects related to experimental design, intending to develop future frameworks that aid in the optimization of camera trapping procedures. The idea that trapping may be influenced by the number of cameras was supported here with increased number of cameras returning significantly higher capture rates specifically in grasslands and deserts. We demonstrated that increased number of cameras also resulted in higher diversity in almost all ecosystem, except for coniferous forest. Additionally, it did not come as a surprise that increasing the number of trapping days past a certain point did not increase the capacity of the number of cameras to detect more animal species. This evidence suggest that the chosen system of study may be key to enhancing trapping effort and offers a great deal of promise for the utilities of camera traps in arid scrubland and grassland.

The number of cameras used in the study affects the trapping effort. We found that the net effect of increasing the number of cameras was positive. As well, the increase in the number of cameras resulted in the highest captures of animal diversity. According to Ferreras et al. 2017) success in detecting all the species in the system depends on many factors, including the number of cameras. They too suggest that it is more efficient to deploy more camera traps for a shorter duration rather than to deploy fewer camera traps for a longer one, for any given number of camera traps days. There is an enormous expansion in the number of sites that camera traps are being used and most literature acknowledges the fact that one cannot discuss the notion of the number of cameras without talking about how far apart cameras were placed and how extensively the site was studied. Trap placement designs are important and the use of systematic trap placement design or a design suited to the habitat may be appropriate if the primary goal of the survey is richness estimation (O’Brien 2008). To limit the chance of missing species, camera traps should not be too close together and maximize the total area covered (O’Connell, Nichols, and Karanth 2011). The interrelatedness of camera trap placement and the number of cameras is not an idea that we explored *per se* though is integral in maximizing the potential of camera traps for wildlife monitoring.

The duration of camera trapping has to be adequate-enough so that rare species can be detected (O’Brien, Kinnaird, and Wibisono 2011). Previously, we discussed the idea of MTE and

Net effect of increasing n\_cam is positive.

1. Ecosystem matters - all significantly positive except coniferous.
2. Increasing n\_cams returns the highest rate of captures and of diversity in animals detected in deserts and grasslands.
3. Increasing the number of days does not increase the capacity of the number of cams to detect more animals (either in captures or diversity).

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**Author’s contributions**

CJL and NG designed the study and methodologies; NG wrote the manuscript; CJL analyzed the data; CJL thoroughly edited the manuscript and contributed critically.