**Finding the sweet spot in camera trapping: a global synthesis and meta-analysis of incidence capture rates and richness as an index of sampling effort.**

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**Abstract**

1. Camera traps have become one of the most common tools in wildlife biology, and their use typically includes documenting? Measuring? Animal activity patterns and behavior. Captures can be used to estimate population parameters such as presence/absence, relative abundance, and species richness.
2. A total of 292 full-text articles were returned from the Web of Science using the search terms camera\* trap\* and richness\*or diversity\*or rarefaction\* curve\*. - correct? Full-text reviews of each for sampling effort in total number of days and total number of cameras provided 149 studies that reported animal abundance and species richness captured using this tool. A meta-analysis of the incidence rates - ok further to our call is this the best term? I thought was said no? Is the term in the literature actually not capture rate? And the effect size metric is just incidence rate? , i.e. number of successful documented animal captures per total photographs, was used to examine whether sampling effort predicted vertebrate abundances or diversity in a meta-regressions. Work on a bit more Capture rate is this… We used an effect size measure to estimate capture rate… etc. simpler and more direct I think
3. The mean net effect of increasing the number of cameras o0m capture rate was positive. Increased deployment of higher numbers of camera traps returns higher net capture rates particularly in grasslands and mixed ecosystems. Diversity of animal communities in a region also increased with more cameras? in most ecosystems. Increasing the duration of trapping (number of days) did not consistently increase capture rate nor diversity suggesting that more cameras and not more days? Is a more viable mechanism to increase sampling efforts at a particular site?. - IF SO wow - super punchline. Is that true?
4. Camera trapping will continue to increase in use in ecology and evolution, and it is thus important to examine the efficacy of different experimental designs.

**Keywords**

Abundance, camera traps, diversity, meta-analysis, meta-regression, population estimates, richness, sampling effort.

**Introduction**

**Monitoring and measuring the number of animals and diversity of animal communities in terrestrial ecosystems comprises an important set of methods in ecology and evolution.** Camera traps are frequently a primary tool to survey wildlife and their interactions with the surrounding environment. These survey devices normally record animal presence via a triggered passive, infrared motion sensor (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 (Meek et al. 2014). Cameras can record activity patterns and be used to infer occupancy, abundance, and species diversity (O’Connell, Nichols, and Karanth 2011; Kelly 2008). Besides their use in wildlife research, camera traps have been used in studies that focus on population? ecology (Smith et al. 2020), detection of rare species in a community (Thomas et al. 2020), estimation of population sizes and species richness regionally? (Whytock et al. 2021), behaviour (Rowcliffe et al. 2014), habitat use (Rovero et al. 2014), and occupation of human-built structures (O’Connell, Nichols, and Karanth 2011) list is really long - can you tidy up please and organize from lower scales to higher etc. Thus, camera trap data can be used to quantify many ecological parameters and help advance the theories of niche partitioning, habitat use, as well as various behavioural models (citations). Camera traps are also a fundamental biodiversity monitoring tool in some ecosystems such as the Sergenti (citation to that project) and … list one more place. Anthropogenic changes are impacting species re-distribution and range shifts (Franklin 2010), and we need to be able to measure biodiversity for mobile species in different ways. Camera traps provide a relatively easy method that enables us to do this and gather big data (citation). These data can then be used to evaluate the efficacy of different survey designs (Kays et al. 2020) to support management and conservation.

?? Sentence here? (Rovero and Marshall 2009; Rowcliffe et al. 2008; Silveira, Jácomo, and Diniz-Filho 2003) 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))??/ what?. 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) lost a bit - need a framework that suits MEE - Experimental design decisions and methods can include…. Then from small to big decisions and organize ideas - which camera, how many, where to put them, how long to put them out> etc… Here, we explore the decisions directly associated with sampling effort.… The factors can be summarized as trapping effort = not type of cameras etc.. see above and trapping design and can affect estimates of abundance and diversity (Yasuda 2004; Wegge, Pokheral, and Jnawali 2004). Trapping or detection rate is a useful index for abundance and diversity estimates - is that what it is called, trapping or detection rate - if so call it that in Abstract too and use the same term throughout ok please. (Rovero and Marshall 2009 = what is this citation - very used here..; Rowcliffe et al. 2008; Silveira, Jácomo, and Diniz-Filho 2003). Minimum trapping effort (MTE) is another important factor for population estimates (Si, Kays, and Ding 2014). 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 (cite review?). 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, globally. The relationship between trapping period and the number of cameras will influence the scope? of fauna community assessments, both in abundance and diversity, provides us with insight into how to plan more effective experimental designs and gather better quantitative data that allow for an enhanced real-life representation of biodiversity across ecosystems worldwide. Needs more work please.

Herein, we used a meta-analysis of the global peer-reviewed literature to test the hypothesis that sampling effort positively but non-linearly influences detection rates (ie use the same term from on that you introduced above and used in abstraact) and animal diversity at a site or region sampled. We tested the threshold for sampling and provided an overview of the relationship between sampling effort in days influenced the incidence rates for animal abundance (number of captures per number of cameras), and total vertebrate species richness (number of animals per number of cameras). The importance of ecosystems was also examined. Given that camera traps are increasingly being used in ecology and evolution in general (Tabak et al. 2019), our study provides an insight into the ‘sweet spot’ in potentially sampling in many different ecosystems. The capacity for this method to provide meaningful and sufficient animal data will better inform conservation and management practices and fundamental theory.

**Methods**

***Literature review***

We conducted a systematic review using the terms Camera Trap\* AND Richness\*, Diversity\*, and Rarefaction\* Curve\* in ISI Web of Science (WoS) (Web of Science, 2021) AND or? Do you mean sequential AND searches? That is what I do but apparently more elegant way?. This search was done in May 2021. Additionally, we conducted supplemental searches in book chapters and Google Scholar to validate the publication coverage of WoS. This process resulted in a total of 557 publications once duplicates were removed spanning the years 2001-2021. A PRISMA diagram illustrates the exclusion and review process (2009) (Supplementary material, Figure A). We used best practices to ensure that workflow and synthesis were reproducible and transparent (Bayliss and Beyer 2015). We screened the abstracts and excluded papers based on relevance, whether they were a review, opinion, or idea paper, focused on aquatic ecosystems, were not in written in English (or English text version was unavailable), were qualitative, did not examine vertebrate species, and if they focused on one species or a group of animals (such as wild cats) and ignored other observed animals. A total of 292 full-text articles were further reviewed for a measure of richness or diversity, the number of captures and/or duration of camera trapping (i.e. days). Data were extracted from article text or table. Variables such as the location of study, number of cameras, sites, and ecosystem were also recorded. PERFECT!

***Meta-Analyses***

All meta-statistical analyses were performed in R version 4.0.4 (R Development Core Team 2021)using the package *metafor* (Viechtbauer 2010). Effect sizes were calculated using the total number of species per site and also the number of animals (captures) flip order - link to detection rate term…, which were independent event count variables, and used as incidence rates (PT Higgins, Li, and Deeks 2021) by division against the total number of cameras and the total number of days via the function *escalc confusing sentence - split into two and be direct*. Mean values and the 95% confidence intervals for each effect size were then plotted on a forest plots for each group of estimates by ecosystem. Random-effects models (*rma)* were applied to analyze estimated values and stand error for the number of animals/number of cameras/number of days and number of species/number of cameras/number of days using the method = "ML", test = “knha" with ecosystem serving as moderator. Knha means… ethod to use for computing test statistics and confidence intervals. Default is "knha", which uses the Knapp-Hartung adjustment. Conventional Wald-type tests are calculated by setting this argument to “z". With ciatation. Maximum likelihood (ML) refers to a method of estimation so that given the particular model the likelihood of producing that similar to ones that were actually observed are maximized (Cam 1990). Hartung and Knapp (knha) is a test statistic based on the estimation function for the variance of the treatment overall effect estimator and keeps the prescribed significance level much better compared to other test used in random-effect models (Hartung and Knapp 2001) great just move up. Regression models were also applied to analyze estimated values for the number of animals/number of cameras and the number of species/number of cameras over the total number of days. The method and test remained the same as above. Heterogeneity in all models was examined to ensure that variance was not unduly inflated from grouping similar measures into the random-effect models (Langan et al. 2019). Heterogeneity was tested with a … test for the Q stats your report. Publication bias was also tested using an Eggers test etc.. do not need to report in results just state you checked them - mostly meaningless but expected.

Check for typos ok - I am seeing quite a few typos, and I am not checking for em :)

**Results**

A total of 149 articles were included in the meta-analysis. Code are published on Zenodo (Ghazian and Lortie, 2021) and data published at KNB (citation - put data there and use my ORCID please so it gets captured in ecoblender portal). The most common ecosystems for the studies were deciduous (25 studies) and tropical (38 studies).

>>> revise all this

Just state results in results, haha, and not methods. Way simpler.

ie..

Increased sampling effort was significant and positive in grasslands and mixed systems on the detection rate effect size estimates for abundance (Figure 1 and Table 1). Ecosystem was a significant moderator for this model (F = 3.056, p = 0.0105, *df* = 6), and there was also significant heterogeneity between the groups (Q = 1445220667.62, p<0.0001). Then do the same for detection rate for species richness etc..

Etc… ok?

Mixed system are…. . A similar random-effect model was also fit to the detection rate effect sizes for species richness, and there was significant heterogeneity between groups (Q = 1131929994.36, p<0.0001). Ecosystem was a significant moderator for richness (F = 15.48, p<0.0001, *df* = 6). Increased sampling effort was positive and significant in … list them (Figure 1, Table 1). A meta-regression analysis was conducted for the number of animal/number (Figure 2, Table 2) of cameras over the total number of days ??/ on what response? which resulted in significant heterogeneity between groups (Q = 549352.8229, p<1000) - I would actually move all the ‘a meta-reg was used to methods - you already actually say that in methods so just state the results. …

**Discussion**

The importance of effective wildlife detection and estimating biodiversity is fundamental to community assessment of resident fauna and ultimately the management, conservation, and restoration of ecosystems globally. The hypothesis that increasing sampling effort was supported in most ecosystems suggesting that deploying more camera traps but not necessarily for more days? are an effective ecological tool to estimate the relative abundance and local species richness for vertebrates - correct ok?. Review a few of the finding in brief here - ie grasslands and mixed etc but not forests with a simple implication (then develop in next paragraphs). Hence, this synthesis demonstrated strong support for careful consideration of parameters such as the number of cameras and the duration of study to obtain accurate population estimates that are a precise (typo…..nooo) representation of the real-life biodiversity for a given region. IF the n cams and not n days important - this is really amazing.and both abundance and richness - very nice. So say can be used for population-level monitoring and for community-level vertebrate? Diversity measures? In results- need to give a sense of animals - large, small, inverts? All verts>? Birds etc.. perhaps cite a table in appendix listing taxa/genuses that were sampled. Someone will ask - does it work for all animals or only big ones?

TOPIC sentence first please… Camera traps work?? Poorly/ well? Etc globally in virtually all ecosystems??. Here, we did not only examine the relative importance of days but also the net positive effects of incidence capture and richness rates, which suggest that sampling effort can be influenced by the number of camera traps as well as the number of days see above - if days not important need to develop. This idea?? Hypothesis was supported here in terms of the number of captures specifically in grasslands and mixed ecosystems and in terms of animal richness in almost all ecosystems meh.. These synthesis findings support previous ?? Syntheses or were they primary? That found detection rates in a given? system depends on many factors including the number of cameras Ferreras et al. (2017) and??? . Similar to this former synthesis?, it is more efficient to deploy more camera traps for a shorter duration rather than to deploy fewer camera traps for a longer time period. This is a critical experimental design decision. ANY other papers you can now mention that further support this? OR contradict it? This is likely the most important finding of paper… There is an enormous expansion in the number of regions? Ecosystems? 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 eh? Clarify. 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 same?? Confusion - not sure what you are trying to argue here - they are other factors that are important in previous research on camera trap designs that were not reported in most? All papers we compiled herein suggesting that additional developments in the research in addition to days versus cameras are important… For instance, placement. Type of camera? etc. Thes are a bit of a tangent…. (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)??? So if one chooses to increase sampling effort through more cameras. They need to consider spacing and placement… sure COOL link to you main finding though like this ok… 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. Understanding how many cameras are needed and how far apart they need to be placed relative to the particular ecosystem of study will ensure more precise wildlife and biodiversity monitoring of any given region. So did n cams trump n days for BOTH richness and abundance or just abundance?

(Kelly 2008; Rovero and Marshall 2009; Wegge, Pokheral, and Jnawali 2004)??? Eh? Sampling effort is a critical design topic in all of ecology and evolution and particularly in field studies. In this study, we explored the relationship between sampling effort and the total number of trapping days and found increasing the number of trapping days past a certain point did not increase the capacity of cameras to detect more animals neither in abundance nor diversity MOVE to former paragraph .

What is MTE again minimum etc. This is directly related to the notion of MTE (Si, Kays, and Ding 2014), as previously discussed. Differences in the number of camera trap days across studies are related to animal richness at the site. MTE can be affected by habitat, local characteristics, target community, and sampling strategy, including camera spacing, presence or absence of bait, and camera models (Kelly 2008; Rovero and Marshall 2009; Wegge, Pokheral, and Jnawali 2004). According to Si, Kays, and Ding (2014), increasing the number of camera sites and rotating cameras to new sites is more efficient for richness estimates as opposed to leaving cameras at the same site for a longer duration of time. This is because regardless of the system of study, after a certain number of days, species rarefactions level off and a longer trapping period does not result in increased diversity. Hence, to increase the likelihood of detection, we suggest considering the above when designing the study and placing more attention on increasing the number of sites and cameras, and rotating cameras, as opposed to increasing the duration of trapping. Weak and redundant…

Need at least ONE pargrgaph here please… why do the ecosystems differ needs to be discussed please.

**Implications**

Anthropogenic change influences species distribution in ways that intensive monitoring of local species in different regions will be critical for the maintenance of biodiversity and the implementation of management practices in the upcoming years good idea but clunky. This synthesis provide novel insight into the utility of camera traps as a tool in monitoring changes in wildlife ranges - no we did not test range… population abundance and species richness…. Future challenges for researchers will include well-planned experimental designs to maximize the extent of surveys and finding common data formats to facilitate the easier transfer of storage and data. Expand on decisions for design as main implication and caveat that is depends on ecosystem. Can propose next steps - test range, test placement, and test?? Etc/

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**Author**’**s contributions**

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

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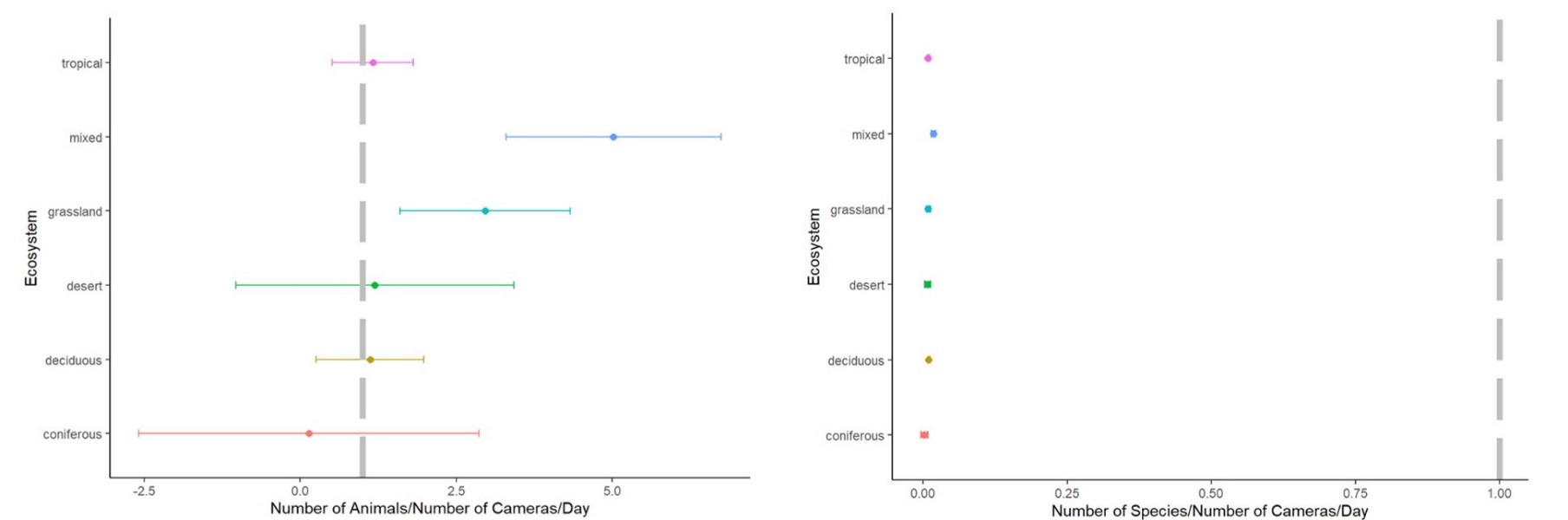
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**Figures and Tables**



Do sort order from greatest to least etc

Make dots a bit bigger even please.

Add grand mean for whole meta as a large black Diana?

Y-axis - ‘detection rate by ecosystem’

Add fig 1 a and b and cite in result text like that.

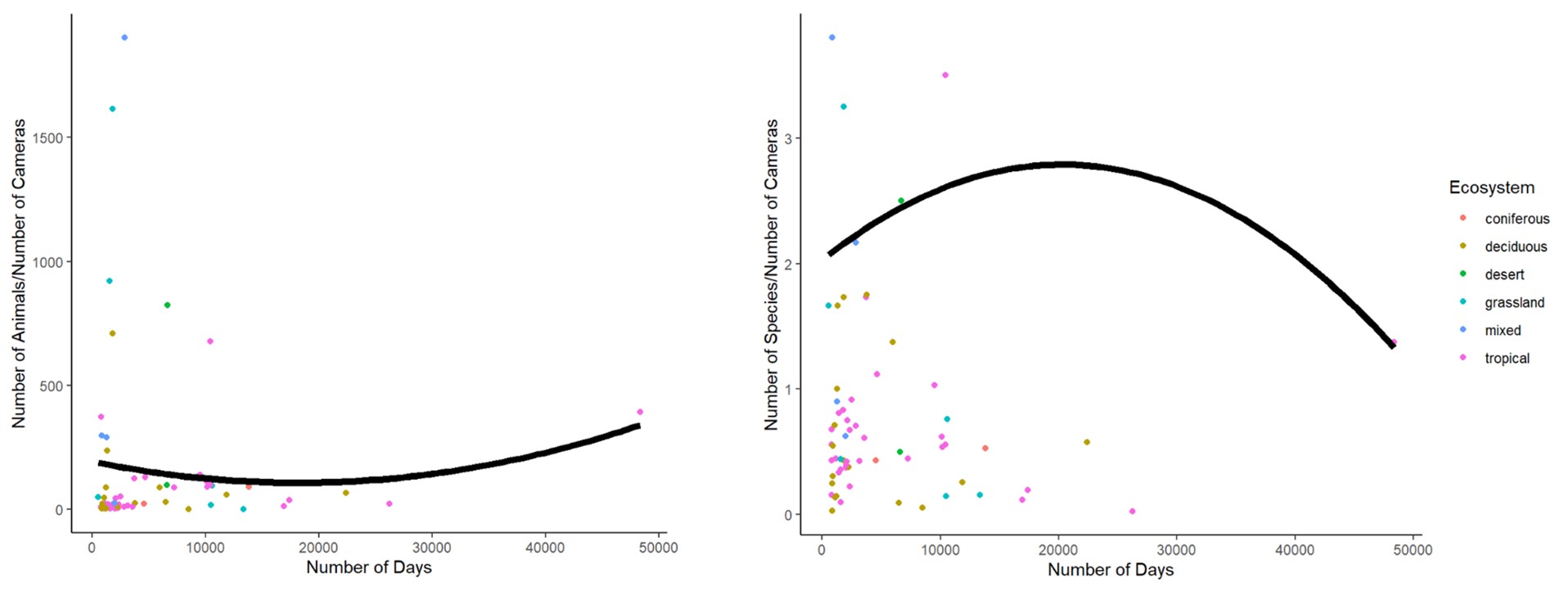
How can you have a negative detection rate? They lowest should be 0… so set x-axis in left plot to 0 only… I know why it is there - error bar but need to fix somehow and not have negative..

The scale on the right plot is TOO compressed. All values are so close to zero… make it go from 0 to 0.125? And these values are tiny..

Add labels abundance and richness in top right of each plot..

etc…

**Figure 1. Forest plots showing estimate effect sizes from random-mixed model output for the number of animals/number of cameras/number of days (left) and number of species/number of cameras/number of days (right) in 6 different ecosystems of study. Dots represent the meta-analytic mean and dashed lines represent the 95% confidence intervals.**



Is fig 2 a meta-regression?

**Figure 2. Meta-regression plot showing the relationship between the number of animals/number of cameras (left) and the number of species/number of cameras throughout the duration of the study (days) weighted by??? I think this is a weighted regression not meta-regression?. Smoothed conditional mean is fitted using a random-mixed model using the method maximum likelihood. Coloured dots represent the ecosystem of study.**

**And why not linear - need to explain in methods etc.**

**Table 1. Mixed-effect regression meta-model?? estimates and standard error (SE) for animal abundance (number of animals/number of cameras/number of days) and animal richness (number of species/number of cameras/number) are given for each ecosystem. Significant p-Values are bolded. Hmmmm not sure about this table.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| ***Animal Abundance*** | | | | | | |
| **Ecosystem** | ***Estimate*** | ***SE(±)*** | ***t-Value*** | ***95% CI.lb*** | ***95% CI.ub*** | ***p-Value*** |
| ***Coniferous*** | 0.1417 | 2.6849 | 0.0528 | -0.2057 | 5.4891 | 0.9580 |
| ***Deciduous*** | 1.0125 | 0.7594 | 1.3333 | -0.5000 | 2.5250 | 0.1864 |
| ***Desert*** | 1.1951 | 2.1922 | 0.5452 | -3.1710 | 5.5612 | 0.5872 |
| ***Grassland*** | 2.9580 | 1.3424 | 2.2035 | 0.2843 | 5.6317 | **0.0306** |
| ***Mixed*** | 6.8013 | 1.5501 | 4.3876 | 3.7139 | 9.8886 | **<0.0001** |
| ***Tropical*** | 1.0870 | 0.6160 | 1.7647 | -0.1398 | 2.3138 | 0.0816 |
| ***Animal Richness*** | | | | | | |
| **Ecosystem** | ***Estimate*** | ***SE(±)*** | ***t-Value*** | ***95% CI.lb*** | ***95% CI.ub*** | ***p-Value*** |
| ***Coniferous*** | 0.0018 | 0.0063 | 0.2825 | -0.0108 | 0.0144 | 0.7784 |
| ***Deciduous*** | 0.0104 | 0.0018 | 5.8472 | 0.0069 | 0.0140 | **<0.0001** |
| ***Desert*** | 0.0069 | 0.0052 | 1.3454 | -0.0033 | 0.0172 | 0.1826 |
| ***Grassland*** | 0.0086 | 0.0034 | 2.5522 | 0.0019 | 0.0153 | **0.0127** |
| ***Mixed*** | 0.0153 | 0.0036 | 4.2010 | 0.0081 | 0.0226 | **<0.0001** |
| ***Tropical*** | 0.0077 | 0.0014 | 5.3384 | 0.0048 | 0.0106 | **<0.0001** |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| ***Animal Abundance*** | | | | | | |
|  | ***Estimate*** | ***SE(±)*** | ***t-Value*** | ***95% CI.lb*** | ***95% CI.ub*** | ***p-Value*** |
| ***Intercept*** | 141.6745 | 45.1943 | 3.1348 | 51.5144 | 231.8346 | **0.0025** |
| ***Days*** | -0.0003 | 0.0046 | 0.9515 | -0.0095 | 0.0089 | 0.9515 |
| ***Animal Richness*** | | | | | | |
| ***Intercept*** | 0.7377 | 0.1076 | 6.8576 | 0.5231 | 0.9523 | **<0.0001** |
| ***Days*** | 0 | 0 | -06081 | 0 | 0 | 0.5451 |

**Table 2. Meta-regression model estimates and standard error (SE) for animal abundance (number of animals/number of cameras) and animal richness (number of species/number of cameras) over the total number of days are given for each ecosystem. Significant p-values are bolded.**

**Tables need work - I think you do not include intercept and actually just cut table 2 I think allotter and put stats in parentheses in results just need chi-share, r2??? Where is that? etc..**

**Supplementary Appendix**

Papers obtained through database searching (Web of Science) Keywords:

Camera\* Trap\* AND Richness\*, Diversity\*, and Rarefaction\* Curve\*

(n= 716)

(n = 1090)

Identification

Papers obtained from other sources, such as book chapter bibliographies

(n= 0)

Eligibility

Records after duplicates removed   
(n = 557)

Records excluded for: relevance, review, opinion or idea paper, focus on one species, qualitative, not English.

Records screened by abstract (n = 557)

Screening

Full-text articles excluded:

Not reporting richness or diversity, number of records, and any measure of duration, aquatic studies.

Full-text articles assessed for eligibility (n = 292)

(n = )

Include in synthesis

(n = 149)

Included

Extracted data:

Location (latitude, longitude), camera trap days, number of records, animal richness, common name, scientific name, year, number of cameras, presence of bait, number of cameras, number of sites, and ecosystem.

**A. PRISMA diagram used for camera trapping effort systematic review (Moher et al. 2009). Search done with keywords: Camera\* Trap\* AND Richness\*, Diversity\*, and Rarefaction\* Curve\* in May of 2021.**