Exploratory and confirmatory conservation research in the open science era

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Abstract:

1. Conservation biology is becoming a more open science, with an increasing focus on large-scale assessments of the patterns and processes of biodiversity dynamics. However, the new challenges arising when it comes to defining exploratory and confirmatory research practices, has been so far overlooked. We discuss how the research community could meet these new challenges by allowing full use of different of scientific approaches, without blurring the distinction between exploration and hypothesis-testing confirmatory research.
2. A rapid screening of a random selection of articles from the literature suggests that neither experimental protocols nor hypothesis testing *sensu stricto* are common in conservation biology. Most experiments are carried out on small spatial scales, which contrast with current global policy processes and research trends towards large spatial and temporal scales.
3. We suggest that a clearer distinction between exploratory and confirmatory research can be achieved by revaluating the important, but different, role that each plays in the scientific process.
4. This clearer distinction could be facilitated by allocating journal sections to the different types of research, embracing new tools offered by the open science era, such as pre-registration of hypothesis, establishing new systems where posthoc hypothesis emerging through exploration can also be registered for later testing, and more broad adoption of causal inference methods that foster more structured establishment of hypotheses about causal mechanisms.

5. To fully gain the benefits from the open science era, researchers, funding bodies and journal editors should explicitly consider how incentives could encourage openness about methods and approaches, and value the full plurality of scientific approaches.

Rigorous science in conservation biology

As a response to global biodiversity loss, conservation biology is increasingly focused on detecting patterns of biodiversity change, isolating the factors that are causing this loss, and ultimately suggesting mitigation measures or management solutions. Conservation biology has inherited scientific tools and traditions from older sciences such as ecology and wildlife management (Caughley 1994), but is at its core an applied, interdisciplinary and mission driven science (Soulé 1996). Because biodiversity loss and ecosystem transformations are expected to cause major challenges to present and future human societies (Millennium-Ecosystem-Assessment 2005), the transparency and rigor of the science that underpins policy and management decisions is decisive to the wellbeing of future generations of humans.

Following some high-profile publications pointing towards a reproducibility crisis in fields like psychology (Nosek & Collaboration 2015) and social research (Camerer *et al.* 2018), there has been much focus on repeatability and reproducibility of scientific results (see e.g. the news feature in Nature by Baker 2016). One of the consequences of this renewed focus is the global focus on FAIR data management and open sharing of research data (Wilkinson *et al.* 2016), software and code used to perform statistical analysis. These changes are all parts of a more general movement towards “open science” (Nosek *et al.* 2015).

Increasing accessibility of new data sources allows researchers to apply a wide range of models to data for exploratory science. This contrast with the pleas for more widespread adoption of confirmatory research where hypotheses are described a-priori and then carefully tested based on empirical data (Caughley 1994; Houlahan *et al.* 2017). A rapid screening of a sample from the conservation literature (**Box 1**) suggest that conservation biology researchers often do not follow the strong inference paradigm (Platt 1964; Sells *et al.* 2018), nor do they follow the hypothetico-deductive method. Our rapid screening of the literature also suggests that large scale studies often have large impacts if measured through citation rates (**Box 1**). Here, we discuss how both exploratory and confirmatory research is needed in the field of conservation biology, how we can improve understanding in the open science era, and how both scientists and journal editors should assist in the task of extracting the maximum value from different scientific approaches without blurring the distinction between exploration and confirmation.

A mature research community should value both exploration and confirmation

Many earlier authors, including Caughley (1994), Sells *et al.* (2018) and Betini, Avgar and Fryxell (2017), have called for more formal use of the hypothetico-deductive method and the strong inference paradigm (sensu Platt 1964) within conservation biology and wildlife management. We agree with that plea, but also underline the fundamental role that descriptive studies documenting the state or trends of local or global biodiversity, or the natural history of species, has for conservation biology (Beissinger & Peery 2007; Pereira *et al.* 2013; Lehikoinen *et al.* 2019). Recently, the emergence of Essential Biodiversity Variables (EBV) emphasises that robust descriptive research combined with observational data is still fundamental to our scientific progress (Pereira *et al.* 2013). Moreover, the developments of the United Nation's Sustainability Goals (SDG) and a movement towards more planetary scale assessments, such as those carried out by the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), makes it unfeasible for policy to rely mainly on insights gained from experimental research (Mazor *et al.* 2018; Box 1).

Nevertheless, to avoid an ever-growing list of un-tested hypothesis emerging from exploratory research, we must also revaluate the fundamental (but different) role that hypothesis-testing and prediction play in conservation biology research (Houlahan *et al.* 2017). Only by testing a-priori articulated hypothesis can we robustly confirm or reject the potential of a scientific hypothesis to describe natural phenomena. However, studies do not always follow such protocols and surveys have revealed the existence of a number of questionable research practices (Ioannidis *et al.* 2014; Fraser *et al.* 2018). Such practices include both "*harking*" (Hypothesis After Results Are Known), where ad-hoc postdictions are presented as if they were already planned before the study was conducted, and "*p-hacking*" where researchers carelessly search for significant associations in the data (and often present them as if they were from a-priori hypotheses). Recent surveys suggest that they might be common also among ecologists and evolutionary biologists (Fraser *et al.* 2018). Without more frequent use of prediction, we risk that confirmation bias and the personal beliefs of the scientists will result in overly self-confident 'storytelling' with weak scientific support (Hayward *et al.* 2019). Basing conservation planning and mitigation actions on such research may lead to costly mis-management.

Novel ways to test ecological theories

Our survey of the literature (**Box 1**) (see also Betini, Avgar & Fryxell 2017; Sells *et al.* 2018) suggest that conservation biology research most often does not confirm to strict hypothesis testing. In the open science era, there are ample possibilities to increase the use and impact of confirmatory research, by more widely embracing new tools and methods, and especially increased data availability.

Strict experiments in conservation biology (**Box 1**) are generally conducted at small local spatial scales (although there are som very notable exceptions, e.g. Krebs, Boutin & Boonstra 1995; Wiik *et al.* 2019). This contrasts with the fact that many ecological and policy processes operate at far larger scales (Estes *et al.* 2018). Better utilization of large-scale unreplicated natural experiments could facilitate an improved understanding of causal relationships in ecological systems (Barley & Meeuwig 2017; Serrouya *et al.* 2019), especially the impacts of rare and extreme events (e.g. Gaillard *et al.* 2003). A complementary approach, when experiments are not feasible, would be to apply methods that allow integration of findings from small-scale manipulative experiments into large-scale synthesis of drivers of biodiversity change. Such integration will necessitate closer collaboration between ecologists working on different spatial scales, and between experimentalists and modellers (Heuschele *et al.* 2017). The increased popularity of hierarchical statistical models and methods to integrate data from disparate data sources (Nilsen & Strand 2018; Miller *et al.* 2019) facilitate such an integration. In the new era of open science, large amounts of data from both field surveys and experiments are now becoming available making such integration much more feasible.

Given our reliance on observational data, conservation biology research could gain more insight into causal processes by more widely applying novel statistical methods that are seek to establish causality from observational data (Law *et al.* 2017). A side effect of adopting causal inference approaches is forcing researchers to think more deeply about the direct and indirect relationships of variables in their study systems (Ferraro, Sanchirico & Smith 2019). Causal inference methods aiming at controlling for confounding factors include matching (to control observable confounders) and use of panel data and synthetic controls to control for unobservable confounders, as well as instrumental variables to eliminate unobservable confounders (reviewed by Law *et al.* 2017), and time series methods such as convergent cross mapping (Sugihara *et al.* 2012). Time-series data might be particularly useful because they are unidirectional implying that cause must precede effect (Dornelas *et al.* 2013). Triangulation, whereby several approaches are formally applied to the same problem, could serve as another model for increasing the reliability of causal claims (Munafo & Smith 2018).

Finally, to effectively synthesize evidence from causal claims across studies, a wider adoption of systematic reviews and other structured evidence synthesis methods would allow more robust assessment of the evidence base (Pullin & Stewart 2006). In the open science era, the time is now ripe to develop models and procedures that conduct evidence synthesis based directly on open data rather than published effect sizes (Culina *et al.* 2018).

Journals, editors, and reviewers should assist in the change

Science is not conducted in isolation in research labs, but rather represents a collective social endeavour involving many people with different roles to fill. Journals could play an important role facilitating scientific rigor of the studies that underpin real-life conservation decisions. This could partly be achieved by creating new incentives for more honest and open reporting from the research process.

Pre-registration of research hypothesis has been advocated (Nosek *et al.* 2018), partly to distinguish exploration and confirmation research. In the open science era, studies are increasingly based on pre-existing data, and even data that have been previously analysed and with results published in a scientific journal. This should however not discourage *a priori* hypothesis development and pre-registration (Nosek *et al.* 2018). Journal editors could facilitate this shift by applying a model where authors declare their study design and identify at which stage in the process they developed their hypothesis (e.g. before or after data collection, before or after initial data analysis etc). This could include a link to the pre-registered hypothesis that might be hosted on e.g. Open Science Framework (www.osf.io), and potentially an associated "open science badge" (Kidwell *et al.* 2016) as a sign of an open research practice.

We also encourage journal editors to more actively encourage fair valuation of case studies that mainly describe and document the state of local and global biodiversity. To accommodate this, we suggest that journals should more explicitly allocate different sections to different types of studies (exploratory, methods, confirmatory/hypothesis testing etc). This will make the publication process more transparent and facilitate more honest reporting of how the study was performed, especially reducing the incentives for *harking*, and lessen publication bias towards significant studies.

Finally, we propose (as a counterpart to pre-registration of hypotheses) a model where hypotheses rising from explicit exploratory research could also be registered so that they are readily available for testing in subsequent studies. Given the rise of global databases and repositories, such a model could make it feasible to track hypothesis to their source, which would allow for fair attribution of credit to those that originally proposed the hypothesis, and it would provide a clearer link between exploratory (hypothesis generating) and confirmatory (hypothesis testing) research.

Outlook

We should value the unique contributions of exploratory and confirmatory studies, but be much clearer about the fundamental differences between them. In the open science era

(Nosek *et al.* 2015), where more and more research is based on pre-existing (and often open) data, and where large scale studies are needed to address key conservation policy challenges, a simple plea to follow the strong inference paradigm (Platt 1964) might not be sufficient. However, current incentives that promote the presentation of studies that are by design and conduct exploratory as if they were confirmatory is a disservice to scientific progress. In applied fields like conservation biology, this will also delay progress to solve real conservation problems. The open science era has already radically improved the reproducibility of research; however, we argue that a cultural shift, involving researchers, journals, and funding bodies, is still needed towards full transparency and valuation of diverse research methods.

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Data accessibility: Data and R-scripts used to perform the randomization routines and produce figures for Box 1 is currently available here: https://osf.io/n8fum/

Authors contributions: EBN conceived the idea for this work, after discussions with DB and JDCL. EBN and DB performed the literature survey for Box 1. EBN were responsible for writing the manuscript, with inputs from JDCL and DB. All authors edited and approved the final version of the manuscript.

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Box 1: State of conservation biology as a science

In a seminal paper from 1994, G. Caughley (Caughley 1994) was concerned that parts of conservation biology (the branch concerned with declining populations) had a very thin theoretical basis, was carried out mainly as a series of case studies, and therefore often had limited generalisable value. In line with many other philosophers of science, Caughley suggested that much more rapid progress would be made if conservation biologists applied the strong inference paradigm (sensu Platt 1964) when designing and conducting research.

To gain a rapid insight into the current state of affairs in the scientific conservation literature, we randomly sampled 159 papers published in eight journals covering conservation biology, applied ecology and wildlife management. We only included studies from terrestrial ecology, that were data-driven (i.e. not reviews or pure simulation studies), that presented the results from at least one statistical test, that presented original data or data from literature surveys, and focused on conservation biology. From these studies, we assessed i) to which extent one or more clearly stated hypotheses were presented in the introduction, ii) whether there were multiple competing hypothesis and, iii) whether they applied an experimental study design. In addition, we extracted the number of citations registered by Web of Science. A more comprehensive description of the inclusion criteria and data extraction procedures can be found in **Appendix S1**.

Based on our sample of research papers, it seems that clearly stating a research hypothesis in the introduction is surprisingly rare in the literature (**Fig 1a**). Overall, only about 19% of the studies presented clear hypothesis, whereas about 26% presented what we term “implied hypotheses” or “partly”, where the hypothesis could be inferred from the text but was not presented clearly. After removing articles mainly focusing on methods development, the corresponding proportions were 23% (clear hypothesis) and 28% (implied), respectively. Presenting multiple competing hypothesis, as described in the original presentation of the strong inference paradigm (Platt 1964) is even rarer, and only 2 of the studies we reviewed.

Another hallmark of science is the use of well planned, randomized and replicated experimental manipulation to test for causal relationships (Platt 1964; Caughley 1994). Based on our review, however, the use of full experimental designs are rare, and only 12% of the studies we reviewed were based on randomized controlled experimental designs. In addition, 15% of the studies in our sample included Before-After-Control-Impact (BACI) or Quasi-experimental protocols. The majority of the randomized controlled experiments were performed on a local spatial scale (**Fig 1b**), although a few studies presented landscape scale experiments. In our sample, local scale studies in general received less attention in the literature compared to studies spanning larges spatial scales (**Fig 1b**).

Figure Legends

Figure 1. *In **a)** the proportion of articles that reported clear hypotheses, implied or partly indicated hypotheses that were tested, and articles that did not present hypotheses. In **b)** the proportion of articles that used experimental, quasi-experimental/BACI or no experimental designs are matched with the corresponding spatial scales of the studies. The size of the circles indicates the number of studies. The colour key indicates citation rates (mean annual number of citations since the year of publication).*

Figures

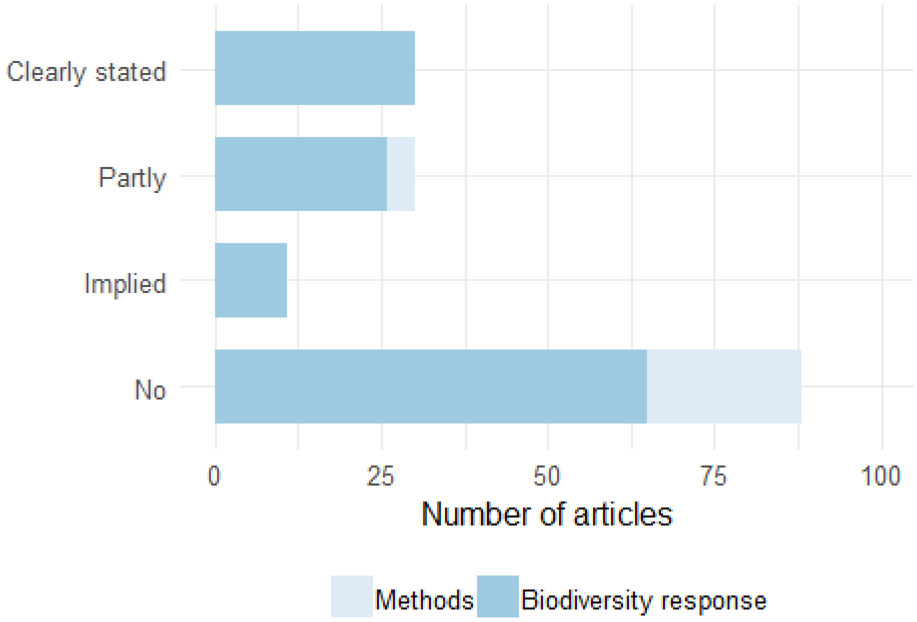

Fig 1a

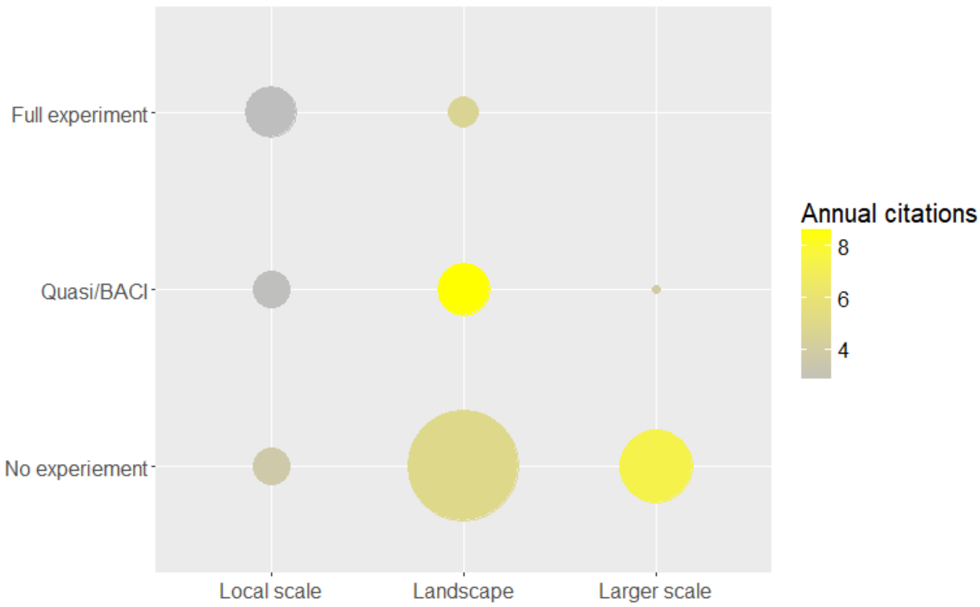
Full experiment
Quasi/BACI
No experiement
Local scale
Landscape
Larger scale
Annual citations
8
6
4

Fig 1b