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Empirical evidence of widespread exaggeration bias and selective reporting in ecology

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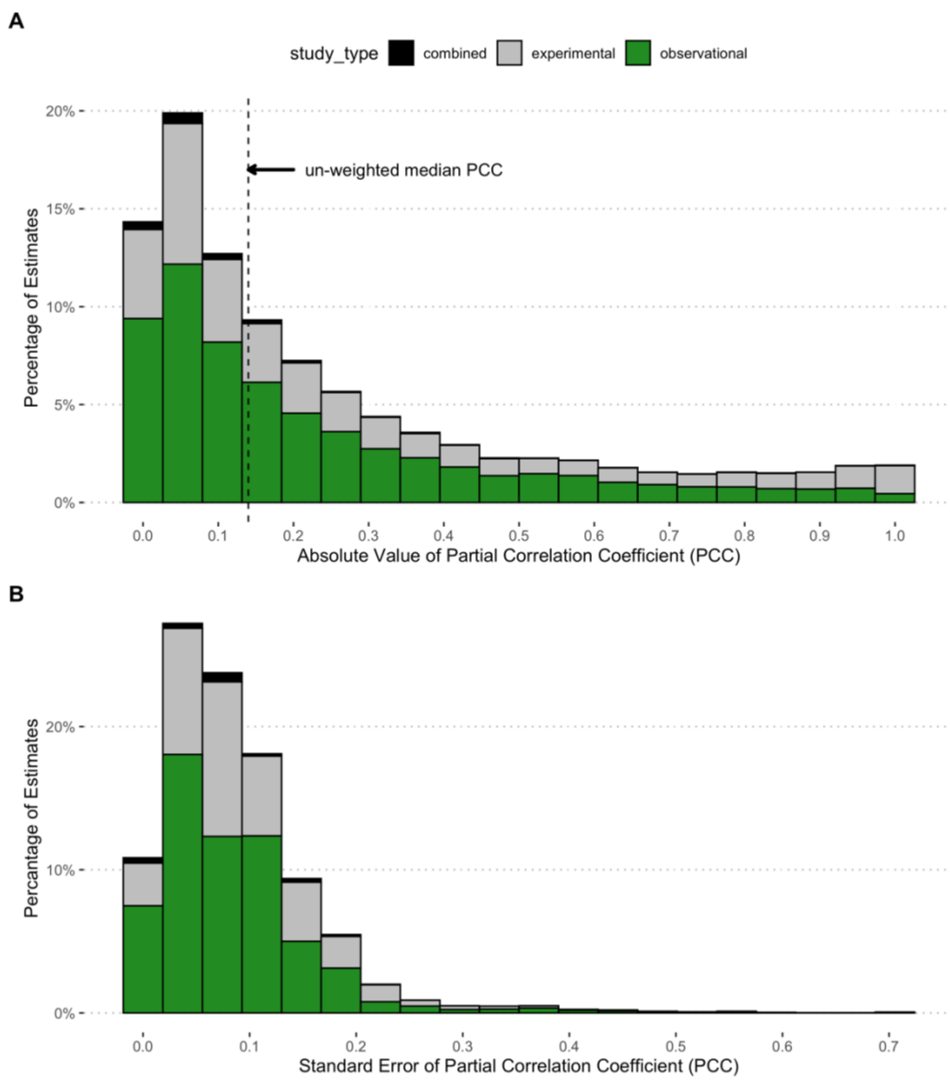
Supplementary Text



Supplemental Figure 1. Unweighted distribution of (A) partial correlation coefficients (PCC) and (B) standard errors of the partial correlation coefficients calculated in our collection of studies. The weighted mean PCC value was 0.06, and the unweighted median is shown at the dashed line in A (~0.15). In both graphs, bars are colored according to the proportion of observational (green), experimental (gray), and combined (black) studies in that bin (n = 18,909 estimates from 353 papers).

Promising actions that contribute to the larger-scale systemic changes that are needed

Checklists & Data and Code Sharing Requirements

We faced multiple challenges in aggregating the data from our set of published articles because studies often did not report key information. For example, determining sample sizes was not always straightforward. In some cases, we had to make assumptions about the total sample size when the authors ran different analyses but did not report changes in sample size across the analyses. We had to exclude 5,484 estimates from 34 studies because we could not determine the sample size that the researchers were using (see "Data Cleaning"). While it is likely that most ecologists do not intentionally leave out important information, leaving this information out makes it difficult to interpret the results or aggregate them into meta-analyses.

So that readers may adequately judge the methods, analysis, and results in a study, ecologists should make sure to report all necessary information. Necessary information includes sample sizes and degrees of freedom for each analysis, estimates of error or uncertainty, and descriptions of the originally planned analyses and any deviations from those plans [1].

Checklists at multiple stages of the publication process can help researchers and reviewers include necessary information [2–4]. Checklists are used to reduce mistakes in other professions like surgery [5] and airplane piloting [6]. Individual labs, departments, or professional societies can provide checklists to researchers for standardized information to report in all publications [2]. More impactfully, journals can provide checklists that authors must fill out before submitting their manuscripts, similar to *Nature* (https://www.nature.com/documents/nr-reporting-summary-flat.pdf). Further, reviewers can be provided checklists as well to standardize what they should be looking for when accessing the soundness of methods, analysis, and reported results [4]. Checklists at the review stage may also reduce bias against negative results, which tend to be scrutinized more than positive results [4,7]. Overall, checklists should provide an easy way to increase the transparency of ecological publications and make it easier for readers to find the necessary information to synthesize effect sizes and uncertainty in those estimates.

Researchers should also be required to provide data and code as a condition for manuscript publication (and the code should run with little or no manipulation). Exceptions can be allowed for some proprietary data. Many journals are moving towards encouraging data and code sharing, but few require archiving of both data and code [8]. Such requirements do, however, seem to increase the likelihood of providing data and code. For example, in our dataset, every paper in *Journal of Ecology* had data available, which highlights the effectiveness of journals requiring data archiving once papers are accepted (https://besjournals.onlinelibrary.wiley.com/hub/editorial-policies#archiving). Indeed, providing data and analytic code increases the transparency of workflows and conclusions reported in studies [1,9–11]. Journals may even consider having a reviewer check code files to see if the study results are reproducible with the code and data that they authors provide (see, for example, the data editor positions at the *American Naturalist* [http://comments.amnat.org/2021/01/note-since-fall-2020-robert-montgomerie.html], the *Journal of Evolutionary Biology* [https://jevbio.net/data-editing-at-jeb/ and http://comments.amnat.org/2021/01/note-since-fall-2020-robert-montgomerie.html], and the *American Economic Review* [12]). This extra step will further ensure the computational replicability of results, even at the potential monetary cost of this extra step.

Pre-registration and Pre-Analysis Plans

A pre-analysis plan describes the research questions, the study design, and the methods that will be used in a study. As its name suggests, the plan is completed before data analysis begins (ideally, before all the data have been collected). Pre-registration is the process of registering, before the study or data analysis begins, a researcher's intent to undertake a study and the study's pre-analysis plan [13]. Ideally, the pre-registration is digitally time-stamped and publicly available, so that third parties can confirm which questions and analyses were anticipated in advance and which were devised only after collecting, and perhaps analyzing, the data. To prevent competing researchers from "scooping" a study prior to its publication, pre-registration platforms typically allow researchers to keep their pre-registration private while the research is completed, although sometimes the length of this embargo is limited to several years [14].

Preregistered analysis plans provide two main benefits. First, they help scholars quantify the "file drawer" problem: studies that were proposed, and perhaps completed, but never published. Studies may not be published for many reasons, but one reason is that the authors believed, or observed, that the results would not be acceptable to editors and peer (e.g., null results or statistically significant, but small estimated effects). Without pre-registration, scholars have no idea how many studies have been proposed and perhaps completed, but never published. That lack of knowledge can be costly for science; costly in terms of unnecessary repetition of studies and, when only serendipitously impressive results get published, exaggerated scientific claims. Knowing the full set of studies that may have been completed is also critical for ensuring that meta-analyses provide an accurate picture of what scientists have discovered [15].

Second, pre-registered plans help scientists to be transparent in all their research decisions. Science benefits when scholars are limited in their ability to selectively report or frame their results after seeing the impact of their decisions on their results. For example, pre-registered plans help to clearly demarcate confirmatory analyses from exploratory analyses [13,14,16]. Confirmatory analyses seek to test a specific hypothesis or estimate a specific parameter, whereas exploratory analyses probe the data to look for interesting patterns. For example, a confirmatory analysis may seek to estimate the effect size of phosphorus addition on plant productivity, whereas an exploratory analysis may use the same data to see whether phosphorous addition is correlated with any other ecosystem functions that are measured in the data set. Exploratory analyses are important because they help scientists generate hypotheses that can then be tested with different data. Yet when exploratory analyses are repackaged in publications as confirmatory analyses, science suffers. Indeed, these repackages exploratory analyses never have the chance to be falsified and may need complex hypothesis to accommodate the results[17]. A related problem is when an author, after seeing the results from an analysis, changes the hypothesis to better match the results (i.e., HARKing). Ideally, the author would report in the article that the published hypothesis was not the original hypothesis and thus readers should treat the analysis as more exploratory than confirmatory. With pre-registration, even if the author does not report this deviation from the original plan, a reviewer or reader of the article could easily check the study's pre-registration document to confirm whether the hypotheses reported were the original hypotheses of the study [14,18].

Although pre-registration and pre-analysis plans are commonly associated with experimental designs, they can, and ought to be, used for all study designs. In fact, given that observational designs typically offer many more degrees of researcher freedom than experimental analyses, pre-registered plans may be even more important in observational designs than experimental designs.

Although journals and funders in ecology could require researchers to pre-register their studies and analysis plans [13,16], we believe the widespread adoption of pre-registration in ecology will take time because ecologists will need to become accustomed to working out details that often were left for the post-data collection phase. When starting the preregistration process, it may be difficult for researchers to anticipate all the choices they will have to make during the analysis phase [16]. For example, a researcher may not have decided what to do with outliers or how to transform skewed data. These additions to, and deviations from, the original plan can be incorporated into amendments to the pre-analysis plan and can be reported in the final publication. The point of preregistration is not to punish researchers for failing to anticipate an obstacle, but to promote transparency during all steps of the research process [13], especially when researchers may forget what the original plan was and what deviations were made. Ideally, all pre-analysis plans would be registered before a study begins, but what does pre-registration mean for ongoing studies? In cases in which data collection is ongoing, researchers should try to preregister their subsequent analyses before new data are collected. As new ideas arise for old datasets, pre-analysis should also be submitted even though some of the data may be known to the researchers [14].

In ecology, pre-analysis plans ought to include detailed methodology that relates to several of the issues we describe above. For example, ecologists should include some reasoning about why they chose a specific sample size, including any design calculations that justify the sample size or elucidate the uncertainty within a study design (e.g., power analyses for frequentist methodologies, assurance analyses for Bayesian methodologies [19], or other design calculations [20]). In many cases, these design calculations will likely show that the number of replicates needed to credibly isolate signal from noise (e.g., power greater than 0.8) is logistically infeasible in terms of space, time, or money. Such conclusions do not mean that the studies should not be undertaken [21], but rather highlight the need for more coordination across study teams and a greater reliance on meta-analyses rather than single studies in ecology [15]. Pre-analysis plans should also include rationale with respect to correcting or not for multiple hypothesis testing. As noted above, studies testing multiple hypotheses in ecology are common, but few papers correct for these comparisons or state why they chose not to use corrections. In some cases, a simple solution is to differentiate, in the pre-analysis plan, the “primary” hypothesis from the “secondary” hypotheses. This differentiation implicitly frames some planned analyses as confirmatory (primary hypothesis) and others as exploratory (secondary hypotheses).

In sum, pre-registration and pre-analysis plans reduce, or at least make more transparent, the practices of HARKing, selective reporting of results, and presenting *ex post* exploratory analyses as if they were part of the original design [14]. Some authors argue that pre-registration and pre-analysis plans are unnecessary if scientists are transparent in all their decisions in their manuscripts and that they create an unnecessary barrier to conducting science [22]. However, when clinical trials in heart, blood and lung treatments were required to be preregistered, the pattern of reported results changed dramatically: in comparison to findings reported before preregistration was required, the magnitudes of the reported treatment effects decreased substantially with a corresponding increase in the number of negative and null findings [23].

Pre-registered plans do not limit science. Rather, they limit the ways scientific results can be reported. Ecologists should be encouraged to explore their data or frame the results in ways that were not originally envisioned – but ecologists should also be required to report those deviations and the scientific community should have a way to confirm that those deviations are reported. Pre-registration and pre-analysis plans help to achieve this goal.

Registered Reports & Results-Blind Reviews

Another step towards increased transparency is Registered Reports – a two stage review process (https://www.cos.io/initiatives/registered-reports). During the Registered Report process, an introduction and methods section outlining the study design and analysis are submitted for peer review. The merit of the study is judged based on the question being asked and the methods used to address that question, rather than the sign, magnitude, or statistical significance of the results. After a study is accepted in the first phase of the review process, reviewers in the second phase judge how closely the study follows the original plan and whether any deviations are substantial enough to affect the study quality [24].

Registered Reports should reduce selective reporting of results. Studies have shown that registered reports decrease the amount of positive findings compared to conventional publication practices [25,26]. Registered reports should also help reviewers focus on the importance of the questions asked and quality of the study design, rather than the sign, magnitude, and statistical significance of the results. Indeed, a study found that researchers rated Registered Reports as being more rigorous in methodology and analysis, while not reducing novelty or creativity compared to non-Registered Report publications [27]. By emphasizing research questions and designs, registered reports make it more likely that ecologists can abandon NHST based on simple binary rules to decide when an estimate is ecologically relevant (e.g., if $p<0.05$ or Bayes Factor > 3), a practice that warps the presentation and interpretation of empirical results [28–32].

While Registered Reports are growing in popularity, few ecology publications are in this format. Currently, 12 ecology-related or general interest journals offer a Registered Reports option for submitting manuscripts (https://www.cos.io/initiatives/registered-reports; Supplemental Table 1). While the option for submitting Registered Reports has been around for several years at some journals, it seems that few researchers are aware of or using the process. For example, *Conservation Biology* has published three Registered Reports, *Ecology and Evolution* has published only one, and none have been received at the *Journal of Plant Nutrition and Soil Science*. These journals are leading the way on Registered Reports, but there may need to be other incentives to have this publication format become more popular. For example, funding agencies could require this format, journals could spotlight these types of publications, or departments could require or up-weight publications in this format for career advancement. A preliminary written dissertation plan, where students' ideas and methods are critiqued by faculty, is already almost in the Registered Report format [16]. Thus, moving from the status quo towards greater use of Registered Reports is feasible and could be easily adopted for both early and later-career researchers.

Supplemental Table 1. Ecology or general interest journals that offer Registered Report format as of January 16, 2023.

Journal Name	Website
BMC Biology	https://bmcbiol.biomedcentral.com/
Ecology & Evolution	https://onlinelibrary.wiley.com/journal/20457758
Ecological Solutions & Evidence	https://besjournals.onlinelibrary.wiley.com/journal/26888319
Environment International	https://www.journals.elsevier.com/environment-international/
Frontiers in Plant Science	https://www.frontiersin.org/journals/plant-science#
Journal of Plant Nutrition and Soil Science	https://onlinelibrary.wiley.com/journal/15222624
Nature Communications	https://www.nature.com/ncomms/
PeerJ Life and Environment	https://peerj.com/life-environment/

PLoS Biology	https://journals.plos.org/plosbiology/
PLoS One	https://journals.plos.org/plosone
Royal Society Open Science	http://rsos.royalsocietypublishing.org/
Scientific Reports	https://www.nature.com/srep/

Similar to Registered Reports, results-blind reviews are another option to reduce publication bias against negative results [33]. In fact, results-blind reviews may be a good first step because they are closest to the current review process. Unlike Registered Reports where the study only starts after the first review, researchers submitting a results-blind review may have completed the study and written a complete manuscript – they simply do not include the results as part of the submitted manuscript. Like Registered Reports, results-blind review can reduce reviewer bias against negative results and can mitigate the pressure to engage in NHST guided by binary decision rules. Unlike Registered Reports, however, it has no mechanism in place to reduce selective reporting of results by the authors [14,24,33].

Changing Incentives

In the "publish or perish" environment in which many researchers operate, the benefits of engaging in these best practices are unlikely to exceed the costs without buy-in from the institutions that matter - namely, employers, funders, and publishers. For example, funding agencies could prioritize studies that use Registered Reports, such that high-profile grant programs reinforce best practices in ecology. Employers should explicitly encourage examples of credible, reproducible research and could require the practices outlined above for career advancement in a way that, as a metric of success, puts best practices on par with number of publications and impact factors of journals.

Among the practices that should be encouraged by employers, funders and publishers are replications of prior studies. Despite prior publications on the importance of replications [11,34], one study found replications were rare in ecology [35]. Employers should value researchers who replicate studies just as much as researchers who find novel results. High impact journals can help make replications more professionally rewarding by publishing replications alongside of ground-breaking research.

Without a change in researcher incentives it is difficult to imagine that a change in research practices will happen on its own – despite how much scientists value credibility within their discipline [36]. Unfortunately, researchers' professional incentives to publish novel and exciting studies are often at odds with their personal values of creating and disseminating credible science [2,36,37]. In fact, an ecology researcher who unilaterally adopts these practices may find herself at a disadvantage in the competition to place studies in high impact journals.

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