RESEARCH ARTICLE

Frontiers of Biogeography
the scientific journal of
the International Biogeography Society

Game of Tenure: the role of "hidden" citations on researchers' ranking in Ecology

Ana Benítez-López[1,2*] and Luca Santini[1,3*]

[1] Department of Environmental Science, Institute for Wetland and Water Research, Radboud University, P.O. Box 9010, NL-6500 GL, Nijmegen, the Netherlands; [2] Integrative Ecology Group, Estación Biológica de Doñana (EBD-CSIC), Avda. Américo Vespucio 26, 41092, Sevilla, Spain; [3] National Research Council, Institute of Research on Terrestrial Ecosystems (CNR-IRET), Via Salaria km 29.300, 00015, Monterotondo (Rome), Italy. *Corresponding authors: ana.benitez@ebd.csic.es; abenitez81@gmail.com; luca.santini.eco@gmail.com

Abstract

Field ecologists and macroecologists often compete for the same grants and academic positions, with the former producing primary data that the latter generally use for model parameterization. Primary data are usually cited only in the supplementary materials, thereby not counting formally as citations, creating a system where field ecologists are routinely under-acknowledged and possibly disadvantaged in the race for funding and positions. Here, we explored how the performance of authors producing novel ecological data would change if all the citations to their work would be accounted for by bibliometric indicators. We collected the track record of >2300 authors from Google Scholar and citation data from 600 papers published in 40 ecology journals, including field-based, conservation, general ecology, and macroecology studies. Then we parameterized a simulation that mimics the current publishing system for ecologists and assessed author rankings based on the number of citations, h-index, impact factor, and the number of publications under a scenario where supplementary citations count. We found weak evidence for field ecologists being lower ranked than macroecologists or general ecologists, with publication rate being the main predictor of author performance. Current ranking dynamics were largely unaffected by supplementary citations as they are 10 times less than the number of main text citations. This is further exacerbated by the common practice of citing datasets assembled by previous research or data papers instead of the original articles. While accounting for supplementary citations does not appear to offer a solution, researcher performance evaluations should include criteria that better capture authors' contribution of new, publicly available data. This could encourage field ecologists to collect and store new data in a systematic manner, thereby mitigating the data patchiness and bias in macroecology studies, and further accelerating the advancement of ecology and related areas of biogeography.

Highlights

- Primary data are often cited in the supplementary materials of papers relying on large quantities of secondary data, thus creating an imbalanced system for researchers that compete for the same grants or positions should they be assessed under the same bibliometric indicators.
- We simulate the current publishing system in ecology and assess how author ranking changes if supplementary citations were accounted for.
- Accounting for supplementary citations does not alter the ranking, with publication rate being the main predictor of authors' performance.
- New researchers' performance metrics measuring authors' contribution of new publicly available data are needed to promote ecological data sharing and further advance the field of ecology.

Keywords: Bibliometrics, citation analysis, ecology, *h*-index, journal impact factor, publish or perish, scientometrics, supplementary materials

e-ISSN: 1948-6596 https://escholarship.org/uc/fb doi:10.21425/F5FBG45195

Introduction

The last century has seen an exponential growth of scientific productivity (Larsen and von Ins 2010, Bornmann and Mutz 2015), and nowadays, several million papers are published every year in about 10,000 scientific journals. Science has also become increasingly competitive, and the second half of the last century has been characterized by a radical shift in academic practice. The widely known "publish or perish" paradigm (Garfield 1996) is more relevant than ever, with authors under the constant pressure to produce papers in order to succeed in an increasingly competitive academic environment (Powell 2015).

Nowadays, more researchers compete with each other for a diminishing number of research grants, funding, and academic positions, resulting in a pyramid where for any given number of PhD students, only a limited number of postdoc positions and even less tenure track positions or professorships are available (Cyranosk et al. 2009, Powell 2015). In turn, hiring or funding committees can hardly evaluate the full scientific production of researchers, and it has become increasingly harder to rank highly specialized researchers applying for a broadly described position. This results in highly subjective and hardly reproducible assessments by evaluation committees (Pier et al. 2018, Forscher et al. 2019), which increasingly rely on quantitative metrics for ranking researchers (Wouters 2014, Chapman et al. 2019). A multitude of indicators has been proposed, but the most commonly used are the number of publications, the total number of citations (Reich 2013), and the h-index, which combines the previous two and corresponds to the number of papers (*h*) that have each been cited at least *h* times (Hirsch 2005). Journals are also ranked according to several metrics (Bradshaw and Brook 2016), but, unarguably, the most commonly used is the impact factor (IF), which measures the average number of citations a journal received in the previous two years (Garfield 1955). The use of IF, despite being repeatedly criticized as a measure of the quality of the papers (Slyder et al. 1989, Hicks et al. 2015, McVeigh and Mann 2009, Callaway 2016, Chapman et al. 2019), is still very influential in the decision-making process of university hiring committees and funding agencies (Callaway 2016, McKiernan et al. 2019).

Ecology is a relatively young science, which started around the end of the 19th century and since then it has rapidly diversified (Benson 2000). Ecology can be studied at multiple organization levels, from individuals to populations, communities, ecosystems, or landscapes. Further, it can be studied at different spatial, temporal, or taxonomic scales, which generally exceeds the scale at which field studies can be conducted (Estes et al. 2018). This has led to the emergence of disciplines that rely on large quantities of secondary data (data originally collected for other research), which we collectively consider as macroecology in this study (McGill 2019). Over the past years the publication of data papers, meta-analyses, and synthetic analyses in ecology has skyrocketed (Carmel et al. 2013). Large-scale synthetic analyses and big data approaches are instrumental to advance ecology because they identify general patterns that escape the idiosyncrasies of local scale studies (McGill 2019, Currie 2019). However, while some macroecological studies rely on citizen science data (e.g., La Sorte et al. 2014), data collected by volunteers in government-sponsored repeated sampling efforts (e.g., North American Breeding Bird Survey, Schipper et al., 2016), or data collected by the same authors of the study (e.g., Bahram et al. 2018, Harpole et al. 2016), many macroecology studies rely heavily on the availability of data originally collected for other studies (movement data in Tucker et al. 2018, e.g., occurrence and abundance data in Dallas et al. 2017, life history traits in Cooke et al. 2019), whose original sources are commonly cited in the supplementary materials on the paper due to journal policies regarding restricted word count and space (Fox et al. 2016). This has created a system where citations to primary data in field-based research articles are published predominantly in the supplementary material and are systematically undercounted (Seeber 2008) simply because they are invisible to search engines such as PubMed, Scopus, or Web of Science (Fig. 1).

It has been argued that the role of empirical field research has faded appreciably in the past decades (Noss 1996, Ríos-Saldaña et al. 2018, Tewksbury et al. 2014), and this has inevitably generated contrasts between authors focusing at different scales of analysis (Ferreira et al. 2016, Ríos-Saldaña et al. 2018, Gaston and Blackburn 1999), but who might compete for the same positions or grants in the near future (but see Arnold 2003). A number of authors argue that this is the result of the current academic status quo which favors studies attracting more citations (but not necessarily of higher quality or broader application) (Fitzsimmons and Skevington 2010). This system would negatively influence the career advancement of authors working on local or single-species studies whose results are a priori less generalizable or have less clear short-term implications to advance ecology. This is further imbalanced by the fact that studies reporting primary data are generally far more expensive and more time-consuming (data collection may entail several seasons and years) than studies that analyze published data, which makes it harder for field ecologists to maintain a high productivity or to secure sufficient funding to ensure a field-based PhD over a computer-based PhD. This exacerbates the inequalities between field ecologists (primary data providers) and macroecologists, who use the data produced by the former in big data analyses (Fig. 1).

As a consequence, traditionally ecologists have had few incentives to share their data (Reichman et al. 2011). Actually, it is common that authors are willing to exchange their data for co-authorship in order to compensate for the perceived unbalanced credit to their work. This in turn can lead to an inflation in their productivity and in their number of citations with respect to the amount of data shared just for being included in data papers (e.g., TRY and PREDICTS databases, Kattge et al. 2011, Hudson et al. 2014), particularly when the databases are not fully accessible

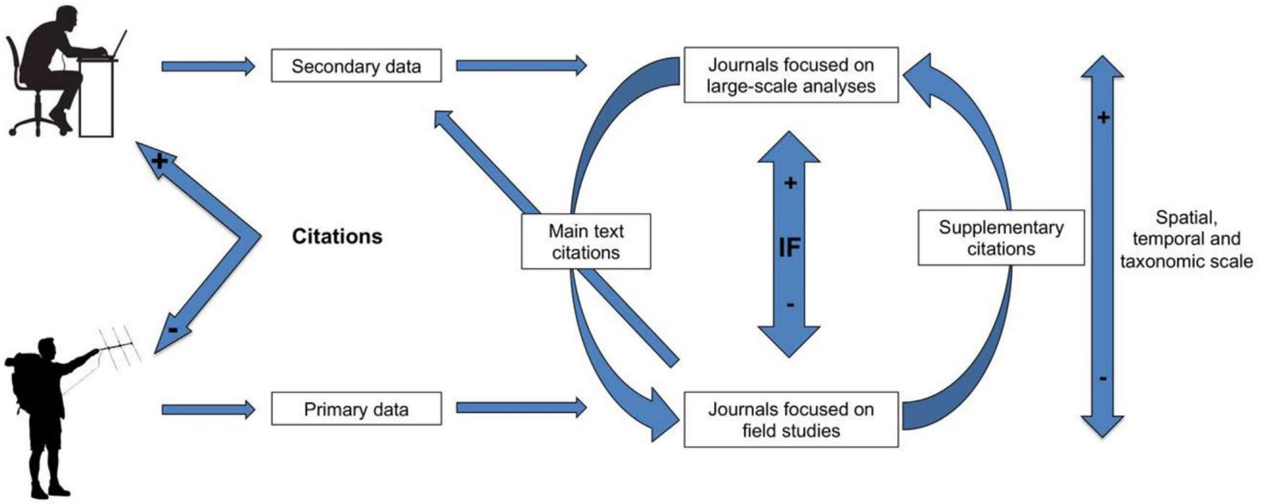

Figure 1. Conceptual framework depicting the dynamics behind the Game of Tenure. Primary data collected in field-based studies at small spatial and taxonomic scales are published in field ecology journals. These data are then collated and assembled by modellers in comparative and large-scale analyses, becoming secondary data (an assemblage of primary data from other local studies) being published as supplementary materials (SM), with the original sources cited also in the SM. This results in a lower impact factor for these journals than if the sources would have been cited in the main text. Field ecology journals usually cite journals focused on large-scale analyses (macroecology but also ecology) to frame the goal of study and, depending on the study, to test ecological hypotheses with a certain species in a certain area. The citations to those journals focused on large-scale analyses are published in the main text, and thus contribute to increase their impact factor.

and co-authorship is a precondition for using the data (e.g., TRY, MoveBANK), notwithstanding that The Ecological Society of America (ESA), The British Ecological Society (BES), or publishers like Wiley, PLOS or Elsevier, among many others, do explicitly state that data sharing alone is not sufficient to warrant authorship. One solution that has been proposed to make the system less biased is to make supplementary citations count for authors' performance metrics and for journals' ranking metrics (Seeber 2008, McDannell 2018, Weiss et al. 2010, Pop and Salzberg 2015). This may promote authors to make their data accessible to other research in exchange for citations. It may also foster research aim at filling current (taxonomic of geographic) data gaps, as these data would be of vast interest for secondary analyses.

In this study we perform a bibliometric analysis to explore the performance of authors preferentially publishing in different journals, and we estimate the flow of citations in main text and supplementary materials between journals with different scopes, broadly classified as Field Ecology, Ecology, Macroecology, Biodiversity Conservation, and Multidisciplinary. Further, we explore how the performance of authors and journals contributing biodiversity data (field-based studies) would change if all the citations to their work would be accounted for by bibliometric indicators. Because currently there is no way to test this based only on empirical data (i.e., there is no metric that accounts for supplementary citations), we used the data to parameterize a simulation model that mimics the current publishing system for ecologists. We used the simulation to assess how journal rankings and author rankings (measured by the number of publications, the total number of citations, the average impact factor of journals where they publish and h-index) vary in a 10-year period, which roughly resembles the academic life of an early-career researcher from the beginning of the PhD until the (unlikely) landing of a tenure-track position. We call this journey the Game of Tenure. Our simulation enables us to assess how the Game of Tenure would change after accounting for citations in the supplementary materials. We assume that in our simulation all researchers would compete for the same limited set of tenure-track positions by the end of year 10, and we optimistically consider that our researchers stay in academia throughout this period even though they might not be able to get a postdoc position after their PhD. Finally, we investigate the drivers that explain the change in author ranking after the model shift, considering their publication rate and target journals. While our focus herein is on ecology, we believe our analyses have bearing on closely related and overlapping disciplines such as biogeography.

Methods

Data collection

We selected 40 of the main journals in ecology within the Web Of Science (WOS) categories of Ornithology, Entomology, Zoology, Plant Sciences, Marine and Freshwater, Biodiversity Conservation, Ecology, and Multidisciplinary (Table S1). We further classified journals based on WOS categories and the online description of the journals' scope. We classified journals falling into Ornithology, Entomology, Zoology, Plant Science, Marine and Freshwater and Ecology as Field Ecology, i.e., field-based studies usually performed at local or landscape scales and generally producing primary data. Journals exclusively classified as Ecology are defined as journals that mostly publish studies that test general ecological theories and may or may not generate primary data for their analyses. Although Journal of Animal Ecology is classified as both Zoology and Ecology by WOS and New Phytologist is classified as Plant Science, we classified them both as Ecology based on their scope. The former publishes field-based research aimed at advancing animal ecology theory and methodologies. Similarly, New Phytologist publishes papers that may or may not produce primary data on a wide range of topics including meta-analyses. We also classified 5 journals in ecology as journals of Macroecology, which we define as journals that mostly publish studies assessing and quantifying large-scale ecological patterns, mostly relying on secondary data from other studies. We also classified journals as Conservation (Biodiversity Conservation in WOS) and Multidisciplinary (Multidisciplinary in WOS). Conservation journals are characterized by a strong conservation focus and include studies ranging from local to global scale, whereas Multidisciplinary journals publish studies on a wide array of research topics (Table S2). We acknowledge that this categorization is not that strict and a certain level of overlap in the scope of the papers published exists. For example, journals classified as Field Ecology may occasionally publish papers that analyze secondary data, and journals classified as Macroecology also often publish papers that include and analyze primary data. Nonetheless, this categorization allows us to classify journals in different categories that broadly reflect different disciplines for facilitating the interpretation of the results. The final list of journals included 14 Field Ecology, 13 Ecology, 5 Macroecology, 4 Biodiversity Conservation and 4 Multidisciplinary journals (Table S2). We downloaded the full list of papers published by these journals in 2008 and 2017 from WOS. For Multidisciplinary journals we restricted our search to papers related to ecology and conservation using the search string Ecology OR Biodiversity OR Conservation.

Journal information

We randomly sampled 15 papers per journal from all articles published in 2008 and 2017 (600 papers per year, ~9.5% of the total in our sample of journals, and approximately 3% of the total number of articles in Ecology indexed in WOS). We extracted the citations to the articles published in 2008 to track a 10-year period of citations (2008-2017) from WOS and calculated the number of citations per year per journal (citations/year per journal). One of the journals, Ecology and Evolution, started in 2011. For this, we could only retrieve the citations received in the last 7 years and assumed that citations in years 8 to 10 were equal to the year 7. With this information we constructed a matrix with the flow of citations within and between journals.

Because supplementary references are not tracked automatically by WOS, we inferred the flow of supplementary citations from the references in the supplementary materials. We sampled articles published in 2017 to better resemble the current state-of-the-art publishing field, with an increasing number of citations located in the Supplementary Materials (SM), particularly after the recent surge in meta-analyses and Data Papers in ecology. We extracted the references in the supplementary material and calculated the average number of references in the main text and SM separately for each journal category (Box 1). We also generated a matrix of citations based on the references in the SM. In order to account for differences in journal age, we only counted citations in SM for those papers published between 2008 and 2017, and to any of the journals in our sample. We also calculated the number of papers published by each journal in 2008 and used this information to calculate the proportion of papers we sampled over the total number of papers published. We used these proportions to correct the flow of citations accounting for the unequal number of papers published per journal. Finally, to account for the increase in supplementary citations received per year by published papers in the simulation, we calculated the proportion of supplementary citations per year across all references.

Author information

We extracted the track record from all first authors with a Scholar profile of all the papers published in 2017 in the selected journals (N = 3165, 59.4% over the total number of authors, N = 5005). We used the "scholar" package (Keirstead 2013) to download the track record of each author, and filtered it by only retaining papers published in journals included in WOS (i.e., we excluded abstracts, technical reports, book chapters and other works that do not contribute to bibliometric indicators). For each author we calculated the rate of publication and the proportion of papers published in the different journal categories in our sample. The authors in our sample can contribute to more than one category, meaning that we did not model, for example, pure macroecologists or pure conservation biologists, reflecting real patterns of authors' publications. To calculate the publication rate, we excluded the first and last year of publication as they are likely to be incomplete, and only considered the first 10 years of publications of an author's track record. From all the track records downloaded, we only retained 2372 authors that published for at least 3 years and whose publication rate could be calculated.

Simulation algorithm

We initialized the simulation with the 40 journals and the number of authors in our sample (2372). The simulation lasts 10 years; all authors start with no citations and the journals with no impact factor. During the simulation, authors publish according to their publication rate and probability of publishing in different journal categories. Each paper published includes a number of supplementary citations sampled from the observed distribution. Main text citations and supplementary citations are redistributed across journals based on the proportion of citations received, which we empirically recorded from our sample (Fig. S3). Every year papers can get cited both in the main text and the supplementary materials. At the end of every year of the simulation we calculated the number of total citations and the H-Index per author. From the third year of the simulation, every year the IF of the journals is calculated as the average of total citations received by papers published in the previous two years. All metrics are calculated under two scenarios: only main text citations count; and both main text and supplementary citations count. We replicated the simulation 10 times and averaged all results.

A more detailed description of the model algorithm, the code of the simulation and all estimated parameters are made available as part of the Supplementary Materials (Appendix S1, https://figshare.com/s/4c77aa0df498e87ec0ca).

Model output

We used the simulation outputs to rank researchers based on their performance under two scenarios: one where only citations from references in the main text count (MainText) and one where references in the supplementary materials also count as citations (SupMat). In each scenario, performance was measured by ranking authors based on their number of publications, total number of citations, their H-Index, and average impact factor of the journal in which they published. Currently, while some funding schemes are trying to move away from using IF or number of citations as performance metrics (Moher et al. 2018), in practice these criteria are still widely used in North America (NSERC Banting Postdoctoral Fellowships Program), Asia (CAS President's International Fellowship Initiative, PIFI), Europe (ERC starting grant), and Australia (DECRA or Future Fellowships). Here we assumed that other criteria typically employed to measure the quality of a researcher remained constant (e.g., leadership, teamwork, intellectual independence, teaching activities, research transparency, awards, contribution to peer-review and editorial roles). This assumption was necessary as it is currently impossible to retrieve this information for each individual researcher; further, a full consideration of these parameters goes beyond the scope of this research. For papers published in the first two years we used the impact factor of the third year. We then averaged the four individual rankings to generate a composite ranking of researchers under the two scenarios. We used random forests (Breiman 2001) to assess which variable was mainly responsible for the ranking of authors and which variables were important for explaining the change in ranking after accounting references in SM as citations. Random forest models were built for the individual rankings and for the composite ranking, for both the main text and main text and supplementary citations scenarios. Change in ranking was modeled as a binary variable with 0 denoting negative change in ranking and 1 positive change in ranking. We used 1000 trees and an 'mtry' parameter equal to the number of predictors divided by 3 (mtry = 2) for regression-based RF (author's ranking), and 1000 trees and an 'mtry' equal to 2 for classification-based RF (change in ranking). Our explanatory variables were the proportion of papers published in each research category, the degree of specialization of the author (calculated using the evenness in the number of categories and proportion of papers in each category for each authors), and the publication rate. Principal Components Analysis and biplots were used to visualize the change in ranking in a bidimensional space. All analyses were performed in R v.3.5.1 (R Core Team 2018) and the R packages "randomForest" (Liaw and Wiener 2002), "randomForestSRC" (Ishwaran and Kogalur 2018), "ggplot2" (Wickham 2016), "ggpubr" (Kassambara 2018), "vegan" (Oksanen et al. 2012), "viridis" (Garnier 2018), "dplyr" (Wickham et al. 2018) and "circlize" (Gu et al. 2015).

Results

Empirical Data results

Number of papers published and references per paper

The mean number of articles published per journal was 159.4 (median: 124, range: 31-502; Fig. S1), with the categories Ecology and Conservation publishing on average more papers per journal (205 and 191) than Field Ecology (130), Macroecology (137) and Multidisciplinary (111). Across categories, the average number of references in the main text and in supplementary materials was 47 (range: 1-172) and 13.1 (range: 0-897), respectively (Fig. S2). Among categories, Macroecology and Ecology had on average more references in the main text (55.9 and 55.8) than the other categories. The number of references in the SM was the highest in Multidisciplinary journals (35.7, 0-365), and the lowest in Field Ecology journals (3.76, 0-246) (Fig. S2).

Flow of citations

Overall, the most cited category was Ecology, followed by Multidisciplinary, Field Ecology, Macroecology, and Conservation categories. The majority of citations made in the journals of each category were mostly directed to journals of the same category (Fig. 2a, Table S3), except for Conservation journals, which mostly cited papers published in Multidisciplinary journals, followed by papers published in Conservation, Field Ecology, and Macroecology. In turn, Field ecology journals substantially cited general Ecology journals, and to a lesser extent Multidisciplinary, Macroecology and Conservation journals. Ecology journals mostly cited Multidisciplinary, Field Ecology and Macroecology journals. Macroecology mostly cited Multidisciplinary and Ecology journals and, to a lesser extent, Field ecology and Conservation journals. Finally, Multidisciplinary journals mostly cited Ecology, and to a lesser extent the other three categories (Fig. 2a, Table S3). Within each category, the most active journals (those with many

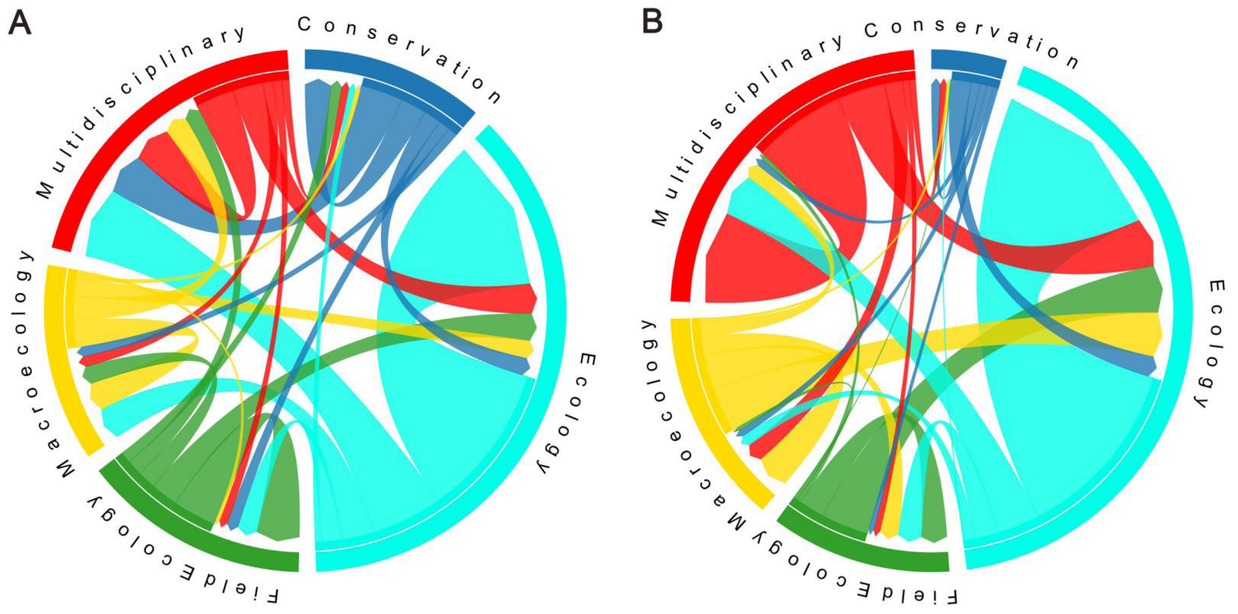

Figure 2. Flow of citations between journal categories for references in (A) the main text and (B) the supplementary material. The citations in the main text are based on all citations received by 600 papers published in 2008 in a 10-year period. The citations from the supplementary material are based on the references included in the supplementary materials of 600 papers published in 2017.

inbound and outbound citations) were Biodiversity and Conservation (Conservation), Hydrobiologia (Field Ecology), Ecology and Evolution (Ecology), PLOS ONE (Multidisciplinary), and Global Change Biology (Macroecology) (Fig. S3).

Supplementary references were less abundant than those from the main text (total 13652 vs 110179 in main text) and highly skewed to the right (Fig. S2). They were rare in Field Ecology and Conservation journals, more frequent in Macroecology, Ecology and, mostly, in Multidisciplinary journals (Fig. S2b). The flow of citations between journals changed considerably when focusing on supplementary references. Contrary to main text citations, the majority of citations from any category were directed to Ecology journals, except for Multidisciplinary journals that tended to cite other journals in the same category, and Macroecology, that cited comparatively a similar number of times Ecology journals and journals of the same category. The second most cited category was Multidisciplinary and Field Ecology, with the latter being mostly cited by Ecology and other Field Ecology journals (Fig 2b). The most active journals within each category were Conservation Biology (Conservation), Freshwater Biology (Field Ecology), New Phytologist and Ecology (Ecology), Science (Multidisciplinary) and Global Ecology and Biogeography (Macroecology) (Fig. S3).

A small proportion of citations were directed to papers published in the same or previous year. Most papers received the most citations after two years from publication, and the number of citations per year remained relatively stable until it gradually started to decline after 7-8 years from publication (Fig. S4). Supplementary citations showed a similar trend, but the proportions of citations to papers published between 2 and 6 years before were more similar, indicating the pressure to cite recent papers is high in the main text, but papers get cited for a longer time in the supplementary materials.

The average yearly publication rate of authors was 1.99, but the distribution is highly skewed to the right (median=1.66; range=0.29-13.00) (Fig. S5a). The distribution of the proportion of papers published in each journal category by authors also varied considerably. The distribution for Field Ecology and Ecology papers was more evenly spread, whereas that of Multidisciplinary, Macroecology and Conservation papers was skewed to the left, indicating that few authors publish most of their papers in these categories (Fig. S5). The relationship between the author's publication rate and the proportion of articles published in different categories was slightly negative for Field Ecology, Conservation and Macroecology, and flat for Ecology (Fig. S6).

Simulation results

The citations of simulated authors increased exponentially from year 1 to 10, the H-index increased linearly (Fig. 3a,b), and the impact factor of the journals obtained after the first two years of simulation fluctuated around a stable average value (Fig. 3c). We did not observe clear differences in ranking between authors publishing in different journal categories. However, authors with a higher number of articles in Field Ecology journals tended to have fewer citations and lower H-index (Fig. 3a,b). Additionally, the ranking of researchers at the end of the simulation was mostly explained by publication rate and, to a much lesser extent, by the proportion of papers with a strong focus on local field ecology (Fig. 4, Fig. S7). Publication rate shows a sharp positive relationship with ranking, reaching an asymptote at about 5 papers per year (Fig. 4b). The proportion of papers published in field ecology showed a negative relationship instead (Fig. 4c). The proportion of papers published in other fields showed slight negative relationships, while the evenness in published papers was positively related to researchers' ranking (Fig. S7). Publication rate was also the main predictor of the individual rankings based on number of citations, number of papers, and h-index. The ranking based on the impact factor of the journals where author publish was negatively related with the proportion of papers published in Field Ecology and Conservation (Fig. S8).

Accounting for supplementary citations in the bibliometric indicators changed the ranking only slightly (Fig. 5) and, overall, positively towards authors with a high proportion of papers published in Field Ecology (Fig. 4f). Authors publishing in different fields had a low probability of improving their performance (Fig. 4e),

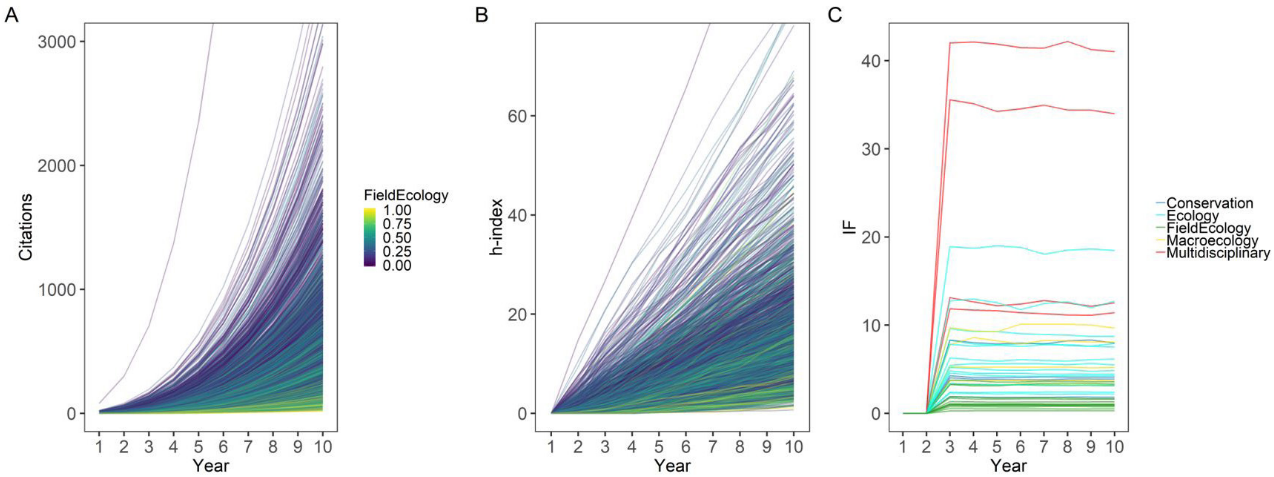

Figure 3. Temporal trends in (A) the number of citations and (B) H-index for authors publishing a different proportion of articles with a strong field ecology focus, and (C) in impact factor for each journal included in the simulation. The colour palette of panels A and B indicates the proportion of papers published in Field Ecology per author. Note that the Y axes of A and B panels have a wider range due to a single outlier but have been cropped for visualization purposes.

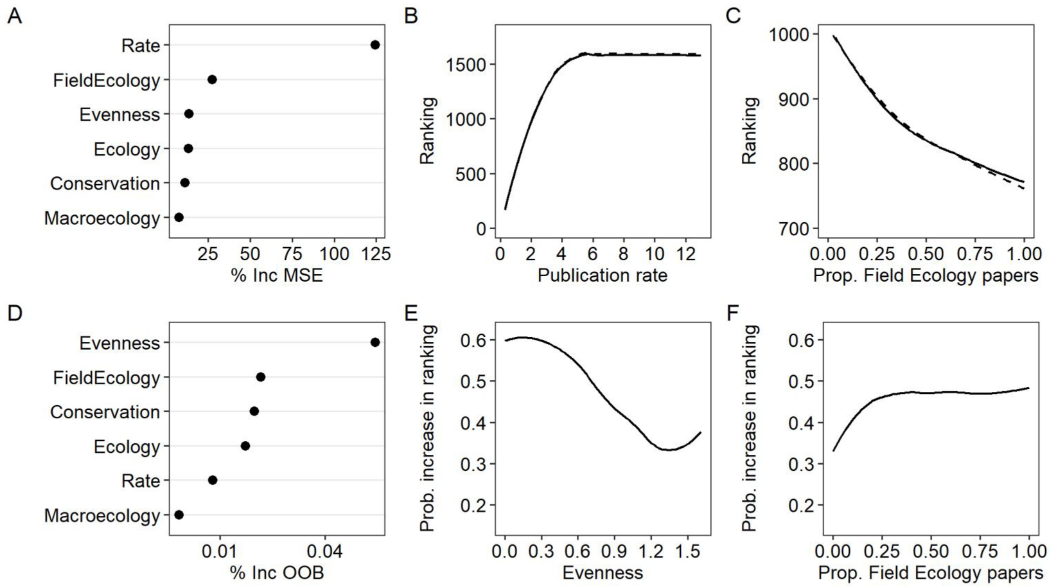

Figure 4. Variable importance (A, D) and partial dependence plots (B, C, E, F) of the most important variables explaining (A, B, C) the author ranking when accounting only main text citations (solid lines) or both main text and supplementary citations (dashed lines) and (D, E, F) the probability of increase in ranking if citations in the supplementary material were taken into account. % Inc = % increase in error estimate by permuting each predictive variable in the model. MSE = Mean Square Error; OOB = Out Of Bag classification error.

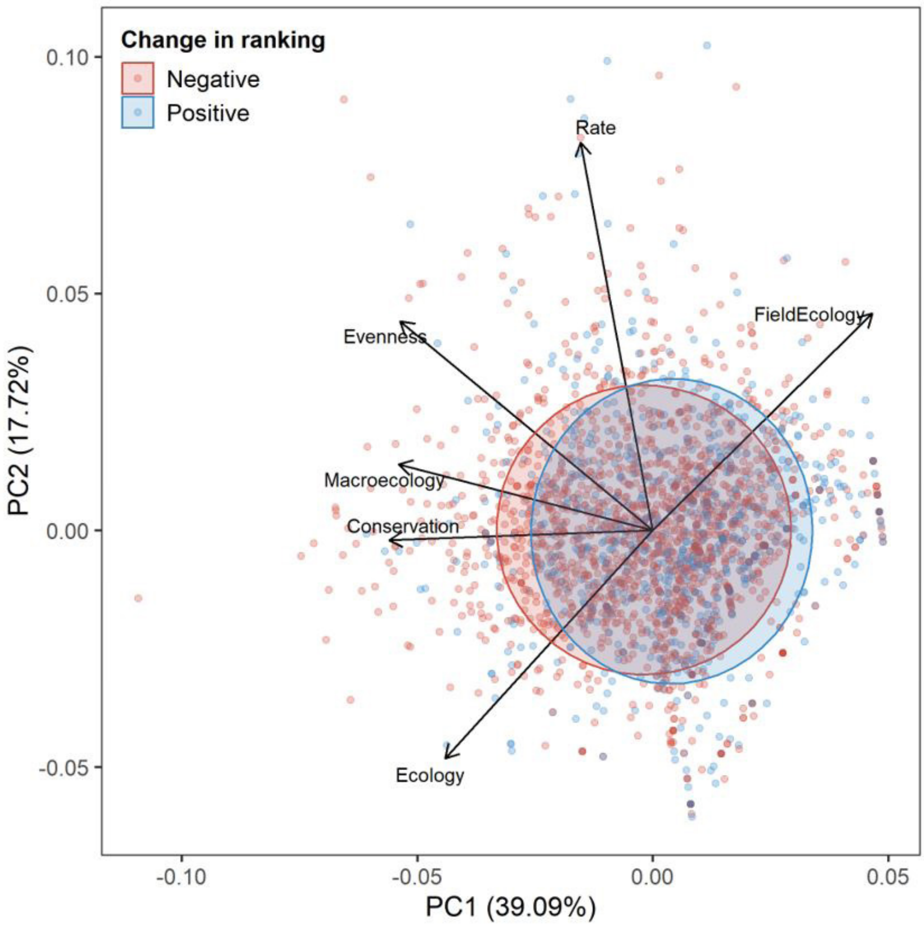

Figure 5. Biplot of a principal components analysis on the proportions of papers published by authors in each journal category, the publication rate, and the degree of specialization of the author (evenness). Percentage values represent the proportion of the total variation explained by the first two principal components. The first axis separates authors that mostly publish in Field Ecology from those that mostly publish in Macroecology, Conservation, Ecology, or several disciplines (Evenness). The second axis separates authors with a high publication rate, who publish in Field Ecology and/or several disciplines (evenness) from those mostly publishing in Ecology. Solid arrows indicate direction and weighting of vectors representing the six variables analyzed. Dots represent authors included in the simulation; colours indicate whether the authors' ranking increased (positive) or decreased (negative) after accounting for supplementary citations. The ellipses represent the normal distribution of authors (68% confidence level) with a positive and negative change in ranking, with an overall slight positive change for authors publishing a high proportion of papers in Field Ecology.

while some general ecologists also marginally benefited (Fig. S9). The distribution of impact factor per journal only changed slightly (Fig. S10), with Journal of Ecology being the most benefited journal.

Discussion

Accounting for supplementary citations in the Game of Tenure

In this paper we unveiled the dynamics of citation flows between journals covering different aspects of ecology and analyzed the extent to which these would be modified by supplementary citations, which normally remain undetected. Our results indicate that the dynamics of citations in the main text are relatively endogamic, with most citations flowing within the same category. These dynamics were relatively different for supplementary citations, with most of them unexpectedly being directed to Ecology instead of Field Ecology journals, and with a considerable share going to journals of the same category. Within the Ecology category, the Journal of Ecology benefited the most, exhibiting a sizeable boost in its IF after accounting for supplementary citations (Fig. S10). We argue that this pattern emerges because many studies published in Ecology journals test ecological hypotheses using a model system or species, with the data collected in the field and thus later available for reuse in other big data analyses. Interestingly, the performance of authors was mostly related to their productivity and to their main field of research, with authors having a high proportion of publications in Field

Ecology being consistently lower ranked that authors publishing papers in other categories. In turn, authors having a diverse publication strategy (i.e., publishing on different topics) tended to perform high in the ranking. Accounting for supplementary materials increased the average ranking of authors publishing in Field Ecology and Ecology journals, but with a high variability (some would move further down the ranking). Indeed, Field Ecology journals got a considerable share of citations from Macroecology and Ecology journals; however, the amount of supplementary citations is overall 10 times lower than the number of main text citations. As a result, accounting for supplementary citations only slightly changed the ranking of authors publishing in Field Ecology, which are usually less cited in the main text (Fig. S8C) and certainly not enough to overcome authors publishing in Ecology journals or high-tier Multidisciplinary journals (Fig. 5, Fig. 4F), making the dynamics in the Game of Tenure more balanced but broadly unchanged. A further explanation for the little difference made by supplementary citations is that several papers heavily relying on secondary data cite entire datasets collated in data papers instead of the original articles (e.g., Böhm et al. 2017, Camacho et al. 2017, Givan et al. 2017 in our sample). Given the increasing trend of publishing data papers in journals such as Ecology (see e.g., ATLANTIC Data series - Galetti and Ribeiro 2019, Amniote database - Myhrvold et al. 2015, or PanTHERIA - Jones et al. 2009), practices like the one described provide a disproportionate number of citations to journals falling in the Ecology category that should be partially shared by Field Ecology journals (Appendix S2; Figure S11). It should be noted that tracing back original publications from published datasets can be far from trivial, as biological values in datasets are often reported as averages over several references listed, or datasets may provide a list of references per species referred to multiple columns (e.g., Jones et al. 2009). Therefore, accounting for supplementary citations in bibliometric indicators, although conceptually fair, would still fall short of properly crediting the contribution of field ecologists as long as citations of data papers (or datasets from previous research papers) do not trace back to the original publications.

At the end of the simulation we had journals with a higher IF than in reality (e.g., Ecology Letters, PLOS One), while others had a lower IF (e.g., New Phytologist). This is because we assumed a closed system where citations can only be exchanged between the journals we sampled. This means that journals that receive most of their references from journals that were not sampled would get a lower IF, while those that are mostly cited by other journals in our sample would get an IF around the real journal's IF. Higher IFs might occur if our sample included papers that received a disproportionately high number of citations on average compared to all papers published by the journals in those years. IF, however, is also influenced by additional factors in reality (Chapman et al. 2019). For example, while most journals now publish online the unformatted version of accepted papers ('early view'), the time of publication in an issue after acceptance varies greatly among journals, from one month to more than one year. The delay of inclusion of papers in an issue normally inflates the IF as the paper is already citable before being accounted for the IF. Further, among the many possible article types (research, reviews, perspectives, commentaries, essays, highlights, spotlights, opinions, among others), Web Of Science only considers those defined as "citable elements", and this definition changes from one journal to another (McVeigh and Mann 2009). Finally, the IF of Multidisciplinary journals such as Science, Nature, or PLOS One is also influenced by the citations received by papers not in ecology, which we did not include in our sample. For all these reasons, it is unsurprising that the IFs that emerge from our simulations do not perfectly match those observed in reality.

It is also worth noting that here we evaluated a hypothetical scenario where common bibliometric indicators are the only indicator that counts in the race for a position or grant acquisition. Yet, we acknowledge that evaluations of researchers' performance often include additional criteria here assumed to be constant across authors (e.g., teaching, outreach, affinity to the mission of the institution, motivation and passion, peer-review or editorial activity, etc.), and the relative weight of all these factors can vary across geographic areas or institutions. Nonetheless, the reliance on the metrics included in our study is still well established and substantially contribute to the researchers' ability to proceed in their career (Callaway 2016, McKiernan et al. 2019, Chapman et al. 2019). In extreme cases, authors are financially rewarded for their academic publications, with more money awarded for publishing in prestigious international high impact journals (Quan et al. 2017, Chapman et al. 2019).

Towards a fairer game

Comparison between researchers working at different scales of analysis and using different analytical tools (e.g., field ecologists vs macroecologists) will never be fair if based on the same metrics. Fieldwork-based investigations are usually perceived as having a lower publication value (Fitzsimmons and Skevington 2010, Bini et al. 2005). They usually receive fewer citations (see our results and Ríos-Saldaña et al. 2018) than wide-scope and large-scale approaches (e.g., meta-analyses or macroecology studies), which usually have a greater impact in the conservation and ecological literature (Hampton and Parker 2011), and receive more citations. This is thought to potentially discourage researchers from conducting studies that require long data collection periods and are less cited, thereby perpetuating the low impact factor of the journals where they are published (Ríos-Saldaña et al. 2018). As long as academics, scholarly journals, and funding agencies continue to positively reinforce paper citation rates and journal impact factors as gold standards of scientific excellence, the chances for field ecologists to thrive in the Game of Tenure may be low (Paulus et al. 2015, Ríos-Saldaña et al. 2018). If field researchers are gradually outcompeted in the race, in the long-term, the number of researchers conducting such studies may also decrease. This may be further exacerbated by a lower number of students willing to pursue a field-based PhD compared to those engaging in a potentially more rewarding modelling-based PhDs. Yet, long-term field data collection periods seem to not be diminishing the publication rate of authors undertaking Field Ecology studies, which was similar across categories (Fig. S6). The penalizing factor appears to be the number of citations that Field Ecology journals receive (Fig. S8). Indeed, while field studies can consist of long field sampling seasons, field ecology journals also commonly publish more anecdotal observations or short surveys, which contribute to keep the IF of such journals low while not affecting the citations received by well-designed, hypothesis-driven articles. This, in addition generates another form of inequity toward macroecologists, as the number of publications is also used as a criterion for evaluation.

Quantitative measures are useful to compare researchers with similar profiles; however, it has been suggested that they should support qualitative, expert-based assessments rather than substitute them (Hicks et al. 2015). The recent San Francisco Declaration on Research Assessment (DORA) advocate for the use of qualitative indicators to complement quantitative metrics by including how scientific research influence policy and practice, and its societal relevance[1]. Similarly, the Leiden Manifesto (Hicks et al. 2015) proposes several good practices including the use of quantitative metrics only as a support of qualitative assessments, the affinity of the researcher to the mission of the institution, and transparency in research practices. The drawback is that qualitative assessment may turn out to be highly subjective and dependent on the committee members' background; furthermore, it remains open to personal judgment how much qualitative should weight over quantitative. While no single system is perfect, we argue that a more complete picture of the quality of a researcher should include an array of elements that goes beyond productivity and impact factor. Accounting for supplementary citations is only one of the possible mechanisms to properly credit researchers that collect hard-earned – financially burdening – ecological data. We thus propose employing additional metrics that measure data collection and sharing, and how much these are used by further research. One example would be the "Data Citation Index" in WOS (Elmore et al. 2013), created in 2012 but, to the best of our knowledge, hardly used to date. In this index, descriptive records are created for data objects and linked to literature articles in the Web of Science. This index aims to provide a clearer picture of the full impact of research output, as well as to act as a significant tool for data attribution and discovery. In this sense, data uploaded to repositories such as Figshare or DataDryad have to be properly cited with a DOI so that proper crediting can be attributed. Another example is the S-Index, an analogue of the H-Index to quantify data sharing (Olfson et al. 2017), but it has also never been applied in practice (Moher et al. 2018). Finally, we envision a system similar to GenBank (Sayers et al. 2018), which is an online database where new DNA sequences are uploaded after publication. By having a similar online database or, alternatively, domain-specific data repositories (Poisot et al. 2019) to store ecological data (e.g., population densities, life history traits, ecological networks, etc.), authors would upload their data once used for their research. This would facilitate citing the single entries by secondary users in a special section of the article that can be screened by search engines, so that these citations are integrated in bibliometric indicators. This would ensure their visibility and would give them the chance to get credit for the data uploaded. This would foster not only data sharing, but also targeted collection of data to fill important data gaps, which would be highly cited.

In this paper we discussed a pervasive problem in modern science. We found that accounting for supplementary citations as suggested by some authors (Seeber, 2008; Weiss et al., 2010; Pop & Salzberg, 2015; McDannell, 2018) makes only a small difference to authors ranking, because many supplementary citations would be hidden in data papers and existing research datasets, so additional solutions are needed. We focused on ecology but the tension between primary data producers and secondary data users exists in many different disciplines, such as biogeography, evolutionary biology, environmental science, psychology, medicine, etc. Within medicine, some have even labeled authors conducting research on secondary data as "research parasites" (Longo and Drazen 2016), a term that, rather than effectively disqualifying researchers, has been embraced by the scientific community[2] (Greene et al. 2017). This competitive environment does not benefit science and risks to hamper its development. We encourage journals to promote the visibility of supplementary citations and evaluation systems to assess researchers' performance with a wider number of metrics that also accounts for supplementary references and sharing of primary data, as well as assesses authors actual contribution to research papers that cannot be limited to data sharing. Hopefully, this will rebalance the delicate equilibria in research practice, generate a more collaborative environment, and prevent the decline of important disciplines.

Acknowledgements

We thank Leonardo Ancillotto, Gentile Francesco Ficetola, Emilio Pagani-Núñez, Francisco Rodríguez-Sánchez, Aafke M. Schipper and Marlee Tucker for their comments and suggestions on an earlier version of the manuscript. We also thank two anonymous reviewers and the handling editor (Dr. Richard Ladle) who provided constructive comments that further improved the manuscript. Ana Benítez-López was supported by a Juan de la Cierva-Incorporación grant (IJCI-2017-31419) from the Spanish Ministry of Science, Innovation and Universities.

Author contributions: Both authors contributed equally to the manuscript.

1 https://sfdora.org

2 https://researchparasite.com/

Supplementary Materials

The following materials are available as part of the online article from https://escholarship.org/uc/fb

Table S1. Web of Science (WOS) categories considered in our analysis.

Table S2. Journals considered for extraction of empirical data and model parameterization.

Table S3. Descriptive statistics of citations received in a 10-year period by the journals in our sample.

Table S4. Number of references in each data compilation that correspond to journals in the categories Conservation, Ecology, Field Ecology, Macroecology, Multidisciplinary.

Figure S1. Number of articles published in 2008 in each journal included in our study.

Figure S2. Number of references in the main text (left) and in the supplementary materials (right) for articles published in each research category and for all categories.

Figure S3. Flow of citations between journals for references in (A) the main text and (B) the supplementary material.

Figure S4. Proportion of citations (number citations/total number citations in a year) that articles receive from references in the main text (solid line) and in the supplementary material (dashed line).

Figure S5. A) Publication rate of authors sampled from Google Scholar and number of authors publishing an increasing proportion or articles in different research categories including B) Field Ecology, C) Ecology, D) Conservation, E) Macroecology, and F) Multidisciplinary.

Figure S6. Relationship between publication rate and the proportion or articles published in different research categories including A) Field Ecology, B) Ecology, C) Conservation, and D) Macroecology.

Figure S7. Partial dependence plots of predictors of author ranking. Predictors are ordered according to their importance.

Figure S8. Variable importance (A, D, G, J) and partial dependence plots (B, C, E, F, H, I, K, L) of the most important variables explaining the authors' individuals rankings based on (A, B, C) number of citations, (D, E, F) number of papers, (G, H, I), journal impact factor where the authors published their articles, and (J, K, L) h-index.

Figure S9. Partial dependence plots of predictors for the probability of increase in author ranking after accounting for supplementary citations.

Figure S10. Journal impact factor at the end of the simulation when considering citations in the main text only (purple) and citations in the main text and the supplementary materials simultaneously (orange).

Figure S11. Proportion of citations corresponding to each category reported in five main data papers, for papers published before 1990, after 1990, and across all periods.

Appendix S1. Model Algorithm

Appendix S2. Proportion of citations in data papers

References

Arnold, S.J. (2003) Too much natural history, or too little? Animal Behaviour, 65, 1065–1068.

Bahram, M., Hildebrand, F., Forslund, S.K., et al. (2018) Structure and function of the global topsoil microbiome. Nature, 560, 233–237.

Benson, K.R. (2000) The emergence of ecology from natural history. Endeavour, 24, 59–62.

Bini, L.M., Felizola Diniz-Filho, J.A., Carvalho, P., Pinto, M.P. & Rangel, T.F.L.V.B. (2005) Lomborg and the litany of biodiversity crisis: What the peer-reviewed literature says. Conservation Biology, 19, 1301–1305.

Böhm, M., Kemp, R., Williams, R., Davidson, A.D., Garcia, A., McMillan, K.M., Bramhall, H.R. & Collen, B. (2017) Rapoport's rule and determinants of species range size in snakes. Diversity and Distributions, 23, 1472–1481.

Bornmann, L. & Mutz, R. (2015) Growth rates of modern science: A bibliometric analysis based on the number of publications and cited references. Journal of the Association for Information Science and Technology, 66, 2215–2222.

Bradshaw, C.J.A. & Brook, B.W. (2016) How to rank journals. PLoS ONE, 11, e0149852.

Breiman L. (2001) Machine Learning. Machine Learning, 45, 5–32.

Callaway, E. (2016) Beat it, impact factor! Publishing elite turns against controversial metric. Nature News, 535, 210.

Camacho, A., Recoder, R., Teixeira, M., Kohlsdorf, T., Rodrigues, M.T. & Lee, M.S.Y. (2017) Overcoming phylogenetic and geographic uncertainties to test for correlates of range size evolution in gymnophthalmid lizards. Ecography, 40, 764–773.

Carmel, Y., Kent, R., Bar-Massada, A., Blank, L., Liberzon, J., Nezer, O., Sapir, G. & Federman, R. (2013) Trends in ecological research during the last three decades - A systematic review. PLoS ONE, 8, e59813.

Chapman, C.A., Bicca-Marques, J.C., Calvignac-Spencer, S., et al. (2019) Games academics play and their consequences: how authorship, h-index and journal impact factors are shaping the future of academia. Proceedings of the Royal Society B, 286, 20192047.

Cooke, R.S.C., Bates, A.E. & Eigenbrod, F. (2019) Global trade-offs of functional redundancy and functional dispersion for birds and mammals. Global Ecology and Biogeography, 28, 484–495.

Currie, D.J. (2019) Where Newton might have taken ecology. Global Ecology & Biogeography, 28, 18–27.

Cyranosk, D., Gilbert, N., Ledford, H., Nayar, A., Yahia, M., Cyranoski, D., Gilbert, N., Ledford, H., Nayar, A. & Yahia, M. (2009) The phd factory. Nature, 472, 276–279.

Dallas, T., Decker, R.R. & Hastings, A. (2017) Species are not most abundant in the centre of their geographic range or climatic niche. Ecology Letters, 20, 1526-1533.

Elmore, A., Lehner, F. & Franke, J. (2013) The Art of Data Sharing: key in future climate science. PAGES news, 21, 92–93.

Estes, L., Elsen, P.R., Treuer, T., Ahmed, L., Caylor, K., Chang, J., Choi, J.J. & Ellis, E.C. (2018) The spatial and temporal domains of modern ecology. Nature Ecology and Evolution, 2, 819.

Ferreira, C., Ríos-Saldaña, C.A. & Delibes-Mateos, M. (2016) Naturalists: Hail local fieldwork, not just global models. Nature, 534, 326.

Fitzsimmons, J.M. & Skevington, J.H. (2010) Metrics: Don't dismiss journals with a low impact factor. Nature, 466, 179–179.

Forscher, P.S., Brauer, M., Cox, W.T.L. & Devine, P.G. (2019) How many reviewers are required to obtain reliable evaluations of NIH R01 grant proposals? PsyArXiv, doi:10.31234/osf.io/483zj.

Fox, C.W., Paine, C.E.T. & Sauterey, B. (2016) Citations increase with manuscript length, author number, and references cited in ecology journals. Ecology and Evolution, 6, 7717–7726.

Galetti, M. & Ribeiro, M.C. (2019) ATLANTIC: Data Papers from a biodiversity hotspot. Available at https://esajournals.onlinelibrary.wiley.com/doi/toc/10.1002/(ISSN)1939-9170.AtlanticPapers

Garfield, E. (1955) Citation indexes for science; a new dimension in documentation through association of ideas. Science, 122, 108–111.

Garfield, E. (1996) What is the primordial reference for the phrase "Publish or Perish"? The Scientist, 10, 11.

Garnier, S. (2018) viridis: Default Color Maps from "matplotlib." R package version 0.5.1.

Gaston, K.J. & Blackburn, T.M. (1999) A Critique for Macroecology. Oikos, 84, 353–368.

Givan, O., Parravicini, V., Kulbicki, M. & Belmaker, J. (2017) Trait structure reveals the processes underlying fish establishment in the Mediterranean. Global Ecology & Biogeography, 26, 142–153.

Greene, C.S., Garmire, L.X., Gilbert, J.A., Ritchie, M.D. & Hunter, L.E. (2017) Celebrating parasites. Nature Genetics, 49, 483.

Gu, Z., Gu, L., Eils, R., Schlesner, M. & Brors, B. (2015) circlize implements and enhances circular visualization in R. Bioinformatics, 30, 2811–2812.

Hampton, S.E. & Parker, J.N. (2011) Collaboration and Productivity in Scientific Synthesis. BioScience, 61, 900–910.

Harpole, W.S., Sullivan, L.L., Lind, E.M., et al. (2016) Addition of multiple limiting resources reduces grassland diversity. Nature, 537, 93–96.

Hicks, D., Wouters, P., Waltman, L., de Rijcke, S. & Rafols, I. (2015) The Leiden Manifesto for research metrics. Use these ten principles to guide research evaluation. Nature, 520, 429.

Hirsch, J.E. (2005) An index to quantify an individual's scientific research output. Proceedings of the National Academy of Sciences, 102, 16569–16572.

Hudson, L.N., Newbold, T., Contu, S., et al. (2014) The PREDICTS database: A global database of how local terrestrial biodiversity responds to human impacts. Ecology and Evolution, 4, 4701–4735.

Ishwaran, H. & Kogalur, U.B. (2018) Random Forests for Survival, Regression, and Classification (RF-SRC). R package version 2.6.1.

Jones, K.E., Bielby, J., Cardillo, M., et al. (2009) PanTHERIA: a species-level database of life history, ecology, and geography of extant and recently extinct mammals. Ecology, 90, 2648.

Kassambara, A. (2018) ggpubr: "ggplot2" Based Publication Ready Plots. R package version 0.1.8. https://CRAN.R-project.org/package=ggpubr.

Kattge, J., Dìaz, S., Lavorel, S., et al. (2011) TRY–a global database of plant traits. Global Change Biology, 17, 2905–2935.

Keirstead, J. (2013) scholar: Analyse citation data from Google Scholar. R package version 0.1.1, URL http://CRAN.R-project.org/package=scholar.

Larsen, P.O. & von Ins, M. (2010) The rate of growth in scientific publication and the decline in coverage provided by science citation index. Scientometrics, 84, 575–603.

Liaw, A. & Wiener, M. (2002) Classification and Regression by randomForest. R News 2, 18–22.

Longo, D.L. & Drazen, J.M. (2016) Data Sharing. The New England Journal of Medicine, 374, 276–277.

McDannell, K.T. (2018) Bring supplementary citations into view. Nature, 555, 311–311.

McGill, B. (2019) The what, how and why of doing macroecology. Global Ecology & Biogeography, 28, 6–17.

McKiernan, E.C., Schimanski, L.A., Muñoz Nieves, C., Matthias, L., Niles, M.T. & Pablo Alperin, J. (2019) Use of the Journal Impact Factor in academic review, promotion, and tenure evaluations. PeerJ Preprints, doi:10.7287/peerj.preprints.27638v2.

McVeigh, M.E. & Mann, S.J. (2009) The Journal Impact Factor Denominator. Jama, 302, 1107–1109.

Moher, D., Naudet, F., Cristea, I.A., Miedema, F., Ioannidis, J.P.A. & Goodman, S.N. (2018) Assessing scientists for hiring, promotion, and tenure. PLoS Biology, 16, e2004089.

Myhrvold, N.P., Baldridge, E., Chan, B., Freeman, D.L. & Ernest, S.K.M. (2015) An amniote life-history database to perform comparative analyses with birds, mammals, and reptiles. Ecology, 96, 3109.

Noss, R.F. (1996) The naturalists are dying off. Conservation Biology, 10, 1–3.

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H. & Wagner, H. (2012) vegan: Community Ecology Package. R package version 1, R package version 2.0-4.

Olfson, M., Wall, M.M. & Blanco, C. (2017) Incentivizing data sharing and collaboration in medical research-the S-index. JAMA Psychiatry, 74, 5–6.

Paulus, F.M., Rademacher, L., Schäfer, T.A.J., Müller-Pinzler, L. & Krach, S. (2015) Journal Impact factor shapes scientists' reward signal in the prospect of publication. PLoS ONE, 10, e0142537.

Pier, E.L., Brauer, M., Filut, A., Kaatz, A., Raclaw, J., Nathan, M.J., Ford, C.E. & Carnes, M. (2018) Low agreement among reviewers evaluating the same NIH grant applications. Proceedings of the National Academy of Sciences, 115, 2952–2957.

Poisot, T., Bruneau, A., Gonzalez, A., Gravel, D. & Peres-Neto, P. (2019) Ecological data should not be so hard to find and reuse. Trends in Ecology and Evolution, 34, 494–496.

Pop, M. & Salzberg, S.L. (2015) Use and mis-use of supplementary material in science publications. BMC Bioinformatics, 16, 237.

Powell, K. (2015) The future of the postdoc. Nature, 520, 144.

Quan, W., Chen, B. & Shu, F. (2017) Publish or impoverish: An investigation of the monetary reward system of science in China (1999-2016). Aslib Journal of Information Management, 69, 486–502.

Reich, E.S. (2013) Science publishing: The golden club. Nature, 502, 291.

Reichman, O.J., Jones, M.B. & Schildhauer, M.P. (2011) Challenges and opportunities of open data in ecology. Science, 331, 703–705.

Ríos-Saldaña, C.A., Delibes-Mateos, M. & Ferreira, C.C. (2018) Are fieldwork studies being relegated to second place in conservation science? Global Ecology and Conservation, 14, e00389.

Sayers, E.W., Cavanaugh, M., Clark, K., Ostell, J., Pruitt, K.D. & Karsch-Mizrachi, I. (2018) GenBank. Nucleic Acids Research, 47, D94–D99.

Schipper, A.M., Belmaker, J., de Miranda, M.D., et al. (2016) Contrasting changes in the abundance and diversity of North American bird assemblages from 1971 to 2010. Global Change Biology, 22, 3948–3959.

Seeber, F. (2008) Citations in supplementary information are invisible. Nature, 451, 887.

Slyder, J.B., Stein, B.R., Sams, B.S., Walker, D.M., Jacob Beale, B., Feldhaus, J.J. & Copenheaver, C.A. (1989) Citation pattern and lifespan: a comparison of discipline, institution, and individual. Scientometrics, 3, 955–966.

La Sorte, F.A., Tingley, M.W. & Hurlbert, A.H. (2014) The role of urban and agricultural areas during avian migration: An assessment of within-year temporal turnover. Global Ecology & Biogeography, 23, 1225–1234.

Tewksbury, J.J., Anderson, J.G.T., Bakker, J.D., et al. (2014) Natural history's place in science and society. BioScience, 64, 300–310.

Tucker, M.A., Böhning-Gaese, K., Fagan, W.F., et al. (2018) Moving in the Anthropocene: Global reductions in terrestrial mammalian movements. Science, 359, 466–469.

Weiss, M.S., Einspahr, H., Baker, E.N., Dauter, Z., Kaysser-Pyzalla, A.R., Kostorz, G. & Larsen, S. (2010) Citations in supplementary material. Acta Crystallographica, F66, 1550–1551.

Wickham, H. (2016) ggplot2: elegant graphics for data analysis. Springer-Verlag, New York.

Wickham, H., François, R., Henry, L. & Müller, K. (2018) dplyr: A Grammar of Data Manipulation. R package version 0.7.6. https://CRAN.R-project.org/package=dplyr.

Wouters, P. (2014) The citation: From culture to infrastructure. In: B. Cronin & C. Sugimoto (eds.) Beyond Bibliometrics: Harnessing Multidimensional Indicators of Scholarly Impact. MIT Press.

Submitted: 13 September 2019
First decision: 04 November 2019
Accepted: 14 December 2019

Editors: Richard J. Ladle and Robert J. Whittaker

