RESEARCH ARTICLE

Writing a massively multi-authored paper: Overcoming barriers to meaningful authorship for all

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Abstract

1. The value of large-scale collaborations for solving complex problems is widely recognized, but many barriers hinder meaningful authorship for all on the resulting multi-author publications. Because many professional benefits arise from authorship, much of the literature on this topic has focused on cheating, conflict and effort documentation. However, approaches specifically recognizing and creatively overcoming barriers to meaningful authorship have received little attention.

2. We have developed an inclusive authorship approach arising from 15 years of experience coordinating the publication of over 100 papers arising from a long-term, international collaboration of hundreds of scientists.

3. This method of sharing a paper initially as a storyboard with clear expectations, assignments and deadlines fosters communication and creates unambiguous opportunities for all authors to contribute intellectually. By documenting contributions through this multi-step process, this approach ensures meaningful engagement by each author listed on a publication.

4. The perception that co-authors on large authorship publications have not meaningfully contributed underlies widespread institutional bias against multi-authored papers, disincentivizing large collaborations despite their widely recognized value for advancing knowledge. Our approach identifies and overcomes key barriers to meaningful contributions, protecting the value of authorship even on massively multi-authored publications.

KEYWORDS
authorship accountability, authorship transparency, distributed experiment, hyperauthorship, inclusive authorship, international collaboration, Nutrient Network (NutNet), team science

1 | INTRODUCTION

The authors on every collaborative publication have a shared goal: the lead author wants to ensure meaningful contributions from all co-authors, and the co-authors want to make meaningful individual contributions that improve the paper. Identifying and assigning tasks is relatively easy when there are few authors. In a small collaborative group, there often are clear roles at the outset (conceived project,

led experiments, led analyses, etc.), and individual contributions are relatively easy to track. But many scientific disciplines, ecology included, are increasingly collaborative, and the number of co-authors on papers has substantially increased through time (Duffy, 2017; Logan, 2016; Nogrady, 2023). Collaborations involving dozens of contributors (or more) are now widespread, in large part because of increasing recognition that diverse groups (e.g. intellectually, culturally, geographically) can more effectively tackle complex problems (Hong & Page, 2004; Muraina & Jimoh, 2022). Large collaborations also can create synergistic opportunities for new questions to emerge, facilitating methodologically and analytically intensive research efforts. In many cases, this work can span scales impossible for small or localized groups. Together, these attributes can support new ways to sample Earth's environments, generating unprecedented insights about the complexities and context dependencies of a changing world that would not otherwise be possible (Borer et al., 2014).

Appropriate attribution of contributions is essential in any collaboration (Brand et al., 2015; Cooke et al., 2021), and a key part of authorship involves providing intellectual input that shapes an individual publication. Because communication of research through writing is as integral to the scientific process as hypotheses, theories and replication, publications are often at the core of assessing individual contributions to a field. Thus, it is critical for a discipline to retain authorship as a meaningful indication of contributions, and not to dilute it by including as authors those who have not shaped the work (e.g. honorary authors or authors who have solely copy edited a final draft; Kumar, 2018; McNutt et al., 2018; Weltzin et al., 2006). In addition, the intellectual

contributions from many perspectives are part of what creates synergistic, high impact scientific advances from teams of scientists (Larivière et al., 2015; Wuchty et al., 2007), so inclusion throughout the creative process, that underlies authorship and attribution, is an important part of these advances. However, as the number of co-authors increases, the barriers to contribution at the development and writing phase of a project also increase. These barriers can be particularly limiting for new collaborators, students, early career faculty, or researchers from countries with limited institutional support. Thus, scientists in increasingly collaborative disciplines need an approach that meets simultaneous needs. First, authorship barriers must be removed to ensure that each potential author can participate, such that authorship on papers stemming from large collaborations remains indicative of meaningful individual contributions. Second, lead authors need an approach that simultaneously allows them to efficiently complete the work and strengthen it by receiving and including input from diverse co-authors.

As leaders and the authorship committee of a long-term, large-scale collaborative ecological experiment, the Nutrient Network (NutNet, www.nutnet.org, Box 1), we spend a lot of time thinking about authorship, including barriers to authorship and retaining authorship meaning. The NutNet project is currently being replicated at more than 170 sites in nearly 30 countries. Hundreds of scientists spanning career stages, continents and scientific cultures have joined this collaboration. Each scientist contributes by installing and annually sampling a site 'node' in this long-term experiment and collecting new data from the site(s) they maintain. The experimental design (Borer et al., 2014) and new insights (>100 publications summarized, in part, in Borer et al., 2017; Borer &

BOX 1 The Nutrient Network

The International Nutrient Network (NutNet) collaboration, begun in 2007, is an experiment being replicated by scientists at more than 170 sites spanning six continents and nearly 30 countries. Sampling methods and experimental treatments (nutrient fertilization and herbivore fencing) are replicated identically across the network, generating unprecedented insights into the individual and joint impacts of ongoing global changes under a globally relevant range of background conditions. To date, this global, experimental collaboration has led to more than 120 publications documenting new insights into Earth's grassland diversity and ecological functioning. All project data are quality checked and curated in a single, central database, and data are published when they are first used in a paper (https://nutnet.org/datadois). Most of these publications include (several) dozens of co-authors.

Authorship in NutNet. The network has clear authorship guidelines (https://nutnet.org/authorship; see S1: Authorship Guidelines), and every network paper is expected to include a published rubric of contributions by each author. This published record provides important internal and external transparency about individual contributions. Authorship requires meaningful contributions by each author in a minimum of two categories of the rubric. While the project's published data (https://nutnet.org/datadois) can be used without restrictions, any interested scientist can propose and lead a new paper using project data that have not yet been published, if they agree to comply with the NutNet authorship expectations. For papers using unpublished data, data contribution alone is not sufficient for authorship. However, all data contributors are alerted to the nascent paper and invited to 'opt in,' if they have interest, expertise and willingness to contribute to its intellectual development in at least one other meaningful category, beyond experimental maintenance and data generation.

Stevens, 2022) from this highly productive collaboration are described elsewhere. This collaboration also has created unprecedented experimental infrastructure and data in parallel with a global scientific network representing an incredible diversity of perspectives, knowledge and expertise. Overcoming challenges of meaningful authorship to maximize the benefits of the diversity of thought represented within this collaborative group has been a process of learning and adaptively shifting our paper writing approach. Many collaborative groups within and beyond our discipline have adopted our authorship guidelines (e.g. Cooke et al., 2021; DIPnet; LEMoN-India; ORPHEE; Smith et al., 2015; SoDaH; Terra-REF). While these guidelines establish an explicit set of rules for expectations, engagement and inclusion (Supporting Information, S1: NutNet Authorship Guidelines), they do not clarify the process of inclusive paper creation that we have developed.

Here, we describe an approach to collaborative authorship that we have developed for large authorship papers to meet the goals of both the lead author and those wanting to contribute as co-authors. This process captures practices that often are an implicit part of paper writing with smaller groups. However, with this approach, we intentionally draw out the creativity, knowledge breadth and collective effort of a large and diverse co-author group (Box 2)—strengths that can simultaneously increase the depth of a contribution and increasingly risk being lost as the author line of a paper grows. To lay the foundation for our approach, we outline a range of important contributions that lead authors may want and co-authors can provide, then reflect on barriers to co-authors making those contributions. We follow this by outlining a multi-stage approach we have developed to overcome engagement barriers and maximize intellectual contributions from all co-authors.

2 | CONTRIBUTION NEEDS AND BARRIERS

There is a substantial literature considering categories of meaningful, authorship-worthy contributions (e.g. McNutt et al., 2018; Weltzin et al., 2006) and many journals now explicitly list these (e.g. idea generation or project design, data collection, data analysis, writing/editing). We do not repeat those points here. Instead, we highlight more specific challenges and solutions from our experience (Box 1), where a richness of co-authors can substantially improves a manuscript and, in some cases, increase efficiency in its production and submission.

2.1 | Areas of meaningful individual contribution that increase the impact of large authorship papers

The conceptualization and writing of a large-authorship publication can lead to a stronger, more impactful product through a range of meaningful contributions that draw on the strengths of a large, diverse team. These range from improving a publication's logic and generality, clarity of communication and even easing the logistical burden that comes as part of working with a large, diverse group. We break these into five broad (non-mutually exclusive) categories.

1. *Intellectual breadth and linkages to new areas.* Co-authors have different expertise, including knowledge of the literature and diverse analytical approaches, so their contributions can enhance the depth and breadth of a paper through linkages to additional lineages of literature, theory, analysis and thought. Co-authors also may have expert knowledge in a range of different ecosystems and geographical regions of the planet, which can increase the general relevance of the work. This kind of synthetic intellectual contribution, often in the introduction or discussion, can significantly increase the impact of a multi-authored paper by explicitly linking a wide range of concepts and subdisciplines.

2. *Clarity of analytical logic and accuracy.* Valuable contributions of co-authors include thinking deeply about the choice of analyses, checking the analytical code (e.g. R or SAS code) that generated the results and providing an independent check of the internal reproducibility of the results by writing new code to recreate the core analyses. Engaging co-authors with diverse expertise in analytical techniques can strengthen analyses and interpretation.

3. *Clarity of logic in the text.* Co-authors read the text from different viewpoints, and more eyes means more perspectives. This can reveal areas of weak logic or phrasing that seemed reasonable and clear to the lead author but are confusing to one or more readers. Co-authors who do not speak English as a first language can provide an incredibly valuable perspective for improving the clarity of presentation.

4. *Clarity of visual presentation.* Related to clarity of logic, co-authors can provide important perspectives on the effectiveness of figures, tables and other Supporting Information to highlight the core results of the paper. What is clear to some may generate confusion for others, so this contribution can significantly improve clarity, outcomes and take-home messages. In some cases, co-authors can take on the task of making or remaking figures and tables.

5. *Assistance with housekeeping.* Co-authors can take on many additional 'housekeeping' tasks that, while unlikely to be authorship-worthy on their own, free the lead author to shape the text and move a paper forward more efficiently. For example, making figures and assembling and formatting tables can take hours to days of effort, tasks that often can be done by co-authors. For papers with many dozens of co-authors, even entering all co-author names, ORCIDs, and work addresses into a journal's online submission system can take many hours per submission, and it may be possible for a co-author to help with this task.

2.2 | Barriers to co-author contribution

While a sizable literature focuses on the problem of unearned authorship (e.g. Brand et al., 2015; Chawla, 2023; Kumar, 2018; McNutt et al., 2018; Weltzin et al., 2006), this literature rarely considers barriers to contribution. These barriers are not a problem solely resting on those who wish to be co-authors, but one that emerges, in part, from the process of paper development and leadership. The solution

BOX 2   A case study of authorship in the Nutrient Network

Data being generated by scientists across the Nutrient Network collaboration (Box 1) have been used in well over 100 publications, to date. Here, we characterize authorship patterns for the 68 multi-authored papers that have focused solely on new, collaborative analyses of data collected across multiple sites in this experiment. For this assessment, we exclude publications that did not require collaboration across the large group of scientists generating data, for example, single site studies within the network (predominantly graduate student publications), meta-analyses using network data, synthetic reviews of network results and publications reanalysing published Nutrient Network datasets.
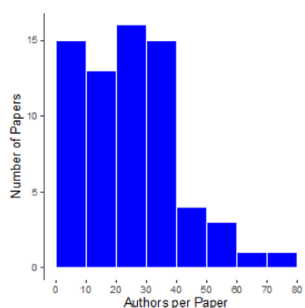

Number of authors per paper for this set of network publications ranges up to 73 authors with a median of 22.5 authors per paper. As the collaboration has grown through time, the average number of authors per paper also has grown. While publications with fewer authors (<10) tend to be graduate student or postdoc projects with additional sampling performed at a few sites, early career authors also have led many of the highest author number (>40 authors) papers.

Career stage of the lead author spans the full range from graduate students to full professors. Across all lead authors, 63% were pre-tenure at the time they led the paper, and more than half of the lead authors were either students or postdocs.
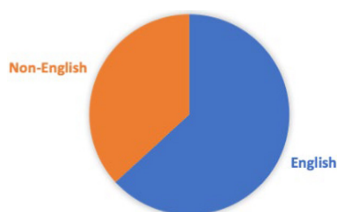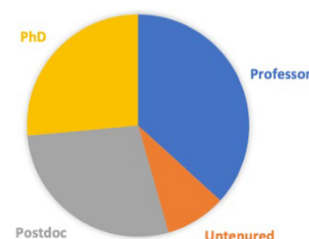
Mother tongue/first language of the lead author includes 9 languages with 37% led by authors who do not speak English as their first language. Across these publications, lead authors hail from all six continents.

Number of countries represented by authors on individual papers ranges up to 17 with a median of individuals from 8 countries contributing as authors to each publication. The number of countries represented by authors on individual publications has increased with time as the network has grown and expanded into new regions.
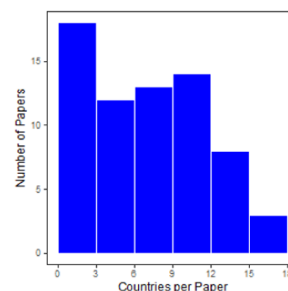
we have pioneered rests on all authors: the lead author must provide clear opportunities for meaningful engagement, and co-authors must take these opportunities to engage intellectually and provide meaningful contributions. Clear communication by all authors throughout the process is essential for efficiency and to avoid frustration and misunderstanding. In our observation, the barriers in this process fall into a few categories, arising from many sources: when to share with

co-authors, how to balance diversity of input against efficiency in moving to publication and openness to feedback.

1. *The conundrum of when to share.* Many of us feel intimidated at the prospect of sharing incompletely formed ideas, and this apprehension likely increases with the number of co-authors. Yet, the early stages of a manuscript represent a point when new

ideas, alternative perspectives and feedback are likely to make a large, positive difference for the final product. Co-authors want to be engaged with the process and will provide feedback when asked. Without clear communication of the type of input the lead author wants (e.g. a non-specific request such as 'Please read and provide feedback'), sharing work early can produce unconstrained responses that are potentially unusable by the lead author, generating frustration for both lead and co-authors. Yet, if the first draft shared with co-authors is close to a fully formed manuscript, this can send the message that only limited contributions are desired. Even if a co-author has a conceptual or structural concern, it may not be raised when a manuscript looks complete, setting up a high likelihood of frustration for both lead and co-authors. Potential co-authors may feel hesitant to sign on as co-authors, because they cannot see a way to meaningfully contribute to idea generation, writing or analyses. Even if co-authors do sign on because of interest and a desire to contribute, if they have not been involved in the process at an earlier stage, co-authors may perceive little room for intellectual contribution, and thus resort to comma editing or other minimal changes. When the conundrum of when to share is solved by the lead author sending out a nearly complete manuscript, this sets up a situation that reduces the ability for co-authors to contribute meaningfully.

2. *Efficiency* vs *diversity of perspectives*. Getting input focused on comma placement is frustrating, but, on the other hand, sorting through and aligning diverse and unconstrained ideas from dozens of co-authors can be extremely time consuming. Again, co-authors will try to provide useful thoughts, but without clear guidance these may not be usable by the lead author, leaving contributors and lead authors feeling like they have wasted valuable time. Even with focused feedback, co-author suggestions may conflict, leaving the lead author with the difficult and time-consuming task of reconciling or choosing among suggested changes.

3. *Maintaining openness to feedback*. The benefits of diverse author teams can be lost if co-authors feel unable to raise concerns or alternative perspectives about a paper to a lead author. Concerns about whether or how to provide feedback that may require substantial rethinking or rewriting can represent a significant barrier to important co-author contributions. This barrier is exacerbated when a first shared draft is in the form of a complete manuscript. Providing critical input can be a particularly large barrier for co-authors earlier in their career, or non-native English speakers. While each co-author should approach even a complete draft with the critical eye of a journal referee, any indication (explicit or implicit) of lack of openness to feedback can diminish this important contribution.

3 | APPROACH TO MEET NEEDS AND OVERCOME BARRIERS

Writing a paper that encourages meaningful input from dozens of co-authors (or more) requires clarity of communication and willingness by the lead author to receive suggestions and modify a paper in response to feedback. Openness to modification does not mean ceding intellectual leadership. Rather, it is an opportunity to reap the benefits of many co-authors in terms of data, analysis and critical assessment. Guiding the feedback received at each step to maximize helpful input can be an art, but the process we lay out here (Figure 1) has been implemented by graduate student, postdoc and faculty lead authors in NutNet (Box 2), resulting in positive feelings about the process (Box 3) and resulting in high impact publications. Breakdowns in communication about, for example, what the lead author wants from co-authors or modifications made (or not made) are among the greatest sources of frustration on multi-authored papers, and this process is developed to emphasize what, when and how to efficiently communicate.

3.1 | Step 0. Conceiving the idea and laying the groundwork

3.1.1 | Paper proposal

Every paper begins with an idea, and this needs to be developed sufficiently to communicate the concept and novelty to collaborators. Because hundreds of scientists are involved in NutNet (Box 1), we require the submission of paper proposals to ensure that analyses are not overlapping across papers. The submission of a paper proposal includes abstract text describing the concept and goals of the paper, a list of network datasets to be used as predictor and response variables, and a statement of how the paper is novel relative to all other network papers in that conceptual area, to date. Proposals are reviewed by a small authorship committee to avoid unintentional overlap of analyses or effort among ongoing papers and to connect and foster communication between subgroups within the collaboration that are tackling similar types of questions. From the point it is uploaded into our project's paper database, each proposed paper is visible to anyone with sign-in access.

3.1.2 | Idea development

The process of developing a paper differs for every author. The lead author of this piece writes to think, so considerable text is often written before she feels the ideas are ready to share. Others think by spending time analysing data and making figures. Regardless of the process for the lead author or core group, what is shared with the network is a critical part of the success of this method.

3.2 | Step 1. First communication with potential co-authors (overcoming all three barrier types: when to share, efficiency vs diversity and openness to feedback)

The initial communication about the paper and opportunity to opt into a paper as a co-author goes out to the entire network of, for example,

FIGURE 1 Overview of the approach and contribution rubric to provide opportunities for—and documentation of—co-author contributions while maximizing communication and efficiency throughout the manuscript production process.

Step 0: Conceive idea

- Paper proposal
  - Communicate with others leading related analyses of shared dataset
- Idea development, initial analyses, & storyboard creation

Step 1: First communication with network

- Paper concept as storyboard
- List of sites & data contributors
- Reading assignment
- Manuscript-related thought assignment
- Online signup form (all authors must contribute to two or more categories)

Contact information				Type of contribution				
Name	Affiliation	Email	ORCID	Question/ Conceptualization	Analyzed data	Contributed to data analysis	Wrote paper	Contributed to writing

- Deadline to sign up & submit assignments

Steps 2 – n: Develop, analyze, and write

- Summary of input & changes/decisions made
- New manuscript-related assignment & deadline
  - When text editing is sought, the document can be provided as a .pdf and edits collected in an online spreadsheet

Coauthor name	Manuscript line #	Suggestion/comment/edit

data contributors. Generally, those who have maintained the experimental infrastructure and contributed data that are being used for a specific analysis have already provided one meaningful contribution and are the most likely to opt in, but all network contributors are notified about each paper.

3.2.1 | First contact

'Opt-in' email contents. The first contact is intended to inform the entire network of a paper that is moving forward and to identify those in the network who would like to contribute intellectually (Figure 1). To this end, a recommended opt in email includes:

1. **The concept as a storyboard**
   a. **Abstract and outline of the framing** (question/hypothesis, approach, in abstract form), and often bullet points or an outline of the introduction paragraphs to help illustrate the concepts and linkages. Provide enough that potential co-authors can see where the paper is being placed intellectually and what the advance will be, but not more.

BOX 3   Reflections from lead authors at contrasting career stages

Reflections on this process from a postdoc lead author:

Even though I have experience with lots of co-authors—of course we are all still learning on this—I still think I let myself get a little too caught up with trying to satisfy all the co-authors. I think at some point I needed to recognize that it's not always possible. I gave people a job and they are doing it! Ha. However, I think having so many [internal] 'reviewers' can make for a much smoother 'in review' period to the journal itself. In hindsight, I wish I had opened things up to feedback sooner, as your advice clearly indicates. I think I struggled to find the confidence in my approach and results before it felt 'perfect' because I was sending it to a crowd full of folks I respect so much, and a lot of whom I hadn't interacted with much yet. I suppose that's intimidating to early career folk. I think if I had circulated things sooner, I could have done a better job at 'directing folks' to give the feedback that's most useful. It might have made the feedback process less overwhelming. A mixture of self and group reflection there.

Reflections on this process from a full professor lead author:

I did NOT want to have people editing my commas; I wanted to get targeted thoughts on the paper and specific feedback. I wanted to give smart but busy people ways to engage effectively—contributing meaningfully without leaving them space to give me edits that were just annoying and a waste of everyone's time. I wrote and shaped the paper myself. For my initial draft concept, I was very intentional about what I did and did not include. I wanted to just provide a teaser of ideas and initial results, not a complete paper. I actually had quite a bit more (rough) text written, but I did not share my text at this stage because the text wasn't what I wanted feedback on at that stage; I ended up massively revising it based on the feedback that I solicited during each stage of the process.

I saw engagement on assignments that made me feel good about each co-author's contributions, even when I didn't end up using some of the ideas. Only after two rounds of feedback and work, did I share a full manuscript and ask for line edits & comments on it. I solicited things that I needed—a self-identified detail-oriented team formatted all the tables, for example, and another co-author checked all of the analysis and figure code. People gave me very positive feedback on the process because they felt that there were ways to contribute meaningfully. For me, I ended up getting thoughts on what I wanted and a lot less of the annoying stuff that I didn't want. There also were a few people who didn't end up contributing to the early assignments, and by keeping track of that, I was able to (a) provide extra assignments at the end (3 people) or (b) remove them as co-authors (2 people).

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b. **Figures and tables** to illustrate the main results. These are intended to provide a thumbnail sketch of the main predictor and response variables.

2. **List of all sites** with data being used in the current analyses (and other network-specific metadata such as site PI; also see Supporting Information, S2: Site table).

3. **Reading assignment**. One or two key publications that serve as the intellectual basis or are otherwise critical for all contributors to read and understand.

4. **Manuscript-related assignment with a clear deadline**. This is an important first opportunity for co-authors to engage and provide intellectual contributions. The lead author should communicate a clear and direct request that draws on the knowledge and expertise of the co-authors and will help the lead author. Examples include asking co-authors to propose alternative hypotheses for an observed pattern, provide citations and describe links to other relevant lineages of literature, provide ideas for complementary or alternative statistical analyses, or to reflect on ideas or perspectives that are missing from the assigned reading. Alternatively, if there are confusing results or technical issues that make data hard to interpret (e.g. issues of correlation vs. causation), consideration of these and a brief response can be posed as an initial co-author assignment. For the lead author, major logical fallacies or problematic statistics that invalidate a key result are much better

discovered at this stage than after the weeks or months it may take to write a complete draft.

5. Link to a **shared online spreadsheet with the authorship rubric**. Those signing up to contribute to the paper add their contact information and check the boxes of the authorship rubric (Figure 1, Supporting Information, S3: Author contribution table) in which they intend to contribute. Ultimately, a final version of this spreadsheet is published as an online supplement detailing each author's personal contribution, for internal and external transparency of contributions (Sauermann & Haeussler, 2017).

6. A **deadline** for signing up and providing the first contribution.

3.3 | Steps 2-n. Subsequent communication with co-authors (overcoming two barrier types: efficiency vs diversity and openness to feedback)

After collaborators indicate their intention to contribute to a paper, subsequent emails are generally sent only to those who have agreed to contribute as a co-author on a specific manuscript. The goal of each contact at this point is to provide effective communication with—and solicit specific, key feedback from—a large group of busy co-authors. Generally, 2–3 whole-group emails are sent by the lead author

through the development of a paper (Figure 1). Standard emails during the paper development include:

1. A **summary of input and changes made** in response to co-author feedback. Because this process involves the lead author considering many, sometimes conflicting, perspectives, summarizing co-author responses to each assignment and changes made is a critical part of ensuring that co-authors feel their time was valued, even when specific suggestions were not followed. A point-by-point response is not necessary (nor is it efficient for anyone), but a short description of key changes or how conflicting suggestions were resolved is helpful for everyone. While this process can feel onerous given many suggestions, it serves to improve the work—by the time the final paper is submitted, it has already been critically peer assessed by many readers.

2. A new, **targeted assignment and deadline**. Assignments at each step depend on the needs of the lead author, but generally follow a similar recipe that includes sharing only the information necessary for co-authors to complete their assigned tasks by clearly soliciting the key conceptual feedback the lead author seeks. For example,

   a. a first contact to the authorship group may include a summary of the first round of co-author feedback, and text of a draft abstract, introduction, figures and tables with very brief text describing key results. This would then be paired with an assignment and reasonable deadline. An assignment could be, for example, to provide thoughts on the key points to highlight in a discussion, key papers to cite that the results build upon and journal recommendation along with an explanation for why the paper is a good fit for the proposed journal.

   b. a second contact may include a draft manuscript with explicit instructions to read but not text-edit; rather, to write an exciting title, statement of the scientific advance or societal relevance of the work, and assessment of whether the key hypotheses and figures tell the story well.

   c. a third contact may request reviewer suggestions, assistance with table formatting, creating the author and affiliation list (which is a large task for papers with dozens of authors, some with multiple affiliations), and, finally, editing of the manuscript.

3.3.1 | Receiving co-author edits to the text of a manuscript

The method of sharing and co-editing may evolve with the paper. We have found that sharing documents for editing (e.g. Microsoft Word) leads to forked versions or deep strata of tracked changes and comments, leaving lead authors frustrated and potentially important comments missed. One effective strategy widely employed in NutNet is sharing the manuscript as a .pdf file and requesting feedback in a shared online spreadsheet (e.g. Google Sheets) with columns for co-author name, line number(s) and comments (Figure 1). All comments can then be sorted by line number for efficient use by the lead author.

4 | CONCLUSIONS

Because of their unique value, large collaborative efforts are being increasingly employed as a tool in the sciences from ecology to medicine, psychology, genomics and particle physics (Borer et al., 2014; Cahn, 1992; Frank et al., 2020; Kiparoglou et al., 2021; Tanjo et al., 2021). The scale and depth of new knowledge arising from these large efforts would simply be impossible to achieve without the contributions of the entire team; every author subtracted creates a loss of data, perspective and spatial extent. However, large collaborations raise a critical point of how to retain authorship as a meaningful indication of contributions (McNutt et al., 2018). Effectively leading and co-authoring a paper arising from a large collaboration can engage diverse authors and retain authorship meaning but requires a somewhat different mindset (and skillset) than is typically employed when writing alone or with a small co-author group. The approach we describe ensures that every person listed as an author has intellectually engaged in the paper, it provides a more satisfying process for those involved (both lead- and co-), and it protects the meaning of authorship, even in an era of large scientific collaborative groups.

Despite the recognized need and benefits to science of large collaborations, there is, nonetheless, a pervasive perception that authorship contributions by individuals in large collaborations are less meaningful. Unfortunately, in cases such as honorary authorships (Kumar, 2018) or when the writing process provides limited opportunities for meaningful co-author contribution, this may be true. Because many professional benefits arise from authorship on publications (Rawat & Meena, 2014), retaining internal and external accountability for each author on all publications—but especially large collaborative ones—is critical for individuals and the profession. The process and mechanisms for transparency we describe here go a long way to assigning as authors those who have contributed meaningfully (e.g. data provision and intellectual contributions) to a publication. Although we have focused on publications arising from a distributed experiment, our approach also is appropriate for meta-analyses, in which all potential coauthors are contributing to data extraction. It also could be relatively easily modified for a multi-authored review or consensus paper (e.g. those with no data component). The efficacy of this approach is not limited to large groups; it also has provided an efficient, streamlined process for smaller co-author groups (e.g. graduate student or lab group publications). By following a process, regardless of group size, that creates opportunities for collaborators to meaningfully contribute to the intellectual development of a publication, and by transparently documenting these contributions (e.g. in a published supplement with each paper, Sauermann & Haeussler, 2017), we will make substantial progress in our discipline towards accountability and

overcoming the perception that the significance of co-author contributions is inversely related to number of authors.

If this type of creative approach is widely adopted, it will provide transparency and a strong counterpoint to those who undervalue—or write off—contributions by individuals in large collaborations. A meaningful example is the ranking by Clarivate, the source of the ISI Highly Cited Researcher rankings that serve as a key indicator for the Academic Ranking of World Universities (according to Clarivate, Highly Cited Researchers represents 20% of an institution's score for ranking). In its 2022 methods for determining Highly Cited Researcher rankings, Clarivate states that they no longer include papers with >30 authors when calculating this metric ('*To award credit to a single author among many tens or hundreds listed on a paper strains reason. Therefore, any highly cited paper with more than 30 authors or explicit group authorship was eliminated from our analysis.*'; Clarivate, 2022). While this reflects the oft-raised concerns about whether authorship indicates meaningful contributions (e.g. Brand et al., 2015; McNutt et al., 2018), particularly on large collaborative authorship lines (Nogrady, 2023), Clarivate's exclusion is a narrow, short-sighted decision that ignores mechanisms in place to ensure meaningful authorship. It also is concerning because this exclusion has the potential to reduce willingness of scientists to contribute to large collaborations that are widely acknowledged for their ability to generate unprecedented insights. By providing opportunities and transparency about contributions, our approach promises to overcome these concerns, clearly stating the contributions of each author for accountability to and recognition by the scientific community.

While helpful for all co-authors, the approach we describe here has important benefits for engaging and retaining early career scientists, female scientists and scientists from underrepresented groups and regions. By creating clear opportunities for intellectual engagement, this method goes a long way to overcoming the 'imposter syndrome' that disproportionately impacts women, minorities and early career academics (Muradoglu et al., 2022). While mentoring and co-authoring can be critical for increasing the gender, racial and cultural diversity of academic disciplines (Zambrana et al., 2015), co-authorship on publications can, at the same time, cause significant professional disadvantage for women (Sarsons et al., 2021) and scientists from underrepresented groups (Rubin & O'Connor, 2018). The transparent attribution of contributions in the form of a rubric published with each paper can—and should—be used as part of any assessment of an individual's intellectual contributions to a discipline, a key metric used for decisions about academic tenure, promotion and awards (Sauermann & Haeussler, 2017). This practice will better align the benefits of collaboration with the professional assessment and career advancement of individual researchers (Soares, 2015).

One of the key reasons many engage in large collaborations is the opportunity to reduce isolation and engage as part of an exciting, intellectually creative scientific group (Beaver, 2001; Green & Johnson, 2015). Yet, this important benefit from participation in a large collaboration can be lost for co-authors during the manuscript generation process without clear communication, opportunities for engagement and thoughtful guidance by the lead author. The process we outline here, which intentionally steps away from paper writing 'business as usual,' creates new ways to engage for both the lead and co-authors. While some in our network have expressed concerns about engaging many dozens of co-authors, particularly early in the process, while still retaining intellectual leadership of the process and the product, the approach we describe here has successfully provided this for lead authors across career stages (Box 3). A creative process, such as starting with, for example, a storyboard and request for a priori predictions engages thought contributions (Cohen et al., 1999), removes the possibility for only the provision of comma editing (i.e. non-author worthy contributions), and is more likely to meet the writing needs of a lead author and provide accessible engagement in the process for co-authors. By meeting the needs of both lead and co-authors while providing opportunities to contribute, it also increases the impact of each paper, benefitting scientific progress (Larivière et al., 2015; Wuchty et al., 2007). In a process where authors do not know how to contribute meaningfully or are not given clear opportunities to do so, the documented benefits of many minds can be lost—along with the meaning of authorship. However, a creative process, as we outline here, with awareness of the motivations and needs of all authors can foster the joint benefits to the scientists and the science.

AUTHOR CONTRIBUTIONS

All authors contributed to the development of the NutNet authorship process; Elizabeth T. Borer was the first to design and beta-test this approach for a NutNet publication. Elizabeth T. Borer led the writing of this manuscript, and all authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

PEER REVIEW

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This paper does not include data analysis.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Supporting Information S1. NutNet authorship guidelines (v. 2022).
Supporting Information S2. Site table: formally acknowledging data contributors, even those who are not authors.
Supporting Information S3. Author contribution table categories.