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Strategies for effective collaborative manuscript development in interdisciplinary science teams

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Abstract. Science is increasingly being conducted in large, interdisciplinary teams. As team size increases, challenges can arise during manuscript development, where achieving one team goal (e.g., inclusivity) may be in direct conflict with other goals (e.g., efficiency). Here, we present strategies for effective collaborative manuscript development that draw from our experiences in an interdisciplinary science team writing collaborative manuscripts for six years. These strategies are rooted in six guiding principles that were important to our team: to create a transparent, inclusive, and accountable research team that promotes and protects team members who have less power to influence decision-making while fostering creativity and productivity. To help alleviate the conflicts that can arise in collaborative manuscript development, we present the following strategies: understand your team composition, create an authorship policy and discuss authorship early and often, openly announce manuscript ideas, identify and communicate the type of manuscript and lead author management style, and document and describe authorship contributions. These strategies can help reduce the probability of group conflict, uphold individual and team values, achieve fair authorship practices, and increase science productivity.

Key words: coauthorship; collaboration; manuscript development; team diversity; team science.

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Introduction

Science is increasingly conducted in collaborative and often interdisciplinary team settings, in order to solve the large-scale and complex problems of our time (Wuchty et al. 2007). Publishing research articles in peer-reviewed journals is the primary mechanism by which these research teams disseminate findings to the broader scientific community, as well as the primary currency for promotion and recognition of individuals. Publishing with science teams has distinct benefits for both the researcher and science; collaborative manuscripts are more likely to be accepted in scientific journals and have higher citation rates once published, presumably reflecting higher quality and impact (Fox et al. 2016, Barlow et al. 2018). Diverse collaborative teams are better problem solvers and produce higher quality science products (Hong and Page 2004, Campbell et al. 2013). Managing and determining coauthorship is therefore a critical component of successful collaboration. However, coauthorship in science teams is difficult, in part, because a large number of participants and distributed tasks can make accountability, intellectual contribution, and obtaining input from all authors difficult and time-consuming (DeHart 2017). Further, because many science teams have both early and later career scientists, there will almost always be inherent power dynamics that can result in conflict if less influential team members, or those without the power to influence team direction, have limited voice in decision-making and do not receive fair credit for their work on publications (Elliott et al. 2017). Finally, as team size and diversity increase, authorship challenges may increase because there may be individuals on the team who do not have a history of working together and who have different backgrounds, disciplines, perspectives, and values related to science in general, and coauthorship in particular (Birnholtz 2006, Eigenbrode et al. 2007, Stokols et al. 2008, Elliott 2017).

Given the importance of coauthorship in collaborative science settings, there has been discussion within disciplines, research groups, and professional societies about what contributions warrant coauthorship (Birnholtz 2006, Weltzin et al. 2006, Duke and Porter 2013) and new approaches to document coauthorship (Cheruvelil et al. 2014, Chawla 2015). For example, most researchers agree that coauthors need to be held accountable for, contribute intellectually, and approve the final manuscript, which is reflected in many existing recommendations in ecology (Weltzin et al. 2006, Duke and Porter 2013). However, there is recent evidence that coauthorship practices are not as effective as they could be. For example, a recent study of current authorship practices in ecology suggests that many authors may not be meeting minimum guidelines established by some professional societies (Logan et al. 2017). Additionally, some teams are overly inclusive in their authorship practices in order to prevent conflict within the team (Elliott et al. 2017). This form of honorary authorship disproportionately negatively affects the early-career scientists who perform much of the work but have diminished rewards due to the long list of authors (Elliott et al. 2017). Therefore, more explicit guidelines are needed to help teams put authorship policies and recommendations into practice.

Ultimately, these authorship challenges can decrease scientific productivity and individual satisfaction. We believe that explicit discussions of strategies and underlying principles of collaborative research early during manuscript development will help reduce the probability of group conflict, uphold individual and team values, achieve fair authorship practices, and increase science productivity. Therefore, we present strategies for effective collaborative manuscript development that were grounded in our team's guiding principles. Our experiences are drawn from participating in an interdisciplinary science team of approximately ~15 people from the fields of ecology, computer science, geographic information science, and ecoinformatics working collaboratively for six years. We present these practices and guiding principles as an example for other teams to draw on to create practices of their own. These strategies and principles can be a starting point to accommodate a wide range of scientific disciplines, team structures, leadership styles, and expectations that exists both within and across teams.

Guiding Principles for Collaborative Manuscript Development

The following guiding principles embody the values we wanted to uphold in collaborative manuscript development. Values in science are not always explicitly stated, but are, in fact, essential and unavoidable in many aspects of research (Elliott 2017). Our guiding principles were to create a transparent, inclusive, and accountable research team that promotes and protects less influential team members while fostering creativity and productivity. We are not suggesting that all teams will select these same principles, but some of them are likely to apply to many research teams. We found that although any individual principle was not particularly difficult to uphold, it was challenging to uphold the full complement of principles because striving for one principle sometimes resulted in sacrificing others. Below, we describe each of the principles in the context of collaborative manuscript development and then describe the strategies that we practiced to help balance these important, and commonly held, values.

Transparency

We strive to ensure that all stages of the publication process are clearly documented and communicated. In large groups with distributed tasks, it can be difficult to document and communicate decisions among all group members. Strategies for ensuring transparency in manuscript development include communicating and documenting ideas, decisions, and actions throughout the lifespan of a manuscript from the inception of an idea to publication. Such documentation is important not only to prevent misunderstandings and conflict within the group, but also to record and recognize individual contributions. Transparent practices that accurately describe methods as well as individual contributions also align with open science goals to make research publicly accessible and reproducible.

Inclusion and fairness

We strive for inclusion and fairness across individuals, ideas, and expectations. Large collaborative groups that are composed of individuals from multiple disciplines, different career stages, and diverse backgrounds face the challenge of creating inclusive and fair environments for all individuals and contributions. Inclusivity and fairness can promote innovation by bringing ideas and approaches together from diverse individuals or across disciplines, which can result in high-impact science (Campbell et al. 2013, Nielsen et al. 2017) and increased creativity (McLeod et al. 1996, Leung et al. 2008). Strategies for promoting inclusion and fairness include maximizing the interpersonal skills and social sensitivity of team members through teamwork exercises, which are effectively done at the team level rather than for individual manuscripts (Cheruvelil et al. 2014).

Protection and promotion

We strive to protect, promote, and empower less influential members of research teams (i.e., students, early-career scientists, minorities, and other underrepresented groups). Hierarchy exists in scientific collaborations; there are very few teams in which all individuals are of equal power. Therefore, power differentials are a fundamental feature of scientific collaborations that need to be considered to ensure fair practices. One strategy to protect and promote team members who lack power to influence team decisions is to use alternate team structures (National Research Council 2015), such as those that are flat-structured (less hierarchical) in which major decision-making occurs among a larger group of individuals across career levels. Flat team structure can reduce power differences among members and the likelihood that power will be abused.

Accountability

We strive to ensure that contributors are responsible and accountable for their contributions to the manuscript content. A fundamental principle of coauthorship is that authors are accountable for the work. However, some manuscripts, such as multidisciplinary manuscripts that rely on specialized skills and expertise, require different distributions of accountability among team members, which has been referred to as "contributorship" instead of authorship by some (Rennie et al. 1997). For example, expecting a computer scientist to understand and be held accountable for the intricacies of ecological topics

such as nutrient cycling is unreasonable. Strategies to facilitate accountability and integrity among team members include drafting author contribution statements, transparency at all stages of manuscript development, and discussions of contributorship vs. accountability (Weltzin et al. 2006, McNutt et al. 2017).

Efficiency and productivity

We strive to promote productive and efficient manuscript development. There is a common perception that large, collaborative groups suffer from a loss of efficiency and productivity by getting mired in inefficient or ineffective group dynamics, debates, or inactions—a too many cooks in the kitchen problem. However, there are many practical strategies and skills in facilitation, communication, and leadership that scientists can learn and use to avoid these common problems and to make collaborative efforts efficient, productive, and highly creative (Kaner et al. 2014, Read et al. 2016). Efficiency and productivity are critical to foster and develop in every collaborative manuscript to ensure that research products are created and disseminated in a timely fashion, and to ensure that scientists who participate in team science are incentivized to do so.

Creativity

We strive to maximize both individual and group creativity and effective idea exchange. Discussions of how to foster creativity as a whole are lacking in science (Scheffer 2014), and when they do occur, strategies to foster group creativity are not always valued as much as those to foster individual creativity. And, group creativity may be sacrificed for other benefits (e.g., productivity), which presents a missed opportunity for collaborative research efforts because there is compelling evidence that group creativity can exceed the creativity of any individual within a team (Woolley et al. 2010) and that high-impact publications come from making connections across disciplines (Uzzi et al. 2013). Therefore, collaborative research efforts should foster both individual and group creativity to maximize novel and innovative science through the use of strategies that include time for both individual reflection and team brainstorming on research topics throughout the manuscript development process.

Six Strategies for Effective Collaborative Manuscript Development

The following strategies for manuscript development are grounded in the above guiding principles and involve practices that apply to all individual manuscripts being developed by any member of the research team (Fig. 1). After a research team has discussed and documented their own guiding principles, they can implement team- and manuscript-level practices that are designed to uphold and balance the guiding principles, including (1) describe and understand their team composition, and (2) create a team coauthorship policy (Fig. 1). Team members then apply the remaining strategies for each manuscript, including (3) announce manuscript ideas and solicit coauthors, (4) identify and communicate the manuscript type, (5) identify and communicate the authorship management strategy, and (6) determine authorship contribution and order. We have found that many of the practices in Fig. 1 are strongly related and can occur in any order and are interactive. Based on our experience, teams will be most successful at collaborative manuscript development when they engage early and often in these practices.

Understand the team composition

Teams differ in many fundamental ways that may influence the implementation of these strategies. Therefore, we suggest that the first practice is to identify what features your team has and what kind of challenges are most likely to inhibit your team from achieving your guiding principles. We describe important dimensions of team makeup and dynamics that greatly influence the practices of effective teams and discuss strategies to foster an authorship culture that prioritizes our guiding principles stated above.

New vs established members and teams.— Research has shown that adding new team members is very beneficial to team productivity (Whitfield 2008), and members of newly formed teams may bring with them research cultures from past collaborations and experiences. When new team members join existing teams, conflict can arise when there are unwritten, and often unspoken, practices that the new team members are not aware. Conflict can arise when team members are operating under a different set of

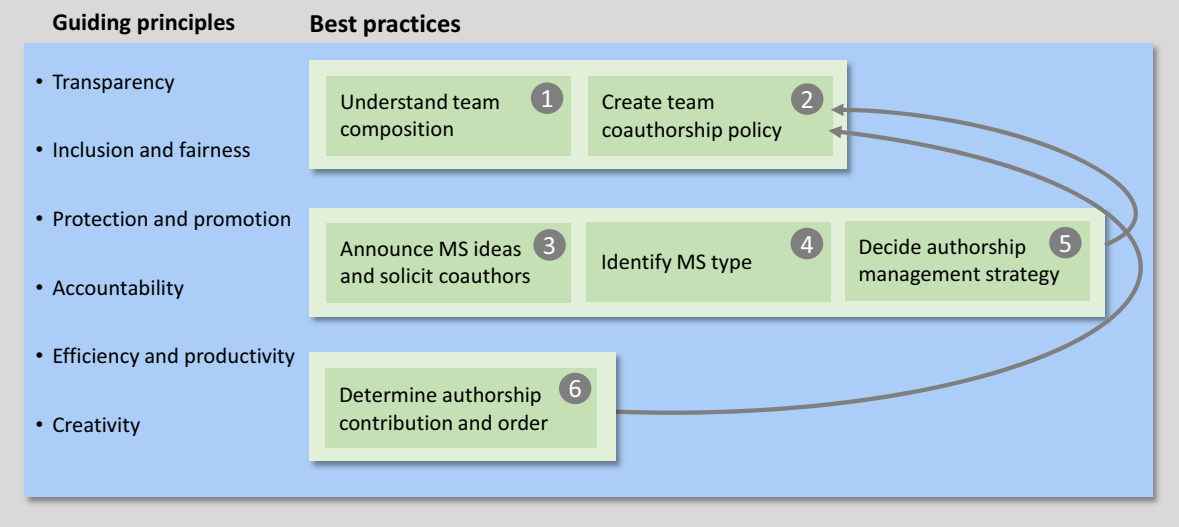

Fig. 1. A conceptual diagram that shows the strategies for effective collaborative manuscript (MS) development being firmly embedded within and balancing the guiding principles, and the relative order that the practices occur (numbers). Strategies that are on the same row are strongly related, can occur in any order, and are in fact iterative. All strategies should feed back into the team coauthorship policy for evaluation and reflection about whether the practices are fulfilling the guiding principles.

assumptions and norms. Written policies and frequent discussions of authorship can help to articulate group expectations and responsibilities, as well as give new members opportunities to shape team practices.

Teams with demographic diversity.—Large collaborative teams likely have diversity in several dimensions, including gender, race, career level, socio-economic background, expertise, training, country of origin, and language. People from underrepresented backgrounds can experience and contribute to group activities and interactions quite differently than those in the majority group (Woolley et al. 2010, Bear and Woolley 2011). Further, such individuals can have different perspectives related to collectivism vs. individualism and justice and fairness (Chiaburu and Lim 2008, Wang and Young 2013). Implicit, unarticulated practices and norms that may be in conflict with some of these perspectives or behaviors, can put some individuals at a disadvantage. Therefore, written policies and ongoing team discussions of practices and norms can place all team members on equal footing.

Multidisciplinary teams.—Teams that include scientists and practitioners with different disciplinary backgrounds, interests, and expertise can lead to research that can be published in more than one discipline. For example, a team of computer scientists and ecologists may publish novel computer science methods in a computer science journal and apply the method and also publish the results in an ecology journal. Cultures regarding publication norms and requirements may be different across disciplines (Eigenbrode et al. 2007, Morse et al. 2007). In computer science, for example, conference publications are the dominant publication form, and these papers have different manuscript submission steps and evaluation criteria compared to ecology journal articles. Having a written authorship policy that includes the breadth of contributions across disciplines can ease associated authorship conflicts.

Teams that did not self-select.—Sometimes, scientists find themselves as part of teams that others put together, or that were created for reasons that are not entirely aligned across all team members. Such teams can be challenging because members may hope for different outcomes from the team, and lack of common goals can limit cohesion and productivity (DeHart 2017). Because team members in these situations may not have the ability to establish and implement the practices that align with their guiding principles, it may take

more time and effort to implement some of the strategies described here.

Create a team coauthorship policy

Authorship guidelines have been developed by multiple societies (e.g., Ecological Society of America), journals (e.g., Proceedings of the National Academies of the Sciences), and individual laboratories and research groups to address the issue of coauthorship contributions. However, it is not always clear how they are implemented by individual research groups. For example, many guidelines attribute substantial contributions to merit coauthorship and list some general actions that are recognized contributions (e.g., analysis, writing). While the generality of these guidelines provides flexibility for research groups to meet their specific needs, it can lead to ambiguity in how policies should be applied. Here, we focus on how team authorship policies can be put into practice and use our team's policy as an example. We do not believe there is a single authorship policy (or practice) that will work for all teams because of the diversity that exists, both within and across teams, in scientific disciplines, team structures, leadership styles, and expectations. Therefore, we suggest that large collaborative research teams implement the following practices: (1) create and/or adapt existing authorship policies to meet their own needs, (2) include all team members in the policy-generation phase, (3) talk early and often about coauthorship policies (and practices), (4) implement the policy by revisiting the document and tracking contributions throughout the life of each manuscript, as well as at the level of the entire project, and (5) treat the policy as a living document that can be adapted to the changing needs of the team and/or project. Next, we expand on these suggestions.

Authorship policies are intended to reduce common uncertainties in the collaborative process (Atkinson et al. 2006) that can create conflict: What work is there to be done, who will do the work, and who will get credit for the work? Articulating the goals for creating an authorship policy can guide its creation. Is the policy in place to ensure all contributions are recognized? To determine author order? To rid your team of freeloading coauthors? For our team, the purpose for a written authorship policy was rooted in three of our guiding principles: We wanted to ensure that while appropriate credit was achieved, (1) coauthorship was determined through a transparent process across the diversity of projects and individuals; (2) all contributors were fairly and inclusively acknowledged with coauthorship, given the diverse ways in which individuals can contribute to manuscripts in a large interdisciplinary team; and (3) early-career scientists who made substantial contributions were protected and promoted. Lead-author papers are the primary currency of promotion in many science fields. In large team science settings, however, individuals spend ample time providing services to the greater good that do not necessarily translate to lead-author papers. In our data-intensive team, our authorship policy was written to protect early-career scientists who might contribute disproportionately to these tasks (e.g., writing metadata, serving as data janitors, writing reusable code) by providing clear routes to recognition through coauthorship. Additionally, we were concerned that people from outside of the team might place little value on these important contributions made by early-career coauthors, relative to that placed on more traditional manuscript contributions. By having clear authorship policies, and then documenting those contributions, we hoped to increase the esteem of coauthorship contributions both within and outside of our group.

It was essential that once the policy was in place, we talked early and often about how to put the policy into practice, and that we revisited the policy throughout the life of the project as we gained experience in the diversity of contributions that might warrant authorship. In fact, our policy evolved through time (for the most recent version, see Appendix S1). It includes five major areas of coauthor contribution to recognize a diversity of contribution types, while also ensuring that all coauthors contributed sufficiently to warrant coauthorship. We defined "substantial contributions" as those that enhance the direction, content, or quality of the manuscript or analysis (e.g., it was not a sufficient contribution to sign up, participate in conference calls, and edit a version of a paper; nor was it sufficient to be listed as a coauthor on any publication because the person was a co-PI on the project). Our contribution table provides examples of

potential activities that warrant coauthorship within each category that are based on our team composition and expected manuscripts, but it also leaves room for other types of contributions that have not been identified at early stages.

Announce manuscript ideas and solicit coauthors

The initial process of sharing research ideas and identifying interested coauthors is extremely important for team functioning (e.g., fosters transparency, trust), scientific creativity, and research productivity. For example, we did not want multiple sub-teams unknowingly working on the same question, we wanted to ensure that all ideas on a topic were heard, and we wanted to ensure that all interested parties were identified and included before the project advanced. Therefore, we advocate that at the start of any new project that may lead to a manuscript, the individual(s) with the idea should announce the project and ask for potential coauthors to identify themselves. This process can be difficult for many reasons. First, it may be difficult to determine when to announce the idea and move forward—Should it be as soon as an idea has been identified or after initial analysis demonstrates that it is likely to lead to a publishable manuscript? Second, it may be difficult to determine who should be involved in the research effort. There may be tensions caused by differences in power dynamics in multi-career-level projects, the needs of early-career scientists to develop new skills and knowledge, and ways to foster collective and individual creativity. We offer two strategies for announcing a new research project and soliciting coauthors that considers these tensions.

One way to approach this process is to err on the side of inclusivity. For example, a new idea can be announced to the entire team relatively soon after coming up with the idea and before conducting analyses. By discussing the idea as a whole group and asking for interested parties to identify themselves early-on, this practice fosters creativity and is inclusive to anyone interested in the research topic or question. However, a potential shortcoming of this early inclusivity is that it could lead to large, inefficient groups. There may be too many people and not enough tasks for meaningful contribution, which can lead to redundant roles and assigning people menial tasks. Thus, revisiting author contributions outlined in the policy document at intermediate stages in the project development is an important step to maximize meaningful contributions.

A second strategy for soliciting coauthors is more targeted solicitation, which may happen later in the process of manuscript development, where the manuscript announcement is made with specific requests for assistance (e.g., "I am seeking coauthors with expertise in Bayesian modeling."). This strategy can be especially useful for papers that are part of a graduate student dissertation or thesis. Multiple authors may not be appropriate for graduate student papers because the majority of work will be conducted by the student, and the student may be left managing the sticky situation where coauthorship is not warranted. However, announcing student project ideas is still an important step to communicate with the group what research questions the student is pursuing.

We recommend talking early and often about expectations and progress over the life of a manuscript, which at the very least normalizes open conversations regarding authorship. One way to revisit the requirements of coauthorship is for lead authors to use a contribution table to list remaining project tasks and ask collaborators to commit to and document tasks in the table through the life of the project. As important as fulfilling coauthorship duties is recognizing when you cannot or have not fulfilled those duties. In these cases, coauthors should consider removing themselves from a project because they are unable to meet coauthorship requirements, which upholds the credibility and integrity of coauthorship. In addition, it alleviates the burden for the lead author who might have been unsure how to handle the situation, especially if the lead author is a graduate student and the coauthor in question is a senior member of the team.

Identify and communicate the manuscript type

Although we suggest that announcing new manuscript ideas is one of the first steps in collaborative manuscript writing, understanding the type of paper may then lead to soliciting coauthors in a very different way. In some cases, it makes little sense to announce an idea and go through the initial rounds of idea generation with the entire group when the project and

related tasks are relatively well defined. The type of manuscript influences the types of contributions that are made, how the project is managed (next section), and ultimately coauthorship decisions. We identified the following common types of manuscripts along with any special considerations that may be needed for each type, including management styles best suited to each manuscript type.

Disciplinary research manuscripts.—These types of manuscripts often make up the bulk of research output from a collaborative science team. Disciplinary manuscripts are flexible to various management styles and generally do not have additional considerations for coauthorship described in this article.

Multidisciplinary research manuscripts.—Multidisciplinary manuscripts may be led by researchers in one discipline and include coauthors from another discipline. For example, quantitative researchers in computer science or statistics may develop novel analytical techniques and need domain experts in ecology for project conception and model interpretation. In fact, such manuscripts may benefit from the project being co-led by someone from each primary discipline. Although it may be difficult for all authors to be accountable for all pieces of the work in such multidisciplinary manuscripts, these efforts can lead to creative outputs. Coauthorship policies should be fair and protect all individuals by considering contributions from all disciplines involved.

Essay, commentary, or concept manuscripts.—These types of manuscripts typically do not include data or analyses, and different practices may be needed to ensure intellectual contributions are fairly credited while balancing other guiding principles (e.g., protection of individuals with less power). These manuscripts may benefit from a distributed management style where all participants are equally involved in idea generation and writing.

Database documentation and data manuscripts.—These types of manuscripts often describe a major product of the team as a whole, such as the conceptual overview, how a project database was built, an experimental design or approach, or the data themselves. Such manuscripts have clear tasks and products and may include all team members as coauthors. This strategy protects, promotes, and includes all team members because the papers are designed to credit individuals who have spent time developing products over several years. Soliciting coauthor participation may use more of an opt-out rather than opt-in approach, where tasks and expectations are included with the announcement to give coauthors a sense of what will be required to participate as a coauthor. Although we do not recommend that providing data alone is grounds for coauthorship for most manuscript types, data papers are explicitly designed to give appropriate credit to people who have collected, maintained, and synthesized important data products, and so coauthorship policies should be flexible for these and similar manuscript types.

Graduate student dissertation manuscripts.—When a graduate student on the team leads a paper that will be part of their thesis/dissertation, that student will likely take more ownership over the manuscript, which by definition requires fewer coauthor contributions. This can be in conflict with an inclusive strategy in which manuscripts are announced earlier and participation from the broader group is solicited. Instead, graduate students may want to identify specific tasks/expertise they need, and target specific collaborators who can meet those needs rather than opening up participation to the entire group. Such a strategy may be especially important for graduate students in traditional PhD programs with an expectation of lone-wolf type dissertation work. However, we propose an alternative strategy whereby students have highly collaborative manuscripts as part of their dissertation; this approach provides professional development for students to gain valuable experience in practical strategies and skills in facilitation, communication, and leadership that are required for leading large collaborative teams (Kaner et al. 2014, Read et al. 2016). This strategy elevates the interpersonal skills required to lead a highly collaborative dissertation chapter, equating their value with individual analytical or computational skills that are often emphasized in a more traditional dissertation chapter.

Choose and communicate an author management strategy

"Author management strategy" refers to how the lead author(s) manage manuscript tasks,

including managing communication and file-sharing with coauthors, establishing timelines, soliciting intellectual contributions from coauthors, and delegating tasks. In fact, given the diversity of author management strategies that exist (described below), the phrase "lead author" can be misleading. Because of the diversity of work and writing styles that exist in interdisciplinary research teams, team members should be open to and accept different authorship management strategies, even if those strategies are outside one's particular comfort zone. Recognition of different management strategies is important because without this framework, some coauthors may feel like their potential to contribute is not being appreciated or fully realized or that they are devoting more time and effort to a manuscript than anticipated. Coauthors should not hold onto preconceived expectations of how a lead author should manage manuscript tasks, as there are several different strategies and all can be effective and result in high-performance, collaborative authorship teams. Lead authors also need to recognize and accommodate the potential risks to achieving guiding principles that are inherent to each management strategy.

Based on our experiences, we identified five authorship management strategies, although there are likely more. The strategy chosen for a manuscript may be a function of the lead author's preferred strategy or the type of manuscript. In addition to describing each management strategy below, we provide details on how each strategy may pose benefits and risks to promoting our guiding principles and thus balancing our team's values, as well as manuscript types that are best suited for each strategy (Table 1). These strategies fall along a gradient of the number of people who actively manage the manuscript tasks described above, as well as how the lead author(s) interact with the larger coauthor group. However, we emphasize that all of these strategies are classified as truly collaborative efforts, so it is assumed that under no strategy does an individual perform all manuscript tasks in isolation or with minimal engagement from coauthors. Such a strategy is only appropriate for single-author publications.

Lone wolf.—The lead author manages the manuscript tasks, does much of the work on parts of the manuscript, but engages coauthors for feedback and brainstorming once materials have been prepared, and is open to revising and altering the approach taken. Lead authors using this management strategy are expected to provide ample opportunity for coauthors to weigh in on all aspects of the manuscript development; however, more of the development may occur by the lead author individually and presented to the coauthors for discussion and potential revision. Because the lead author is taking on more of the individual tasks, the group size should be smaller, and the authorship table should be used heavily to maintain appropriate coauthor contributions.

Dynamic duo.—Two clearly defined co-leads manage the manuscript tasks equally and are listed as co-leads in the manuscript author list. The co-lead model is particularly useful when the team is writing an interdisciplinary paper, and the co-leads are from different disciplines. The same issues of engagement with and feedback from the rest of the coauthors that were raised for the lone wolf approach apply here. This strategy has advantages such as of having two people to keep momentum going on a manuscript when busy periods hit, having individuals who can learn from each other by working together on all aspects of a manuscript closely, and taking advantage of different strengths of individuals.

Board of directors.—A small group (3–5) of coauthors, including the lead author, manage the manuscript tasks by dividing up tasks, and working closely together on the vision for the manuscript. This group interacts frequently to develop the manuscript, tasks are delegated among group members, and then the group engages with other coauthors for feedback and is open to revising based on that feedback. This strategy shares many of the advantages of the dynamic duo, but may be better for collaborations that would benefit from a larger or more diverse leadership group.

Round table.—A group of coauthors that follow a flat or distributed leadership model in which all authors jointly participate in managing the manuscript tasks, in particular related to major decision-making. The role of the first author in this case is to coordinate and keep track of all of the different efforts and monitor the timeline for completion of tasks. This management strategy

Table 1. Lead author management strategies, along with example papers that may be well suited for the strategy, and the potential benefits and risks of employing each strategy.

Management strategy (example paper)	Potential benefits	Potential risks
Lone wolf (graduate student or postdoc papers)	• Improves **efficiency and productivity** by allowing for quick progress on parts of the manuscript by an individual	• **Lack of creativity** because lead author is not engaging as much with a wider range of expertise • One author doing most work may limit **accountability** and **transparency**
Dynamic duo (interdisciplinary projects with co-leads from two disciplines)	• Co-leads hold each other **accountable** • Maintain **productivity** by co-leads sharing tasks during busy times • Increases **creativity** by having detailed discussions about all aspects of the project	• Co-leads may quickly move forward without engaging coauthors, leading to lack of engagement, **accountability, transparency, and inclusion** • **Lack of creativity** from engaging with an even larger number of individuals
Board of directors (disciplinary paper)	• Maintains **productivity** through small group work ensuring progress through delegation, high levels of communication, meeting deadlines • Goals may be met **efficiently** when members have diversity of expertise	• Broader coauthor group may be **excluded** from decision-making, leading to lack of **transparency** in process • Co-leads may have shared interest or past working relationship, limiting diversity and **creativity**
Round table (disciplinary papers)	• All members engaged in **transparent** decision-making, with clearly defined contribution expectations • **Inclusive** to all coauthors who can be held **accountable** for work • Maximize **group creativity** by many coauthors involved in decision-making	• Strong leadership and facilitation skills by lead author is required otherwise **efficiency** and **productivity** can be decreased • Delegation and equal input from all coauthors may make **fair** determination of author order difficult
Organized chaos (data or database papers)	• **Inclusive** of all team members who are **promoted/protected** through recognition of involvement in larger effort • Maximizes **creativity** by bringing all expertise, backgrounds, experiences to the table	• Difficult to maintain **efficiency** due to number of interactions/meetings required to delegate and keep momentum • High level **accountability** unlikely for most individuals who are responsible for small, compartmentalized tasks

Note: Benefits and risks are related to the guiding principles (bolded) and thus highlight the difficulty in balancing all team values.

may be the most unusual for science teams, but can be effective with the right manuscript. For example, manuscripts that have several large tasks that can be completed individually may benefit from this strategy.

Organized chaos.—In this management strategy, the lead author(s) manages the manuscript tasks, but the overall structure to the workflow differs significantly from the first four strategies. The strategy is best suited for manuscripts that include everyone on the project (and sometimes more) as coauthors, often for less common manuscript types, such as data papers or project synthesis papers. Because there are many more tasks than a traditional manuscript, it is often more efficient for the lead author to delegate and coordinate tasks independently rather than collaboratively. For example, coauthors may need to perform several small, unrelated tasks throughout the manuscript effort (e.g., writing portions of the text related to their own work and proofing metadata) as needed by the lead author. As with the round table, this manuscript style is distinct from traditional manuscript types, and can be facilitated, even more than traditional manuscripts, by using collaboration tools such as simultaneous cloud-based editing platforms (e.g., Google docs), video-conferencing software with large numbers of participants, and cloud-based file-sharing.

Determine author contributions, author order, and write contribution statement

Regardless of which strategy is used to solicit coauthors, what type of manuscript is written, and which management strategy is employed, we encourage a process for determining individual author contributions and author order (see Appendix S1). In our case, the lead author(s) shared the team's authorship policy with all potential coauthors in the form of a memo. This memo asked each person to indicate the specific contributions they would like to make to the project. This process was meant to align with the guiding principles of transparent and fair authorship assignment. Throughout each manuscript effort, the lead author(s) periodically revisited the memo to ensure that coauthors were fully engaged and meeting the expectations of sufficient contribution to ensure credit was being correctly allocated. This memo describing each coauthor's contributions was used to determine the author order and draft the author contribution paragraph that we submitted for each manuscript (Appendix S1).

Summary and Conclusions

The success of the strategies for effective collaborative manuscript development described above depends in part on how they are executed and implemented by each research team. We strongly recommend that teams foster a culture in which such strategies can be effectively created and applied. In particular, time should be devoted to fostering individual skills that are necessary for effective work in highly collaborative teams. For example, it is important for all team members to understand how they and their teammates perceive and handle conflict to promote clear and productive communication (Dance 2012). Ultimately, time devoted to these important skills will facilitate smoother research collaborations in the future. Some of the specific skills that our team found useful to discuss and practice include: time management and prioritization, conflict resolution, meeting facilitation, and effective verbal and non-verbal communication. We suggest that teams implement exercises to build self-awareness and skills in these areas in team workshop settings (Cheruvelil et al. 2014) and that individuals take advantage of skill-building opportunities offered by individual institutions or professional societies (e.g., Global Lake Ecological Observatory Network [GLEON] Graduate Fellowship Program). Encouraging and facilitating participation in such workshops will elevate individual's skills and team performance, as well as increase the value of these skills more generally in the scientific enterprise.

We have offered strategies for effective collaborative manuscript development that were framed by our team's guiding principles and that emerged from our experiences working on an interdisciplinary team. These principles and practices facilitated manuscript development and authorship decisions, both of which can be increasingly challenging as team size and diversity increase. By sharing our experiences, we hope to encourage other teams to discuss and develop their own principles and practices that are suited to their team composition, research objectives, and values. Early and frequent discussion of these topics can promote productive and satisfying collaborations that result in better and more impactful publications. Further, a successful collaborative team can conduct meaningful science while upholding their guiding principles, thus meeting the needs of both the team and its individual members.

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style, whereby substantial writing and editing tasks were performed to convert the first drafts into a cohesive manuscript which was distributed among the three. New ideas and revised drafts were then brought back to the rest of the coauthors once substantial progress had been made. The first three authors are listed in order of contribution to the leadership effort; the remaining authors are listed in reverse alphabetical order, with the exception of PAS who was included as the last author in recognition of her overall group leadership and advisory role.

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