WILEY

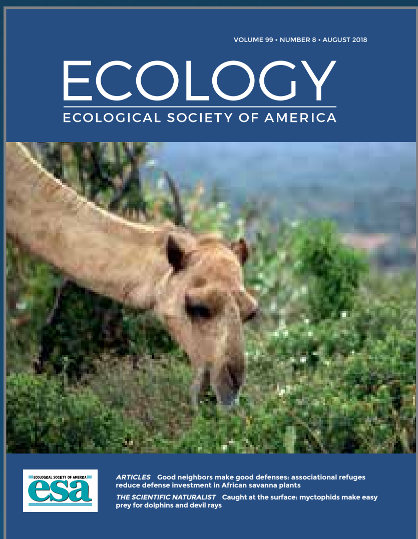
ECOLOGICAL SOCIETY OF AMERICA
esa

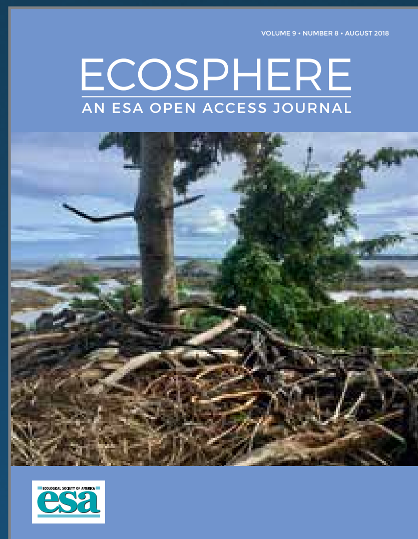
A Guide to Scientific Writing

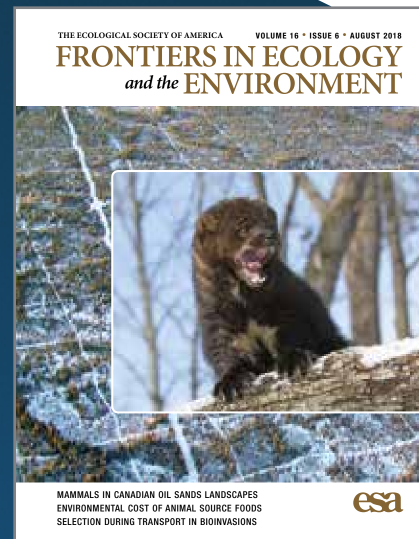
From the Ecological Society of America

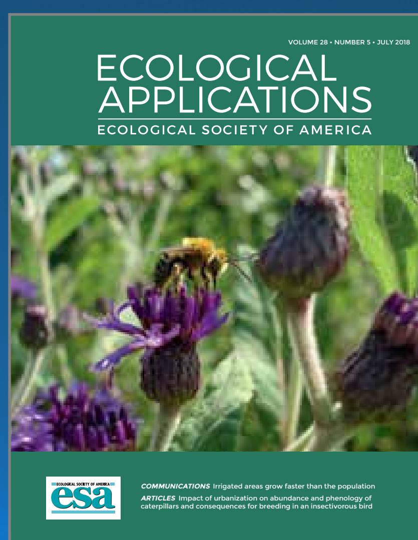
- Scientific Writing Made Easy
- Finding the "Pitch" in Ecological Writing
- Effective Collaborative Manuscript Development

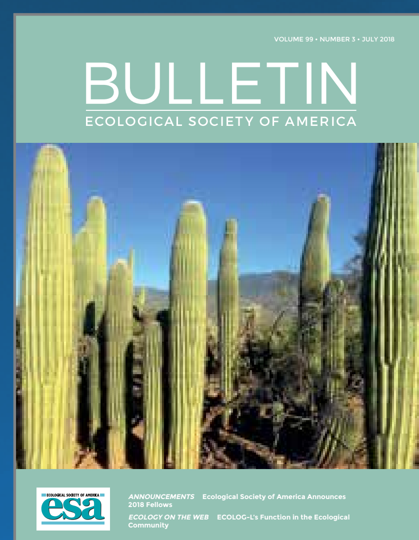
@ESA_org www.facebook.com/esa.org www.esa.org











https://esajournals.onlinelibrary.wiley.com/

ECO 101

Note: Charlene D'Avanzo is the editor of **Ecology 101**. Anyone wishing to contribute articles or reviews to this section should contact her at the School of Natural Sciences, Hampshire College, 893 West Street, Amherst, MA 01002. E-mail: cdavanzo@hampshire.edu

Scientific Writing Made Easy: A Step-by-Step Guide to Undergraduate Writing in the Biological Sciences

Sheela P. Turbek,[1] Taylor M. Chock,[1] Kyle Donahue,[1] Caroline A. Havrilla,[1] Angela M. Oliverio,[1,2] Stephanie K. Polutchko,[1] Lauren G. Shoemaker,[1] and Lara Vimercati[1]
[1]Department of Ecology and Evolutionary Biology, University of Colorado, Boulder, UCB 334, Ramaley Hall, Boulder, Colorado 80309 USA
[2]Cooperative Institute for Research in Environmental Sciences, University of Colorado, UCB 334, Boulder, Colorado 80309 USA

Abstract. Scientific writing, while an indispensable step of the scientific process, is often overlooked in undergraduate courses in favor of maximizing class time devoted to scientific concepts. However, the ability to effectively communicate research findings is crucial for success in the biological sciences. Graduate students are encouraged to publish early and often, and professional scientists are generally evaluated by the quantity of articles published and the number of citations those articles receive. It is therefore important that undergraduate students receive a solid foundation in scientific writing early in their academic careers. In order to increase the emphasis on effective writing in the classroom, we assembled a succinct step-by-step guide to scientific writing that can be directly disseminated to undergraduates enrolled in biological science courses. The guide breaks down the scientific writing process into easily digestible pieces, providing concrete examples that students can refer to when preparing a scientific manuscript or laboratory report. By increasing undergraduate exposure to the scientific writing process, we hope to better prepare undergraduates for graduate school and productive careers in the biological sciences.

An introduction to the guide

While writing is a critical part of the scientific process, it is often taught secondarily to scientific concepts and becomes an afterthought to students. How many students can you recall who worked on a laboratory assignment or class project for weeks, only to throw together the written report the day before it was due?

For many, this pattern occurs because we focus almost exclusively on the scientific process, all but neglecting the scientific *writing* process. Scientific writing is often a difficult and arduous task for many students. It follows a different format and deviates in structure from how we were initially taught to write, or even how we currently write for English, history, or social science classes. This can make the scientific writing process appear overwhelming, especially when presented with new, complex content. However, effective writing can deepen understanding of the topic at hand by compelling the writer to present a coherent and logical story that is supported by previous research and new results.

Clear scientific writing generally follows a specific format with key sections: an introduction to a particular topic, hypotheses to be tested, a description of methods, key results, and finally, a discussion that ties these results to our broader knowledge of the topic (Day and Gastel 2012). This general format is inherent in most scientific writing and facilitates the transfer of information from author to reader if a few guidelines are followed.

Here, we present a succinct step-by-step guide that lays out strategies for effective scientific writing with the intention that the guide be disseminated to undergraduate students to increase the focus on the writing process in the college classroom. While we recognize that there are no hard and fast rules when it comes to scientific writing, and more experienced writers may choose to disregard our suggestions these guidelines will assist undergraduates in overcoming the initial challenges associated with writing scientific papers. This guide was inspired by Joshua Schimel's *Writing Science: How to Write Papers that Get Cited and Proposals that Get Funded*—an excellent book about scientific writing for graduate students and professional scientists—but designed to address undergraduate students. While the guide was written by a group of ecologists and evolutionary biologists, the strategies and suggestions presented here are applicable across the biological sciences and other scientific disciplines. Regardless of the specific course being taught, this guide can be used as a reference when writing scientific papers, independent research projects, and laboratory reports. For students looking for more in-depth advice, additional resources are listed at the end of the guide.

To illustrate points regarding each step of the scientific writing process, we draw examples throughout the guide from Kilner et al. (2004), a paper on brown-headed cowbirds—a species of bird that lays its eggs in the nests of other bird species, or hosts—that was published in the journal *Science*. Kilner et al. investigate why cowbird nestlings tolerate the company of host offspring during development rather than pushing host eggs out of the nest upon hatching to monopolize parental resources. While articles in the journal *Science* are especially concise and lack the divisions of a normal scientific paper, Kilner et al. (2004) offers plenty of examples of effective communication strategies that are utilized in scientific writing. We hope that the guidelines that follow, as well as the concrete examples provided, will lead to scientific papers that are information rich, concise, and clear, while simultaneously alleviating frustration and streamlining the writing process.

Undergraduate guide to writing in the biological sciences

The before steps

The scientific writing process can be a daunting and often procrastinated "last step" in the scientific process, leading to cursory attempts to get scientific arguments and results down on paper. However, scientific writing is not an afterthought and should begin well before drafting the first outline. Successful writing starts with researching how your work fits into existing literature, crafting a compelling story, and determining how to best tailor your message to an intended audience.

Research how your work fits into existing literature.—It is important to decide how your research compares to other studies of its kind by familiarizing yourself with previous research on the topic. If you are preparing a laboratory write-up, refer to your textbook and laboratory manual for background information. For a research article, perform a thorough literature search on a credible search engine (e.g., Web of Science, Google Scholar). Ask the following questions: *What do we know about the topic? What open questions and knowledge do we not yet know? Why is this information important?* This will provide critical insight into the structure and style that others have used when writing about the field and communicating ideas on this specific topic. It will also set you up to successfully craft a compelling story, as you will begin writing with precise knowledge of how your work builds on previous research and what sets your research apart from the current published literature.

Understand your audience (and write to them).—In order to write effectively, you must identify your audience and decide what story you want them to learn. While this may seem obvious, writing about science as a narrative is often not done, largely because you were probably taught to remain dispassionate and impartial while communicating scientific findings. The purpose of science writing is not explaining what *you* did or what *you* learned, but rather what you want *your audience* to understand. Start by asking: *Who is my audience? What are their goals in reading my writing? What message do I want them to take away from my writing?* There are great resources available to help science writers answer these questions (Nisbet 2009, Baron 2010). If you are interested in publishing a scientific paper, academic journal websites also provide clear journal mission statements and submission guidelines for prospective authors. The most effective science writers are familiar with the background of their topic, have a clear story that they want to convey, and effectively craft their message to communicate that story to their audience.

Introduction

The Introduction sets the tone of the paper by providing relevant background information and clearly identifying the problem you plan to address. Think of your Introduction as the beginning of a funnel: Start wide to put your research into a broad context that someone outside of the field would understand, and then narrow the scope until you reach the specific question that you are trying to answer (Fig. 1; Schimel 2012). Clearly state the wider implications of your work for the field of study, or, if relevant, any societal impacts it may have, and provide enough background information that the reader can understand your topic. Perform a thorough sweep of the literature; however, do not parrot everything you find. Background information should only include material that is directly relevant to your research and fits into your story; it does not need to contain an entire history of the field of interest. Remember to include in-text citations in the format of (Author, year published) for each paper that you cite and avoid using the author's name as the subject of the sentence:

"Kilner et al. (2004) found that cowbird nestlings use host offspring to procure more food."

Instead, use an in-text citation:

Fig. 1. Framing a scientific paper. The structure of a paper mirrors that of an hourglass, opening broadly and narrowing to the specific question, hypothesis, methods, and results of the study. Effective papers widen again in the discussion and conclusion, connecting the study back to the existing literature and explaining how the current study filled a knowledge gap.

“Cowbird nestlings use host offspring to procure more food.”(Kilner et al. 2004)

Upon narrowing the background information presented to arrive at the specific focus of your research, clearly state the problem that your paper addresses. The problem is also known as the knowledge gap, or a specific area of the literature that contains an unknown question or problem (e.g., it is unclear why cowbird nestlings tolerate host offspring when they must compete with host offspring for food) (refer to the section “Research how your work fits into existing literature”). The knowledge gap tends to be a small piece of a much larger field of study. Explicitly state how your work will contribute to filling that knowledge gap. This is a crucial section of your manuscript; your discussion and conclusion should all be aimed at answering the knowledge gap that you are trying to fill. In addition, the knowledge gap will drive your hypotheses and questions that you design your experiment to answer.

Your hypothesis will often logically follow the identification of the knowledge gap (Table 1). Define the hypotheses you wish to address, state the approach of your experiment, and provide a 1–2 sentence overview of your experimental design, leaving the specific details for the methods section. If your methods are complicated, consider briefly explaining the reasoning behind your choice of experimental design. Here, you may also state your system, study organism, or study site, and provide justification for why you chose this particular system for your research. Is your system, study organism, or site a good representation of a more generalized pattern? Providing a brief outline of your project will allow your Introduction to segue smoothly into your Materials and Methods section.

Materials and Methods

The Materials and Methods section is arguably the most straightforward section to write; you can even begin writing it while performing your experiments to avoid forgetting any details of your experimental

TABLE 1. Constructing a hypothesis.

A hypothesis is a testable explanation of an observed occurrence in nature, or, more specifically, *why* something you observed is occurring. Hypotheses relate directly to research questions, are written in the present tense, and can be tested through observation or experimentation. Although the terms "hypothesis" and "prediction" are often incorrectly used interchangeably, they refer to different but complementary concepts. A hypothesis attempts to explain the *mechanism* underlying a pattern, while a prediction states an expectation regarding the results. While challenging to construct, hypotheses provide powerful tools for structuring research, generating specific predictions, and designing experiments.
Example:
Observation: Brown-headed cowbird nestlings refrain from ejecting host offspring from the nest even though those offspring compete for limited parental resources.
Research question: Why do nestling cowbirds tolerate the presence of host offspring in the nest?
Hypothesis: The presence of host offspring causes parents to bring more food to the nest.
Prediction: Cowbird nestlings will grow at a faster rate in nests that contain host offspring.

design. In order to make your paper as clear as possible, organize this section into subsections with headers for each procedure you describe (e.g., field collection vs. laboratory analysis). We recommend reusing these headers in your Results and Discussion to help orient your readers.

The aim of the Materials and Methods section is to demonstrate that you used scientifically valid methods and provide the reader with enough information to recreate your experiment. In chronological order, clearly state the procedural steps you took, remembering to include the model numbers and specific settings of all equipment used (e.g., centrifuged in Beckman Coulter Benchtop Centrifuge Model Allegra X -15R at 12,000 × *g* for 45 minutes). In addition to your experimental procedure, describe any statistical analyses that you performed. While the parameters you include in your Materials and Methods section will vary based on your experimental design, we list common ones in Table 2 (Journal of Young Investigators 2005) that are usually mentioned. If you followed a procedure developed from another paper, cite the source that it came from and provide a general description of the method. There is no need to reiterate every detail, unless you deviated from the source and changed a step in your procedure. However, it is important to provide enough information that the reader can follow your methods without referring to the original source. As you explain your experiment step by step, you may be tempted to include qualifiers where sources of error occurred (e.g., the tube was supposed to be centrifuged for 5 minutes, but was actually centrifuged for 10). However, generally wait until the Discussion to mention these subjective qualifiers and avoid discussing them in the Materials and Methods section.

The Materials and Methods section should be written in the past tense:

> *"On hatch day, and every day thereafter for 9 days, we weighed chicks, measured their tibia length, and calculated the instantaneous growth constant K to summarize rates of mass gain and skeletal growth." (Kilner et al. 2004)*

While it is generally advisable to use active voice throughout the paper (refer to the section "Putting It All Together," below), you may want to use a mixture of active and passive voice in the Materials and Methods section in order to vary sentence structure and avoid repetitive clauses.

TABLE 2. Common parameters included in the Materials and Methods section.

• Site characterization:
Study organism used, its origin, any pre-experiment handling or care
Description of field site or site where experiment was performed
• Experimental design:
Step-by-step procedures in paragraph form
Sample preparation
Experimental controls
Equipment used, including model numbers and year
Important equipment settings (e.g., temperature of incubation, speed of centrifuge)
Amount of reagents used
Specific measurements taken (e.g., wing length, weight of organism)
• Statistical analyses conducted (e.g., ANOVA, linear regression)

Results

The Results section provides a space to present your key findings in a purely objective manner and lay the foundation for the Discussion section, where those data are subjectively interpreted. Before diving into this section, identify which graphs, tables, and data are absolutely necessary for telling your story. Then, craft a descriptive sentence or two that summarizes each result, referring to corresponding table and figure numbers. Rather than presenting the details all at once, write a short summary about each data set. If you carried out a complicated study, we recommend dividing your results into multiple sections with clear headers following the sequence laid out in the Materials and Methods section.

As you relate each finding, be as specific as possible and describe your data biologically rather than through the lens of statistics. While statistical tests give your data credibility by allowing you to attribute observed differences to nonrandom variation, they fail to address the actual meaning of the data. Instead, translate the data into biological terms and refer to statistical results as supplemental information, or even in parenthetical clauses (Schimel 2012). For example, if your dependent variable changed in response to a treatment, report the magnitude and direction of the effect, with the *P*-value in parentheses.

> *"By day 8, cowbirds reared with host young were, on average, 14% heavier than cowbirds reared alone (unpaired $t_{16} = -2.23$, $P = 0.041$, Fig. 2A)."(Kilner et al. 2004)*

If your *P*-value exceeded 0.05 (or your other statistical tests yielded nonsignificant results), report any noticeable trends in the data rather than simply dismissing the treatment as having no significant effect (Fry 1993). By focusing on the data and leaving out any interpretation of the results in this section, you will provide the reader with the tools necessary to objectively evaluate your findings.

Discussion and conclusion

The Discussion section usually requires the most consideration, as this is where you interpret your results. Your Discussion should form a self-contained story tying together your Introduction and Results sections (Schimel 2012). One potential strategy for writing the Discussion is to begin by explicitly stating the main finding(s) of your research (Cals and Kotz 2013). Remind the reader of the knowledge gap identified in the Introduction to re-spark curiosity about the question you set out to answer. Then, explicitly state how your experiment moved the field forward by filling that knowledge gap.

After the opening paragraph of your Discussion, we suggest addressing your question and hypotheses with specific evidence from your results. If there are multiple possible interpretations of a result, clearly lay out each competing explanation. In the cowbird example, a higher feeding rate in the presence of host offspring could indicate either (1) that the parents were more responsive to the begging behavior of their own species or (2) that the collective begging behavior of more offspring in the nest motivated the host parents to provide additional food (Kilner et al. 2004). Presenting and evaluating alternative explanations of your findings will provide clear opportunities for future research. However, be sure to keep your Discussion concrete by referring to your results to support each given interpretation.

Intermingled with these interpretations, reference preexisting literature and report how your results relate to previous findings (Casenove and Kirk 2016). Ask yourself the following questions: *How do my results compare to those of similar studies? Are they consistent or inconsistent with what other researchers have found?* If they are inconsistent, discuss why this might be the case. For example, are you asking a similar question in a different system, organism, or site? Was there a difference in the methods or experimental design? Any caveats of the study (e.g., small sample size, procedural mistakes, or known biases in the methods) should be transparent and briefly discussed.

The conclusion, generally located in its own short section or the last paragraph of the Discussion, represents your final opportunity to state the significance of your research. Rather than merely restating your main findings, the conclusion should summarize the outcome of your study in a way that incorporates new insights or frames interesting questions that arose as a result of your research. Broaden your perspective again as you reach the bottom of the hourglass (Fig. 1). While it is important to acknowledge the shortcomings or caveats of the research project, generally include these near the beginning of the conclusion or earlier in the Discussion. You want your take-home sentences to focus on what you have accomplished and the broader implications of your study, rather than your study's limitations or shortcomings (Schimel 2012). End on a strong note.

Putting it all together

No matter how many boards you stack on top of each other, you still need nails to prevent the pile from falling apart. The same logic applies to a scientific paper. Little things—such as flow, structure, voice, and word choice—will connect your story, polish your paper, and make it enjoyable to read.

First, a paper needs to flow. The reader should easily be able to move from one concept to another, either within a sentence or between paragraphs. To bolster the flow, constantly remind yourself of the overarching story; always connect new questions with resolutions and tie new concepts to previously presented ideas. As a general rule, try to maintain the same subject throughout a section and mix up sentence structure in order to emphasize different concepts. Keep in mind that words or ideas placed toward the end of a sentence often convey the most importance (Schimel 2012).

The use of active voice with occasional sentences in passive voice will additionally strengthen your writing. Scientific writing is rife with passive voice that weakens otherwise powerful sentences by stripping the subjects of action. However, when used properly, the passive voice can improve flow by strategically placing a sentence's subject so that it echoes the emphasis of the preceding sentence. Compare the following sentences:

"The cowbird nestlings tolerated the host nestlings."(active)

"The host nestlings were tolerated by the cowbird nestlings."(passive)

If host nestlings are the focus of the paragraph as a whole, it may make more sense to present the passive sentence in this case, even though it is weaker than the active version. While passive and active voices can complement each other in particular situations, you should typically use the active voice whenever possible.

Lastly, word choice is critical for effective storytelling (Journal of Young Investigators 2005). Rather than peppering your report or manuscript with overly complicated words, use simple words to lay the framework of your study and discuss your findings. Eliminating any flourish and choosing words that get your point across as clearly as possible will make your work much more enjoyable to read (Strunk and White 1979, Schimel 2012).

Editing and peer review

Although you have finally finished collecting data and writing your report, you are not done yet! Re-reading your paper and incorporating constructive feedback from others can make the difference between getting a paper accepted or rejected from a journal or receiving one letter grade over another on a report. The editing stage is where you put the finishing touches on your work.

Start by taking some time away from your paper. Ideally, you began your paper early enough that you can refrain from looking at it for a day or two. However, if the deadline looms large, take an hour break at the very least. Come back to your paper and verify that it still expresses what you intended to say. *Where are the gaps in your story structure? What has not been explained clearly? Where is the writing awkward, making it difficult to understand your point?* Consider reading the paper out loud first, and then print and edit a hard copy to inspect the paper from different angles.

Editing is best done in stages. On the first run-through of your paper, make sure you addressed all of the main ideas of the study. One way to achieve this is by writing down the key points you want to hit prior to re-reading your paper. If your paper deviates from these points, you may need to delete some paragraphs. In contrast, if you forgot to include something, add it in. To check the flow of your paragraphs, verify that a common thread ties each paragraph to the preceding one, and similarly, that each sentence within a paragraph builds on the previous sentence. Finally, re-read the paper with a finer lens, editing sentence structure and word choice as you go to put the finishing touches on your work. Grammar and spelling are just as important as your scientific story; a poorly written paper will have limited impact regardless of the quality of the ideas expressed (Harley et al. 2004).

After editing your own paper, ask someone else to read it. A classmate is ideal because he/she understands the assignment and could exchange papers with you. The editing steps described above also apply when editing someone else's paper. If a classmate is not available, try asking a family member or a friend. Having a fresh set of eyes examine your work may help you identify sections of your paper that need clarification. This procedure will also give you a glimpse into the peer review process, which is integral to professional science writing (Guilford 2001). Don't be discouraged by negative comments—incorporating the feedback of reviewers will only strengthen your paper. Good criticism is constructive.

Conclusion

While the basics of writing are generally taught early in life, many people constantly work to refine their writing ability throughout their careers. Even professional scientists feel that they can always write more effectively. Focusing on the strategies for success laid out in this guide will not only improve your writing skills, but also make the scientific writing process easier and more efficient. However, keep in mind that there is no single correct way to write a scientific paper, and as you gain experience with scientific writing, you will begin to find your own voice. Good luck and happy writing!

Additional resources

For those interested in learning more about the skill of scientific writing, we recommend the following resources. We note that much of the inspiration and concrete ideas for this step-by-step guide originated from Schimel's *Writing Science: How to Write Papers that Get Cited and Proposals that Get Funded*.

1. Journal of Young Investigators. 2005. Writing scientific manuscripts: a guide for undergraduates. Journal of Young Investigators, California.
2. Lanciani, C. A. 1998. Reader-friendly writing in science. Bulletin of the Ecological Society of America 79: 171–172.
3. Morris, J., T. Jehn, C. Vaughan, E. Pantages, T. Torello, M. Bucheli, D. Lohman, and R. Jue. 2007. A student's guide to writing in the life sciences. The President and Fellows of Harvard University, Massachusetts.
4. Schimel, J. 2012. Writing science: how to write papers that get cited and proposals that get funded. Oxford University Press, Oxford.

Acknowledgments

We thank Nichole Barger and the University of Colorado, Boulder 2016 graduate writing seminar for helpful discussions that greatly enhanced the quality of this essay.

Potential Conflicts of Interest

None.

Literature Cited

Baron, N. 2010. Escape from the ivory tower: a guide to making your science matter. Island Press, Washington, D.C.

Cals, J. W., and D. Kotz. 2013. Effective writing and publishing scientific papers, part VI: discussion. Journal of Clinical Epidemiology 66:1064.

Casenove, D., and S. Kirk. 2016. A spoonful of science can make science writing more hedged. Electronic Journal of Science Education 20:138–149.

Day, R., and B. Gastel. 2012. How to write and publish a scientific paper. Cambridge University Press, Cambridge.

Fry, J. C. 1993. Biological data analysis: a practical approach. IRL Press Ltd, Oxford.

Guilford, W. H. 2001. Teaching peer review and the process of scientific writing. Advances in Physiology Education 25:167–175.

Harley, C. D., M. A. Hixon, and L. A. Levin. 2004. Scientific Writing And Publishing-A Guide For Students. Bulletin of the Ecological Society of America 85:74–78.

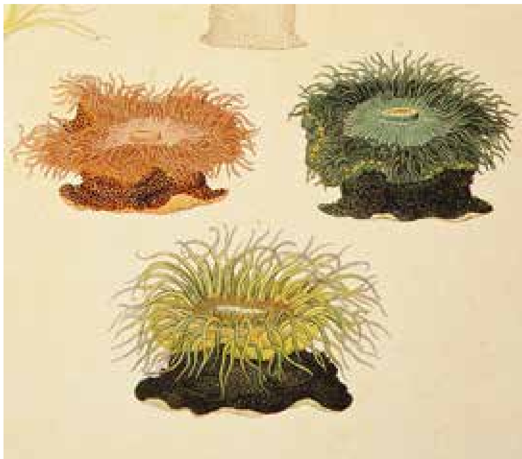
Journal of Young Investigators. 2005. Writing scientific manuscripts: a guide for undergraduates. Journal of Young Investigators.

Kilner, R., J. Madden, and M. Hauber. 2004. Brood parasitic cowbird nestlings use host young to procure resources. Science 305:877–879.

Nisbet, M. C. 2009. Framing science: a new paradigm in public engagement. Pages 40–67 *in* L. Kahlor and P. Stout, editors. Understanding science: new agendas in science communication. Taylor and Francis, New York, New York.

Schimel, J. 2012. Writing science: how to write papers that get cited and proposals that get funded. Oxford University Press, Oxford.

Strunk, W., and E. B. White. 1979. The elements of style. Third edition. Macmillan Publishing Co, New York, New York.



ECO 101

Note: William Bromer is the editor of **Ecology 101**. Anyone wishing to contribute articles or reviews to this section should contact him at the Department of Natural Sciences, University of St. Francis, 500 N. Wilcox, Joliet, IL 60435, (815) 740-3467, e-mail: wbromer@stfrancis.edu.

Finding the "Pitch" in Ecological Writing

James F. Cahill, Jr, Devin Lyons, and Justine Karst, Department of Biological Sciences, University of Alberta

This paper is the product of a seminar led by JC Cahill in response to a request by many graduate students and post-docs in our department to teach effective writing strategies. Rather than go over the mechanics of writing, JC introduced the concept of "pitch" and its importance in scientific writing. Many students requested a text version of his presentation, which was ultimately transformed into the current document. In this paper, we define and present "pitch," and layout guidelines for bringing pitch to the two most common types of scientific writing, papers and grant applications. We suggest that once students have learned the mechanics of writing, the single most important thing students can do to write effectively is to find a clear pitch.

A decade ago, the "top" ecological journals tended to be those that focused on integrative papers, allowed the researcher to develop arguments, and commonly involved multiple studies in single papers. Many established researchers looked derisively at those scientists who published LPUs "Least Publishable Units," rather than telling a more complete story. Those scientists who decried the LPU approach also sat on the editorial boards, grants panels, and search committees, and today, most of our top-ranked journals increasingly focus on publishing short papers. Whether one likes it or not, we live in the age of the LPU and the call is out for short, focused papers. One of the best ways for students to increase the likelihood of getting their papers published in top journals and having their grant applications funded is to learn to write with "pitch."

Writing with pitch requires a unique set of skills, the most important of which is having a story and not deviating from the narrative. This goes against the instinct of the scientist, as we typically want to explain every implication, caveat, and limitation of what we do. These tendencies will result in much agony. Here, we describe some alternatives. None of what we discuss below, however, will help unless a good research question has been asked, a solid study design developed, and data properly collected, analyzed, and interpreted. With students in mind, we define pitch, and outline tips for finding pitch for the two most common types of scientific writing, papers and grant applications.

What is pitch?

"to attempt to promote or sell, often in a high-pressure manner. (American Heritage Dictionary 2000)

"promotion by means of an argument and demonstration." (WordNet, Princeton University 2010, *available online*)[1]

When one writes a great novel, it is fine (perhaps even preferred) to have the readers connect the dots in the story; to have them use some brainpower to understand how the pieces of the book connect to each other and to larger issues. This form of writing will typically fail in science at one of two stages: (1) peer review, and, if that is somehow passed, (2) use by colleagues. Professors are busy. Really busy. Professors also tend to be editors, reviewers, and researchers—the people who will judge written work at every stage, both for suitability of publication or funding, and less explicitly, for whether it has any impact in the field. When it comes to developing pitch, there are two things that are likely going to reduce success:

1. **A high-pressured "sell" won't work** in scientific writing, at least not for peer-reviewed writing. Scientists tend to be independent, strong-willed people. We don't like to be told what to believe. Instead, we like to be shown what is likely true.
2. **A paper without pitch won't work**, as we don't have time to figure out what you mean to say, and why it is important. If you don't lay these things out right in front of us, we are not likely to give your paper or grant application a positive review, nor are we likely to use your work as we prepare our own manuscripts.

Thus the right pitch in ecology has to navigate these two constraints rising like mountains of rejection; too much of a "sell" and reviewers get grumpy; too little, and reviewers get grumpy. Grumpy reviewers result in rejection. The middle ground, what you should be aiming for, we will call the "valley of happiness." So what does this valley look like? In that world, single papers will typically have a single story. The research objectives are an obvious extension of the introduction. The research methods are succinct, and their connection to the research objectives are clear. The results are short and directly answer the research questions. The most important information comes first. The discussion is brief and focused, with clear topic sentences. It will read as a coherent whole. A key aspect of a well-written paper with a solid pitch is that someone reading ANY section of the paper should have a clear understanding of the main objectives of the paper, even without reading any other parts of the paper. Or put another way, your pitch is your research question, and this should be returned to in every part of the paper. Importantly, the wording of your research questions in your paper rarely would be the wording you used in your original research proposal. You must modify your pitch as your project develops, and as your interpretation changes.

1 ‹http://wordnet.princeton.edu›

Below, we provide some suggestions on how to develop your pitch in scientific writing, the first of which is a need to understand who your audience is, and to tailor your pitch to their needs and expectations.

Different audiences and different goals

The most common types of scientific writing are (1) peer-reviewed papers, and (2) grant applications. Each has a different goal, and different audiences. We do not write these documents for ourselves, instead we write them for others. Once you realize this, it becomes obvious that you need to write according to what other people want to see and need to know. An effective pitch is tailored to your audience.

When we write a paper, we hope the ultimate audience will be other scientists, in fields related to our own. However, to reach that audience we first have to satisfy an audience made up of specialist peer reviewers and editors. Reviewers are typically specialists in your field who will focus most on the details of your study. Prior to reading your manuscript, some reviewers might think positively of your prior work, some will think negatively, and others won't have any idea who you are. This doesn't mean they are unable to fairly review your manuscript, but the peer review is a socio-political process, and you need to be aware of this. Reviewers will want to see that you both understand what research has already been done in your field, and that your research will truly make advances. It is critical that you develop the context for your research questions from a broad literature, and not focus exclusively on work done in your lab. Similarly, your impact needs to be on the field as a whole, not just your lab.

The handling editor is a secondary audience with some unique concerns. They tend to be strongly influenced by the quality of the reviews, but they will also judge a submitted manuscript based upon their own read of the paper. Believe it or not, split decisions among reviews are the exception, not the rule. Bad papers are obvious, as are outstanding papers. As a result, it is very easy for the handling editor to reject or accept these papers without needing to fret too much about the decision. When split decisions do occur, the handling editor judges the reviews and weighs their own feelings about the potential impacts of the work on the field as a whole. Here, pitch is critical. The handling editor is generally looking for a reason to reject, not accept. If the strengths of your work are hidden, then you had better hope that you received two outstanding reviews; otherwise don't hold your breath. Historically, handling editors used the "reject and resubmit" option when they and the reviewers felt that the underlying data were strong, but poorly presented (e.g., bad pitch) and/or incorrectly analyzed and interpreted. Some journals are encouraging handling editors to use this option less frequently and instead to reject papers outright. This will put increased emphasis on getting one's pitch right in the first submission.

Many journals frequently reject papers without review, and in such cases, the Editor-in-Chief may be an important audience. Typically, they will focus on the more general aspects of the paper presented in the abstract and cover letter. Satisfying the Editor-in-Chief requires stating your pitch in clear, general terms and making sure that all parts of your writing relate to your central ideas.

The goal of a grant application is simple: to get money for future research. Grant applications need to be very well written (sloppy writing suggests careless research). Your pitch will lead the reader to a specific conclusion, one for which there is no answer, and thus money is needed to solve it. There are no shortcuts here; you must be very knowledgeable about your field, understand how the pieces fit together, and identify real holes in understanding. The audience for a grant application depends upon the specific grant, but will generally consist of specialists in your field (reviewers) and generalists in ecology (some panel members). However, many grant panels also include stakeholder representatives and/or administrators**.** Within a single grant you will need several different pitches, each tailored to these different audiences.

Specialists are reviewers with objectives similar to those described for papers. They focus on the quality and originality of the science. Panel members are usually scientists who may not be from your specific field. This group will focus most on the general objectives of your study, and the quality of the reviews, so obviously having strong reviews will help you. Doing your research on likely panel members makes sense, as there will be some opportunities for you to use examples from the panel member's areas of expertise. You do this, not to pander, but to frame your objectives partly in a context that they are already familiar with. One must make it easy for reviewers to understand why your work is important. Stakeholders are a group of readers who will focus most on *their own objectives*, and whether yours match theirs. You need to be certain you are using the language they are used to, and that you link your ideas to the specific objectives they list in the call for proposals. You are unlikely to convince them to fund great ideas unless you show very explicitly in your pitch that your work meets their goals. This form of writing needs to be plain and succinct. Pay attention to the front and back ends of your grant application —the summary and conclusion. These sections are typically targeted to stakeholders.

Whether you are writing a paper or a grant application, you need to convince all of your reviewers of the great merit in your elegant ideas in a single document of limited length. How? First, have elegant ideas. Second, write well. Third, have a sense of what your pitch is, and how it will interest the reviewers (and thus likely influence other scientists too). Aside from this, you need also to pay attention to how you reference other researchers. Researchers have egos, and they are not usually small. If you work in a relatively small field, you can likely identify a specific person (or laboratory) that will provide a review, and you would be crazy not to include their work in the development of your story. If you need to critique their work, cast that critique in a way that highlights the positives of their contributions, even when you disagree with other aspects of their work. A pitch should not antagonize your reviewers, nor should it be biased in presentation of material. Be sure to be very balanced in your writing, because you won't know who all of your reviewers are. You want to be certain not to unintentionally snub one faction of researchers through omission and/or sloppy writing that conveys critique when you don't intend it. This does not mean you need to cite everyone; instead, you must show balance.

Writing with "pitch"

Trying to add pitch at the end of constructing a document will be a frustrating experience for you, your co-authors, and your supervisor. The key is to construct your document in a way that lets you integrate your pitch into every section from the beginning. Here we focus on developing pitch for papers (see Table 1 for guidelines on specific sections). There are at least two common approaches to constructing a paper. We call the first "Intelligent Design." This is the traditional approach of working from front to back that most students initially use, as this is what is typically taught in school. In conversations with colleagues, this approach appears to be used relatively rarely by scientists. Nonetheless, here is the idea:

First, make a clear outline of the story from front to back. This outline forms the skeleton of your paper. The backbone of this skeleton is your well-crafted research question, and it connects to every other part of the skeleton. Next, add guts and muscle. These are the essential references that the intended audience needs to understand your research question; the methods needed to answer that question; the data and figures needed to answer the question; and the conclusions that immediately emerge from the answers. It is absolutely essential that every single thing you add be directly connected to the skeleton. Avoid constructing any vestigial organs, tumors, or unsightly growths that will need to be excised. Regularly ask yourself whether your creature could still live if you removed certain bits and pieces. If the answer is yes, remove them. Remember, the goal of the paper is NOT to tell the audience everything you know. Instead, it is to get your paper published and have it be cited. So, just because you spent many hours of hard labor collecting certain data does not justify their inclusion in this paper. Also remember that you are not trying to create the most attractive creature on the planet—just one that is functional enough to get published and cited. Perfectionism reduces research productivity (Sherry et al. 2010), and any time you spend on the bells and whistles (e.g., wonderfully elegant writing) is time that is neither needed to meet your goals, nor time you can spend on your next paper or grant application.

A second approach to writing papers is called "writing backwards" (Magnusson 1996). Modifications of this approach appear to be the most commonly used, at least among our colleagues. According to Magnusson (1996), writing backwards involves the following steps: (1) Write conclusions first (succinctly). (2)Write only the results necessary for those conclusions. (3) Write only the needed methods. (4) Write the discussion as it relates to results. And (5) write the introduction, the minimum needed to present the questions. The advantage of this approach is that it puts the emphasis on the emergent findings that you have, and these are often different from the exact goals of the study you intended to conduct when you started your research project. Good pitch focuses on what you have, not what you intended. We demonstrate two example of writing with pitch in mind in Box 1.

As scientists we disseminate our findings through published papers with the goals of being cited, influencing policy, shifting public opinion, or establishing oneself in a field. Importantly, the goal of a paper is NOT to produce the "best" written paper possible. Instead you should aim for a paper that is written *well enough* for your target journal. Unlike grants, we typically have choices about the journals to which we choose to submit a paper. The choice has importance, and affects our ability to achieve our short-term goals, as well as the potential impact of a paper on longer-term career development. It is important to recognize that the choice of venue influences the necessary pitch and the relative importance of your cover letter. In brief, the broader the audience of the journal (e.g., *Science* vs. *American Fern Journal*), the more general your pitch needs to be. The quality of the science needs to be strong in all cases, but you need to be able to relate your work to increasing numbers of nonspecialists as you move from field-specific to broader-impact journals. It is critical that you structure your entire manuscript accordingly; know your audience and write for them.

Using your supervisor effectively

Working on a paper or grant application with your supervisor can be a (mutually) frustrating experience. Learning how to work effectively with co-authors is an important part of scientific writing. You can help to minimize frustrating your supervisor by working with them *as needed*, rather than *as* *desired*. In other words, go to them when you run into a problem that you can't solve for yourself. If you are going to be a successful scientist, you need to learn to work independently, so don't turn to your supervisor because they would do something faster. Also, do not waste your supervisor's time with first drafts, poorly constructed verbiage, or manuscripts with 20 figures and no focus. When it comes to receiving feedback on your manuscript, understanding why your supervisor does certain things can help to limit your frustration. For example, try not to be offended when your supervisor edits part of your paper, and sends it back without reading the rest. As described above, we typically write in a logical sequence, and if one section needs to be completely gutted, time spent on any other section will be time wasted. Also, do not be surprised when supervisors contradict themselves in subsequent drafts. Typically they do this because as the story changes, so too do the needed bits. This is no different from you cutting and repasting. It is part of the writing process. Of course, other times they do it just because it's fun.

Final advice

You write in the academic world of today, not that of the last century. As such, you will be expected to produce more, shorter, papers than previous generations of ecologists. Staying focused on your pitch will help make these papers better, and easier to write. Remember your goals. At some point, you need to submit your paper. Your goal is not perfection, it is simply for your paper to be good enough. Learn to know where that bar is. Similarly, grant applications have deadlines. Writing a clear, cogent argument as to why your research deserves funding demands pitch. Make pitch your path through all the rubble.

Sources and inspirations

Craine, Joseph. The haiku of writing a paper. (Online at his web page ‹http://www.k-state.edu/craine/Reprints/WritingGuidelines.pdf›)

Houghton Mifflin. 2000. The American heritage dictionary of the English language. Fourth edition. Houghton Mifflin, New York, New York, USA.

Magnusson W. 1996. How to write backwards. ESA Bulletin 77:88.

Sherry, S. B., P. L. Hewitt, D. L. Sherry, G. L. Flett, and A. R. Graham. 2010. Perfectionism dimensions and research productivity in psychology professors: implications for understanding the (mal) adaptiveness of perfectionism. Canadian Journal of Behavioural Science 42:273–283.

Author's e-mail for correspondence: jc.cahill@ualberta.ca

Table 1. Specific advice for sections of a scientific paper

Title	• Don't be overly cute, vague, boring, or long. • Do be precise and accurate. Your title should relate to your main finding.
Abstract	• Do not start with a throwaway line, "XXX has been studied for decades; XXX is an indicator of climate change; XXX is important." Instead, start with the real issue. • Do not be vague in your results. Either say it or leave it out of the abstract, and don't allude to something hidden in the text (e.g., XXX will be discussed). • Do not end with a throwaway line, "these results have significant implications of our understanding of XXX; more research is needed."
Introduction	• If a point isn't directly needed to set up the research questions, cut it. • Introductions should not be long. • End with a very clear set of specific research questions. Take a long time to really think about how these are worded and what order you want to present them in.
Methods	• Relate everything you talk about to the research questions described above. • Do not swap the order, such that if you list questions 1, 2, 3 in the introduction, do not discuss the methods as 3, 1, 2. • When you discuss statistical methods, be sure to relate each test to a specific research objective. If the test is complicated, let the reader know what type of statistical result would indicate what type of answer to your question.

Results	• For nearly every paper, this should be your shortest section. For a regular, ~20 page paper, the results of a tightly written paper with a strong story should be about 1 page (excluding tables/figures). • Use fewer figures and tables than you think you need. Put the extras online. The problem with figures is that simple ones are more briefly stated with text, while complex ones take a long time to understand. The latter is fine if, and only if, they are directly related to your main research questions. If tables or figures are simply supportive, then putting them in the main paper will greatly subtract from your overall pitch. • When discussing statistical results, focus on the answer to your research questions, not test statistics, *P* values, or AIC values. These are tools for interpretation; they are not meaningful in and of themselves. They are to be used to support your story. • Answer your research questions in the same order you presented them.
Discussion	• Discuss your research questions in the same order you originally presented them. • When interpreting, it is essential that you come back to the same ideas you laid out in your introduction, but now indicate how your results alter our understanding. If some ideas in your introduction don't get referred to in the discussion, they probably didn't belong in your introduction. • You should extrapolate from your results one step, but no more than that. For example, if you found X, you can suggest Y. But you cannot say that since X is true, Y might be too, and therefore Z happens.

Box 1: Examples of how to modify text to incorporate pitch.

Before	
To understand *Mimulosa pudica's* strategy for minimizing lost opportunity cost, we measured the length of time it took the pinnules to reopen given a particular stimulation, under various amounts of Photosynthetically Active Radiation (PAR).[1] If *M. pudica* has evolved strategies to maximize fitness, then the relationship between hiding (anti-herbivore behaviour) and optimal foraging should be configured in the way most advantageous to the plant.[2] This basic assumption leads to the hypothesis that when light is limited, each unit of time that the leaves are open is more photosynthetically valuable.[3] Therefore, in bright light, the cost of having the leaves closed is less than in dim light.	[1]The opening sentence contains jargon (e.g. lost opportunity cost) and focuses on the specific details of measurements rather than the identifying concept for the research. [2]Wordy. [3]Incomplete sentence and difficult to quickly grasp concept.

After	
A common finding by behavioural ecologists is that animals will accept a greater risk of predation when energetically stressed than when energy is not limiting.[1] Such behaviours can be found in a variety of animal taxa ranging from sessile barnacles to highly mobile birds.[2] Theory suggests there is a balance between risks and rewards faced by individuals, such that at very low energy levels the costs associated with starvation are greater than the risk of predation.[3] Whether plants exhibit the same behavioural tendency to accept more risk under stressed conditions has not previously been tested.[4]	[1]This opening sentence situates work in a broad context. [2]This sentence points out the widespread nature of specific behaviour, implying that it is important. [3]This sentence identifies expectations based on theory, moving the behaviour from being animal specific to one applied to any organism. [4]The closing sentence identifies the need to do research because there is an obvious gap in our understanding.

Before

When herbivory treatments were excluded from the analysis, whole-pot plant biomass was significantly higher in mixtures than in monocultures (Mixture: 0.2051 ± 0.1612 g/pot, Monoculture: 0.1698 ± 0.1659 g/pot; $F1, 248 = 185.311$, $p = 0.008$; pooled density and fertilization) at all density and fertilizer levels (Fig. 1).[1] Growth at high-density also significantly increased whole-pot biomass ($F1, 248 = 15.788$, $p < 0.001$), as did fertilization ($F1, 248 = 71.897$, $p < 0.001$), resulting in a maximum plant biomass in fertilized, high density mixtures (0.3664 ± 0.1554 g).[2] No significant two- or three-way interactions were detected by the model ($0.276 < p < 0.740$).[3]

[1]This sentence is disrupted by statistical reports.

[2]Wordy and vague.

[3]Overall, this section is dominated by statistical reporting with little emphasis on ecology.

After

In the absence of any herbivores, plant genetic diversity significantly increased whole-pot plant biomass by 17% relative to genetic monocultures (Fig. 1 a,b; Table 1).[1] High plant density and fertilization also increased plant biomass (Fig. 1 a,b; Table 1), such that maximum biomass occurred in high density, fertilized mixtures (Fig. 1 a,b).[2] No significant two- or three-way interactions were observed (Table 1).[3]

[1]This result emphasizes both the underlying ecology and the magnitude of the effect. Statistical results are moved to relevant table.

[2]The wording is simplified.

[3]Observer interpretations are emphasized over model results, and p-values are moved to the relevant table.

esa ECOSPHERE

INNOVATIVE VIEWPOINTS

Strategies for effective collaborative manuscript development in interdisciplinary science teams

Samantha K. Oliver,[1,8,]† C. Emi Fergus,[2] Nicholas K. Skaff,[3] Tyler Wagner,[4] Pang-Ning Tan,[5] Kendra Spence Cheruvelil,[6] and Patricia A. Soranno[7]

[1]*Center for Limnology, University of Wisconsin-Madison, 680 N Park Street, Madison, Wisconsin 53706 USA*
[2]*Western Ecology Division, National Research Council Research Associate, U.S. Environmental Protection Agency, 200 SW 35th Street, Corvallis, Oregon 97333 USA*
[3]*Department of Fisheries and Wildlife, Michigan State University, 480 Wilson Road, East Lansing, Michigan 48824 USA*
[4]*Pennsylvania Cooperative Fish and Wildlife Research Unit, U.S. Geological Survey, The Pennsylvania State University, 402 Forest Resources Building, University Park, Pennsylvania 16802 USA*
[5]*Department of Computer Science & Engineering, Michigan State University, 428 South Shaw Land, Room 3115, East Lansing, Michigan 48824 USA*
[6]*Department of Fisheries and Wildlife & Lyman Briggs College, Michigan State University, Natural Resources Building, 480 Wilson Road, Room 334D, East Lansing, Michigan 48824 USA*
[7]*Department of Fisheries and Wildlife, Michigan State University, 480 Wilson Road, East Lansing, Michigan 48824 USA*

Citation: Oliver, S. K., C. E. Fergus, N. K. Skaff, T. Wagner, P.-N. Tan, K. S. Cheruvelil, and P. A. Soranno. 2018. Strategies for effective collaborative manuscript development in interdisciplinary science teams. Ecosphere 9(4):e02206. 10.1002/ecs2.2206

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.

Received 30 November 2017; revised 13 March 2018; accepted 14 March 2018. Corresponding Editor: Debra P. C. Peters.

[8] Present address: Upper Midwest Water Science Center, U.S. Geological Survey, 8505 Research Way, Middleton, Wisconsin 53562 USA.
† **E-mail:** oliver.samanthak@gmail.com

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

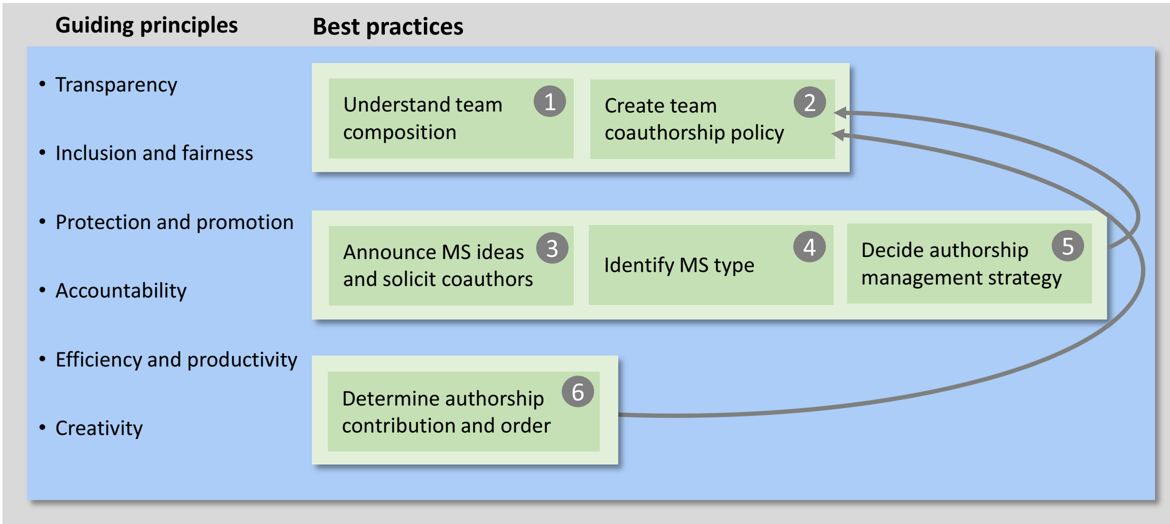


Fig. 1. A conceptual diagram that shows the strategies for effective collaborative manuscript (MS) development being firmly embedded within and balancing the guiding principles, and the relative order that the practices occur (numbers). Strategies that are on the same row are strongly related, can occur 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.

Acknowledgments

The authors wish to thank the entire CSI Limnology team who participated in six years of creating, refining, and implementing the authorship policies and practices that informed this work. Funding sources include the U.S. National Science Foundation's Macrosystems Biology Program (EF-1065786, EF-1065649, and EF-1065818); a fellowship to SKO from the University of Wisconsin Graduate School; a USDA National Institute of Food and Agriculture Hatch Project (176820) to PAS; and the US National Science Foundation's Cultivating Cultures for Ethical STEM Program (SES-1449466) to KSC and PAS. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. For this manuscript, we followed a round-table management style for much of this project, whereby all coauthors contributed equally to the generation of the manuscript scope, outline, and ideas, and whereby each coauthor drafted first drafts of portions of the text during bi-weekly working video-calls. The manuscript was eventually led by the three early-career scientists (CEF, NS, SKO) in a board-of-directors

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.

Literature Cited

Atkinson, R., L. Crawford, and S. Ward. 2006. Fundamental uncertainties in projects and the scope of project management. International Journal of Project Management 24:687–698.

Barlow, J., P. A. Stephens, M. Bode, M. W. Cadotte, K. Lucas, E. Newton, M. A. Nuñez, and N. Pettorelli. 2018. On the extinction of the single-authored paper: the causes and consequences of increasingly collaborative applied ecological research. Journal of Applied Ecology 55:1–4.

Bear, J. B., and A. W. Woolley. 2011. The role of gender in team collaboration and performance. Interdisciplinary Science Reviews 36:146–153.

Birnholtz, J. P. 2006. What does it mean to be an author? The intersection of credit, contribution, and collaboration in science. Journal of the Association for Information Science and Technology 57:1758–1770.

Campbell, L. G., S. Mehtani, M. E. Dozier, and J. Rinehart. 2013. Gender-heterogeneous working groups produce higher quality science. PLoS ONE 8:e79147.

Chawla, D. S. 2015. Digital badges aim to clear up politics of authorship. Nature 526:145–146.

Cheruvelil, K. S., P. A. Soranno, K. C. Weathers, P. C. Hanson, S. J. Goring, C. T. Filstrup, and E. K. Read. 2014. Creating and maintaining high-performing collaborative research teams: the importance of diversity and interpersonal skills. Frontiers in Ecology and the Environment 12:31–38.

Chiaburu, D. S., and A. Lim. 2008. Manager trustworthiness or interactional justice? Predicting organizational citizenship behaviors. Journal of Business Ethics 83:453–467.

Dance, A. 2012. Authorship: Who's on first? Nature 489:591–593.

DeHart, D. 2017. Team science: a qualitative study of benefits, challenges, and lessons learned. The Social Science Journal 54:458–467.

Duke, C. S., and J. H. Porter. 2013. The ethics of data sharing and reuse in biology. BioScience 63: 483–489.

Eigenbrode, S. D., et al. 2007. Employing philosophical dialogue in collaborative science. BioScience 57:55–64.

Elliott, K. C. 2017. A tapestry of values: an introduction to values in science. Oxford University Press, UK.

Elliott, K. C., I. S. Settles, G. M. Montgomery, S. T. Brassel, K. S. Cheruvelil, and P. A. Soranno. 2017. Honorary authorship practices in environmental science teams: structural and cultural causes and solutions. Accountability in Research: Policies and Quality Assurance 24:80–98.

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

Hong, L., and S. E. Page. 2004. Groups of diverse problem solvers can outperform groups of high-ability problem solvers. Proceedings of the National Academy of Sciences of the United States of America 101:16385–16389.

Kaner, S., K. Berger, and L. Lind. 2014. Facilitator's guide to participatory decision-making. Third edition. Jossey-Bass, Hoboken, New Jersey, USA.

Leung, A. K., M. W. Maddux, A. D. Galinksy, and C. Chiu. 2008. Multicultural experience enhances creativity. American Psychologist 63:169–181.

Logan, J. M., S. B. Bean, and A. E. Myers. 2017. Author contributions to ecological publications: What does it mean to be an author in modern ecological research? PLoS ONE 12:e0179956.

McLeod, P. L., S. A. Lobel, and T. H. Cox. 1996. Ethnic diversity and creativity in small groups. Small Group Research 27:248–264.

McNutt, M., et al. 2017. Transparency in authors' contributions and responsibilities to promote integrity in scientific publication. bioRxiv 1:140228.

Morse, W., M. Nielsen-Pincus, J. Force, and J. D. Wulfhorst. 2007. Bridges and barriers to developing and conducting interdisciplinary graduate-student team research. Ecology & Society 12:1–14.

National Research Council. 2015. Enhancing the effectiveness of team science. National Academies Press (U.S.), Washington, D.C., USA.

Nielsen, M. W., S. Alegria, L. Börjeson, H. Etzkowitz, H. J. Falk-Krzesinski, A. Joshi, E. Leahey, L. Smith-Doerr, A. W. Woolley, and L. Schiebinger. 2017. Opinion: Gender diversity leads to better science. Proceedings of the National Academy of Sciences of the United States of America 114:1740–1742.

Read, E. K., M. O'Rourke, G. S. Hong, P. C. Hanson, L. A. Winslow, S. Crowley, C. A. Brewer, and K. C. Weathers. 2016. Building the team for team science. Ecosphere 7:e01291.

Rennie, D., V. Yank, and L. Emanuel. 1997. When authorship fails: a proposal to make contributors accountable. JAMA 278:579–585.

Scheffer, M. 2014. The forgotten half of scientific thinking. Proceedings of the National Academy of Sciences of the United States of America 111:6119.

Stokols, D., S. Misra, R. P. Moser, K. L. Hall, and B. K. Taylor. 2008. The ecology of team science: understanding contextual influences on transdisciplinary collaboration. American Journal of Preventive Medicine 35:S96–S115.

Uzzi, B., S. Mukherjee, M. Stringer, and B. Jones. 2013. Atypical combinations and scientific impact. Science 342:468–472.

Wang, X., and M. N. Young. 2013. Does collectivism affect environmental ethics? A multi-level study of top management teams from chemical firms in China. Journal of Business Ethics 122:387–394.

Weltzin, J. F., R. T. Belote, L. T. Williams, J. K. Keller, and E. Engel. 2006. Authorship in ecology: attribution, accountability, and responsibility. Frontiers in Ecology and the Environment 4:435–441.

Whitfield, J. 2008. Collaboration: group theory. Nature 455:720–723.

Woolley, A. W., C. F. Chabris, A. Pentland, N. Hashmi, and T. W. Malone. 2010. Evidence for a collective intelligence factor in the performance of human groups. Science 330:686–688.

Wuchty, S., B. F. Jones, and B. Uzzi. 2007. The increasing dominance of teams in production of knowledge. Science 316:1036–1039.

Supporting Information

Additional Supporting Information may be found online at: http://onlinelibrary.wiley.com/doi/10.1002/ecs2.2206/full


Join the largest community of ecologists in the world
esa.org/join
ECOLOGICAL SOCIETY OF AMERICA
esa
CAREER
INFORMATION
CONNECTIONS
Members receive