Authorship in ecology: attribution, accountability, and responsibility

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Quality and quantity of publications are among the most important measures determining the success of ecologists. The past 50 years have seen a steady rise in the number of researchers and collaborative manuscripts, and a corresponding increase in multi-authored articles. Despite these increases, there remains a shortage of useful and definitive guidelines to aid ecologists in addressing authorship issues, leading to a lack of consistency in what the term "author" really means. Deciding where to draw the line between those who have earned authorship and those who are more appropriately credited in the acknowledgments may be one of the more challenging aspects of authorship. Here, we borrow ideas from other scientific disciplines and propose a simple solution to help ecologists who are making such decisions. We recommend improving communication between co-authors throughout the research process, and propose that authors publish their contributions to a manuscript in a separate byline.

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Articles published in peer-reviewed journals are the medium by which scientists present their findings to the scholarly community. The quality and quantity of publications are essential components for building careers, funding projects, and generating a sense of accomplishment and self-worth (Lindsey 1980). The past five decades have seen a proliferation of scientific subdisciplines, an increase in the number of researchers and collaborative manuscripts, and a corresponding increase in multi-authored articles (Regalado 1995; Cronin 2001). Multiple authorship is an increasing trend that has now become the norm, but there remains a paucity of useful and definitive guidelines to aid researchers in addressing authorship issues (Rennie *et al.* 1997; Klein and Moser-Veillon 1999). Although several journals (eg *The Lancet*, *Journal of the American Medical Association*, and *Proceedings of the National Academy of Sciences of the United States of America*) have adopted clearly defined guidelines that specify criteria for authorship and communicate that information to the readers, most journals have only vague or non-existent guidelines (Rennie *et al.* 2000).

In the absence of standardized definitions or guidelines on authorship (eg criteria for author inclusion or order), scientists employ a variety of personal criteria that are unknown to readers and that probably differ from criteria employed by other authors, even for articles in the same journal. For example, individual authors, laboratory groups, or even subdisciplines may determine byline composition and order based on arbitrary or idiosyncratic traditions, customs, or habits. As such, the order in which authors are listed communicates little information about the importance of the contribution of each individual, since a wide variety of undisclosed methods are used to assign order (Rennie *et al.* 2000). This can create an environment in which credit, accountability, and responsibility for research are neither personally accepted nor publicly acknowledged (Zuckerman 1968). A lack of communication about authorship may engender interpersonal issues and ethical dilemmas if undeserving individuals are included as authors, or if contributing researchers are not included (Rennie and Flanagin 1994; Rennie *et al.* 1997). The purpose of this article is to discuss potential approaches to deciding who should be included in the authorship byline, and in what order. We recommend improved communication among authors during the writing process, and outline an approach used by other science disciplines, wherein authors publish their contributions to a manuscript in a separate byline (eg Panel 1).

In a nutshell:

- Ecology is becoming an increasingly collaborative science, with researchers from various disciplines involved in ecological research projects; decisions about authorship of a manuscript are therefore becoming more difficult
- The Ecological Society of America's Code of Ethics provides only vague guidelines to determine who should be granted authorship; it is therefore time for ecologists to develop a more substantial framework for attributing credit to authors
- Here, we propose a byline statement summarizing the contribution of each author to the research, to be published with the article (a practice now commonly used in biomedical journals)

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Authorship trends in ecology

Ecologists are in a particularly challenging situation when dealing with authorship, since our discipline has

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Panel 1. Author contributions for this article

JFW co-conceived and co-developed the idea for the manuscript, co-refined the intellectual content and scope, edited all drafts, prepared the final version of the manuscript, and facilitated the gathering of contributors. RTB co-conceived and co-developed the idea, edited all drafts, and assessed historic trends in authorship in *Ecology*. LTW initiated the project, co-developed and co-refined the intellectual content, and wrote the first two drafts. JKK co-developed the idea, edited all drafts, and conducted the keyword search. ECE co-developed the idea and coordinated the authorship survey. JFW is the guarantor for the integrity of the article as a whole.

developed into a collaborative science which frequently produces multiple-author articles without simultaneously developing useful guidelines for handling this issue. Interdisciplinary teams of scientists are often required to investigate questions in ecology, and these teams typically include several layers of participants, such as principal investigators, graduate and undergraduate student researchers, technicians, statisticians, and field assistants. Increases in the diversity of funding sources, larger laboratories and centers of research, and advances in technology all promote the growth of research teams and networks. This trend is mirrored by patterns of authorship for articles published in the journal *Ecology*; between 1925 and 2005, the mean (± 1 SE) number of authors credited per article tripled from 1.1 ± 0.06 to 3.3 ± 1.1, and the maximum number of authors on a single paper increased from 2 to 17 (Figure 1).

Ecological research continues to be increasingly collaborative and interdisciplinary, a pattern that is encouraged by the National Institute for Health and the National Science Foundation and facilitated by institutions such as the National Center for Ecological Analysis and Synthesis. Despite this, and the fact that ecological research continues to move in the direction of large-scale, long-term projects, ecologists and the majority of their journals have yet to formally address the authorship issue. An ISI Web of Knowledge search on the keyword "authorship" yields only two matches in the top 20 ecology journals (ranked by impact factor). In contrast, the same search yields 34 results for the *Journal of the American Medical Association*, 13 results for *Nature*, and 14 for *Science*. There were 1090 results when all journals were included in the search (Thomson ISI 2005). While we acknowledge that not all search results are relevant to the topic at hand, this pattern suggests that ecology may be lagging behind other scientific disciplines when addressing the complexities associated with authorship. The trend towards increasing author numbers in the absence of guidelines for acknowledging involvement in projects will continue to complicate this already sensitive issue.

The meaning of "author"

The difficulties associated with selecting both who will become an author on the final manuscript and in what order those authors should appear are neither trivial nor easily resolved (Panel 2). In the absence of clear guidelines, scientists use individualized criteria, creating a lack of consistency in what is really meant by the term "author" (Rennie *et al.* 2000). In ecology, it is generally assumed that the person placed first in the list of authors contributed the most time and energy to the project, but how does one compare their relative contributions to the second, third, or eighth person named? Are all authors equally responsible for the work presented, and can each be held accountable for the claims made in the article? Are certain authors earning undeserved credit for projects, while others are unfairly denied credit for perhaps greater contributions? There is currently too much disparity between the criteria employed by each set of authors when submitting a manuscript, allowing researchers to lose track of who is truly responsible and accountable, and therefore deserving of credit for the research. This can also lead to situations where potentially unaccountable authors (ie those not obliged to accept responsibility for content) are given credit for the article. This dilutes the impact of having one's name listed on a manuscript, and may detract from the professional value of the published article for the secondary authors who appear as "*et al.*", rather than having their full name listed in all citations.

The contribution of each author is diminished when "ghost" authors, "guest" contributors, and those who acquired the initial funding for the project are included in the list of authors (Rennie and Flanagin 1994). Ghost authors, ie those who receive author credit for simply editing completed research, are more often found in the biomedical sciences, but probably occur in all disciplines. Guest contributors are invited to participate in manuscript preparation in an undemanding capacity, mainly to justify the addition of their name to the authorship list for the positive impact gained from their celebrity in a given field. Finally, there are all-too-common occurrences of honorary authors, who obtain authorship by providing funding or lab space, or even by "trading" authorship rights on one paper for inclusion on another (Flanagin *et al.* 1998). Inclusion of such guest contributors and ghost authors generates ethical questions, because researchers and co-authors differ in opinion over the appropriateness of including "authors" who contributed neither intellectually nor physically to the production of the article (Culliton 1988).

For ecologists, the issue is further complicated when assessing the contribution of participants, such as technicians and student researchers, who may have been vital to one portion of a project but not another (Panel 2). Participants without a PhD may feel as though they have contributed substantially to the completion of an experiment, but they may have no standards on which to stake their claim for inclusion on the authorship list (Heffner 1979). Alternatively, investigators may be undecided about including a technician as an author when that person worked for only a few years on a longer-term project and meets only some of their criteria for authorship. In

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sum, the lack of guidelines leads to an environment in which individuals involved in a project are often unsure about their own right to claim or dispute authorship and provides no means to resolve situations that arise over the selection of authors and their order.

Developing authorship guidelines for ecologists

Scientific journals, professional societies, and individual scientists have previously attempted to create definitions of authorship and to provide guidelines on how to determine which participants should be credited on the manuscript. A variety of approaches exist among the various scientific disciplines, including listing authors based on seniority, extent of contribution, importance of contribution, or simply by alphabetical order or the outcome of a coin toss (Rennie *et al.* 1997). However, these approaches are infrequently communicated to readers, who must make their own assumptions about how authors were selected and the order in which they are listed. Furthermore, these approaches are often ignored by the authors who submit manuscripts, so that even if a journal attempts to provide a standardized definition of authorship, the scientists may fail to adopt it (Klein and Moser-Veillon 1999).

The Ecological Society of America (ESA) currently suggests that its members employ a rather vague set of guidelines presented in the publication section of its Code of Ethics (ESA 2006). Specifically, the ESA guidelines related to the selection of authors state:

1. Researchers will claim authorship of a paper only if they have made a substantial contribution. Authorship may legitimately be claimed if researchers
   (a) conceived the ideas or experimental design;
   (b) participated actively in execution of the study;
   (c) analyzed and interpreted the data; or
   (d) wrote the manuscript.
2. Researchers will not add or delete authors from a manuscript submitted for publication without consent of those authors.
3. Researchers will not include as co-author(s) any individual who has not agreed to the content of the final version of the manuscript.

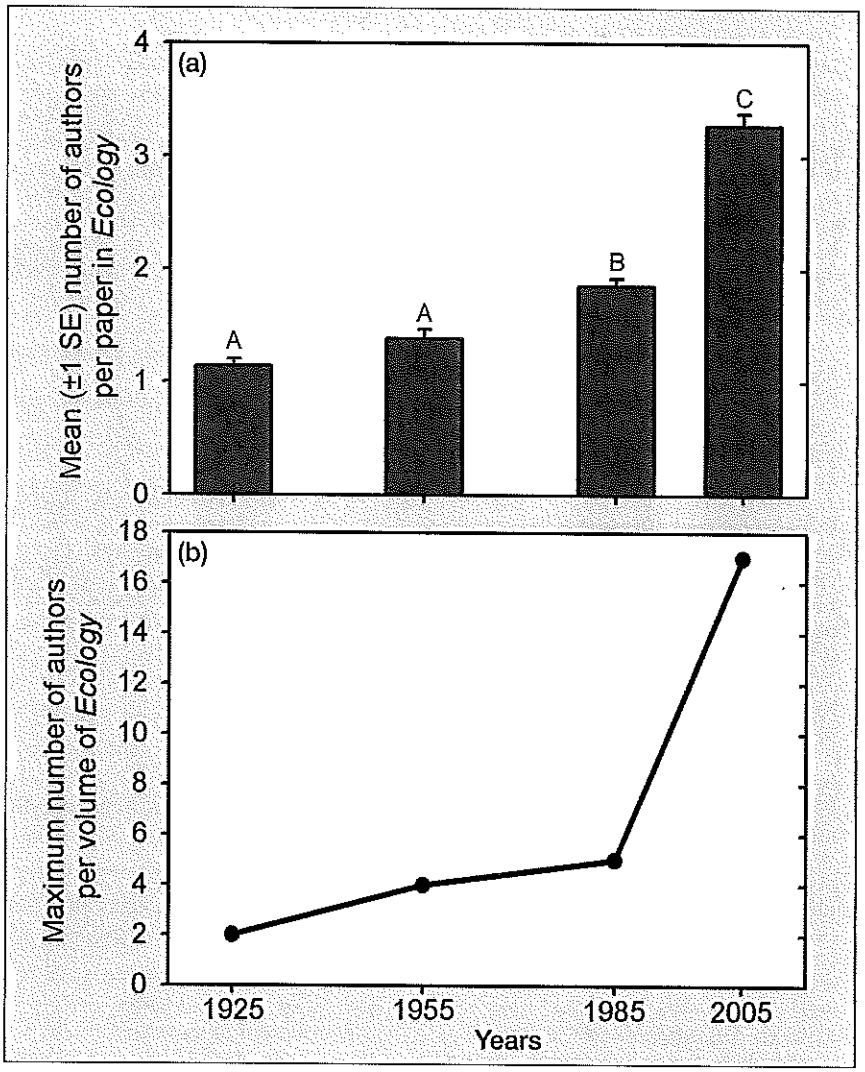

Figure 1. (a) Mean and (b) maximum number of authors per article published in Ecology *during 1925, 1955, 1985, and 2005. Notes and comments were excluded from the analysis. Mean (± 1 SE) number of authors with the same capital letter did not differ ($P > 0.05$, Tukey's HSD; issues as replicates, thus n = 4, 4, 6, and 12; data were normal).*

Although these guidelines describe who should be included as an author, they do not address the question of author order. They also leave interpretation of "substantial contribution" to the individual(s) making the decisions, leading to confusion and inequities. The ESA guidelines are more lenient than those employed by other journals, in that authorship may be granted even if only one of the four criteria is met. By comparison, the *Uniform Requirements for Manuscripts Submitted to Biomedical Journals*, developed by the International Committee of Medical Journal Editors, states that contributors only qualify as authors if they meet *all* of these criteria (ICMJE 2005).

Seeking a more definitive approach, Galindo-Leal (1996) suggested a two-stage process, using a modified scoring system originally proposed by Hunt (1991). The first stage involves improving communication between co-authors by drafting a pre-research agreement for all

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Panel 2. Authorship survey

We invited attendees of the 2004 Annual Meeting of the Ecological Society of America (Portland, OR) to participate in an informal, voluntary survey about authorship. Participants were presented with six hypothetical scenarios involving research collaborators, and were asked which characters should be authors, and in what order those authors should appear on manuscripts. Hardcopies of the surveys were posted on a bulletin board in the main foyer of the conference hall at the meeting; respondents returned completed surveys onsite, or mailed them at a later date. We received 57 completed surveys. In Part A below, we present three scenarios from the survey. In Part B, we include follow-up questions to spur discussion and present highlights of the results from survey respondents.

Part A	Part B
Scenario 1: Professor *X* and new graduate student *Y* are developing a research project for *Y*. *Y* is interested in a project that *Z*, a graduate student colleague/professor in the department, is conducting. *Y* discusses project concepts with *X*, and decides to conduct a project descended from and closely related to *Z*'s project. The questions, methods, and analysis were developed solely by *X* and *Y*, and all physical work was conducted by *Y*. *Y* and *Z* met a few times to discuss methods for analysis, but *Z* contributed nothing to manuscript preparation.	*Follow-up questions:* • Should *Z* be included as an author? • Who should be first author? *Survey responses:* • 25% of respondents thought that *Z* deserved authorship. • 84% of respondents indicated that *Y* should be first author, whereas 16% of respondents indicated that *X* deserved to be the first author.
Scenario 2: Principal Investigator *X* developed the intellectual ideas, wrote a proposal, and received monies for a new, well-funded project. *X* hires technician *T* to handle project logistics, and to ensure that the project follows *X*'s original vision; *T* collects much of the empirical data, and supervises undergraduate students who assist during data collection. Research assistant *A* is responsible for manipulation, analysis, and interpretation of data collected by *T* et *al.*	*Follow-up question:* • Who should be included as an author, and in what order? *Survey responses:* • 78% of respondents thought all three characters should be included as authors. • 78% chose *X* as first author. • 14% chose *A* as first author. • 82% included *T* as an author. • Respondents listed 10 unique combinations for authorship order.
Scenario 3: Professor *X* initiates writing of a synthesis paper with graduate student *Y* on their favorite topic. After the two meet several times to outline a paper, *Y* takes the task of writing the first draft. *X* and *Y* pass the manuscript back and forth several times before *X* does the final revision and submits the manuscript for publication.	*Follow-up question:* • Who should be the first author? *Survey responses:* • 46% of respondents thought that *X* should be the first author. • 46% thought that *Y* should be the first author. • 8% could not decide.

parties to use as a guideline or protocol. Co-authors monitor their involvement and progress throughout the duration of the research project by using the scoring system, which assesses their participation in planning, executing, analyzing, interpreting, and writing the manuscript. The second stage involves reviewing the scoring system and using the scores to determine who has earned credit as an author; the authorship order is selected by arranging names in the descending order of their scores. Although this scoring system may work well for research teams involving few participants, it is less useful for the multi-year, large-scale complex collaborative projects that are becoming the norm in ecology. Complications may arise when participants are highly involved for only a portion of the project or when participants are not asked to be involved in all aspects of the project. Weighting the various categories, such as "planning" or "analysis", is difficult because it is often a matter of opinion as to how much credit is earned by conceiving the project or analyzing the data relative to credit earned by physically collecting the data. Informal intellectual contributions from technical staff may go unnoticed or be underappreciated by researchers preparing a manuscript. The practice of discussing authorship before, during, and after a project is surely one that should be adopted by all scientists to avoid confusion and discord over issues of authorship. However, in our opinion, using the scoring system may allow too narrow a scope for contemporary projects in ecology.

Proposals to resolve these challenges and establish a realistic and functional set of guidelines for authors should include a way to recognize both credit and accountability for the article, while maintaining flexibility for a diverse set of research participants, projects, and situations. These guidelines must be available to the participants for any given project, as well as to the readers of each manuscript, to ensure that the meaning of the authorship list is communicated to the scientific community. Standards for determining authorship order, and for differentiating between authors and those whose names more appropriately appear in the acknowledgments, must also be established.

Establishing accountability and responsibility

Rennie *et al.* (1997) proposed a system that stresses the importance of accepting responsibility and accountability for research in order to earn credit for it (see also Davis and Gregerman 1969; Garfield 1983; Moulopoulos *et al.* 1983; Huth 1986; Saffran 1989; Mancini 1990; Hunt 1991; and Green 1994). They propose a system of "contributorship" (as opposed to "authorship") that recognizes the contribution of each individual to the manuscript, and establishes the accountability of that person to the content of the manuscript; in short, the "word and concept *contributor*" is substituted for the "word and concept *author*" (Rennie *et al.* 1997). Contributors disclose which particular aspects of a manuscript they were responsible for in a byline that is

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published with the article (see, for example, the contributorship byline [Panel 1] for this article). This system requires each author to publicly accept accountability for their particular contribution; moreover, it would enable readers to more objectively ascribe credit to the named individuals, as well as determining the credibility of the article as a whole. A "contributorship" policy was recently adopted by *Proceedings of the National Academy of Sciences of the United States of America* (PNAS 2006), which posts the byline as a footnote to the paper, albeit only online (Panel 3). Similarly, authors submitting a manuscript to *Nature* are "strongly encouraged to include a statement in the end notes to specify the actual contribution of each co-author" (Nature 2006; see also Anonymous 1999).

Alternatively, journals could establish standards and consistency for bylines by providing a list of possible tasks or responsibilities to contributors (Rennie *et al.* 1997; Klein and Moser-Veillon 1999; see also Panel 3). That said, it is probably unnecessary and overly complicated to attempt to standardize all job descriptions for all research projects. It is probably more important to create an opportunity for authors to declare individual contributions, whatever they may be, and to publish them with the manuscript. Only by disclosing this information can the contributors guarantee that their relative responsibilities, and thus their relative accountability and credit, are publicly accepted and acknowledged.

Rennie *et al.* (1997) advise researchers to "meet, discuss, and decide on their respective contributions to the project, as well as the relative value of the contributions to the whole, and in what order to list them in publications". As Galindo-Leal (1996) stressed, communicating with collaborators before, during, and after the project is an important part of ensuring that responsibility is accepted and acknowledged, credit is assigned fairly, and conflicts are avoided (Figure 2).

By committing to ongoing discourse about authorship throughout a particular project, contributors can make informed decisions as to individual contributions, which may facilitate ordering of authors. Authorship order is generally understood to be designated by placing the name of the persons involved in order of the importance of their duties, "in descending order, starting with the collaborator who made the most substantial contributions" (Rennie *et al.* 1997). Since each research team may employ unique criteria, such as allowing someone to take the last position on the authorship list for providing funding, it is particularly important that the ordering methodology is disclosed to the readers (Klein and Moser-Veillon 1999). In sum, open communication between all participants involved in a research project can yield the best results for understanding and determining authorship order.

Guarantors and acknowledgees

Although published papers are typically (and appropriately) considered as a whole, complex projects involving multiple collaborators, each involved in one aspect of the project, may obscure internal assignment or external perception of accountability and responsibility. Thus, it is good practice for each research team also to designate at least one contributor as a *guarantor* for the whole project (eg Panel 1). Guarantors are individuals who have contributed substantially to the manuscript and who have also made an extra effort to ensure the integrity of the paper as a whole. Guarantors may organize the various tasks associated with manuscript preparation, ensure the internal consistency of the final manuscript, and solicit and organize contributorship statements; as such, they are prepared to be accountable for all parts of the completed manuscript, before and after publication (Rennie *et al.* 1997). Recognizing a guarantor ensures that someone on the research team accepts and publicly acknowledges responsibility and accountability for the entire project, including each component of the manuscript. Guarantors serve the scientific community by certifying that all work was done properly and thoroughly, and by guarding against dishonest scientific practices. Acknowledging a guarantor improves trust and credibility in science and promotes good research practices.

Deciding where to draw the line between those who have earned authorship and those who are more appropriately credited in the acknowledgments may be one of the more challenging aspects of authorship. One meaningful way of thinking about the differences between these two sets of participants may be to consider whether or not the participant is responsible and accountable for the article. A contributor receiving credit for the article should be

Panel 3. Guidelines for authorship, *Proceedings of the National Academy of Sciences of the United States of America* (PNAS 2006)

Authorship should be limited to those who have contributed substantially to the work. The corresponding author must have obtained permission from all authors for the submission of each version of the paper and for any change in authorship.

All collaborators share some degree of responsibility for any paper they co-author. Some co-authors have responsibility for the entire paper as an accurate, verifiable report of the research. These include co-authors who are accountable for the integrity of the data reported in the paper, carry out the analysis, write the manuscript, present major findings at conferences, or provide scientific leadership to junior colleagues. Co-authors who make specific, limited contributions to a paper are responsible for their contributions, but may have only limited responsibility for other results. While not all co-authors may be familiar with all aspects of the research presented in their paper, all collaborators should have in place an appropriate process for reviewing the accuracy of the reported results.

Authors must indicate their specific contributions to the published work. This information will be posted online as a footnote to the paper. Examples of designations include:

- Designed research
- Performed research
- Contributed new reagents or analytic tools
- Analyzed data
- Wrote the paper

An author may list more than one contribution, and more than one author may have contributed to the same aspect of the work.

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Figure 2. Intellectual contribution in ecology can be difficult to quantify because field technicians or undergraduate students may provide important, informal observations that can easily be under-acknowledged by principal investigators. The informal contributions may drive future research, direct data analyses, and contribute to manuscripts. Communication among potential contributors before, during, and after a project is critical to ensure assignment and acceptance of responsibility. Each contributor is responsible for drafting his or her own byline; the guarantor is responsible for evaluating each byline relative to the others, and for maintaining internal consistency.

willing to be held accountable for its contents and not be just responsible for a portion of the work involved. In contrast, an acknowledgee may contribute formal or informal ideas to ongoing projects, collect enormous amounts of data, and develop and/or conduct statistical analyses, but may not be accountable for the final contents of all or even portions of the final manuscript. Open communication about the roles, responsibilities, and expectations for authors as opposed to acknowledgees should be ongoing during the writing process.

Will a system of contributorship work for ecology?

Critics of similar proposals for contributorship advance several reasons why these systems may not work (Rennie *et al.* 1997; Flanagin *et al.* 1998; Yank and Rennie 1999; Rennie *et al.* 2000). Skeptics argue that the system of naming contributors and disclosing individual responsibilities is no different than current author and acknowledgment lists. This system is different, however, because it eliminates the "artificial distinction, mostly of a social nature, between authors and non-author contributors – that is, between authors and acknowledgees. The contributions of all (not just those of acknowledgees) are described and disclosed" (Rennie *et al.* 1997). Critics also worry that any systematic change would be resisted by researchers, but this could be overcome through the leadership of journals, professional societies, and indexers by requiring that article submissions use the system. While no system will put an end to disagreements over authorship rights, forcing participants to think critically and publish the contribution of each individual may attenuate problems and abuses of authorship.

Acceptance of a contributorship system will require behavioral changes on the part of researchers and technical changes by journals and professional societies. Those who argue that a system such as this would already be in place if it were a good idea may be comfortable with the status quo. In fact, as described above, this system has been used by numerous biomedical journals for some time, and is being used or considered by top quality journals that publish ecology papers, such as *PNAS* and *Nature*. It will take effort to bring about this change, but we argue that such a modification is necessary in a publishing environment where more and more researchers are likely to experience issues related to authorship.

Conclusions

Although no system will completely resolve the challenges associated with authorship, substituting "contributors" for "authors" and asking that all researchers disclose their reasons for including authors and their relative order may go a long way towards ensuring proper credit and appropriate responsibility for articles. Including this information as a byline, in addition to a statement of acknowledgments, will enable readers (as well as contributors) to better understand where responsibility, accountability, and credit belong. As the number and frequency of multi-author papers continues to rise, ignoring authorship issues may dilute the meaning of "author". Our ecological journals and professional societies should adopt this system, or its equivalent, as a reasonable response that would provide much needed guidance for all contemporary researchers and scholars. It is time for ecologists to join the rest of the scientific community in discussing authorship issues and developing guidelines for our articles.

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Authorship in ecology

I read "Authorship in ecology" by JF Weltzin *et al.* (*Front Ecol Environ* 2006; 4(8): 435–41) with much interest. The authors brought up several valid points, of which I felt the most important was not that some codified standard is needed, but rather that discussion about authorship (contributorship) should be open and frequent throughout the research and writing phases. In the end, even an additional "byline", as suggested by the authors, will be subjective. An example is in the paper itself. Can readers of the article clearly distinguish the difference in importance to the end product of "co-developing", "co-refining", and "initiating" the project? My reading of their Panel 1 was that Leigh Williams would have been the lead author, but assuming they followed their own guidelines, their authorship order was determined by an open and deliberative process – something that is much needed in authorship determination and throughout research projects.

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Ensuring that "authors" write

Having authors publish their contributions to a manuscript in a separate byline is a good idea for a variety of reasons (cf Maddox 1994), but in promoting this notion, Weltzin *et al.* (*Front Ecol Environ* 2006; 4[8]: 435–41) still do not identify the means to distinguish study participants as authors versus acknowledged contributors. They in fact add a bit to the authorship/editorship/contributorship conundrum by explicitly identifying their third author as the one who "wrote the first two drafts" of their own article. One would assume that such a contribution would be from the first author. Aside from missing several helpful citations of ecologists (Dickson and Conner 1978; Hunt 1991), including one from ESA (Schmidt 1987), it appears that Weltzin *et al.* (2006) do not disapprove of the notion that some contributors who do not write might be identified as "authors", and might not support the notion that those who contribute most to writing should be considered as the first author. While I agree that the extent of contributions needs to be acknowledged in publication, does not "authorship" connote some actual, original writing? As Mares (1992) proclaimed, "Authorship of a scientific publication is not a reward for having assisted in some way, however trivial, in making a research report possible"; rather, it should identify actual participation in the production of the manuscript. Of the many guidelines available to help sort out this issue, all but those including actual authorship can be used to identify who is asked to help co-author, or even take the lead in writing, an article, but then co-authors should ensure that each truly deserves the appellation. Those who can't or choose not to write should be acknowledged.

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The authors reply

The letters from Drs Fisher and Fuller reflect the breadth of opinion as to what constitutes "authorship" in ecology. Interestingly, both responses identified Leigh Williams as the most likely candidate for primary author, based on our contributorship statement (Panel 1). Indeed, this was our original intent; however, like other ecological research, our article is the product of a multiyear collaboration. The full contributorship byline thus reflects the shifting nature of intellectual and writing contributions within our collaborative group. Open and sometimes difficult conversations were required over the course of the project, which was initiated during weekly lab-group meetings involving several of the "acknowledgees". Ironically, the addition of details leaves the importance of various contributions more open to interpretation. In sum, we agree that our proposed approach offers little in terms of objectivity, let alone insight into byline order. The transparency of this approach, however, reflects its benefits: self-selection, evaluation, and public acknowledgement should produce few contributorship bylines where individual contributions have been minimal.

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Beyond data: reproducible research in ecology and environmental sciences

We applaud Clifford Duke (*Front Ecol Environ* 2006; 4[8]: 395), Crall *et al.* (*Front Ecol Environ* 2006; 4[8]: 414-8), the Ecological Society of America (ESA), the National Science Foundation, and others who have been advocating for greater access to, and better documentation of, ecological and environmental data. Many of the most important questions of our time will require this. However, we feel that in this push to garner greater accessibility to data, full access to the computational methods used to pro-

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duce results is an important facet that is often forgotten or overshadowed.

While we would never argue that providing access to the results and methods of a particular study is a novel idea (ie see the past several hundred years of scientific research), we would argue that providing open access to the entire data analysis sequence is a departure from the norm in the ecological and environmental sciences. This idea of "reproducible research" is certainly not ours to claim. The idea has roots in "literate programming" from the computer sciences (Knuth 1992), has been further developed through the efforts of the Stanford Exploration Project (http://sepwww.stanford.edu/research/redoc/) and the Bioconductor Project (Gentleman and Lang 2004), and is starting to see wider application in health sciences and epidemiology (Peng *et al.* 2006). Applying similar approaches to ecology and environmental science is a rather small step. In fact, very recent efforts in climate change circles have embraced the idea (Ammann 2006). Continuing such efforts makes tremendous sense as we transform our discipline into one that freely shares and distributes data and uses increasingly complex computational methods.

It may be surprising to some that we are currently capable of providing full access to our computational methods and making our research truly reproducible. For instance, Ecological Archives currently accepts supplements to other ESA publications that can include code and software tools. Also, many open-source statistical and programming languages (eg Python, R and Sweave, XML) are already being used to develop reproducible research products, but using these in a reproducible framework is not often done by ecologists and environmental scientists. Furthermore, it appears that the ongoing efforts of the many projects of www.ecoinformatics.org are increasing the number of computational tools available to ecologists to make our research more reproducible. Perhaps most importantly, they are providing a venue to train and educate current and future ecological and environmental researchers. These efforts are still quite young. As such, we agree with Clifford Duke's suggestion that the main stumbling block to realizing both greater data accessibility and generating reproducible research is not solely the availability of technology and tools but how individual scientists conduct their work and how well each of us are trained in the tools that are currently available.

Again, we applaud the efforts of many in their attempts to increase access to data, but we fear that publication of computational methods that can be easily reproduced by others and adapted for their own use is often forgotten. In the future, including both will certainly improve our ability to address the increasingly complex ecological and environmental questions with which we will be faced.

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Disclaimer: This letter has not been subjected to Agency-level review; therefore, it does not necessarily reflect the views of the agency.

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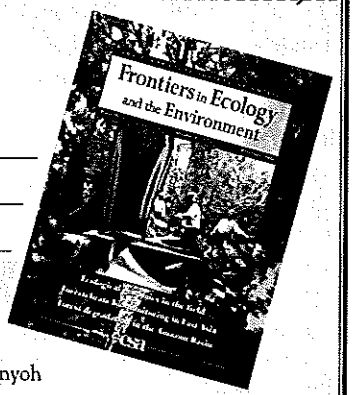

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