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On the extinction of the single-authored paper: The causes and consequences of increasingly collaborative applied ecological research

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In 1963, Price analysed authorship patterns in chemical science and identified that "...the proportion of multi-author papers has accelerated steadily and powerfully, and it is now so large that if it continues at the present rate, by 1980 the single-author paper will be extinct" (Price, 1963). An analysis of all research papers published in *Journal of Applied Ecology* since 1966 shows that the trends identified by Price also apply to our field: an exponential increase in the mean number of authors per published article has been mirrored by a sharp decline in the proportion of single-authored papers (Figure 1). From over 60% of all publications in the 1960s, single-author papers now make up less than 4% (averaged over the past 10 years). Although the single-author paper has hung on well beyond 1980 in *Journal of Applied Ecology*, their extinction now appears imminent.

The widespread trend towards multi-authored papers identified by Price has since been observed across all sciences (Adams, 2012), and is widely believed to reflect a growth in collaboration (Glänzel & Schubert, 2004). Intriguingly, an analysis of manuscript submission and citation data from *Journal of Applied Ecology* highlights some of the potential benefits for larger author teams. Over the last 10 years, submissions with four or more authors were almost 2.5 times more likely to be accepted than single-authored manuscripts (Figure 2), and had significantly higher citation rates when published (Figure 3), reflecting citation trends observed across 32 ecology journals (Fox, Paine, & Sauterey, 2016).

Although higher acceptance and citation rates could suggest that the growth in author numbers is resulting in higher quality science that has greater impact, the drivers of these changes and their implications for applied ecological research remain unclear. In this editorial, we consider some of the underlying causes and consequences of longer author lists for applied ecological research.

1 | IMPROVEMENT IN THE TEMPORAL SCALE AND/OR SPATIAL BREADTH OF STUDIES

In the late 1960s, most research was conducted on a limited scale, and the lack of spatial replication was often apparent in the titles (e.g. *The Food of Trout* (Salmo trutta) *in a Dartmoor Stream;* Elliot 1967, *The Distribution of Slugs in a Potato Crop* Stephenson 1967). But ecologists have come to recognise the importance of considering spatial scale (Wiens, 1989) and temporal replication (Vaughn & Young 2010) in analyses, increasing the amount of data required to test hypotheses by orders of magnitude. In a review of metaanalyses (Cadotte, Mehrkens, & Menge, 2012), the increase in author number coincided with increases in the numbers of datasets and species, and in the time span assessed. In 2017, a typical applied ecological field study will have collected data over multiple years and across large spatial scales, while ecological science has seen a growth in the number of scientific networks that replicate standardised methodologies across the world (Reynolds, 2015; Stokstad 2011). It seems likely that some of the growth in author numbers reflects these trends in data collection, which are improving scientific rigour, repeatability, generality and reliability of inferences.

2 | MULTIPLE SKILL SETS AND INTERDISCIPLINARITY

The increased number of authors may also reflect the growing need for multiple skill sets in applied ecological research. As technology has advanced, scientific studies are able to draw on a broader set of skills and resources, and it is not unusual to find multidisciplinary studies requiring taxonomists, ecologists, remote sensing specialists, modellers and statisticians. These changes reflect advancements in the discipline of applied ecology, and support the delivery of a stronger evidence base to improve management of the world's ecological resources. Applied ecology has also drawn more on methods and insights from the social sciences, with recent papers engaging with economic analyses (e.g. Prowse, Johnson, Cassey, Bradshaw, & Brook, 2014) and multidisciplinarity (e.g. Quinlan, Berbés-Blázquez, Haider, & Peterson, 2015). Such integrative and interdisciplinary approaches are essential to help understand and resolve the unprecedented socio-ecological problems of the Anthropocene (Brondizio et al., 2016).

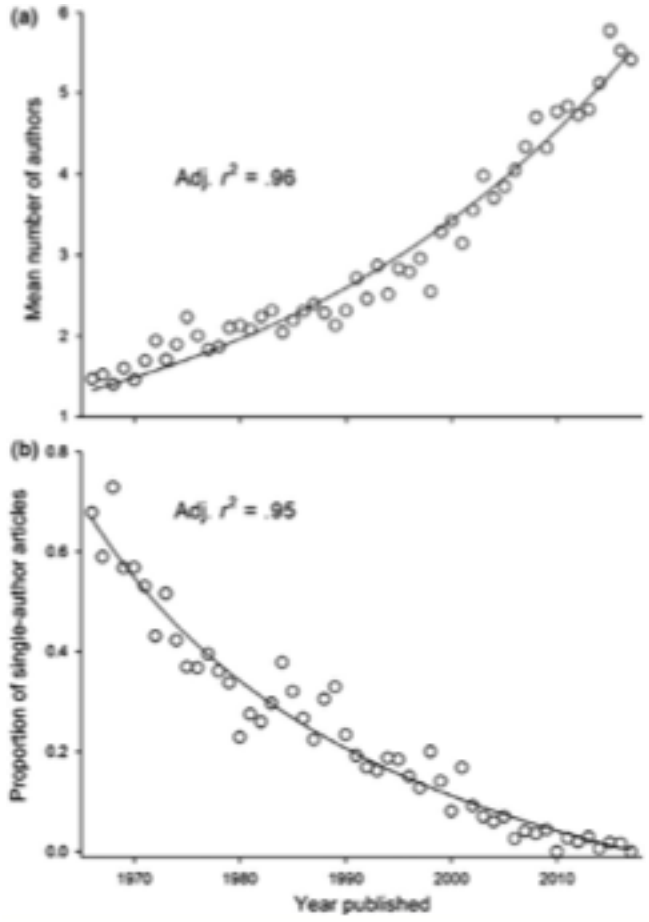


FIGURE 1 Changes in the number of authors on standard research articles published in *Journal of Applied Ecology* since 1966, showing (a) the exponential growth in the mean number of authors per article and (b) the exponential decline in single-author articles

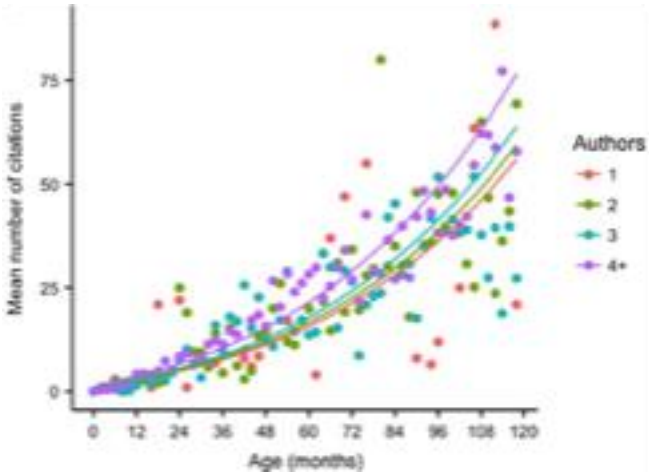
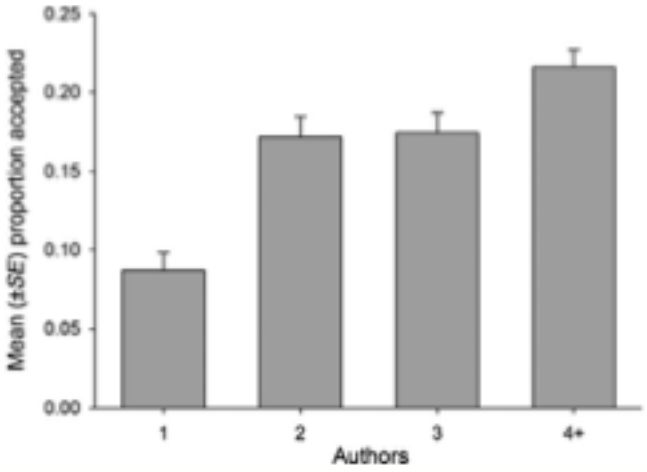


FIGURE 3 Effect of number of authors on the mean accumulation of citations for standard research articles over the last 10 years. We used a GLMM with square root of age as a continuous predictor, author

number (1, 2, 3 or greater than three authors) as a fixed effect and paper ID as a random factor (to account for overdispersion). Error was assumed to follow a normal-Poisson distribution, and a single outlier (with over 500 citations) was removed. Citation rates increased with author number, and papers with more than three authors were significantly more highly cited than single-author papers

3 | INCREASED FOCUS ON IMPACT AGENDA

While the science of applied ecology guides policy and management of natural resources, it also has an important role in driving discussions and debates between researchers and practitioners, thus enabling findings to be translated to real-world impact (Cadotte, Barlow, Nuñez, Pettorelli, & Stephens, 2017). This transdisciplinarity will be most effective if the research itself is genuinely co-designed with practitioners, which would ensure the questions that are posed are most relevant to the user groups (Cadotte et al., 2017). We are hopeful that at least some of the increase in the size of author lists reflects such changes, as many recent papers involve a mix of authors from a range of institutions, including research institutes, universities and regional government agencies (e.g. Carboneras et al., 2017; Giljohann et al., 2017; Linkie et al., 2015).



F I G U R E 2 Acceptance rates categorised by number of authors, based on submissions to *Journal of Applied Ecology* over the last 10 years (2007–2016). Single-author submissions were significantly less likely to be cited than other author number classes (pairwise *t*-tests, $p < .01$), while submissions with more than three authors were significantly more likely to be accepted than all other author number classes (pairwise *t*-tests, $p < .02$)

4 | INCREASED INTERNATIONALISATION

The increased spatial breadth of studies has been accompanied by increasingly international author teams (Leydesdorff & Wagner 2008; Witze, 2016). This internationalisation has been facilitated by dramatic changes in our ability to communicate and collaborate remotely through email and videoconferencing, and is encouraged by funding agencies promoting multinational research collaborations (e.g. European Research Council, Research Councils UK's Newton Fund, National Science Foundation's Partnerships

for International Research and Education) and the promotion of international working groups from national centres such as NCEAS (National Center for Ecological Analysis and Synthesis) and iDiv (the German Centre for Integrative Biodiversity Research). The growth in internationalisation is clearly beneficial if it supports the development and dissemination of novel ideas and good practice, and improves the chances of research being translated into national policies. Yet, potential challenges are also worth consideration. Many applied problems—and solutions—are local in nature and context-specific. Adams (2012) highlights the risk that increased internationalisation will result in a blending of objectives, resulting in science that is further from national and institutional agendas. Internationalisation could also increase the gap between practitioners and academics if international collaborations come at the expense of regional collaborations. We believe these issues can be avoided through careful co-design of study objectives, as there is no obligatory trade-off between producing results that are locally relevant (i.e. a context-specific management practice) and of broad interest in terms of theory, policy or method (Barlow et al., 2016).

5 | BROADER CONTRIBUTOR RECOGNITION AND MORE INCLUSIVE AUTHOR LISTS

Author lists could also be growing if scientists are giving greater recognition to everyone who contributes to a manuscript, from data collectors to research students. Yet longer author lists can also create issues for recognition of effort, especially for those authors who contribute significantly but are not lead authors (or last, second or corresponding). This "credit confusion" affects careers and could be problematic for the development of applied ecology if it discourages researchers from working in large networks (Reynolds, 2015). To counter this, there have been proposals to weight citation indices by author rank (Zhang, 2009) or contribution (Arandjelovic, 2016), but these revised indices have not yet gained momentum. Other approaches include detailed contributor role taxonomies (Brand, Allen, Altman, Hlava, & Scott, 2015), which aim to clarify roles and help ensure that all listed authors merit inclusion. *Journal of Applied Ecology's* approach requires all standard articles with more than one author to include an Authors' contributions statement. We also welcome manuscripts where the lead authorship is shared between one or more authors, which provides another route to share recognition between a larger set of contributing authors (Conte, Maat, & Omary, 2013).

6 | GROWTH IN THE NUMBER OF ECOLOGISTS

Finally, it may be that authorship trends reflect the growth of ecological science as a whole. There has been a rapid rise in the number of members of societies such as the British Ecological Society (which currently has nearly 6,500 members—more than 2.5 times the number of members in 1975), while UK higher education institutions now offer 383 courses with Ecology in the title (UCAS, 2017, https://digital.ucas.com/search). The field of ecology has also grown exponentially in developing countries such as Brazil (Ferreira et al. 2012). Just as the number of potential ecological interactions in a food web increases with species richness (Martinez et al. 1999), it is not surprising that with a greater pool of active, trained ecologists working in a larger number of institutions, we see an increase in the number of authors on each manuscript. Growth in the number of active ecologists is important as it offsets any potentially negative consequences of the increasing number of authors on papers, such as the possibility of homogenous thinking or becoming mired in consensus (Whitfield 2008), or the difficulty of finding independent peer reviewers.

7 | CONCLUSIONS

As the world's population is rapidly approaching 10 billion, there is broad recognition that ecological problems have reached unprecedented levels. Applied ecology appears to be meeting these challenges

though increased collaboration on research articles, resulting from the use of longer term and larger scale studies, multidisciplinary data and skill sets, improved interand transdisciplinarity and increasingly international author teams. While these changes are almost all positive, the growth in author lists raises a number of important challenges that journals, universities, research councils and government assessment panels need to consider when evaluating scientific contribution. Although the exponential increase in author number in *Journal of Applied Ecology* (Figure 1) supports Price's (1963) prediction of a "move steadily toward an infinity of authors per paper", it also seems likely that negative feedback—including issues around author recognition and the high transaction costs of working in large teams—will eventually limit the growth in authorship and move towards stability (Figure 1).

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