doi: 10.1111/brv.12185

The evolution of peer review as a basis for scientific publication: directional selection towards a robust discipline?

Catarina Ferreira[1,2,3,*], Guillaume Bastille-Rousseau[1], Amanda M. Bennett[1], E. Hance Ellington[1], Christine Terwissen[1], Cayla Austin[1], Adrian Borlestean[1], Melanie R. Boudreau[1], Kevin Chan[1], Adrian Forsythe[1], Thomas J. Hossie[1], Kristen Landolt[1], Jessica Longhi[1], Josée-Anne Otis[1], Michael J. L. Peers[1], Jason Rae[1], Jacob Seguin[1], Cristen Watt[1], Morgan Wehtje[1] and Dennis L. Murray[1]

[1] *Department of Biology, Trent University, 1600 West Bank Drive, Peterborough, K9J 7B8 Ontario, Canada*
[2] *CIBIO, InBIO - Research Network in Biodiversity and Evolutionary Biology, Universidade do Porto, Campus de Vairão, Rua Padre Armando Quintas, 4485-661, Vairão, Portugal*
[3] *Instituto de Investigación en Recursos Cinegéticos (IREC-CSIC-UCLM-JCCM), Ronda de Toledo, s/n, 13071, Ciudad Real, Spain*

ABSTRACT

Peer review is pivotal to science and academia, as it represents a widely accepted strategy for ensuring quality control in scientific research. Yet, the peer-review system is poorly adapted to recent changes in the discipline and current societal needs. We provide historical context for the cultural lag that governs peer review that has eventually led to the system's current structural weaknesses (voluntary review, unstandardized review criteria, decentralized process). We argue that some current attempts to upgrade or otherwise modify the peer-review system are merely sticking-plaster solutions to these fundamental flaws, and therefore are unlikely to resolve them in the long term. We claim that for peer review to be relevant, effective, and contemporary with today's publishing demands across scientific disciplines, its main components need to be redesigned. We propose directional changes that are likely to improve the quality, rigour, and timeliness of peer review, and thereby ensure that this critical process serves the community it was created for.

Key words: peer review, maladaptation, structural flaws, long-term solutions, critique.

CONTENTS

* Author for correspondence at address 1 (Tel: +1 (705) 748-1011 # 6127; E-mail: catferreira@gmail.com).

I. INTRODUCTION

Peer review is the process by which scientific work is gauged, consisting essentially of the assessment of manuscripts submitted for publication in a scientific journal by an independent body of qualified reviewers (i.e. peers). Herein we use 'peer-review system' (or 'peer-review process') to refer specifically to the implementation of manuscript review by the scientific community and publishers, to evaluate its scientific merit and suitability for publication. Therefore, the peer-review process is by design a procedure for distinguishing rigorous science; however, the process itself has received severe criticism following the systematic exposure of several deficiencies. For example, recent cases of scientific fraud leading to an increase in the number of retractions across fields of expertise (e.g. Grieneisen & Zhang, 2012; Tanimoto, Kami & Shibuya, 2014), in concert with the mounting difficulty in securing reviewers and obtaining high-quality reviews highlights the vulnerabilities of the peer-review system and the urgent need to address them (e.g. Relman & Angell, 1989; Siegelman, 1991; Feurer *et al.*, 1994; Aarssen & Lortie, 2009; Hochberg, 2010; Lortie, 2012).

Since its inception in the 1600s, central features of the peer-review process, such as its voluntary basis for reviewer participation, lack of tangible credit for service, its subjective nature, and reliance upon the integrity and objectivity of researchers, have remained largely unchanged (or have experienced only minor changes). This stasis in the system is notwithstanding substantial change in the academic environment and publication process during that time (Fig. 1), resulting in a considerable disconnect consistent with others observed in fields that have recently experienced rapid technological growth. For example, recent advances in medical technology (e.g. *in vitro* fertilization, stem cell technology, and gene therapy) have not met with commensurate changes in non-material culture like policy and legislation due to the injection of ethics and morality into the debate, slowing the pace of adoption and implementation of those new technologies (e.g. Marshall, 1999). Addressing such cultural lags is critical because failure to develop a consensus on how best to implement new technologies can lead to delays in their broader adoption, and thereby foster periods of stasis in cultural evolution. We suggest that the peer-review process is currently governed by a cultural lag, whereby a disconnect has arisen between the state of the science and publication technology *versus* the peer-review process itself. Ultimately, a largely static peer-review system remains the primary means of quality control for scientific knowledge, to which no fundamental, reasonable alternatives have been so far established (Smith, 2006), compromising societal goals in the effective validation of scientific discovery (Van Noorden, 2014).

The numerous shortcomings of the peer-review system have triggered passionate debate within the academic community about ways to improve it (e.g. Ware, 2008; Lortie, 2011; Nosek & Bar-Anan, 2012). Unfortunately, these proposed changes have not been critically evaluated, not received widespread adoption, or else have been slow to implement. Moreover, these potential remedies tend to address singular problems of the system and thereby lack a comprehensive approach that could help implement broad change (but see e.g. Allesina, 2012). Yet, the search for holistic solutions that mitigate the system's weaknesses is not productive without first critically assessing the peer-review process in the context of the current scientific climate and societal needs. Such a critical assessment will also ensure that all reasonable opportunities to improve peer-review efficiency, efficacy, and currency receive proper consideration (e.g. Baxt *et al.*, 1998).

Herein we revisit the history of the peer-review process and illustrate the resistance to change from its main structural features relative to changes in the scientific and publishing environment. We identify current attempts to improve the system and argue that these are unlikely to resolve longstanding structural weaknesses. We argue that large, multidirectional changes are likely required to discover new regions of the 'peer-review landscape' (*sensu* Wright, 1932) with higher peaks corresponding to greater efficiency, efficacy, and quality control in the peer-review process. We then propose future directions that we believe will allow the system to correct the mismatch and evolve to meet current scientific publishing and societal demands. Thus, the ultimate objective is to prompt discussion, debate, and developments that will reduce the lag time currently facing evolution of the peer-review process. Throughout, we focus our synthesis on the fields of ecology and evolutionary biology as being candidates for peer-review reform, with the understanding that the need for changes is ubiquitous and that our findings can apply broadly to the majority of scientific disciplines.

II. THE HISTORY OF PEER REVIEW AND THE RISE OF AN EVOLUTIONARY MISMATCH

(1) Historical flux in the peer-review system

The history of the peer-review system is well described (see e.g. Burnham, 1990; Kronick, 1990; Rennie, 1999; Biagioli, 2002). During the mid to late 1600s, western science was centralized around a few societies that had royal permission to publish scientific findings (Kronick, 1990; Biagioli, 2002;

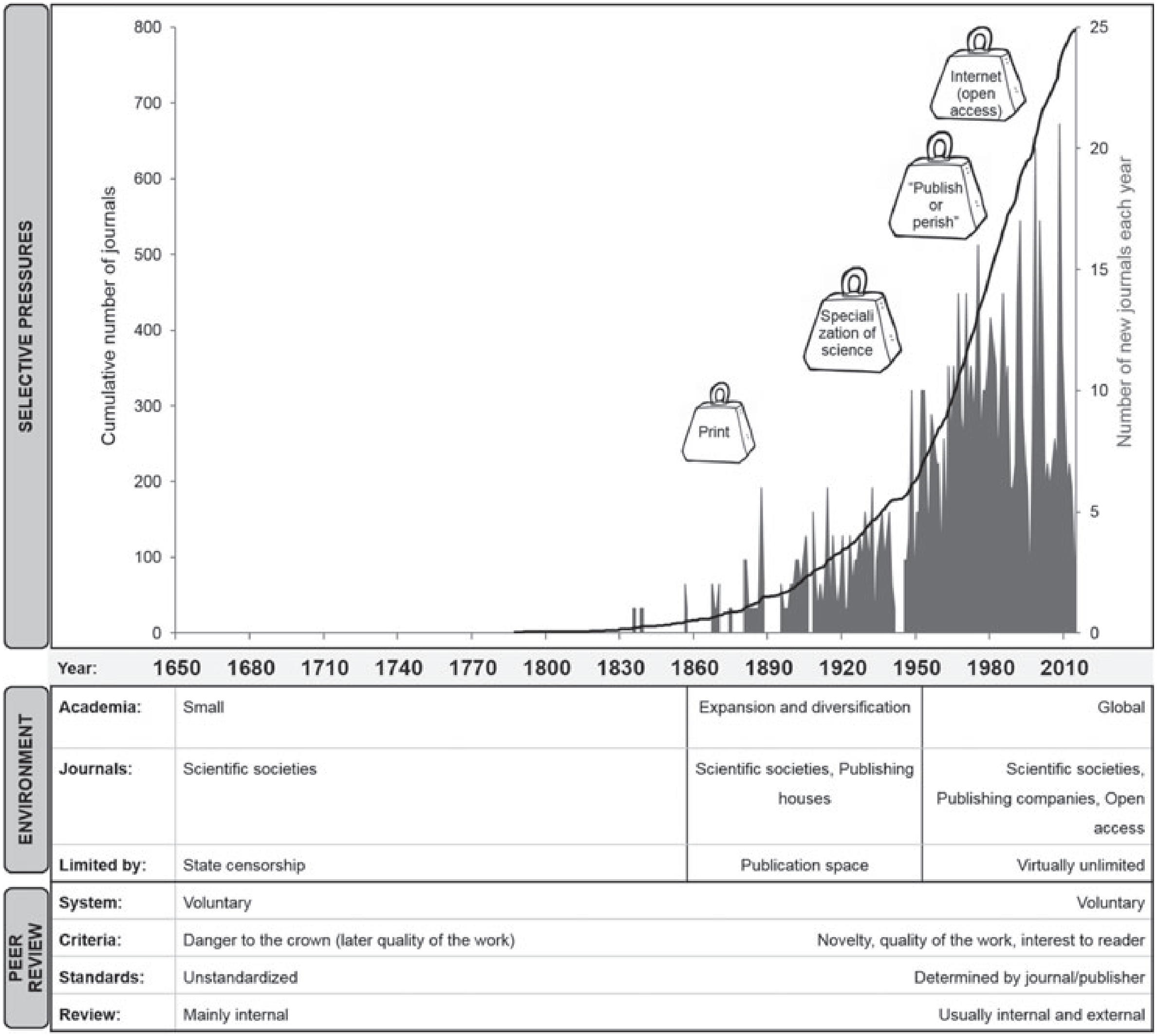

Fig. 1. Schematic representation of the mismatches between the peer-review system and the academic and publishing environment. We highlight key selective pressures (weights) that acted on the system over time. The shift in the number of journals publishing in ecology and evolutionary biology from 1650 to 2014 exemplifies the proliferation of scientific journals and represents an additional selective pressure. The total number of new journals in each year is presented as grey bars (right axis) and cumulative number of journals is shown as a black line (left axis). The bottom of the figure summarizes key changes in the academic and publishing environment and corresponding limited changes to the peer-review system.

Spier, 2002). The progenitor of the modern review system developed as a voluntary process within these societies, composed of a small body of scientists (editors and society members) who determined internally a manuscript's scientific quality and censored any danger to the crown (Kronick, 1990; Biagioli, 2002; Spier, 2002; Fig. 1). Since those early days the number of scientists and fields of active research have grown dramatically (Burnham, 1990; Gascoigne, 1992) and this trend of expansion is maintained to the present time (e.g. Cyranoski *et al.*, 2011).

A parallel expansion, diversification, and specialization of scientific journals has also governed scientific publishing. Since the mid-1800s, journals have not been the sole purview of established royal scientific societies, but instead became linked to professional societies, specialized fields, or were independently published (Biagioli, 2002). To illustrate this change, we searched for journals publishing in ecology and evolutionary biology using *Web of Science*, JSTOR, BioOne, Springer Publishing, Wiley-Blackwell, and Elsevier B.V. When possible, we used available ecology and evolution categories (e.g. browsing Elsevier's 'Ecology and Conservation' subcategory). If not available, we conducted key word searches using 'ecolog*' and 'evolution*'. We found a total of 797 journals with start years ranging from 1797 to 2014, with an estimated annual increase in the number of ecology and evolutionary biology journals averaging $2.0 \pm 0.9\%$ (mean ± S.D.) per year, between 1960 and today (Fig. 1).

The increase in the number of scientific journals inevitably augmented the amount of publication space available, which was further facilitated by the advent of new technologies, such as the invention of the linotype machine in the mid-1880s. This increase in available publication space and need to fill pages with scientific output became so great that journal editors often would relax the review system and acceptance guidelines, allowing manuscripts to be more easily published (Rennie, 1999). By the mid-1900s, the ratio of number of submissions to publication space seemed to stabilize gradually, however, after World War II, scientific output rapidly increased yet again, leading to submissions outpacing available publication space (Spier, 2002). Concomitantly, the now common practice of a two-tiered review system (internal review followed by external peer review) was first used in the late 1800s but did not become ubiquitous until the 1970s (Benos *et al.,* 2007).

(2) Shift in the role of the scientific publication and its impact on peer review

The political and economic climate post-World War II, coupled with an increasing number of scientists conducting and seeking to publish research, led science and scientific funding to become increasingly competitive (de Solla Price, 1986; Kronick, 1990). The emphasis on quantitative metrics of scientific output (i.e. number of publications, number of citations) in determining the quality of an individual scientist increased (Rennie, 1999), eventually playing a strong role in hiring and funding decisions such that the publication itself has now assumed an economic role that goes well beyond that of simply communicating science. This role has helped promote the 'publish or perish' mindset, which is now a driving force underlying scientific careers, and a strong predictor of future professional success (Van Dijk, Manor & Carey, 2014).

Journals themselves have not been immune to the economic influence on science. Given that consumers still rely heavily on metrics like the Impact Factor when deciding to which journals they should subscribe (i.e. purchase; Adam, 2002), journals may seek to publish the most novel and interesting papers which may receive more rapid citation. Therefore, this economic incentive is likely to drive many journals to encourage manuscript evaluation on the basis of novelty, importance, and reader interest, in addition to true scientific quality. This, coupled with the concept of open access, has given rise to so-called 'predatory journals' that exploit this system by charging high publication fees while not providing paid-for editorial, publishing, or archiving services, and by either poorly conducting or entirely neglecting peer review (Bohannon, 2013; Butler, 2013). Predatory journals are fast becoming a major issue in scientific publishing: thousands of journals are considered predatory and it is estimated that 5–10% of all open access articles are published by predatory journals (Butler, 2013).

The importance of publication as an economic unit has also promoted several alarming practices in academic publishing. Scientists are increasingly publishing by piecemeal: partitioning comprehensive, coherent research formerly published as a single paper into multiple smaller publications that increase an individual's perceived level of productivity. However, this increased quantity of manuscripts undoubtedly taxes the review system while having little impact on the overall merit and quality of scientific output (Nature Editorial, 2005; Martin, 2013). Additionally, the continued reliance on voluntary peer review creates a system in which altruistic players (i.e. volunteer reviewers) are potentially decreasing their academic success (i.e. fitness) by spending time reviewing others' manuscripts rather than writing their own research results. Finally, an increase in the amount of submissions has put undue pressure on the review process (e.g. Riisgård, 2003; Akst, 2010), while concurrently scientists are increasingly reluctant to devote time to peer review since publication volume, particularly in high-impact journals, is the benchmark used for receiving grants, and therefore demands priority.

If scientists have an economic incentive to publish science by piecemeal and engage in scientific fraud, and if journals have an economic incentive to publish manuscripts with a cursory peer (or editorial) review, then there is a strong potential for the publication of pseudo-science (Goldacre, 2008; Bohannon, 2013). Not surprisingly, the ease with which the review system can be abused or misused has resulted in an increase in retraction rates (e.g. the number of articles retracted per year increased by a factor of 11.36 from 2001 to 2010, after accounting for repeat offenders and increase in publication volume; Grieneisen & Zhang, 2012) due to combinations of scientific misconduct (e.g. Fanelli, 2009; Ferguson, Marcus & Oransky, 2014; Tanimoto *et al.,* 2014), and questionable data or interpretations, which often go unnoticed during the traditional review system (Vogel, Proffitt & Stone, 2004; Odling-Smee *et al.,* 2007). For example, the recent case of fraudulent reviews in the *Journal of Vibration and Control* (JVC), conducted by the author of the manuscripts himself, by using fabricated identities and template reviews, led to the retraction of 60 scholarly papers and clearly highlights the vulnerability of our current peer-review system (http://www.uk.sagepub.com/aboutus/press/2014/jul/7.htm). In their press release, JVC (and its publisher, SAGE) stated that they are committed to introducing new measures to reinforce the peer-review process, but what those measures might be remains unclear.

(3) Ultimate implications of an evolutionarily mismatched peer-review system

The peer-review system was first developed when academia was small and sought mainly to improve the quality of a scientific work through debate. However, faced with a growing number of venues for publication, a contemporary peer-review system has to address several societal needs, namely: scientific rigour, transparency and consistency in the review process, timely completion of reviews, and accountability of reviewers. In a preliminary attempt to assess how the current peer-review system performs and whether it successfully meets the aforementioned societal needs, we contacted the top journals in ecology ($N = 20$) and evolutionary biology ($N = 20$) [as listed by Google Scholar Metrics (scholar.google.ca)] for details regarding their peer-review process between March and April 2014. We looked both online for details and contacted the journals directly *via* email (see online Appendix S1 for list of questions). We removed the journal *Annual Review of Ecology, Evolution and Systematics* from our analysis because publication therein is by invitation only and consists exclusively of reviews that do not undergo a typical peer review. Since this journal appears in the top 20 list for both ecology and evolutionary biology, we ultimately included 38 journals in our analysis (Table 1). Out of the 38 journals examined, 16 replied to our request to provide information, and additional data were obtained directly from the websites of eight additional journals (total $N = 25$). Of the 25 journals, 22 (88%) were sister publications sharing the same review guidelines (e.g. *Ecology*, *Ecological Applications*, and *Ecological Monographs*: available online at http://esapubs.org/esapubs/reviewers.htm). In addition, multiple journals were published by a single publisher (Springer) that provides detailed and singular instructions for its peer-review system online through the Springer Peer Review Academy (http://www.springer.com/authors/journal+authors/peer-review-academy?SGWID=0-1741413-0-0-0). Across our sample of journals, we found 15 unique peer-review guidelines on which to base our comparison. The majority of journals we contacted published both a print and online version (89.5%), no journal published exclusively in print, and the remaining 10.5% published exclusively online. Twelve journals reported their submission and rejection rates, which ranged from 164 to 1400 submissions per year (mean = 670, median = 675), and 21–85% (mean = 62%, median = 71%) rejection rates (including submissions that were rejected without review; Table 1). Mean of the 'mean time to first decision' (assuming the manuscript passed the internal screening system) was 49 days (median = 41), although the range was 18–90 days and multiple editors commented that extensions could be made to reviewers upon request. Occasionally, timeframes could be much longer depending on the reliability and consistency of the reviewers. Most journals send manuscripts out to at least two external reviewers, chosen by the expertise of the Handling or Associate Editor, from an internal database of reviewers or from recommendations by the authors (although editors are unlikely to choose both reviewers from these recommendations; Table 1). On occasion, a third reviewer is requested, usually if the two reviews are polarized or if the Handling Editor is unsatisfied with their quality. The final decision is made by a Handling or Associate Editor, and usually one of the following decisions are made: rejection, rejection with invitation to resubmit, major revisions required, minor revisions required, or outright acceptance.

Standards for peer review are currently determined by individual journals showing no consistent format among them, as illustrated by our own survey of ecology and evolutionary biology journals (Table 1). The majority of the journals in our survey do not provide online guidelines for how reviewers should undertake manuscript peer review ($N = 22$, 58%), although some journals do provide either forms ($N = 2$) or general guidelines ($N = 7$) to reviewers after their acceptance to review a given manuscript (Table 1). Additionally, of the 15 journals for which we could obtain unique information about peer-review guidelines (see 'Review format' column in Table 1), 5 journals (33%) provide forms to reviewers with specific targets for manuscript peer review, whereas the majority provide general instructions ($N = 8$, 53%) or none at all ($N = 2$, 13%; Table 1). All reviewer guidelines allowed reviewers to make detailed comments to both the authors and the editors (confidentially). Most journals allowed reviewers to either remain anonymous or sign their reviews, with only one expressly stating that all reviews were double-blind.

Moreover, any attempt to define common standards for peer review that serve its main purpose of ensuring that only good science is published, is further complicated as the criteria governing the publication of scientific work largely relies on the power held by the publishing industry, which has specific economic interests (e.g. King, 2007; King & Tenopir, 2013). In this respect, our own survey showed the variety of publication criteria defined by ecology and evolutionary biology journals, which were not necessarily consistent among them (Fig. 2). As a result, journals were most concerned that manuscripts were comprehensible and presented a novel advancement in the field (63%; Fig. 2). Secondly, manuscripts were evaluated on their appeal to the journal's readership (relevance; 56%), the validity and appropriateness of the methods (quality of the science 56%), as well as how interesting they were in general. About a third of journals expressly evaluate whether the manuscript matches the journal's scope and formatting guidelines, and whether conclusions made by the authors were justified by the results they found. Lastly, a few journals (13%) also included an evaluation of whether the literature cited provided appropriate context for the research (Fig. 2). Therefore, the results of our own survey seem to confirm that the current peer-review system retains many criteria that were originally imposed by limited publication space, specifically coupling the importance of identifying work of high scientific quality (Castillo, 2012) with an assessment of novelty, relevance, and interest to readers (Grivell, 2006; Benos *et al.*, 2007; Fig. 2). This remains widespread today despite the advent of the digital revolution and the move away from print media creating virtually unlimited publication space.

Thus, we note a degree of entropy in the peer-review system, with publishers, societies, and individual journals dictating the criteria, publication speed, and accessibility for the communication of scientific findings. On the other hand, publishing conditions have undergone drastic changes and to some degree the peer-review system can be considered as an organism that has failed to evolve substantially in a changing environment. This mismatch creates conditions

Table 1. Summary data collected between March and April 2014 from our survey to the 38 top journals publishing in ecology and evolutionary biology

Journal	Impact factor[a]	No. submissions/ year	Online description of PR?	Internal review	No. external reviewers	How reviewers are chosen	Review format	Time frame – internal	Rejection rate – internal	Time frame – external	Rejection rate – external
Ecology Letters	17.950	-[b]	No	Editors	Mean 2.6	EXP	Form	-	-	Mean 42 days	-
*Trends in Ecology and Evolution**	15.389	249 (in 2012)	Yes	Editor	-	-	-	-	26%	21 days (0–>81; 2012)	21% (2012)
Systematic Biology	12.169	-	No	BM	Minimum 2	-	-	<1 week	-	<4 weeks	-
Molecular Biology and Evolution	10.353	>1000	No	Editors and AE	2 (1–3)	AS, EXP, LC	Open	-	-	43–46 days	27–30%
Ecological Monographs	8.085	-	Yes	-	-	-	-	-	-	-	-
*Molecular Ecology Resources**	7.432	-	No	EIC (or BM if necessary)	-	-	Form	-	-	-	-
*Global Ecology and Biogeography**	7.223	-	No	EIC and SbE (double review)	2–3	-	-	-	-	Within 3 months	-
*Molecular Ecology**	6.275	-	No	-	-	-	-	-	-	-	-
Diversity and Distributions	6.122	-	No	Editors and AE	-	AS, ED	Semi	3–5 days	-	3–4 weeks	-
Journal of Ecology	5.430	-	No	Editor	2	EXP	Semi	-	-	-	-
*Ecology**	5.175	-	Yes	Editor	≥2	-	Semi	-	-	-	-
*Ecography**	5.124	-	No	Editor	2	EXP	Semi	-	-	-	-
Cladistics	5.043	-	No	Editor	2	EXP	Semi	-	-	-	-
*Evolution**	4.864	-	No	EIC (or BM if necessary)	2	EXP	-	-	-	2 months	-
Journal of Biogeography	4.863	-	No	EIC (or BM if necessary)	2	EXP	-	-	-	-	-
Journal of Animal Ecology	4.841	-	Yes	EIC, RE, or DE	2	-	-	-	-	-	-
Genome Biology and Evolution	4.759	-	No	-	-	-	-	-	-	Mean 22 days, max 8 weeks	-
*Journal of Applied Ecology**	4.740	1400	No	Editors	2 (1–3)	ED, LC, EXP	Semi	<1 week	-	71 days	74%
*Functional Ecology**	4.680	800	No	Editors	2 (1–3)	ED, LC, EXP	Semi	<1 week	-	83 days	79%
*Evolutionary Applications**	4.153	180 (in 2013)	Yes	-	Minimum 2	EXP	Form	<1 month	-	Mean 3 months	71
Heredity	4.111	~500	Yes	Editor	2 (1–3)	EXP, ED	Form	24 h	-	Reviewers given 18-day deadline	~40%
Molecular Phylogenetics and Evolution	4.066	-	No	Editors	-	AS, EXP	-	-	Up to 50%	3 months	-
*Freshwater Biology**	3.933	-	No	-	-	-	-	-	-	29 days	-
*Ecological Applications**	3.815	-	Yes	-	-	-	-	-	-	-	-

Table 1. Continued

Journal	Impact factor[a]	No. submissions/ year	Online description of PR?	Internal review	No. external reviewers	How reviewers are chosen	Review format	Time frame – internal	Rejection rate – internal	Time frame – external	Rejection rate – external
Journal of Evolutionary Biology	3.479	-	No	-	-	-	-	-	-	-	-
*Oikos**	3.322	939	No	SE	2–3	AS, EXP	Semi	-	~33%	-	85%
BMC Evolutionary Biology	3.290	-	Yes	-	-	-	-	-	-	-	-
Ecosystems	3.165	-	Yes	-	-	-	-	-	-	-	-
*Oecologia**	3.011	470 (in 2013)	Yes	EIC (and BM if necessary)	Minimum 2	EXP, REP, AS, PREV	Form	-	-	Median: 40 days	60% (2013)
Landscape Ecology	2.897	164 (in 2010)	Yes	-	-	-	-	-	-	-	66% (2010)
Biological Invasions	2.509	-	Yes	-	-	-	-	-	-	-	-
*Biological Journal of Linnean Society**	2.413	800	Yes[b]	Editor	2–3	AS, EXP	-	-	-	-	83%
Evolutionary Ecology	2.407	-	No	-	-	-	-	-	-	-	-
Biodiversity and Conservation	2.264	-	Yes	-	-	-	-	-	-	-	-
Conservation Genetics	2.183	-	Yes	-	-	-	-	-	-	-	-
*Journal of Molecular Evolution**	2.145	-	No	EIC	Minimum 2	-	-	-	-	Extremely variable	-
Genetica	1.681	-	Yes	-	-	-	-	-	-	-	-
Systematic Botany	1.517	650–700	No	Editors	2–3	AS, EXP, ED	Open	-	-	~30 days	~75%

Asterisks indicate journals that replied to our request to provide information ($N = 16$). 'Online description of PR' refers to whether general guidelines on the peer-review process are provided on journal websites. Under 'Review Format', Form refers to the provision of standardized forms for completing manuscript peer reviews, and Semi refers to the lack of such forms (Open) but with general guidelines/instructions being provided. Dashes (-) represent missing data where it was not possible to obtain accurate information.

PR, peer review; AE, Associate Editor; EIC, Editor-in-Chief; BM, Board members; SbE, Subject Editor; RE, Review Editor; DE, Deciding Editor; SE, Senior Editor; EXP, Editor's selection based on knowledge of reviewers' expertise; AS, authors selection; LC, reviewer chosen based on literature cited in the manuscript; ED, Editorial database (database retained by journals from which to select reviewers); REP, reviewer reputation; PREV, previous experience with the journal.

[a]Impact Factors were taken from those reported on the journal's website in March 2014.

[b]Needed to create an account to access.

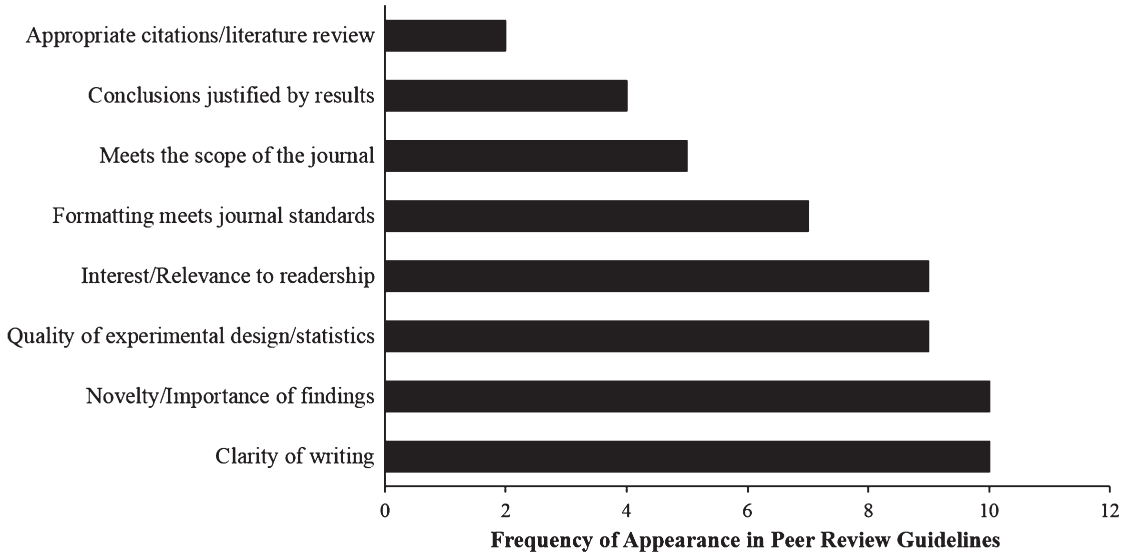

Fig. 2. Frequency of appearance of leading criteria in the peer-review guidelines of 15 journals publishing in ecology and evolutionary biology.

that do not favour a robust and efficient peer-review system, and leads to widely acknowledged setbacks for the scientific community. Accordingly, we propose that large, multi-dimensional changes are likely necessary to push the peer-review system toward novel regions of its potential evolutionary space.

III. CURRENT ATTEMPTS TO CHANGE THE SYSTEM

Faced with major issues in the peer-review system, both publishers and academics have struggled over the last decades to offer solutions that may alleviate some of the most complex problems. Solutions presented so far may be broadly classified as: (1) rewarding authors for their contributions to review, (2) standardizing peer-review protocols and leading criteria for publication by refining measures of impact of publications and speeding up the system, and (3) opening peer review to increase transparency and reviewer accountability.

(1) Voluntary peer review: rewarding the reviewers

Concerns exist about increasing rates of declining to review submitted manuscripts (e.g. for ecologists, this rate is estimated to be 49%; Lortie, 2012). Standardized performance indices ascribed to individual researchers that would take into consideration the number of reviews conducted could help sustain the voluntary review process but have yet to be implemented fully (see Veríssimo & Roberts, 2013, for a correction factor to the h-index). To date, incentives have instead been either proposed (Hauser & Fehr, 2007) or used to entice scientists into accepting reviewing opportunities (e.g. small stipends or honoraria), like those adopted by Rubriq™ (http://www.rubriq.com/), book publishers, and by select journals (e.g. BMJ; Groves, 2006). Rubriq™, in particular, is a for-benefit organization (i.e. one that generates earned income, but gives top priority to an explicit social mission) that proposes to provide standardized peer review that is independent from journals, where qualified peer reviewers are paid to review manuscripts. More commonly, small perks are offered to attract prospective reviewers, such as providing free or reduced subscription fees, annual recognition through publication of reviewer's names, awards and certificates for the best reviews, etc. (Groves, 2006; Nature Editorial, 2014). Alternatively, some initiatives, like PeerJ (https://peerj.com/), have implemented a mandatory review system to ensure continued membership, thereby alleviating the task of finding reviewers. Small one-time publishing plans, providing life-time publishing rights within the journal, require that each member perform one review per year or risk losing their publishing plan (see details in peerj.com/about/publications/#PeerJ). One additional initiative publicly to register and recognize the otherwise invisible efforts of referees is brought by Publons (https://publons.com), a New Zealand-based firm that encourages researchers to establish cross-publisher profiles by posting their peer-review histories online (Nature Editorial, 2014). Under this model, researchers can add their publisher-verified peer-review contributions to their resume *via* Official Reviewer Records (issued in the website), while applying for rewards packages. As a more extreme option, Fox & Petchey (2010) proposed to fix the problem by privatizing the peer-review system. In their proposal, reviewers would obtain credits (pubcreds), which are subsequently required when submitting a paper. For example, submission of a manuscript would cost three credits and performing a review would give one credit. All authors would need to have an account within the PubCred bank. This proposal deserves careful consideration, with the understanding that its implementation is limited by the difficulty in being trialled without the involvement of a critical mass of journals in a given field.

(2) Standardization: unifying review guidelines and leading criteria for scientific publications, through shifts in impact and speeding up the system

In its current form, peer-review standards and protocols are determined solely by scientific journals/publishers. This has generated a panoply of review guidelines, similar only across families of journals, most of which are extremely vague and subjective (Table 1). Some efforts to standardize publication criteria are taking place within groups of journals from the same publisher (e.g. British Ecological Society), and a few guides for best practices to peer review have been made available (e.g. Sense About Science; Wilson, 2012). In the particular case of ecology and evolutionary biology journals, external reviewers are occasionally provided with standardized forms to fill out (Table 1), ranging from boxes or numbers to check off corresponding to different criteria, while also asking to give brief descriptions of expectations.

Although the latter efforts clearly aim to establish a more rigorous evaluation process, peer-review guidelines are still defined individually by thousands of different journals, with little consensus among them, even within disciplines (Rennie, 1999). This is aggravated by the fact that the leading criteria ruling publication decisions may not be linked primarily to the scientific quality of the work (Table 1). For example, first-tier impact journals (e.g. *Science*, *Nature*) strongly favour novel ideas, a criterion often considered deleterious to science (Arnqvist, 2013), and that sometimes is elevated to the detriment of technically sound scientific work (Marcus & Oransky, 2011; Pennisi, 2011). Such bias could be unfavourable to both the rate of scientific innovation and quality of science, since authors try to maximize the 'sexiness' of their studies rather than the quality. To this end, newer open-access journals (e.g. *PLoS One* and *PeerJ*) have adopted a peer-review model where article quality is based solely on being technically sound rather than on novelty. This approach presents the scientific community with a selection of papers expressing a much broader range of ideas, while allowing the reader, instead of the editors and selected reviewers, to be the most powerful judge of the merits of each published submission. However, one possible disadvantage of such a model is that it can make it difficult to discover high-quality articles relevant to a specific topic when they are buried in a large assortment of articles that vary in quality and subject.

In an additional attempt to deal with divergent review criteria, recent attention has been especially directed at standardizing how impact (of publications and researchers) is measured. This has prompted development of alternatives to the classic journal Impact Factor, which applies to peer-reviewed journals but not to grey literature (Garfield, 1999). For instance, the h-index, which represents the highest number of papers that an author has that have been cited at least that many times (e.g. h-index of 5 means that an author has five papers each cited at least five times; Hirsch, 2005), provides a statistic based on an individual's scientific productivity and impact using citation rates of papers regardless of journal impact factors. Other alternatives that weigh post-publication opinions of registered members (e.g. http://www.cureus.com/siq) or mentions of an article on the web (journal, blog, etc.; e.g. http://www.altmetric.com/whatwedo.php) also have been developed, although impact assessment based on blogging/web may also be biased. *PLoS One* has developed its own method of ranking individual articles, combining modern (e.g. social media) and traditional sources, using a variety of categories including views, citations, saves, discussions and recommendations. There is evidence that some of these alternative approaches are useful for ranking research quality (Thewall *et al.*, 2013), but they offer no immediate resolution to the problem of lack of standardization across journals or disciplines. This concern highlights another concomitant problem, namely, the slowness of the peer-review process.

Previously, manuscript submission meant that authors waited several months before they received notice of the fate of the submission (Hochberg *et al.*, 2009). Owing to the advent of technologies like email and automation, the process has been shortened to an average of 3–6 weeks (ALPSP/EASE, 2000), although more commonly this timeframe ranges from 2 to 9 months (average 5 months for ecology journals; Pautasso & Schäfer, 2010). In our own survey, the editorial (internal) review process alone undertaken by ecology and evolutionary biology journals could take at least 4 weeks (Table 1). Typically, such a review was conducted by an Editor-in-Chief or a Senior Editor. About a third to half of submissions are rejected at this stage (termed 'rejected without review'), though only a few journals reported on this number ($N = 3$; Table 1). Notwithstanding some improvement in timelines between submission and editorial decision, some journals have sought to further accelerate the process by offering pre-print services for accepted manuscripts (e.g. ArXiv, bioRxiv, peerJ pre-prints, Haldane's Sieve, FigShare, Peer Evaluation and GitHub). Pre-print services allow both rapid dissemination of new ideas and immediate visibility and quick feedback (see Desjardins-Proulx *et al.*, 2013, for a broader discussion of pre-print advantages). Portable peer review is another way to speed up the system, as it allows previous reviews to be associated with the manuscript. For example, in May 2013, the Welcome Trust, BioMed Central (BMC), the Public Library of Science (PLoS) and the European Molecular Biology Organization, announced that they will allow authors of papers rejected from their journals the opportunity to make those reviews available to other publishers. Currently, Peerage of Science is the leader in this approach (others include e.g. Axios Review, http://axiosreview.org), as it allows multiple journals to look at the reviews produced internally and make an offer of publication to the authors regarding their manuscript. Lastly, some services (like F1000 Research) simply remove the pre-publication review system altogether and rely only on a post-publication review and comments (Smith, 2010). Each of these solutions has the potential to speed up the review process and reduce load on the peer-review system. However, the diversity of current approaches highlights the unresolved lack of standardization that pervades the peer-review system.

(3) Transparency: opening up the peer-review system

The lack of standardization and structure across journals extends also to the transparency of the review process itself. For example, some journals require reviewer disclosure whereas the majority allow retention of reviewer anonymity. Yet, reviewer anonymity can promote a lack of accountability that facilitates editorial decisions based on poorly justified criticisms and the lack of constructive comments (Suls & Martin, 2009). Identifying reviewers (the so-called 'open peer review') was first seen in BMJ in 1999, and since then the journal does not allow anonymous review (Smith, 1999). This type of system has also been used by the publishing service Peerage of Science, the online journal *PeerJ*, and by F1000 Research. Still, a general fear of future retribution for unfavourable reviews is at the heart of low acceptance to review non-anonymously (Suls & Martin, 2009; Nature Editorial, 2014), alongside an increased tendency to accept a manuscript for publication when reviewers are identified (Godlee, 2002). Even high-impact journals like *Nature* have dismissed the possibility of open peer review, because it was not deemed to be widely popular either among authors or by journal readership, following a brief trial period (see Greaves *et al.*, 2006). Therefore, despite this recent exploration, open peer review has yet to be widely embraced by reviewers and publishers.

However, open peer review can increase the quality of the reviews; reviewer accountability is taken a step further in Peerage of Science by subjecting reviews themselves to a peer review (a system known as PROPR – 'peer review of peer review'). In this system, each review is sent to all of the reviewers of the manuscript, and each reviewer gives a rank to each review (see peerageofscience.org/how-it-works). A fairly similar approach is taken by the journal *Science*, now offering the opportunity for cross-review. This means that once all reviews for a submitted paper are received, each individual reviewer will be invited to read the other reviews and make additional comments/edits to their own review before a final editorial decision is made (http://www.sciencemag.org/site/feature/contribinfo/review.xhtml). eLife (http://elifesciences.org) also provides a similar model, wherein timelines are guaranteed to be quick by providing a single consolidated list of comments (instead of two or three potentially conflicting sets of reviews), with specific instructions about any needed modifications to the manuscript. Also, pending author approval, the review, decisions, and responses can be made public to increase transparency. Doubtless, such changes in transparency increase the incentive for high-quality reviews by imposing consequences for substandard reviews, although they have the added cost of intensifying the commitment expected from reviewers. This may result in limited support for such a system. Nevertheless, these efforts still represent isolated attempts to increase standardization of peer-review criteria by increasing the degree of independence between reviewers and publishers. In our assessment, this increased independence is essential as a basis for improvements to the peer-review system.

IV. PEER REVIEW: TIME FOR AN EVOLUTIONARY LEAP?

Peer review currently represents a largely antiquated system that struggles to serve its original intent effectively. A call for 'radical' changes to the system has been made previously (e.g. Campanario, 1997; Smith, 1997; Hochberg *et al.*, 2009; Buchanan, 2010; Birukou *et al.*, 2011), and the aforementioned attempts to improve it are testament to the fact that the status quo is simply not adequate and that scientists are eager for progress in the discipline. The mismatch between current scientific needs and the publishing process *versus* the peer-review system represents a lag in cultural evolution that has not been eliminated despite major environmental perturbations and related selective pressures that otherwise could have prompted widespread change in the process. This cultural lag is becoming increasingly apparent by, for example, a recent call for the abolition of journal abbreviations in the digital era (Bond & Green, 2014) where actual printing costs are becoming increasingly obsolete.

That recent attempts to revise the peer-review system have failed to result in lasting change strongly suggests that large and/or multi-dimensional shifts are required for the system to evolve towards significant improvement. Hence, change of the peer-review system requires a cohesive and collective attempt to address weaknesses that are now so evident (Table 2). Such change can arise, in part, through adoption or modification of some of the aforementioned options that are currently being explored.

(1) The long-term alternatives: directional selection in the system

(*a*) *To review or not to review: dealing with altruism*

That researchers are becoming increasingly unwilling or unable to review altruistically and in a timely manner, suggests that the voluntary feature of the peer-review process is simply not sustainable over the long term. All of the short-term attempts to mitigate this problem rely on some form of reviewer compensation. Still, in a world where digitization of information and accessibility likely will increase even further the demand on peer review, perhaps the only way forward will be to make peer review to some degree mandatory for publishing scientists. This would imply unequivocally incorporating the time allocated to reviewing other researchers' works in the researcher's performance assessment indices, using any of the metrics already proposed (e.g. Veríssimo & Roberts, 2013) or new

Table 2. Major current structural weaknesses of the peer-review system. Mismatches arise from changes in the scientific publishing environment but a lack of corresponding changes in the peer-review system. We include current short-term solutions provided by publishers/academics as well as potential longer-term solutions to these weaknesses

	Proposed solutions	
Peer-review weaknesses	Short term	Long term
Voluntary	Rewarding reviewers (e.g. monetary, Pubcreds, mentions and awards)	Mandatory (based on researcher's experience and productivity)
Unstandardized (diversity and nature of the leading criteria)	Standardization of leading criteria and guidelines (across families of journals/publishers)	Design formal peer-review guidelines shaped according to field of expertise
	Changing view on impact of publications and researchers	Incorporate reviewer training in academic curricula (increasing scientific literacy, including of the scientific method)
	Speeding up the system	
Decentralized (dictated by publishers)	Increasing transparency by opening up the system	Creation of Global Peer Review Platform that reclaims the system

ones to be developed. A balanced way to implement a mandate on peer review would be to determine a minimum number of reviews a researcher would be required to make, perhaps in proportion to the total number of papers published by the individual over a period of one or more years. For instance, an early career researcher might publish 1–2 papers per year and would be expected to review a comparable number of papers during a similar time period; established researchers might have a higher review load that is commensurate with their productivity. It follows that any additional reviews by both junior and senior researchers over the minimum required would be strictly voluntary. Credit could be given for related work that also is deemed 'altruistic', such as journal editorships, grant proposal reviews, and sitting on boards of professional societies. This system could provide overall performance ratings that could be used in other adjudication such as faculty tenure, promotion, and merit. Naturally, a mandatory system does not necessarily ensure that peer reviews will be high quality, and in fact some individuals may seek to cheat the system by conducting substandard reviews (however, this could be prevented through open peer review). Multi-dimensional solutions are more likely to work in this case (e.g. by eventually paying reviewers) even within a mandatory system. In isolation, either solution (mandatory reviews or paying reviewers) has failed to meet current needs, but together they may provide a more robust solution (i.e. being paid should help mitigate shoddy mandatory reviews, and mandatory paid reviews retain incentives even when the reviewer is not financially motivated). Still, the widespread adoption of a mandatory peer review calls for standardization and centralization of the system, which remains perhaps the most challenging impediment to date.

(*b*) *Standardization of independent peer review*

The way peer-review guidelines have been implemented is highly variable among scientific journals, ultimately to the detriment of authors and science in general. Moreover, current partial efforts (e.g. standardization across families of journals) are unlikely to produce long-term or substantive changes to peer review. Rather, a movement towards standardization has to be led by the community of scientists and thereby be driven independently of publishers and scientific journals. If peer review aims to evaluate scientific work, it makes sense that the guidelines for that assessment be set by scientists (not publishers). Additionally, if the peer review system is to return to its original purpose of discriminating between good *versus* poor science, scientists (not publishers) need to find consensus about what leading criteria must be applied successfully to accomplish this, perhaps independently of those that are promoted by publishers and driven by economics. This could mean that criteria like novelty and interest to readers probably could be downgraded to some extent, although some degree of fine-tuning for specific disciplines is to be expected as in some rapidly growing fields there may be more priority on technical novelty than in more established fields. In any case, standardization would provide sound opportunities to improve the quality of the communication of scientific findings. For example, standardization could require the incorporation of fundamental data often missing from scientific publications (like effect size, variance, and sample size, Ellington *et al.*, 2014) or reinforce the implementation of the scientific method through the establishment of formulaic prose for information like hypotheses, predictions and methods, frequently understated in many fields of scientific research (Platt, 1964; Wolff & Krebs, 2008). Such long-term change brought about through standardization would allow researchers to more efficiently scan articles and assess key points of their study design.

A way of ensuring long-lasting peer-review standards would be to incorporate appropriate training in academic curricula and conference workshops. Such training is already offered by select publishers (e.g. Springer's Author Academy), although they are inevitably focused on their own peer-review guidelines. Since there is a general and largely ubiquitous lack of knowledge about the peer-review system within the scientific community, improved education on its process and pitfalls will benefit a momentum towards new solutions. Therefore, if scientists know what rules to follow, it will be easier to implement a mandatory system. However, implementing a standardized peer-review model will almost certainly be intractable without centralizing the system.

(*c*) *Centralization: giving peer review back to the scientific community*

Currently, most of the players in the peer-review game have little incentive to change their behaviour drastically in the short term, meaning that relatively few will willingly transition to a mandatory and standardized system. For example, many publishers have a vested interest in protecting the status quo because they stand to lose power and are open to critical scrutiny if the system changes (Jennings, 2006; Bohannon, 2013); this poses a serious obstacle to progress on this front.

A potential solution could arise by decoupling the peer-review system from journal publishing. Although this may prove to be challenging, such a radical call is not without precedent. For example, the establishment of Genbank, a repository for genetic profile information (Benson *et al.*, 2008), is a clear example that collective efforts by scientists can prompt adoption of worldwide community standards that are accepted by publishers. Genbank currently represents the most important and influential genetic sequence database in almost all biological fields, and submissions to Genbank are often mandatory prior to publishing in the field of genetics. Similarly, other international standards organizations have arisen that illustrate the community-driven establishment of standards and practices, consensus processes, and collaborative efforts, both inside and outside the scientific world (see online Appendix S2). Many of these standards have naturally evolved from those designed in-house by industry or by a particular country, while others have been built by groups of community-minded experts.

In the case of peer review, current partial efforts are clearly being made independently to take peer review away from publishers. This is illustrated by Peerage of Science and Rubriq$^{\mathrm{TM}}$, although other external committees have been formed to offer guidance to editors and improve standards through networking and education. These include organizations such as the Council of Science Editors (which sets standards for editing), the World Association of Medical Editors, and the Committee on Publication Ethics (which evaluates codes of conduct for editors and shares information on dealing with problems). Although the majority of members and participating journals have a biomedical focus, editors of all scientific journals are encouraged to draw on these organizations for resources, advice and support in developing their own policies and procedures. Therefore, a complete control of the peer-review system by the scientific community may be possible, although it would likely require the establishment of an independent regulatory entity, for example, a Global Peer Review Platform (GLOPERP). The model for such a platform could build upon worldwide professional organizations that represent neutral forums for scientists, and that issue global standards (e.g. International Union for Conservation of Nature; see online Appendix S2).

Regardless of its format, there are clear advantages for the development of such a platform. First, it would be solely responsible for defining the rules for peer review by designing the protocols/guidelines and standardizing criteria according to field of expertise. This would streamline peer review, increasing its speed, fairness and objectivity, thereby benefiting both authors and editors/publishers. Part of the standardization process would require the design of training workshops for peer review, with specific curricula shaped to a given field of expertise by this centralized entity. Second, through a system of registration and membership, such an entity would be a valuable repository for a database of potential reviewers, stratified by field and degree of expertise. The admission of potential members to this database could include formal interview panels and research-assessment exercises, as a way to ensure quality control (Groves, 2006). If the peer-review system becomes mandatory, an evaluation of the reviews would be vital but simplified. Similarly, such a platform would be instrumental in informing publishers of potential reviewers, substantially decreasing the time spent in the process of reviewer selection and minimizing the risk of unhelpful/unqualified reviews. This would also benefit young researchers, whose willingness to perform reviews is sometimes undermined by a lower number of review invitations (Donaldson *et al.*, 2010; Petchey, Fox & Haddon, 2014). Moreover, centralizing such a database would be an asset for ‘interdisciplinary peer review’ (different reviewers from different fields), facilitating the dissemination of interdisciplinary work that is often blocked by its unique set of challenges for peer review, for which many traditional single-discipline journals are not fully prepared (Lee, 2006). Third, such a platform could potentially exert counter-control of publishers, certifying journals that regularly demonstrate the implementation of peer-reviewing standards defined by the platform (e.g. journal’s performance database), or, by contrast, keeping a list of journals with editorial misconduct, providing recourse for authors and reviewers who have been unfairly treated (Lee & Bero, 2006). Fourth, building on the model developed by the biomedical sciences (http://www.peerreviewcongress.org/index.html), this platform could be responsible for the organization of a World Peer Review Congress to help disseminate not only common challenges to peer review but also transversal solutions between fields of expertise.

V. CONCLUSIONS

(1) The peer-review system was created to ensure the communication of quality science. Over time, a cultural lag emerged from a slow-to-change peer-review system that has created a mismatch between this process and contemporary

needs. Currently, the system is characterized by several structural flaws (voluntary review, unstandardized review criteria, decentralized process) that have led to weakened efficiency, efficacy, and quality control. We suggest that the current peer-review system is trapped on what can be considered an adaptive peak in the 'peer-review landscape'. Scientists – not people or organizations with vested interests in maintaining the current system – should be deciding what qualifies as publishable science. As such, scientists need to choose conscientiously to adopt a new system, rather than wait for the environment to alter selection pressures sufficiently for the system to adapt to modern conditions on its own. Moreover, without large and/or multi-dimensional changes, any deviation from the current peer-review system is unlikely to have positive, long-lasting effects.

(2) We propose three main directional changes in the current peer review system that we expect will rapidly mitigate the structural flaws identified herein. These include: (*i*) making peer review mandatory and eventually coupling it with paid reviews; (*ii*) standardizing the review criteria and guidelines for review by field of expertise; and (*iii*) creating a Global Peer Review Platform, responsible for the centralization of the process (including the aforementioned standardization).

(3) To our knowledge, the means for optimizing the peer-review system has received no formal scientific study. Such investigations should examine not only how to optimize the peer-review system, but also how to transition effectively to an improved system (e.g. mandatory, standardized and the creation of GLOPERP). Specifically, evolutionary game theory provides an appropriate theoretical framework to discover future directions for the peer-review system to evolve. Important insights could arise by modelling scenarios of non-cooperative *versus* cooperative games and empirically testing predictions arising from these models. Some key challenges to defining these directions properly will include: (*i*) non-adaptive aspects influencing peer review (e.g. establishment of reputation); (*ii*) proper identification of the players in each game (e.g. authors/reviewers *versus* editors/publishers, or authors/reviewers *versus* publishers); and (*iii*) the deconstruction of the peer-review system into simple, representative scenarios that can be modelled within this framework (e.g. voluntary *versus* mandatory peer review, open access *versus* subscription journals).

VI. ACKNOWLEDGEMENTS

All authors were supported by grants to D.L.M. from the Natural Sciences and Engineering Research Council (Canada) and the Canada Research Chairs program; C.F. was additionally funded by a Post-Doctoral grant (Ref. SFRH/BPD/88643/2012) from the Fundação para a Ciência e Tecnologia of the Ministério da Ciência, Tecnologia e Ensino Superior, Portuguese government, and by a Marie Curie Outgoing International Fellowship for Career Development (PIOF-GA-2013-621571) within the 7th Framework Programme of the European Union.[1]

VII. REFERENCES

Aarssen, L. W. & Lortie, C. J. (2009). Ending elitism in peer-review publication. *Ideas in Ecology and Evolution* **2**, 18–20.

Adam, D. (2002). Citation analysis: the counting house. *Nature* **415**, 726–729.

Akst, J. (2010). I hate your paper. *The Scientist Magazine* **24**, 36–41.

Allesina, S. (2012). Modeling peer review: an agent-based approach. *Ideas in Ecology and Evolution* **5**(2), 27–35.

ALPSP/EASE (2000). *Current Practice in Peer Review. Results of a Survey Conducted during Oct/Nov 2000*, Worthing: Association of Learned and Professional Society Publishers, http://www.alpsp.org/peeref.pdf.

Arnqvist, G. (2013). Editorial rejects? Novelty, schnovelty!. *Trends in Ecology & Evolution* **28**(8), 448–449.

Baxt, W. G., Waeckerle, J. F., Berlin, J. A. & Callaham, M. L. (1998). Who reviews the reviewers? Feasibility of using a fictitious manuscript to evaluate peer reviewer performance. *Annals of Emergency Medicine* **32**(3), 310–317.

Benos, D. J., Bashari, E., Chaves, J. M., Gaggar, A., Kapoor, N., Lafrance, M., Mans, R., Mayhew, D., McGowan, S., Polter, A., Qadri, Y., Sarfare, S., Schultz, K., Splittgerber, R., Stephenson, J., Tower, C., Walton, R. G. & Zotov, A. (2007). The ups and downs of peer review. *Advances in Physiology Education* **31**(2), 145–152.

Benson, D. A., Karsch-Mizrachi, I., Lipman, D. J., Ostell, J. & Wheeler, D. L. (2008). GenBank. *Nucleic Acids Research* **36**, D25–D30.

Biagioli, M. (2002). From book censorship to academic peer review. *Emergences* **12**(1), 11–44.

Birukou, A., Wakeling, J. R., Bartolini, C., Casati, F., Marchese, M., Mirylenka, K. & Wassef, A. (2011). Alternatives to peer review: novel approaches for research evaluation. *Frontiers in Computational Neuroscience* **5**, 1–11.

Bohannon, J. (2013). Who's afraid of peer review? *Science* **342**, 60–65.

Bond, A.L. & Green, J.R. (2014). Journal title abbreviations should be eliminated in the digital age. *PeerJ PrePrints* 2:e445v1 (https://dx.doi.org/10.7287/peerj.preprints.445v1).

Buchanan, M. (2010). Come the revolution. *Nature Physics* **6**, 2.

Burnham, J. C. (1990). The evolution of editorial peer review. *The Journal of the American Medical Association* **263**(10), 1323–1329.

Butler, D. (2013). The dark side of publishing. *Nature* **495**(7442), 433–435.

Campanario, J. (1997). The journal scout. *The Scientist* **11**, 9.

Castillo, M. (2012). Peer review: past, present, and future. *American Journal of Neuroradiology* **33**, 1833–1835.

Cyranoski, D., Gilbert, N., Ledford, H., Nayar, A. & Yahia, M. (2011). Education: the PhD factory. *Nature* **472**, 276–279.

Desjardins-Proulx, P., White, E. P., Adamson, J. J., Ram, K., Poisot, T. & Gravel, D. (2013). The case for open preprints in biology. *PLoS Biology* **11**, e1001563.

Donaldson, M. R., Hasler, C. T., Hanson, K. C., Clark, T. D., Hinch, S. G. & Cooke, S. J. (2010). Injecting youth into peer-review to increase its sustainability: a case study of ecology journals. *Ideas in Ecology and Evolution* **3**, 1–7.

Ellington, E.H., Bastille-Rousseau, G., Austin, C., Landolt, K.N., Pond, B.A., Rees, E.E., Robar, N. & Murray, D.L. (2014). Using multiple imputation to estimate missing data in meta-regression. *Methods in Ecology and Evolution* **6**(2), 153–163.

Fanelli, D. (2009). How many scientists fabricate and falsify research? A systematic review and meta-analysis of survey data. *PLoS One* **4**(5), e5738.

Ferguson, C., Marcus, A. & Oransky, I. (2014). The peer review scam. *Nature* **515**, 480–482.

Feurer, I. D., Becker, G. J., Picus, D., Ramirez, E., Darcy, M. D. & Hicks, M. E. (1994). Evaluating peer reviews: pilot testing of a grading instrument. *The Journal of the American Medical Association* **272**(2), 98–100.

Fox, J. & Petchey, O. (2010). Pubcreds: fixing the peer review process by "privatizing" the reviewer commons. *Bulletin of the Ecological Society of America* **91**, 325–333.

Garfield, E. (1999). Journal impact factor: a brief review. *Canadian Medical Association Journal* **161**(8), 979–980.

Gascoigne, R. (1992). The historical demography of the scientific community, 1450–1900. *Social Studies of Science* **22**(3), 545–573.

[1]Correction added on 17 February 2016, after first online publication: Additional information in the acknowledgement section has been added on this version to appropriately acknowledge additional source of funding.

Godlee, F. (2002). Making reviewers visible: openness, accountability, and credit. *The Journal of the American Medical Association* **287**(21), 2762–2765.
Goldacre, B. (2008). *Bad Science*. Fourth Estate, London.
Greaves, S., Scott, J., Clarke, M., Miller, L., Hannay, T., Thomas, A. & Campbell, P. (2006). Nature's trial of open peer review. *Nature* (doi: 10.1038/nature05535).
Grieneisen, M. L. & Zhang, M. (2012). A comprehensive survey of retracted articles from the scholarly literature. *PLoS One* **7**(10), e44118.
Grivell, L. (2006). Through a glass darkly: the present and the future of editorial peer review. *The European Molecular Biology Organization* **7**(6), 567–570.
Groves, T. (2006). How can we get the best out of peer review? *Nature* (doi: 10.1038/nature04995).
Hauser, M. & Fehr, E. (2007). An incentive solution to the peer review problem. *PLoS Biology* **5**(4), e107.
Hirsch, J. E. (2005). An index to quantify an individual's scientific research output. *Proceedings of the National Academy of Sciences of the United States of America* **102**, 16569–16572.
Hochberg, M. E. (2010). Youth and the tragedy of the reviewer commons. *Ideas in Ecology and Evolution* **3**, 8–10.
Hochberg, M. E., Chase, J. M., Gotelli, N. J., Hastings, A. & Naeem, S. (2009). The tragedy of the reviewer commons. *Ecology Letters* **12**, 2–4.
Jennings, C. (2006). The true purpose of peer review. *Nature* (doi: 10.1038/nature05032).
King, D. W. (2007). The cost of journal publishing: a literature review and commentary. *Learned Publishing* **20**, 85–106.
King, D. W. & Tenopir, C. (2013). Some economic aspects of the scholarly journal system. *Annual Review of Information Science and Technology* **45**(1), 295–366.
Kronick, D. A. (1990). Peer review in 18th-century scientific journalism. *Journal of the American Medical Association* **263**, 1321–1322.
Lee, C. (2006). Peer review of interdisciplinary scientific papers. *Nature* (doi: 10.1038/nature05034).
Lee, K. & Bero, L. (2006). Increasing accountability. *Nature* (doi: 10.1038/nature05007).
Lortie, C. J. (2011). Money for nothing and your referees for free. *Ideas in Ecology and Evolution* **4**, 43–47.
Lortie, C. L. (2012). May the odds be ever in your favor: a brief comment on the review games in ecology. *Immediate Science Ecology* **1**, 1–6.
Marcus, A. & Oransky, I. (2011). Science publishing: the paper is not sacred. *Nature* **480**, 449–450.
Marshall, P. (1999). Has technology introduced new ethical problems? *Journal of Business Ethics* **19**(1), 81–90.
Martin, B. R. (2013). Whither research integrity? Plagiarism, self-plagiarism and coercive citation in an age of research assessment. *Research Policy* **42**(5), 1005–1014.
Nature Editorial (2005). The cost of salami slicing. *Nature Materials* **4**, 1 (doi: 10.1038/nmat1305).
Nature Editorial (2014). Review rewards. *Nature* **514**, 274.
Nosek, B. A. & Bar-Anan, Y. (2012). Scientific utopia: I. Opening scientific communication. *Psychological Inquiry: An International Journal for the Advancement of Psychological Theory* **23**(3), 217–243.
Odling-Smee, L., Giles, J., Fuyuno, I., Cyranoski, D. & Marris, E. (2007). Where are they now? *Nature* **445**(7125), 244–245.
Pautasso, M. & Schäfer, H. (2010). Peer review delay and selectivity in ecology journals. *Scientometrics* **84**, 307–315.
Pennisi, E. (2011). Concerns about arsenic-laden bacterium aired. *Science* **332**, 1136–1137.
Petchey, O.L., Fox, J.W. & Haddon, L. (2014). Imbalance in individual researcher's peer review activities quantified for four British Ecological Society journals, 2003–2010. *PLoS One*, **9**(3), e92896 (doi: 10.1371/journal.pone.0092896).
Platt, J. R. (1964). Strong inference. *Science* **146**(3642), 347–353.
Relman, A. S. & Angell, M. (1989). How good is peer review? *The New England Journal of Medicine* **321**, 827–829.
Rennie, D. (1999). Editorial peer review: its development and rationale. In *Peer Review in Health Sciences* (eds F. Godlee and T. Jefferson), pp. 3–13. BMJ Books, London.
Riisgård, H. U. (2003). Misuse of the peer-review system: time for countermeasures? *Marine Ecology - Progress Series* **258**, 297–309.
Siegelman, S. S. (1991). Assassins and zealots: variations in peer review. *Radiology* **178**, 637–642.
Smith, R. (1997). Peer review: reform or revolution? *The British Medical Journal* **315**, 759–760.
Smith, R. (1999). Opening up BMJ peer review. a beginning that should lead to complete transparency. *The British Medical Journal* **318**, 4–5.
Smith, R. (2006). Peer review: a flawed process at the heart of science and journals. *Journal of the Royal Society of Medicine* **99**, 178–182.
Smith, R. (2010). Classical peer review: an empty gun. *Breast Cancer Research* **12**, S13.
de Solla Price, D. J. (1986). *Little Science, Big Science... and Beyond*. Columbia University Press, New York,.
Spier, R. (2002). The history of the peer-review system. *Trends in Biotechnology* **20**(8), 357–358.
Suls, J. & Martin, R. (2009). The air we breathe: a critical look at practices and alternatives in the peer review process. *Perspectives on Psychological Science* **4**, 40–50.
Tanimoto, T., Kami, M. & Shibuya, K. (2014). Japan to learn from biomedical cases. *Nature* **512**(7515), 371.
Thewall, M., Haustein, S., Lariviere, V. & Sugimoto, C. R. (2013). Do altmetrics work? Twitter and ten other social web services. *PLoS One* **8**(5), 1–7.
Van Dijk, D., Manor, O. & Carey, L. B. (2014). Publication metrics and success on the academic job market. *Current Biology* **24**(11), 516–517.
Van Noorden, R. (2014). Publishers withdraw more than 120 gibberish papers. *Nature* (doi: 10.1038/nature.2014.14763).
Veríssimo, D. & Roberts, D. L. (2013). The academic welfare state: making peer-review count. *Trends in Ecology & Evolution* **28**(11), 623–624.
Vogel, G., Proffitt, F. & Stone, R. (2004). Ecologists roiled by misconduct case. *Science* **303**(5658), 606–609.
Ware, M. (2008). Peer review in scholarly journals: perspective of the scholarly community – Results from an international study. *Information Services & Use* **28**, 109–112.
Wilson, J. (2012). Peer review: the nuts and bolts. *Sense About Science*, Available at http://www.senseaboutscience.org/data/files/resources/99/Peer-review_The-nuts-and-bolts.pdf Accessed 15.4.2014
Wolff, J. O. & Krebs, C. J. (2008). Hypothesis testing and the scientific method revisited. *Acta Zoologica Sinica* **54**, 383–386.
Wright, S. (1932). The roles of mutation, inbreeding, crossbreeding, and selection in evolution. *Proceedings of the Sixth International Congress of Genetics* **1**, 356–366.

VIII. SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article.

Appendix S1. List of questions addressed to the 38 top journals of ecology and evolutionary biology surveyed for this study.

Appendix S2. Examples of international standards platforms, inside and outside the scientific community.

(*Received 31 August 2014; revised 13 March 2015; accepted 18 March 2015*)