

Open access increases citations of papers in ecology

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Abstract. Open access (OA) can effectively increase the accessibility and visibility of scientific articles and thus potentially confer them with citation advantages. Such an impact may be more pronounced in developing countries where the cost for journal subscription is comparably expensive and usually unaffordable. By comparing one OA article with one non-OA article published in the same issue, we tested the impact of OA on citation advantages of articles published in 46 ecology journals indexed in the Journal Citation Reports (JCR). We compared OA to non-OA articles published in the same issue of these journals, thereby controlling for potentially confounding effects of publication requirement and period. OA articles received significantly more citations than non-OA articles, and this citation advantage of approximately one citation per year was sustained across publication years from 2009 to 2013. The OA citation advantage did not depend upon income of the country of origin of the citing scientists, and the OA citation advantage was found for citing scientists from North America, Europe, Asia, Africa, and Oceania, but not for Latin America. A total of 10 countries contributed more than 1000 citations each, and the OA citation advantage was found in all the 10 countries except Canada. Therefore, in ecology journals OA confers articles with citation advantages and such an impact accumulates with years and independent of the economic status of the countries. This information may guide decisions of scientific societies, journals, and individual authors as they weigh the relative costs and benefits of open electronic accessibility of scientific research.

Key words: citation advantage; citation pattern; gross national income; hybrid journals; open access.

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INTRODUCTION

In the recent decades, there has been a rapid growth of open access (OA) publishing (Craig et al. 2007, Swan 2010, Wagner 2010, Moed 2012). The number of gold OA journals (i.e., those publish only OA articles, such as *Ecosphere*) has increased from 4767 in 2009 to 10,528 in 2015 (Björk and Solomon 2012, DOAJ 2015). Open access can effectively increase the accessibility and potentially the visibility of articles, especially during the first year after publication (Brody et al. 2006, Davis 2010, Wang et al. 2015). Furthermore, OA articles have steady and sustained downloads for a relatively longer time compared

to non-OA ones (Davis et al. 2008, Davis 2010, Wang et al. 2015). These impacts can potentially confer OA articles with citation advantages.

Many studies have analyzed impacts of OA on citation advantages of articles, but the results are inconsistent (Lawrence 2001, Craig et al. 2007, Moed 2007, Davis et al. 2008, Calver and Bradley 2010, Laakso et al. 2011). Lawrence (2001) first reported that OA could increase citation advantages in computer science and related disciplines. His conclusion has received support (Antelman 2004, Hajjem et al. 2005, Eysenbach 2006, Harnad et al. 2008, Norris et al. 2008, Evans and Reimer 2009, Gargouri et al. 2010, Riera and Aibar 2013, Clements 2017). In a review, for instance, OA

citation advantages were reported in 27 out of 31 studies of different disciplines, including computer science (Lawrence 2001), physics and mathematics (Harnad and Brody 2004), electric and electronic engineering (Antelman 2004), and political science (Atchison and Bull 2015). However, there are also many studies showing that OA did not confer citation advantages to articles (Kurtz et al. 2005, Moed 2007, Davis et al. 2008, Calver and Bradley 2010). For instance, OA citation advantages were not found for articles published in journals of high-energy physics (Gentil-Beccot et al. 2010), in journals of the American Physiological Society (Davis et al. 2008, Davis 2010), in journals of conservation biology (Calver and Bradley 2010), and in low-impact civil engineering journals (Koler-Povh et al. 2014).

Numerous factors are involved in the evaluation of the impacts of OA (Eysenbach 2006, Davis et al. 2008, Lansingh and Carter 2009, Gaule and Maystre 2011, McCabe and Snyder 2014, 2015). The number of authors, country of publication, subject area, language, funding sources (Lansingh and Carter 2009), and the rank/quality of journals (Koler-Povh et al. 2012, 2014, Xia and Nakanishi 2012, McCabe and Snyder 2014) can significantly influence the citation advantages of OA articles. It has also been argued that authors may prefer to put their most important work to OA (self-selection bias effect) and that articles might be cited more when they appear online sooner (early access effect; Kurtz et al. 2005). Thus, the OA effect may not be so definite and consistent (Kurtz et al. 2005, Moed 2007, Gentil-Beccot et al. 2010, Gaule and Maystre 2011), especially in the fields of astronomy and physics. In these fields, scientists have traditionally deposited their articles, including pre- and post-print versions, in OA repositories or personal websites (Evans and Reimer 2009). Hassall (2012) also found that a high proportion (52%) of papers published in 165 ecology and evolution journals in 2011 have been self-archived.

Most of the studies mentioned above only investigated whether there are citation advantages of OA articles and possible factors that can influence it. However, few studies have been carried out to analyze the citing patterns of OA articles (Evans and Reimer 2009, Frandsen 2009, Calver and Bradley 2010). One advantage of OA is that it may provide free access to authors from

developing countries where the cost for journal subscription is comparably expensive and usually unaffordable. Therefore, authors from developing countries may benefit more from, and consequently also cite more, OA articles than those from developed countries. Similarly, authors from regions with mostly developing countries (Africa and Latin America) may also benefit more from, and consequently also cite more, OA articles than those from regions with mostly developed countries (North America and Europe), and the benefits of OA for the authors from Asia and Oceania will be in between. Indeed, Evans and Reimer (2009) revealed that on average OA articles were cited more than twice as many as non-OA articles in the developing world, though it was less apparent in the very poorest countries. However, we still do not know much about whether citation advantages of OA articles differ among citing authors from different geographic regions. The scientific author community who has traditionally excellent access to research literature may not pay so much attention to OA (Davis 2010). Therefore, it is also interesting to test whether there is still a citation advantage for authors from countries that have a major contribution to articles published in ecology journals (Lansingh and Carter 2009, Lanchon-Barrantes et al. 2013, McCabe and Snyder 2015). Testing the influence of OA on science dissemination could help to further understand and identify the consequences of our rapidly changing science publication environment (Evans and Reimer 2009).

A hybrid journal publishes both OA and non-OA papers (Prosser 2003). Different from non-hybrid journals (i.e., green and gold OA journals that publish only OA articles or non-OA journals that publish only non-OA articles), hybrid journals provide an effective platform for testing the impact of OA (Harnad and Brody 2004, Koler-Povh et al. 2012). When comparing one OA article with one non-OA article randomly selected in the same issue, we could effectively restrict the impact of other confounding factors, for example, publication criteria or early access effect

journals. By comparing the number of citations and the contribution of citing articles to OA and non-OA articles, we aim to address the following three questions: (1) Do OA articles generally receive more citations than non-OA articles in the field of ecology? (2) Does the impact of OA on citations differ among citing authors from countries with different income levels? (3) Does the impact of OA on citations differ among citing authors from different geographic regions?

METHODS

Journal and article selection

Journal Citation Reports of 2014 of Institute for Science Information listed a total of 141 journals in the field of ecology. To examine the effect of open access in the field of ecology, we first selected 60 top-ranked ecology journals with the highest impact factors based on JCR 2014. Of these 60 journals, three are gold OA journals, and in 11 journals, no OA articles were found. Hence, these 14 journals were excluded, and a total of 46 journals (Appendix S1: Table S1) with both OA and non-OA articles were analyzed.

We checked articles published in all the issues in these 46 journals from 2009 to 2013. The duration of five years allowed us to assess the impact of time on OA. When we found one OA research article, we paired one non-OA article randomly selected from articles published in the same issue (even in the same subject section if available). We only selected research articles and excluded reviews, letters, and other types of articles. In total, 3534 articles were used in the analysis.

When analyzing the effect of OA, the comparison between OA and non-OA articles from the same issues of the same journals could avoid the influence of many confounding factors, which provides a uniform platform, in regard of subject matter, quality standard, and time after being published (Harnad and Brody 2004).

Citation data

In February 2015, we recorded the number of citations for each OA and each paired non-OA article through Web of Science. Through checking the institutional address of the corresponding author, we also recorded the authors' affiliation of all citing articles indexed by Web of Science, for both OA and non-OA articles. We categorized

citing articles by geographic region: North America (i.e., United States and Canada), Europe, Latin America (comprising Central and South America, and the Caribbean), Africa, Asia, and Oceania. Mexico was included in Latin America, but not in North America.

According to the economic status, that is, gross national income (GNI) per capita (World Bank 2014), of the corresponding author's country, the citing articles were grouped into three categories: developed countries (high-income, GNI per capita of \$12,736 or more), relatively rich developing countries (middle-income, GNI per capita ranging from \$1,046 to \$12,735), and relatively poor developing countries (low-income, GNI per capita no more than \$1,045).

The distribution of country of citing articles was highly skewed. According to the country of corresponding author, authors from a total of 134 countries cited the articles, with most authors coming from the United States (14,408), UK (4323), Germany (3334), Australia (3054), and Canada (2785; Table 1). Authors from 50 countries contributed no more than five citations, and authors from 14 contributed only one citation.

Statistical analysis

We used linear mixed models to test the effects of open access status (OA and non-OA), year, and journal on total number of citations per article from all countries, from each of the low-, middle-, and high-income countries, and from each of the six regions (North America, Europe, Latin America, Africa, Asia, and Oceania). We also selected the countries that had total number of citations larger than 1000 over the five years and tested the

Table 1. Number of citations and gross national income (GNI) per capita of countries with citation numbers above 1000.

Country	Citation number	GNI per capita
United States	14,408	55,200
England	4323	42,690
Germany	3334	47,640
Australia	3054	64,680
Canada	2785	51,690
France	2169	43,080
China	2046	7380
Spain	1745	29,940
The Netherlands	1316	51,210
Italy	1030	34,280

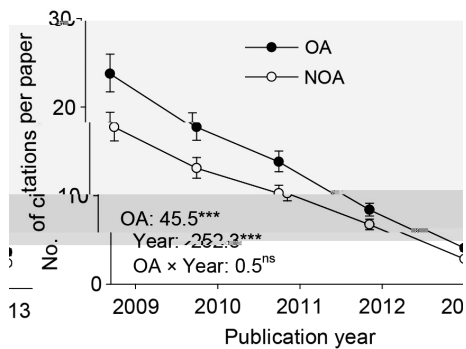


Fig. 1. Number of citations per article for articles published in major ecology journals from 2009 to 2013 with open (OA) or non-open access (NOA). Data are back-transformed means and SEs. F and significance levels ($***P < 0.001$, $^{ns}P > 0.1$) of ANOVA are also given.

number of citations per article from each of these countries. In these analyses, OA status and year were treated as fixed factors and journal as a random factor. Identification of journal and its interactions as random effects allows tests for consistent differences of OA across the 46 publications. Before analyses, citation numbers were log-transformed to normalize the heavily skewed distributions. Note that, while log transformation corrects the distribution problem, it also changes interpretation of the interactions of OA with year, as accumulations of citations over time will not register as significant when the annual additions are in proportion to the mean (see Fig. 1).

We randomly selected five article pairs, if any, from each journal and collected the data of article length (number of pages). If there were no more than five article pairs in a journal, then we included all the articles. We analyzed the data and found that average length of OA articles (11.1 ± 0.2 pages) was significantly greater than that of non-OA ones (10.2 ± 0.2 pages; $F = 8.71$, $P = 0.0064$). Since short articles may be cited and read more frequently than long ones, this result means that the impact of OA on citation advantage might be even higher. All analyses were implemented in SAS 9.1 (SAS Institute 2004).

RESULTS

In ecology journals, OA articles showed significant citation advantages in each year from 2009

to 2013 (Fig. 1). Overall, OA articles received significantly more citations than non-OA articles, and the citation advantage averaged approximately one citation per article per year and increased cumulatively over time after publication (Fig. 1).

A significant OA advantage was found in countries of all three income categories according to per capita GNI, no matter whether the income was high, middle, or low (Fig. 2). Simultaneously, an

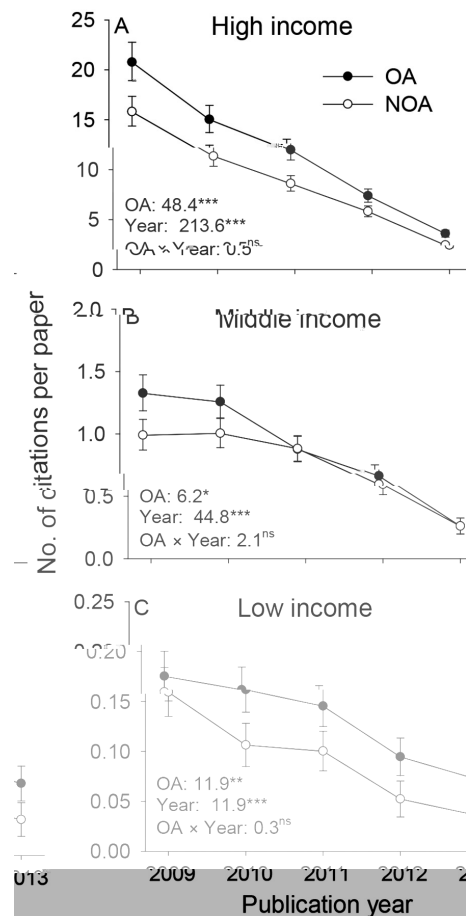


Fig. 2. Number of citations per article for articles published in major ecology journals from 2009 to 2013 with open (OA) or non-open access (NOA). Authors of the citing papers came from countries of (A) high, (B) middle, and (C) low incomes classified based on gross national income (GNI). Data are back-transformed means and SEs. F values and significance levels ($***P < 0.001$, $**P < 0.01$, $*P < 0.05$, $^{ns}P > 0.1$) of ANOVA are also given.

OA citation advantage was found in North America, Europe, Asia, Africa, and Oceania (Fig. 3). For Latin America, there was no OA citation advantage (Fig. 3).

Ten countries contributed more than 1000 citations (Fig. 4). Among them, nine were in the category of high-income countries, only one (China) was in the category of middle-income countries, and none was in the category of low-income countries (Fig. 4). Again, an OA citation advantage was found in all the 10 countries except Canada (Fig. 4).

DISCUSSION

We revealed citation advantages of OA articles compared with non-OA articles published in the ecology journals. This citation advantage of approximately one citation per article per year was maintained across years after publication, accumulating to approximately five more citations to approximately five more citations per article five years after publication. Similarly, an up to 36% increase in citations with OA was reported in the field of biology (Swan 2010). In conservation biology, book chapters with OA

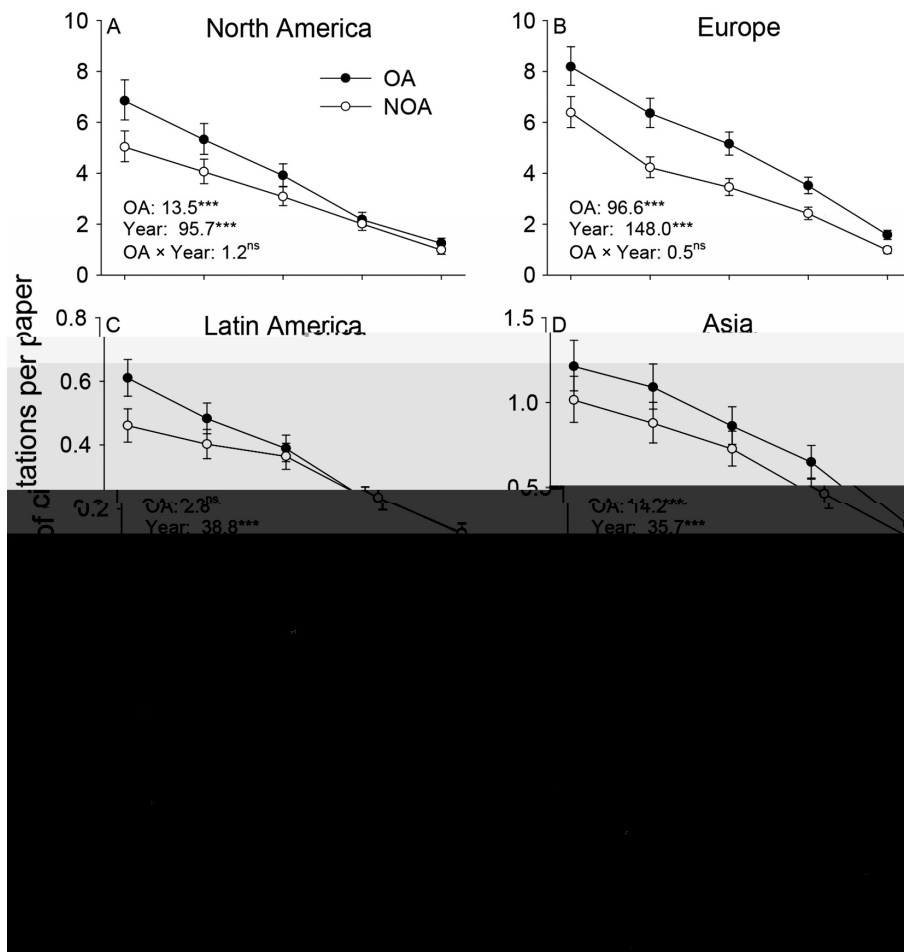


Fig. 3. Number of citations per article for articles published in major ecology journals from 2009 to 2013 with open (OA) or non-open access (NOA). Authors of the citing papers came from countries located in (A) North America, (B) Europe, (C) Latin America, (D) Asia, (E) Africa, and (F) Oceania. Data are back-transformed means and SEs. *F* values and significance levels (***P* < 0.001, **P* < 0.05, #*P* < 0.1, ^{ns}*P* > 0.1) of ANOVA are also given. Note that the scales of the *y*-axes are different.

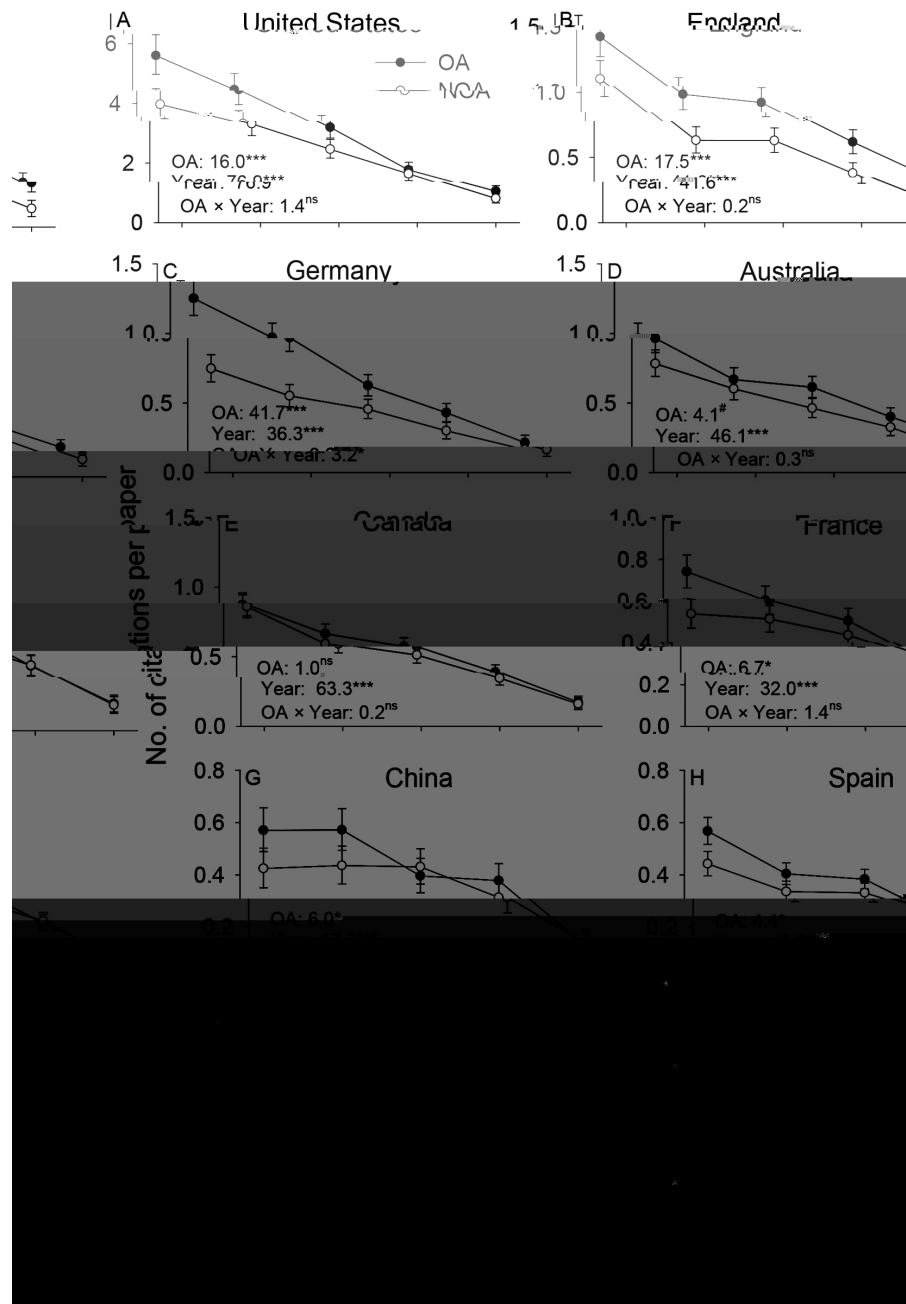


Fig. 4. Number of citations per article for articles published in major ecology journals from 2009 to 2013 with open (OA) or non-open access (NOA). Authors of the citing papers came from 10 countries with a total citation number of over 1000. Data are back-transformed means and SEs. F values and the significance levels ($***P < 0.001$, $*P < 0.05$, $^{\#}P < 0.1$, $^{ns}P > 0.1$) of ANOVA are given. Note that the scales of the y -axes are different.

received more citations than book chapters without OA, but no OA citation advantage was found in journals (Calver and Bradley 2010). Number of citations is an important index for evaluating

the quality of journals and the achievement of authors. Our findings quantify potential benefits of open electronic accessibility of scientific research, a service to scientific societies, journals,

and individual authors as they weigh these benefits against publication costs.

By comparing OA and non-OA articles within hybrid journals, our estimate of the citation advantage of OA articles sets controls for many factors that could confound other comparisons. Numerous studies have compared articles published in OA journals to those in non-OA journals (e.g., Antelman 2004, Hajjem et al. 2005, Eysenbach 2006, Evans and Reimer 2009, Calver and Bradley 2010, Riera and Aibar 2013, Clements 2017), but such comparison between different journals could not rule out the impacts of potentially confounding factors such as publication time (speed) and quality and impact (rank) of the journal (McCabe and Snyder 2014, Stankus 2014). These factors are effectively controlled with our focus on hybrid journals, thereby providing robust and general estimates of citation advantages on which to base publication decisions.

At present, the boundary between OA and non-OA is becoming increasingly blurred. For example, Hassall (2012) found that a high proportion (52%) of papers published in 165 ecology and evolution journals in 2011 have been self-archived. The so-called delayed open access also commonly occurred in subscription journals (Laakso and Björk 2012), which allow the articles to be accessed for free after a certain embargo from the time of publication. Some journals, like Proceedings of the National Academy of Sciences of the United States of America (PNAS), even have such a policy to make its articles free to readers in developing countries. All these measures potentially reduce the citation advantages of the traditional OA, that is, advantages publishers use to motivate payment from authors and/or their associated institutions. In spite of these forces, the citation advantage of OA articles was consistent across the 46 ecology journals included in our study.

One caveat is that publishing gold OA in hybrid journals is usually quite expensive. Thus, authors that choose to publish gold OA in hybrid journals might have more financial resources, which potentially allow them to conduct more elaborate studies and thus attract more attention and citations. Additionally, it could be that authors willing to pay for OA in hybrid journals are also generally more willing to invest in other "best practices," which might lead in turn to higher citations. The design of our study was unable to control such

potential confronting factors. However, the fact that authors that have more financial resources do not always result in good publications and have more citations suggests that OA is very likely to play a role for the increased citations.

Open access is thought to increase accessibility, particularly for scientists without access to wealthy libraries, such as from developing countries (McCabe and Snyder 2015) or from geographic regions with mostly developing countries. One then expects a greater citation advantage of OA in developing countries than in developed countries, as was found by Evans and Reimer (2009), and in regions with mostly less wealthy countries (i.e., Africa and Latin America) than in regions with mostly wealthy countries (i.e., North America and Europe). However, Frandsen (2009) and Calver and Bradley (2010) did not find increasing citation advantages to OA articles by authors from developing countries. Frandsen (2009) focused their attention on the comparison between OA and non-OA journals and Calver and Bradley (2010) selected only eight journals (six subscription journals and two hybrid journals), which may fail to provide robust tests. While we presented a more powerful test using paired OA and non-OA articles from the same issues of a number of hybrid journals, we observed similar citation advantages of OA articles regardless of whether the citing authors came from high-, middle-, or low-income countries, or also for the citing authors came from most geographical regions. Therefore, not only authors from developing countries, but also those from developed countries are benefiting from OA. Free accessibility to OA articles, to a certain degree, helps and promotes authors more frequently download, read, and then refer to them in their research papers. The absence of a significant citation advantage in Latin America, and weak effect in Africa, likely reflects low power because of the low total citation numbers from these areas (Appendix S1: Table S2).

Not surprisingly, the United States was a major contribution to articles published in ecology journals (Lansingh and Carter 2009, Lancho-Barrantes et al. 2013, McCabe and Snyder 2015). According to a review by Davis and Walters (2011), authors in the United States and Canada were most satisfied with access to research papers; that is, 85% reported good or excellent access. Davis (2010) argued that the scientific

author community who has traditionally excellent access to research literature may not pay so much attention to OA. Therefore, it is interesting to find through our research that authors from the United States, as well as from other developed countries, still show a preference to read and cite OA articles, even when they have a good access to research literature. We also note that even in wealthy countries, access to journals at many universities is being threatened by budget crises.

CONCLUSIONS

While controlling for journal impact and publication date, we find that the OA status of an article increases the citation rate for that article by approximately one citation per year. In this era of rapid change to the scientific publication industry, this information may guide decisions of scientific societies, journals, and individual authors as they weigh the relative costs and benefits of open electronic accessibility of scientific research.

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