Enhancing climate change research with open science

Travis C. Tai[1*] and James P.W. Robinson[2]

[1]Institute for the Oceans and Fisheries, 2202 Main Mall, University of British Columbia, Vancouver, Canada V6T 1Z4

[2]Lancaster Environment Centre, Lancaster University, Lancaster, UK LA1 4YQ

[*]Corresponding author at t.tai@oceans.ubc.ca.

Abstract

Effective climate change science requires interdisciplinary research that is rapidly conducted and widely disseminated. We argue that these goals can be achieved by comprehensive adoption of open science practices. Opening data and code will increase collaboration opportunities and enable climate change triage. Citations and altmetrics indicate that open access studies receive more citations and are communicated more widely in news media and policy documents, suggesting that open science has the potential to improve research communication among scientists and public institutions. By enhancing both the academic and societal impact of climate change research, open science can facilitate mitigation and adaptation efforts for the most vulnerable regions of the world.

Main text

Climate change research aims to understand global environmental change and how it will impact nature and society. The broad scope of climate change impacts means that successful adaptation and mitigation efforts will require an unprecedented collaboration effort that unites diverse disciplines and is able to rapidly respond to evolving climate issues (IPCC, 2014). However, to achieve this aim, climate change research practices need updating: key research findings remain behind journal paywalls, and scientific progress can be impeded by low levels of reproducibility and transparency (Ellison, 2010; Morueta-Holme *et al.*, 2018), individual data ownership (Hampton *et al.*, 2015), and inefficient research workflows (Lowndes *et al.*, 2017). Furthermore, the level of public interest and policy engagement on climate change issues relies on fast communication of academic research to public institutions, with the result that the societal impact of climate change studies will differ according to their public availability and exposure. Here, we argue that by adopting open science (OS) principles, scientists can advance climate change research and accelerate efforts to mitigate impacts; especially for highly vulnerable developing regions of the world where research capacity is limited. We underscore the specific benefits of OS in raising the academic and societal impact of climate change research using citation and social media metrics.

OS facilitates collaboration and triage

The pace of climate change combined with a need to address societal and ecological impacts with limited resources mean that climate change research is fast-moving and interdisciplinary. Some fields, such as biological conservation, can be considered triage disciplines that require efficient and rapid decision making (Bottrill *et al.*, 2008). To this end, OS principles can help to minimize scientific uncertainty while increasing collaboration potential. For example, OS encourages data and code sharing (Ram, 2013), assists the peer-review process with fully-reproducible manuscripts (Lowndes *et al.*, 2017), and reduces time to publication with preprints and open access (OA) journals (Vale, 2015). Most scientists agree that publicly-funded research should be freely available (Dallmeier-Tiessen *et al.*, 2011) and several institutions have successfully implemented OS practices to share data and research in open-access archives. For instance, research on climate-driven thermal bleaching events in coral reef ecosystems has benefited hugely from open access to NOAA's large-scale monitoring data (*e.g.* NOAA CoralWatch; Harris *et al.*, 2017). Although comprehensive open data policies have been implemented by some governments (*e.g.* USA; Obama, 2013) and journal groups (*e.g.* Nature editors, 2018), journal policies on data sharing are typically insufficient for adequate reproducibility (Stodden *et al.*, 2018). Nonetheless, these examples demonstrate importance of adopting open data principles; comprehensive uptake of these practices will substantially enhance the application of academic research to climate change issues.

Academic and non-academic communication of climate change may be especially important for developing nations. Most climate change research is published through institutes within the developed world (McSweeney, 2015), yet the greatest impacts will be observed in some of the least developed and most vulnerable regions of the world (*e.g.* IPCC, 2014; Blasiak *et al.*, 2017). Inability to access subscription-only publications may inhibit science-based policy in developing countries, with the rise of pirated publication repositories such as Sci-Hub (https://sci-hub.mu) indicative of a widespread demand for OA research (Bohannon, 2016; Himmelstein *et al.*, 2018). For example, inaccessibility of primary research has contributed to low citation rates in policy plans for tropical marine protected areas, implying that environmental management may fall behind current scientific knowledge (*e.g.* Cvitanovic *et al.*, 2014).

OA benefits to research communication: citations and Altmetric data

Open science practices can result in greater public engagement (Wang *et al.*, 2015) and, through OA publications, increase citation rates ('the OA citation advantage') (Lawrence, 2001; Eysenbach, 2006). Using Scopus citation data, we show that the proportion of OA studies increased substantially over time in publications containing 'climat* change' in their title, abstract or keywords between 2007-2016 (Scopus; www.scopus.com), accounting for only 4% in 2007 and increasing to 25% in 2016 (Fig. 1). However, this varied by journal rank (JR). We categorized journals into four groups, using JRs that are 3-year weighted citation rates obtained from SCImago Journal Rankings (see Fig. 1 caption for category breakdown; SCImago, n.d.). For the low JR category, OA publications in 2016 accounted for <20%, while the medium category had the largest OA proportion at 30%. High and very high categories had 23% and 26% OA, respectively. Popular OA journals such as PLoS ONE and Scientific Reports comprised 71% and 24% of OA publications within their JR groups (medium- and high-ranked, respectively), and 15% and 3% of all publications within their groups, respectively. Across all journal ranks, OA climate change studies were cited more than closed studies (Fig. 2a), indicating that adopting OA could lead to earlier and increased citations of climate change research, and thus accelerate scientific progression by building upon existing science at a faster rate (Eysenbach, 2006; Lowndes *et al.*, 2017). Though we used SCImago Journal Rankings to keep consistency with the Scopus citation database, such citation-based metrics are coarse measures of journal research quality, and do not represent research impact for individual papers (Lariviere *et al*. 2016) or non-academic audiences.

Beyond academic citation advantages, OA climate change research can have a greater societal impact when studies are communicated to non-academic audiences by mainstream news and social media, as well as used by policymakers (Wang *et al.*, 2015; Bornmann *et al.*, 2016). In 'mentions' of climate change studies in online news sources, Twitter feeds, and policy documents (www.altmetric.com), we show that OA studies were communicated more frequently (Fig. 2b-d), likely due to those studies being more accessible to non-academic audiences. Despite the positive OA effect, the most widely-communicated papers were high impact and closed access papers (*e.g.* 88% of studies with >100 news mentions were closed access). High-ranking journals such as *Nature* and *Science* are often promoted with academic press releases, highlighting how paywalls can limit public understanding and engagement of academic knowledge (Parker, 2013). Nonetheleess, higher news and Twitter activity for OA studies—irrespective of journal rank—supports a longstanding perception that open research is more widely disseminated and discussed online (Wang *et al.*, 2015; Côté & Darling 2018).

Policy documents cited open studies more often than closed, and this difference was consistent across JRs (Fig. 2d). Thus, when policymakers lack institutional access to pay-walled journals, the OA effect may result in greater uptake of primary research into policy. However, because Altmetric tracks major policy groups in North America and Europe (Bornmann *et al*. 2016), we note that these policy trends may be biased towards academic authors working for international organizations (*e.g.* Food and Agriculture Organization of the United Nations, World Bank, Intergovernmental Panel on Climate Change). While our results show a positive trend towards OA (Fig. 1) and higher OA mentions in policy documents (Fig. 2d), important research still remains behind paywalls and there is evidence that subscription-only publishing models can limit the uptake of current scientific knowledge by policymakers (*e.g.* Cvitanovic *et al.*, 2014; Fuller *et al*., 2014; Rafidimanantsoa *et al.*, 2018). For example, OA may be especially important for small-scale, low-impact studies which are relevant for local policy but may not receive much media attention.

Transitioning to open climate change research

OS principles are simply the open sharing of data, code, and papers throughout the research process (Hampton *et al.*, 2015; McKiernan *et al.*, 2016). Such practices have transformed entire disciplines (*e.g.* preprints in mathematics, open genome data in genetics; Nielsen, 2011), but the transition to OS for climate change research is incomplete. OS benefits specific to climate change research include improved collaboration, reproducibility, and scientific progression through sharing of data and code (Ellison, 2010; Ram, 2013; Lowndes *et al.*, 2017) and, because of the success of OS in other fields, tools for OS are already freely available (Table 1). For example, several preprint and data repositories target climate change fields (*e.g.* MarXiv for marine science), while existing version control and coding tools have been adapted for an OS workflow in environmental research (*e.g.* RStudio and Github, Lowdnes *et al*., 2017).

Despite the clear benefits of OS in enhancing research output and communication to stakeholders, considerable barriers to OS uptake persist, including closed publishing, fear of being ‘scooped’, and clarity of data ownership (Nosek *et al.*, 2015). Research outputs—usually publications—are already required by most granting agencies, where OA publishing costs are typically covered by grants and institutions (Dallmeier-Tiessen *et al.*, 2011). Furthermore, most climate change research is funded by developed countries yet may focus on climate issues in developing countries that often lack the institutional capacity for journal subscriptions and OA fees (van Helden, 2012; McSweeney, 2015). Thus, to incentivize OS climate change research, we propose funding bodies should require grant holders to openly publish datasets, papers and code, and mandate active dissemination of climate change findings to stakeholders rather than passive dissemination by publication.

Scientists across disciplines have argued, convincingly, for improving research practices by adopting OS principles (Hampton *et al.*, 2015; Nosek *et al.*, 2015; McKiernan *et al.*, 2016). We extend these arguments to show that adoption of OS practices, such as OA publications, OS workflows, and sharing data, is particularly needed to improve the academic and societal impact of climate change research. Given that global efforts to combat climate change impacts will require both rapid collaborative research and communication among academics, policymakers and the public, climate change research is in urgent need of strong OS stewardship.

Table 1. Recommendations to advance climate change research with open science tools.

Open science practice	Benefits	Application to climate change research
Publish open access	Increase uptake of primary research by public institutions (government and policy)	Limited uptake of scientific knowledge by policymakers (Cvitanovic *et al.*, 2014) may be addressed with open access (Fig. 2d)
	Improve access to science by developing countries, thus enhancing climate change adaptation and mitigation efforts	Developing countries, which are most at risk to climate change impacts (IPCC, 2014), can access up-to-date climate research
	Improve public communication of scientific evidence, thus raising public understanding of science	Prior knowledge of climate change causes are correlated to heightened concern (Shi *et al.*, 2016)
Adopt reproducible and transparent research workflows	Increase efficiency of research and robustness of findings	Progression of open science data tools and practices for increased transparency (Lowndes *et al.*, 2017)
Archive data, code, and preprints	Greater sharing of data, code, and ideas will stimulate more collaborative and interdisciplinary research	Journals publishing climate change research should adopt transparency policies (Nosek *et al.*, 2015)
		Standardized metadata reporting will facilitate literature comparisons and meta-analyses (Morueta-Holme *et al.*, 2018)
		Openly-available environmental monitoring datasets have been critical sources of information (*e.g.* NOAA's SST product; Reynolds *et al.*, 2002)
		Open science workflows facilitate large collaborations (*e.g.* GitHub, Open Science Framework) (Ram, 2013; Wilson *et al.*, 2014)
	Data availability will advance practices of 'climate change triage'	Climate change triage that supports long-term values of multiple stakeholders (*e.g.* scientists, Indigenous communities, government, industry) (Wheeler *et al.*, 2016) will require integration of diverse datasets from multiple disciplines
		Access to open datasets at global and local scales facilitates conservation triage of coral reefs (Harris *et al.*, 2017)
	Fast release of ideas and improved research before peer-review	Archiving pre- and post-prints on open access repositories such as arXiv, biorXiv, MarXiv, and EarthArXiv.

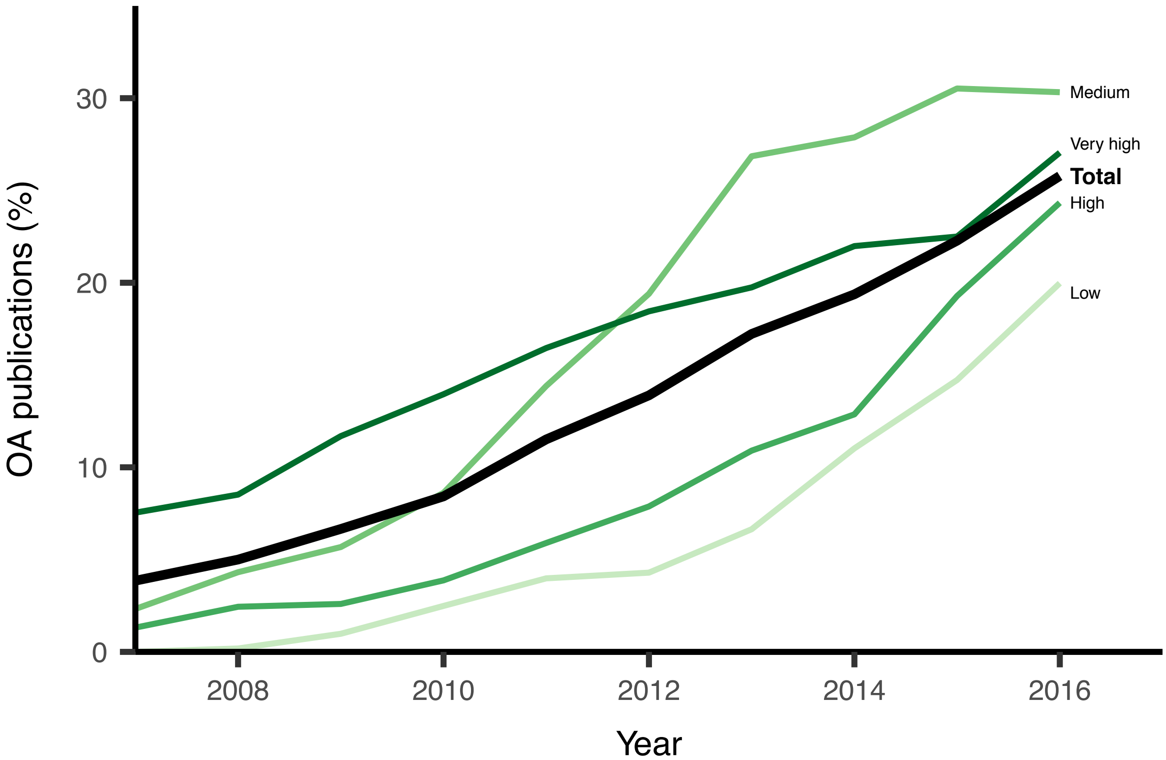

Figure 1. Increasing prevalence of open access (OA) climate studies published between 2007-2016. Proportional increase in OA climate change publications (black line) and across four journal ranking categories (colored lines; low = 0.14-0.93, medium = 0.93-1.5, high = 1.5-2.2, very high = 2.2-18.1). Publications were extracted from Scopus (www.scopus.com) for articles and reviews published between 2007-2016 containing the term "climat* change" in title, abstract, or keywords. We further restricted publications to those journals with >100 total citation records (*i.e.* journals which regularly published climate change research, n = 225). Journal rankings are 3-year weighted citation rates (SCImago Journal Rankings; www.scimagojr.com), ranging from 0.14 to 18.13. Bins are the 25th, 50th, and 75th quantiles of the journal rank distribution.

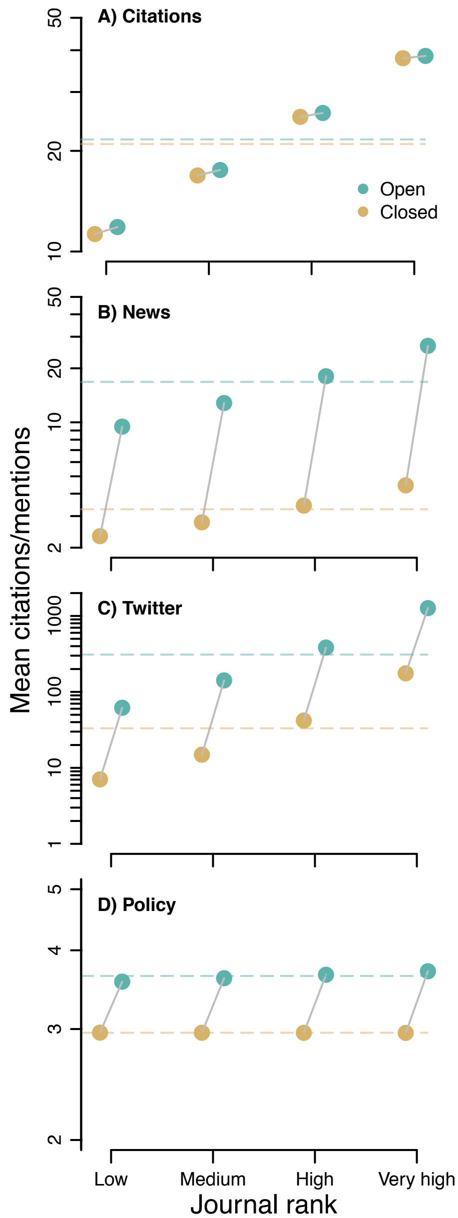

Figure 2. Citations, communication, and media influence of closed and open access climate change studies published between 2007-2016. Points are predicted mean number of citations (a), news mentions (b), twitter mentions (c), and policy mentions (d) in four journal ranking categories, controlling for effects of publication year and journal on citations/mentions. Dashed lines are mean citations/mentions controlling for journal rank, publication year and journal name. Citations were extracted from Scopus for the same studies in Fig. 1. News, twitter and policy

mentions were extracted from Altmetric (www.altmetric.com) for study DOIs in Fig. 1. Citations and mentions were averaged for each journal in each year, and fitted to linear mixed effects models with journal ranking bin (4 bins represented by the 25^{th}, 50^{th}, and 75^{th} quantiles) and access (open/closed) as fixed effects and year and journal as random intercepts. Citations and mentions were $\log_{10}$ transformed for normality and presented on a $\log_{10}$ scale. All analyses were conducted in R 3.4.4 (R Core Team, 2018).

Code and Data availability

Journal citations and mentions were extracted from Scopus (www.scopus.com) and Altmetric (www.altmetric.com). We provide our queried search terms and R coding scripts at github.com/travistai2/open-science-cc.

Acknowledgements

TT is grateful for funding support from OceanCanada Partnership and MEOPAR. We thank Jonathan Adams for discussions about altmetrics, and William Cheung, Andres Cisneros, Cameron Freshwater, Nick Graham, Laura Kehoe, Sally Keith and Rashid Sumaila for useful comments on the manuscript.

Author contributions

TT conceived the idea. Both authors contributed equally to data analysis and writing.

Funding

The authors did not receive any specific funding for this work.

Conflict of interest statement

The authors declare no competing financial or non-financial conflicts of interest.

References

Bohannon, J. (2016). Who's downloading pirated papers? Everyone. *Science (80-.).* 352, 508–512. doi:10.1126/science.352.6285.508.

Blasiak R, Spijkers J, Tokunaga K, Pittman J, Yagi N, Osterblom H (2017) Climate change and marine fisheries: Least developed countries top global index of vulnerability. *Plos One*, **12**, e0179632.

Bornmann L, Haunschild R, Marx W (2016) Policy documents as sources for measuring societal impact: how often is climate change research mentioned in policy-related documents? *Scientometrics*, **109**, 1477–1495.

Bottrill MC, Joseph LN, Carwardine J *et al*. (2008) Is conservation triage just smart decision making? *Trends in Ecology and Evolution*, **23**, 649–654.

Côté IM, Darling ES (2018) Scientists on Twitter: Preaching to the choir or singing from the rooftops? *FACETS* **3**, 682–694

Cvitanovic C, Fulton CJ, Wilson SK, van Kerkhoff L, Cripps IL, Muthiga N (2014) Utility of primary scientific literature to environmental managers: An international case study on coral-dominated marine protected areas. *Ocean and Coastal Management*, **102**, 72–78.

Dallmeier-Tiessen S, Darby R, Goerner B *et al*. (2011) *Highlights from the SOAP project survey. What Scientists Think about Open Access Publishing*.

Ellison AM (2010) Repeatability and transparency in ecological research. *Ecology*, **91**, 2536–2539.

Eysenbach G (2006) Citation advantage of open access articles. *PLoS Biology*, **4**, e157.

Fuller RA, Lee JR & Watson JEM (2014) Achieving Open Access to Conservation Science. *Conservation Biology* **28,** 1550–1557.

Hampton SE, Anderson S, Bagby SC *et al*. (2015) The Tao of Open Science for Ecology. *Ecosphere*, **6**, 120.

Harris JL, Estradivari E, Fox HE, McCarthy OS, Ahmadia GN (2017) Planning for the future:

Incorporating global and local data to prioritize coral reef conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **27**, 65–77.

Himmelstein, DS, Romero AR, Levernier JG, Munro TA, Mclaughlin SR, Tzovaras BG, Greene CS (2018) Sci-Hub provides access to nearly all scholarly literature. *eLife* **7**, e32822.

IPCC (2014) *Climate change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lariviere V, Kiermer V, MacCallum CJ, McNutt M, Patterson M, Pulverer B, Swaminathan S, Taylor S, Curry S (2016) A simple proposal for the publication of journal citation distributions. *bioRxiv,* 062109.

Lawrence S (2001) Free online availability substantially increases a paper's impact. *Nature*, **411**, 521.

Lowndes JSS, Best BD, Scarborough C *et al*. (2017) Our path to better science in less time using open data science tools. *Nature Ecology and Evolution*, **1**, 160.

McKiernan EC, Bourne PE, Brown CT *et al*. (2016) How open science helps researchers succeed. *eLife*, **5**, e16800.

McSweeney R (2015) Analysis: the most "cited" climate change papers. *Carbon Brief*. Accessed on 05-02-2018, from https://www.carbonbrief.org/analysis-the-most-cited-climate-change-papers

Morueta-Holme N, Oldfather MF, Olliff-Yang RL *et al*. (2018) Best practices for reporting climate data in ecology. *Nature Climate Change*, **8**, 92–94.

Nature editors (2018) Two documents for greater transparency. *Nature*, **555**, 6.

Nielsen M (2011) *Reinventing Discovery: The New Era of Networked Science*. Princeton University Press, Princeton, USA, 272 pp.

Nosek BA, Alter G, Banks GC *et al*. (2015) Promoting an open research culture. *Science*, **348**, 1422–1425.

Obama B (2013) Executive Order—Making open and machine readable the new default for government information. Accessed on 05-02-2018, from https://obamawhitehouse.archives.gov/the-press-office/2013/05/09/executive-order-making-open-and-machine-readable-new-default-government-

Parker M (2013) The ethics of open access publishing. *BMC Medical Ethics*, **14**, 16.

R Core Team (2018) R: A Language and environment for statistical computing.

Rafidimanantsoa HP, Poudyal M, Ramamonjisoa BS and Jones JPG (2018) Mind the gap: the use of research in protected area management in Madagascar. Madagascar Conservation & Development 13, 1:xx–xx. http://dx.doi.org/10.4314/mcd.v13i1.3//EarlyView

Ram K (2013) Git can facilitate greater reproducibility and increased transparency in science. *Source Code for Biology and Medicine*, **8**, 7.

Reynolds RW, Rayner NA, Smith TM, Stokes DC, Wang W (2002) An improved in situ and satellite SST analysis for climate. *Journal of Climate*, **15**, 1609–1625.

SCImago, (n.d.). SJR — SCImago Journal & Country Rank [Portal]. Retrieved 05-02-2018, from http://www.scimagojr.com

Shi J, Visschers VHM, Siegrist M, Arvai J (2016) Knowledge as a driver of public perceptions about climate change reassessed. *Nature Climate Change*, **6**, 759–762.

Stodden, V., Seiler, J., and Ma, Z. (2018). An empirical analysis of journal policy effectiveness for computational reproducibility. *Proc. Natl. Acad. Sci.* 115, 2584–2589. doi:10.1073/pnas.1708290115.

Vale RD (2015) Accelerating scientific publication in biology. *Proceedings of the National Academy of Sciences*, **112**, 13439–13446.

van Helden P (2012) The cost of research in developing countries. *EMBO Reports*, **13,** 395.

Wang X, Liu C, Mao W, Fang Z (2015) The open access advantage considering citation, article usage and social media attention. *Scientometrics*, **103**, 555–564.

Wheeler HC, Berteaux D, Furgal C, Parlee B, Yoccoz NG, Grémillet D (2016) Stakeholder Perspectives on Triage in Wildlife Monitoring in a Rapidly Changing Arctic. *Frontiers in Ecology and Evolution*, **4**, 1–14.

Wilson G, Aruliah DA, Brown CT *et al*. (2014) Best Practices for Scientific Computing. *PLoS Biology*, **12**, e1001745.