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Environmental sciences benefit from robust evidence irrespective of speed

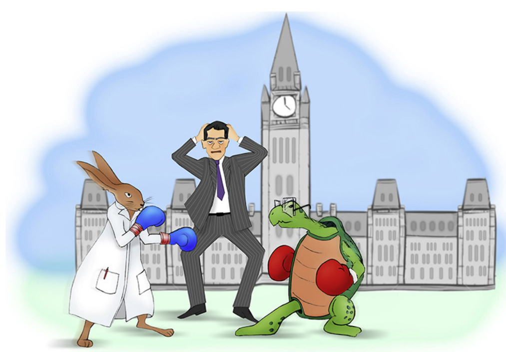
Dominique G. Roche [a,*], Joseph R. Bennett [a], Jennifer Provencher [b], Trina Rytwinski [a], Neal R. Haddaway [c,d], Steven J. Cooke [a]

[a] *Canadian Centre for Evidence-Based Conservation, Department of Biology and Institute of Environmental and Interdisciplinary Sciences, Carleton University, Ottawa, ON, Canada*
[b] *Canadian Wildlife Service, Environment and Climate Change Canada, Gatineau, QC, Canada*
[c] *Stockholm Environment Institute, Stockholm, Sweden*
[d] *Africa Centre for Evidence, University of Johannesburg, Johannesburg, South Africa*

HIGHLIGHTS

- Slow science is a return to long research projects and lower publication rates.
- However, fast-paced science is important to tackle urgent environmental problems.
- Slow and fast science are synergistic and should be judged on quality, not duration.
- Researchers must engage in transparent and reproducible research, irrespective of speed.

GRAPHICAL ABSTRACT



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ABSTRACT

Discussions around the "slow science movement" abound in environmental sciences, yet they are generally counterproductive. Researchers must focus on producing robust and transparent knowledge, regardless of speed. Slow versus fast science is irrelevant - what we need is reproducible research to support evidence-based decision making and tackle urgent and costly environmental problems.

An increasing number of scholars are calling for a "return" to slow science (e.g. Garfield, 1990, Alleva, 2006, Slow Science Academy, 2010, Lutz, 2012, McCabe, 2012, Stengers, 2018, Souto Salom, 2019; see the Twitter hashtag #slowscience). Slow science is based on the belief that research should be a slow, steady, methodical process, and that scientists should not be expected to focus their efforts on devising "quick fixes" to the problems of today (Frith, 2015). "Sloppy, conformist,

* Corresponding author.
E-mail address: dominique.roche@mail.mcgill.ca (D.G. Roche).

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opportunistic and in thrall to a boom-and-bust economy", have all been used to describe today's modern, "fast-paced" science (Kiser, 2017). The slow science movement stems from observations that competitive pressures in academia lead to perverse incentives associated with rewarding science that is overly focused on speed and productivity (i.e. publishing papers at a fast rate) (Fischer et al., 2012; Lutz, 2012). While there is no denying this sad reality (Sarewitz, 2016; Smaldino and McElreath, 2016) and the negative consequences of a "publish-or-perish" academic culture (Souto Salom, 2019), ignoring the urgent need for research to inform the pressing environmental challenges of today is equally misguided. The urgency expressed in the United Nations Sustainable Development Goals (https://sustainabledevelopment.un.org) or various "grand challenges" of the 21st century (Reid et al., 2010; https://grandchallenges.org) exemplifies the gravity of the task before us and the benefits that would arise from addressing global, wicked problems rapidly. If we could solve climate change, habitat degradation, or environmental pollution, would it not be better to do so in the year 2020 than 2200?

Recently, we witnessed Twitter interactions criticizing an "excessive" increase in publications on plastics in aquatic environments. One Tweet stated: "Catching up on #microplastics: 85 new papers published in the last three weeks. And those are only the ones I am interested in…We are definitely publishing too much! #slowscience" (Wagner, 2018). Follow-up comments included calls to "slow down" the research in this field because there is too much to read while others expressed concern that excessive speed and quantity might result in decreased quality, illustrating the general sentiment of the slow science movement. We acknowledge the need for long-term research and monitoring to understand the temporal trends in plastic pollution and their long-term biological consequences. Similarly, we acknowledge that scientists require time to think carefully about complex problems and foster creativity (Slow Science Academy, 2010). However, we also argue that good science can proceed at any pace, and that slow- and fast-paced research are often highly complementary, if not synergistic. Much of the theoretical and methodological foundation for fast-paced discovery is anchored in the slower-paced research that preceded it (Cooke, 2011). In addition, evidence synthesis allows garnering key, generalizable lessons on global processes from the careful analysis of accumulated studies, many of which are often limited in spatial or temporal scope. Therefore, supporting science that is "two-speed" or "multi-speed" (McCabe, 2012) appears more sensible than slowing research altogether (Fig. 1).

Calling for less research on emerging topics at the center of government environmental policy seems counterproductive. Even for well-known and thoroughly-studied environmental issues such as acid rain and silt pollution, calls are routinely made for additional evidence in specific and/or understudied areas. Importantly, methods for evidence synthesis such as systematic review (including meta-analysis) depend entirely on there being a sufficient, high quality body of evidence to synthesize (Pullin and Stewart, 2006). Given the inherent variability and context specificity of individual studies, evidence synthesis activities are more informative when a large number of studies are undertaken by independent research groups. Furthermore, meta-analysis generally weighs each study according to some measure of its reliability, usually as a function of sample size or some other related metric (e.g. the inverse of the effect size variance). Therefore, more weight is given to large studies with precise effect size estimates versus small, underpowered studies with fuzzy estimates. These weights are used as a proxy of study precision and are independent of study speed. When meta-analysis is accompanied with a critical appraisal of studies, as should be done in systematic review, the influence of study validity on the results of meta-analysis can be examined by means of sensitivity analysis (i.e. comparing results of models that include all studies to those that only include the highest quality studies) or by including critical appraisal as a moderator in the analyses (Collaboration for Environmental Evidence, 2018). The power of such approaches comes from pulling upon a large and reliable, yet diverse body of research.

Some researchers believe that a slow scientific and publication process impedes effective conservation action and policy (e.g. Nguyen et al., 2015; Cooke et al., 2016). This view appears to be supported by the rising popularity of preprint services (e.g. bioRχiv, EcoEvoRxiv, PeerJ Preprints) allowing faster dissemination of research results in addition to improved pre-publication peer review and reduced publication bias (Desjardins-Proulx et al., 2013). Arguably, the speed at which science is conducted is irrelevant, and calls for 'slow science' distract from the main issue at hand. Our collective goal as scientists should not be to slow down research but rather to establish a rigorous and robust body of scientific evidence which furthers our understanding of the natural world and helps inform decision-making, irrespective of speed. Regardless of whether it is conducted fast or slow, research replete with irreproducible results arising from poor research practices leads to low quality science (e.g. confirmation bias, poor experimental design and/or execution, poor statistical practices and reporting) (Colquhoun, 2014; Nuzzo, 2015; Parker et al., 2016; Cooke et al., 2017; Forstmeier et al., 2017; Munafò et al., 2017). Recent critical appraisals of research methods and published studies reveal that a considerable amount of slow and fast research is deemed of low scientific quality (e.g. Cornwall and Hurd, 2015; Fraser et al., 2018). The consequence of this 'reproducibility crisis' (Baker, 2016) is a slowing of knowledge advancement and undermining of sound, evidence-based decision-making (see Sutherland et al., 2004).

The slow science movement is sometimes interpreted as a call for greater work-life balance in academia (Leeming, 2018) rather than a return to "the only science conceivable for hundreds of years" (Slow Science Academy, 2010). This interpretation likely results from researchers wanting various aspects of their work life, not necessarily their research, to slow down. Indeed, most university researchers feel overworked by ever increasing competition for grants and positions, as well as high workloads and institutional expectations when it comes to publishing, teaching, student supervision, and administrative duties (Woolston, 2019). Successfully managing these aspects of today's academic life can be demanding and may require personal sacrifices (e.g., relationships, wellness) in favour of one's professional life. If the fundamental objective of slow science was to increase work-life balance and equalize opportunities in science (e.g. for researchers with families and/or health problems, women and other underrepresented groups), then we would certainly champion this movement. However, at present, many aspects of the slow science movement and its definition are inherently problematic. For example, the slow science movement assumes that:

1. "Fast science" is inherently flawed. Yet, speed itself does not necessarily have any bearing on study quality unless there is a temporal mismatch between a response being studied and the endpoints used to do so. We note that long-term research is often underfunded and may be uncommon in some subfields, perhaps correlated with the publish-or-perish mentality.

2. "Slow science" is inherently robust. Arguably, science should not be judged on the speed with which it was conducted but rather on the care and rigour that went into its design, execution and interpretation. There are many examples of ideas that scientists spent decades examining, which we know to be wrong; a flat Earth for one (Garwood, 2008).

3. There is a problem with engaging in mission-oriented, applied research (McCabe, 2012; Frith, 2015). However, research that occurs along the entirety of the fundamental-applied continuum is all of inherent value (Cooke, 2011). It is well-established that fundamental science underpins addressing complex environmental problems (Courchamp et al., 2015). Similarly, there should be no odium with engaging in goal-oriented research to rapidly address real problems of today.

4. Research needs to occur in a steady manner (e.g. Garfield, 1990). However, for various reasons, research often occurs in fits and spurts, with outputs varying through time. This may be the result of access to funding (availability of funds to apply for or success with grant applications), other professional duties (administration and leadership positions, teaching responsibilities), opportunities for collaboration,

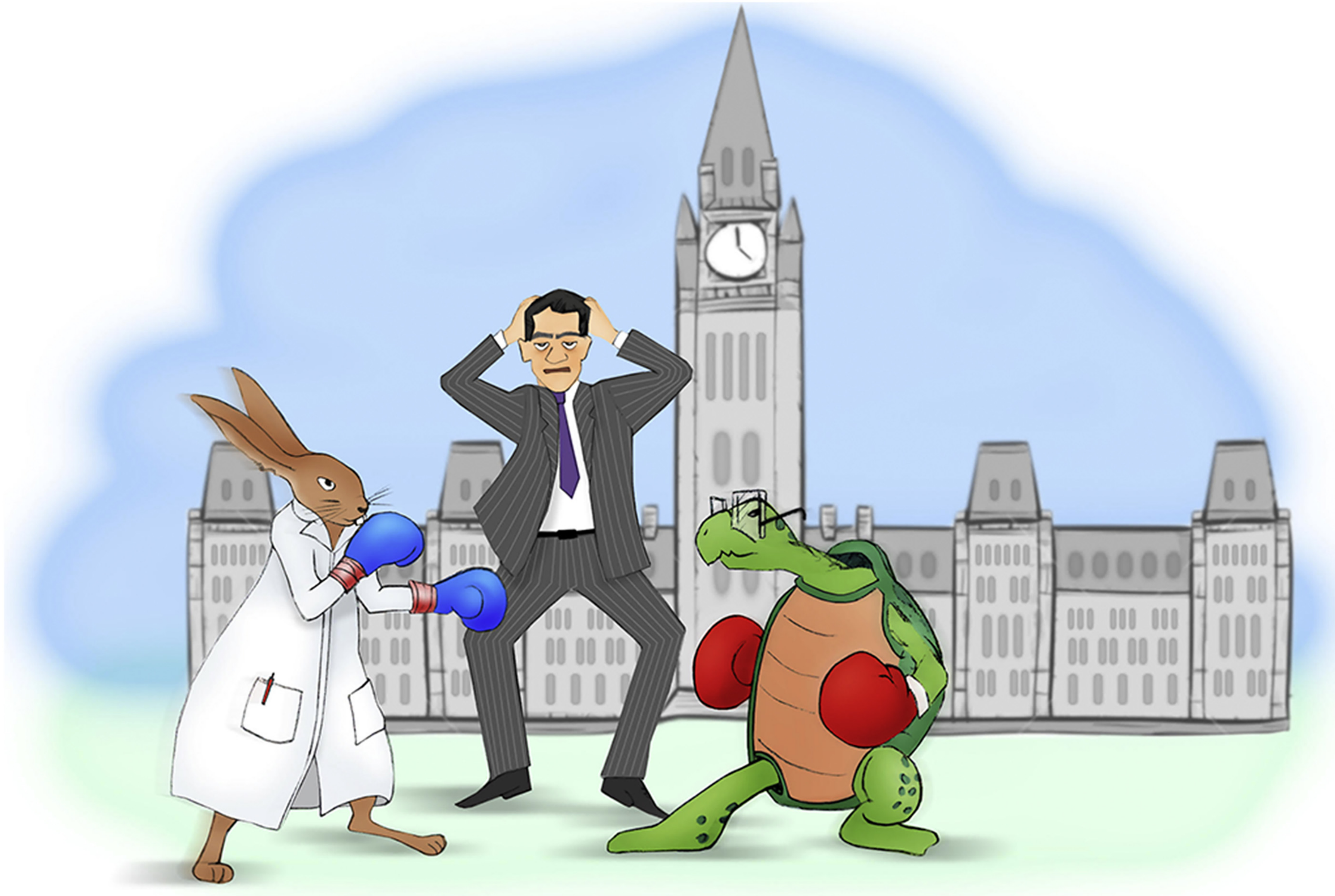

Fig. 1. Scientific studies are conducted and published at an increasingly rapid pace, resulting in concerns about the volume and quality of published research, and calls to #slowscience. Solving pressing environmental problems requires a multi-speed approach including slow- and fast-paced research. Therefore, the slow science movement likely confuses the public and policy-makers, particularly in light of the ongoing reproducibility crisis. Scientists must conduct rigorous and robust science, irrespective of speed. Arguing for slow versus fast science is counterproductive - the research community must shift the focus of these discussions towards adopting approaches that promote transparency, openness and reproducibility to increase the reliability of all scientific findings, slow and fast. (Illustration: Stephanie Rowan)

personal duties (parental or medical leave), and one's team (transient students with different interests and output levels), among others. Despite these realities, we acknowledge the value of having a focused research program that pursues key themes over time (which could be viewed as related to the slow science movement).

Instead of slow science, we would argue that there is a need for critical synthesis and reflection. Doing so does not require putting restraints on research since evidence synthesis can be done cyclically and in parallel. Importantly, critical appraisals (see Collaboration for Environmental Evidence, 2018) are useful to establish community standards for high quality science and to guide future research activity (Mupepele et al., 2016). If the recent landslide of research on plastics ends up all being of high quality, then there is no reason to critique the speed of the research conducted to date. However, if much of the research on the topic has sufficient issues that it is excluded during critical appraisal (Mupepele et al., 2016; Cooke et al., 2017), then one must question how that came to be. One possibility is that excess speed results in low study validity (i.e. methods resulting in error and bias), but poor scientific practices and misconduct (e.g. p-hacking, selective reporting, HARKing, fraud; Clark et al., 2016, Parker et al., 2016) are not inherently related to speed. Rather than encouraging scientists to simply ‘slow down’, the research community must adopt approaches that promote transparency, openness and reproducibility to increase the reliability of scientific findings. Many such approaches exist and can be readily integrated in the research workflow. Examples include, pre-registration (Parker et al., 2019), open data/code (Roche et al., 2014), and greater reliance on dynamic assessments of the literature via pre- and post-publication peer-review (e.g. https://pubpeer.com).

Clearly, there is a need for research conducted across various timescales, including longitudinal studies extending across decades (Callahan, 1984; Owens, 2013), and fast-paced studies over much shorter time periods. Rapid studies are particularly relevant to gain insight into the scale and severity of emerging problems (such as the plastics in aquatic ecosystems issue alluded to earlier) – for example, ‘Where is this happening?’, ‘Does it require urgent attention?’. In some cases, good research can be done very quickly because some disciplines, methods, and experimental protocols require only a matter of days or weeks. Similarly, we should value, fund and celebrate long-term research even if it does not generate the rapid return on publications that seem to be important in today's academic culture.

We conclude that the slow science movement is a distraction from the real issue of our day – the need for high quality, reproducible science that is conducted ethically and with minimal bias. Evidence-based decision making (including policy and practice) relies on high-quality scientific outputs (Sutherland et al., 2004). As such, incentives and rewards in academia should consider the quality of the science conducted and its collective influence on the scholarly and broader community rather than novelty and prestige as is too often the case (Arnqvist, 2013; Donaldson and Cooke, 2013). Efforts put forth to address the ongoing reproducibility crisis are far more important than the slow science movement.

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