*Response to reviewer comments on the manuscript “The importance of open science for biological assessment”, by M. W. Beck, C. O’Hara, J. Stewart Lowndes, R. D. Mazor, S. T. Theroux, D. J. Gillett, B. Lane, and G. Gearheart.*

*We thank the associate editor and both reviewers for providing detailed and thoughtful comments on our manuscript. Our responses to these comments are below.*

**Associate editor comments:**   
  
I believe the manuscript addresses an extremely important topic that should be relevant to virtually all Freshwater Science readers. Overall, the arguments are convincing and the writing is adequate. Both reviewers and I have provided numerous suggestions that should greatly improve the manuscript. Reviewer 2 is a state-level bioassessment expert, and provides several additional questions/issues that, if addressed, could make your paper more appealing to that audience. Consider their suggestions—although some are a bit off topic. Reviewer 3 is from academia and provides many excellent suggestions to improve the flow and simplify your message. They suggest a change in the tone of your manuscript—to one that is less pontificating. I didn’t get the same impression—but largely because open science has been drilled into my head as a federal government scientist. I provide below a few general suggestions, followed by detailed notes as I read through the manuscript.  
  
Terminology is inconsistent. For example, “methods,” “tools,” “products,” etc. are used interchangeably and it leads to confusion. There were sentences where “tool” made more sense but you used “method” instead. If you want to keep using all these terms, you need to define them up front. Otherwise, use a consistent term that encompasses all these aspects of bioassessment.

*We have revised the text for consistency in terminology. In short, the text now refers only to “bioassessment products” and “open science tools”, with definitions for both provided in the introduction. Please see our specific response to your comment on Line 80.*   
  
Reviewer 2 was troubled by redundancy throughout the manuscript. On the one hand, redundancy is helpful when you’re trying to, in essence, teach readers a new thing. But you also run the risk of an excessively long manuscript, and annoying readers who feel like they’re reading the same things over and over. I’ve indicated in my specific comments where you might trim some material so that redundancy is less glaring (as did Reviewer 3). But I also urge you to take a close look at how you could minimize redundancy throughout the manuscript. Another idea to consider is that you seem to discuss the concepts of, say, open data in the “Principles” section, but then repeat a lot of the same material in the “Bioassessment” section. I suggest carefully wording each section so there is less redundant information.

*Our repetitive approach was somewhat intentional in order to emphasize key concepts, as you suggested. However, the manuscript is quite long, and we agree it can be shortened in some instances while still communicating critical ideas. We have removed portions of the text where you and reviewer three have commented specifically. As one example, the content from the section “Open science in practice” that described the SCAPE tool was shortened from ten paragraphs to four. See our responses below for specifics. In total, these omissions have shortened the manuscript by approximately nine pages (double-spaced).*  
  
I’ve also indicated sections in the document that stray from the main topic (e.g., discussion of thresholds), and that are burdened by excessive detail (SCAPE tool description). These sections should be removed and / or dramatically trimmed.   
  
AE SPECIFIC COMMENTS  
  
Line 50: Not sure how “methods” could be transformed into actionable information. I can envision results and tools being transformed.

*Agreed, sentence was revised to “…that transform bioassessment products into actionable information.”*  
  
Lines 59-62: This sentence is too complex and also unclear. Consider splitting and rewording to clarify. Do you mean that bioassessment tools are being used in a post hoc fashion rather than for protective/preventative purposes (e.g., anti-degradation)? OK, the sentences after this one provide clarity & examples. DELETE THIS sentence.

*Sentence was deleted.*  
  
Line 67: Unclear what you mean by “discoverability of existing products by other research teams…” I sort of know what you’re getting at, but the sentence needs to be more clear. I think you’re saying that more discoverability and open sharing of bioassessment data, methods, and tools among researchers is essential to…

*Paragraph was removed in response to comments from reviewer three.*  
  
Line 72: Have bioassessment tools really become “diagnostic?” To me, a diagnostic tool reveals WHY someone is sick. I don’t think we’re there yet with biological assessments. We do a good job of determining WHETHER a stream is impaired, but can you cite evidence that we’ve been able to develop tools that diagnose the potential causes?

*Agreed, most indices do not provide this information and causal assessments could be used to identify specific stressors. I replaced “diagnostic” with “sensitive”.*

Line 80: You seem to be using bioassessment “products,” “methods”, and “tools” interchangeably. I think you need to define what these mean, or stick with a single general term.

*We agree our use of different terms was inconsistent and confusing. We have chosen to use “products” for bioassessment and “tools” for open science. We feel this adds consistency of meaning and have included a brief description in the introduction to clarify each term. From the second paragraph: “In the United States, the CWA gives power to states, tribes, and territories for bioassessment development, where final products (i.e., assessment indices or other products that support biointegrity decisions) require federal approval…”. From the final paragraph of the introduction: “Herein, open science "tools" describe best practices and specific applications that use an open philosophy to support applied science.”*  
  
Line 87: Not sure what you mean by “…existing methods may not be discoverable beyond immediate research applications…” Are you referring to actual bioassessment tools such as an IBI for a region? Or are you referring to the actual methodology, which is typically “discovered” by reading the literature?

*Sentence was revised to: “Moreover, existing indices may not be easily replicated beyond initial research applications…”*  
  
Lines 90-92: Here you focus on “methods,” but I don’t see how managers would be interested in choosing methods. It seems like that is a challenge for the scientists. Again, are you referring to tools or applications?

*This sentence was revised based on the general comments above about consistency of terminology: “The abundance of available products can be a point of frustration for managers given a lack of guidance for choosing among alternatives, particularly as to how different assessment products relate to specific management, monitoring, or policy objectives (Dale and Beyeler 2001; Stein et al. 2009).”*

Line 105: Publicly funded science is not unique to bioassessment, so I don’t see why this sentence is relevant.

*This was revised as our original intent was to highlight the link to public natural resources, not public-funding: “Legal and ethical precedents in bioassessment may also necessitate open data sharing given that environmental monitoring programs are often established to protect and maintain publicly-owned natural resources.”*  
  
Lines 124-153: Nicely written!  
  
Line 174: Most synthesis products are, in my opinion, GREATER than the sum of the individual datasets. The SUM, would be just a summary of the individual datasets. A synthesis implies taking the additional step of advancing the science.

*Sentence was revised: “Collaborative publications have increased in the environmental sciences as research teams leverage open data to create synthesis products that allow novel insights from comparisons across multiple datasets”*  
  
Lines 202-258: This section should be reconsidered. In it, you provide an introduction to the sections that follow, but in so doing you discuss many of the ideas that will follow. So, when readers actually read the next section, they get the impression they’ve heard this before. I suggest dramatically reducing this section and dropping ideas and examples that you’re going to flesh out in the subsequent section.

*This section was shortened to retain only key ideas that support the introduction of the following sections. Lines 208-231 were removed – these lines described molecular advances in bioassessment, which are important but unnecessary to describe for our larger goals. Lines 245-258 have also been removed as they are almost entirely redundant with the following sections.*

*We have retained most of the content on lines 203-214 and 232-244 because it provides a good lead-in to the following sections by 1) describing the overall workflows in figure 2 (lines 203-214), and 2) clarifies that openness occurs on a continuum (lines 232-244). We feel that this material is not redundant and emphasizes key points to provide additional context in the following sections.*   
  
Line 286: This is an example of a redundant idea. You talked about this in Line 250.

*Line 250 was removed.*   
  
Lines 352: Again, I get the feeling I’ve read this in previous paragraphs.

*This line was removed.*  
  
Line 364: I’m not sure what you mean by “ bioassessment translation” You describe it in the opening paragraph, but it still doesn’t seem like the correct word choice. Why not “application” or “implementation?”

*Agreed, “translation” is a bit loose and we’ve changed it to “bioassessment application” in the subsection title and other instances in the text. We also provide a clear definition of what this means in the opening paragraph: “Bioassessment application is the linkage of products between the research and management community, where links are enabled through open science tools that can deliver the products using a reproducible and accessible platform.”*   
  
Line 390: You’re using jargon (geometries, aesthetics) from Wickham here. The readers that you’re trying to convince to use these types of tools will not understand these terms.  
*Replaced “geometries and aesthetics” with “instructions”.*

Lines 526-537: This paragraph seems to be straying off topic. Here, you’re delving into the challenges of setting thresholds. Suggest dropping paragraph.

*Paragraph was removed*.  
  
Lines 538-552: Same as last paragraph. You’re getting into one technical challenge of bioassessments that is a good topic for another paper, but seems tangential to this one. Drop paragraph.

*Paragraph was removed.*  
  
Lines 570-639: Pointing to this tool is a good idea, but you go into WAY too much detail about its development. Reduce these paragraphs by 90% by simply stating the problem that the tool was developed solve, that it was developed using open science principles (no need for detail here), and how it has been received. Cite your forthcoming paper for the details.  
*Lines 553 – 639 were shortened substantially to highlight the key points of SCAPE that are relevant for understanding open science applications in a practical example. This reduced the content down to two paragraphs, one describing the problem that SCAPE addresses and another that describes the open science components. Many details for the latter were minimized to reduce redundancy with previous sections.*

**Reviewer 2 comments:**

This paper is ambitious in scope. It includes a philosophy, a catalog of tools, and a realized example of the philosophy and tools in action. The open science paradigm is a bold proposal that is certainly worthy of debate in the scientific community.   
  
The manuscript is well written, well organized, includes sound science, and communicates concepts clearly. However, it has some gaps, particularly in the area of the underlying assumptions of the open science philosophy and its possible real world implications. Because the novelty of this paper is philosophical rather than technical per se, and the authors are calling for a philosophical paradigm shift, these areas need to be addressed.

*We appreciate the insightful comments and suggestions provided below. We have made every attempt to address your concerns either through revisions and additions to the text or responded directly herein where we felt elaboration was needed. Please see the detailed responses below.*   
  
It is this reviewer's opinion that the manuscript would be more defensible and better received in the wider community if gaps and potential concerns are addressed. To wit:  
  
1. To some, the "democratization of [any professional field]" can be viewed, alternatively, as a "shackling of the [professional]" to the lowest common denominator. In the case of a scientist, for example,  
a. When the scientist is required to work in a fishbowl and defend (or at least "sell") every step of his or her work, the process becomes a beauty contest or a sales competition, rather than a scientific pursuit. The very reason we have civil service is to provide a measure of stability and impartiality, and insulate professionals to some degree from political biases and public whims.  
b. Subjecting the processes (rather than merely the inputs and outputs) of a scientist's work to the political will of nonprofessionals denies them their professionalism and erodes the very idea of what it means to be an educated, knowledgeable specialist. The silent corollary is that every aspect of a professional's work should be made publicly understandable, so that public judgment can replace professional judgment in the course of work. Yet there is a reason that our society is built on Division of Labor - it allows professionals the luxury of mastering special knowledge and understanding that not everyone else has. This specialization advances the society as a whole.  
c. An example may be illustrative. My doctor and I are user (manager) and consumer (stakeholder) of what the pharmacist dispenses to me based on a prescription, and we both have high stakes in the quality of the pharmaceutical products. We may express our political, personal, or professional will regarding what drugs are brought to market, and we may express our (dis)satisfaction with the end results. However, we have no expectation that we be directly involved in the pharmaceutical development process. Rather, we trust that the work is peer reviewed, tested, and judged by the appropriate professionals whose special knowledge is appropriate to the task.

*You provide valid counter-arguments to the openness that we advocate for in our paper. My interpretation of your comments is that 1) openness has the potential of degrading scientific integrity by allowing potentially unqualified individuals a greater say in the process, and 2) increasing openness can indirectly force scientists to pursue projects with wider appeal (or less controversial) that may not have as much scientific rigor as less “charismatic” products. So, your overall concern is that openness can degrade the quality of science.*

*I think these are valid concerns and our current section on “limitations and opportunities” provides commentary on some of these issues. For example, line 685 in the previous draft stated that “research teams using transparent workflows could expose themselves to increased criticism by their peers and the public.” Moreover, line 677 states a common argument against open science in cases when data are sensitive or otherwise proprietary. We believe that specific situations may preclude the use of open science tools and a researcher should be aware of these concerns so they can assess the costs/benefits of openness – which was our intent of including this section. However, we stress that the current literature includes many examples of how open science can improve the quality of the scientific product (e.g., Hampton et al. 2015; Ihle et al. 2017; Lowndes et al. 2017). Other examples have demonstrated that a lack of inclusion, either through “siloing” of research processes (as can be common in academia; Mitchell 2005; Liu et al. 2008) or exclusion of stakeholders, can seriously hinder the utility of an applied product. Thus, there is an increasing amount of evidence that openness has net positive benefits for scientific integrity. We draw on some of your concerns in our response to point three below.*

2. The authors quickly dismiss the idea of any government agency or personal "ownership" of the data, methods, work processes, and work products of government scientists. They also characterize bioassessment as different from other science in that it is meant not to stand alone (for example, simply to determine whether a waterbody is healthy and supporting aquatic life), but to serve the aims of managers. The unspoken corollary to this view is that bioassessment scientists are not "real" scientists, but rather mere functionaries. I would caution the authors to be careful here. On a regular basis, many government employees design protocols, methods, and studies, and then generate data, tools, reports, and publications that meet or exceed the standards of academic work. Moreover, their work products are not biased by a "positive results" publication imperative, and their data have the added advantage of residing in an institutional repository where they will be retrievable for generations, or as long as the internet infrastructure is intact.

*We disagree that an unspoken corollary of this work is that “bioassessment scientists are mere functionaries”. Rather, our intent was to make a distinction between more traditional fields of science (e.g., theoretical disciplines) vs those described as applied science. Bioassessment is one of many fields in the latter category that provide valuable knowledge and services, often with the objective of protecting public goods and resources. One of our statements in the introduction clarifies this point: “The explicit link to environmental management distinguishes bioassessment from basic ecological research. Although bioassessment can and has been used to inform basic research, its intended use is to inform the protection and restoration of ecological integrity.” I do not think most bioassessment scientists would disagree with these statements. Linking bioassessment to its applied components is a central piece of this paper, where this link can be greatly strengthened through the use of open science tools. De-emphasizing this link would of course weaken our arguments.*

*We also disagree with the idea that government research is somehow less valid than research produced in other institutional frameworks (e.g., academia). Nowhere in the text did we make this claim, nor do we feel is it implied by our statements that “ownership” of data by an institution has systematically lowered the quality of science produced through government research. Our discussion of open data as a fundamental component of open science was meant to highlight how openness can facilitate application, particularly in a field like bioassessment where the products often have a clear intended use. Many government agencies are seeing the value of open data (e.g., AB1755 in California), not because science was internally hindered from closed data, but because science can have a greater impact through openness. Anecdotally, AB1755 has encouraged more government data stewardship, including the use of data in government programs and services aimed at addressing underlying water quality programs. It is this openness and stewardship that encourages collaboration.*

3. We live in an era in which many loud political voices devalue science and even denigrate and attack it. Many stakeholders are, in fact, critics who have particular self interested motives and will find any chink in the armor of those who seek to protect natural resources. The authors seem to tacitly assume that opening up the workspaces of professional scientists to the public and to policymakers will not make our natural resources more vulnerable, but rather will restore public trust in our work and our institutions. This belief seems, at best, naïve. It would be helpful if the authors could explain the mechanism by which the shrill enemies of science would become allies, if only they could impose their will on the process - and how this would not erode the foundations of impartiality upon which the scientific method is founded.

*Our previous paragraph on line 676 spoke to these concerns. In particular, lines 688-691 stated the following: “An argument made throughout this paper is that regulatory, management, and stakeholder groups that will both use and be affected by bioassessment products should be integral contributors to the development process.* *An open science bioassessment process welcomes criticism and feedback as a natural part of development that will facilitate adoption by ensuring the product meets the needs of all parties.”*

*To better address your concerns, we have elaborated on these ideas and included the following text in “limitations and opportunities” section:*

*“Feedback and criticism are fundamental and natural parts of the scientific process. Scientists receive feedback at many stages in the conventional scientific workflow (e.g., internal review, peer-review, presentations at conferences). Potentially new and challenging avenues for feedback are created in an open workflow. A concern is that openness can provide a platform for antagonistic or even hostile views, which could alter or degrade the scientific product (Landman and Glantz* [*2009*](file:///C:\proj\manuscripts\bioassess_opensci\manu_draft.docx#ref-Landman09)*, Lewandowsky and Bishop* [*2016*](file:///C:\proj\manuscripts\bioassess_opensci\manu_draft.docx#ref-Lewandowsky16)*). However, opportunities for addressing alternative viewpoints are critical to the open process of creating applied products, even if some voices are politically charged. This is especially true in bioassessment where finished products that could be adopted in regulation are often heavily scrutinized. It is in the interest of applied scientists to hear the concerns of all parties during the development phase. This is not to provide an avenue to erode the integrity or objectives of the science, but to enable full knowledge of the very real barriers to adoption that exist when science is applied in regulation. Openness that invites all voices to participate is a much more agreeable path to consensus than producing the science in isolation of those that it affects (Pohjola and Tuomisto* [*2011*](file:///C:\proj\manuscripts\bioassess_opensci\manu_draft.docx#ref-Pohjola11)*). Ultimately, these products are developed to improve the environment as a public resource and the ideals promoted by an open science process directly align with these goals.”*

4. The authors have demonstrated clarity of thought and expression. It is very good that they draw a clear distinction between "open data" and "open tools," versus "open science." It is true that government could do somewhat better with "open tools," though more and more government scientists are converting tools to the R programming environment and contributing packages to CRAN, for example. However, the authors do a significant disservice to government agencies by failing to catalog or even mention the extensive effort that has been invested in ensuring both the quality and availability of data. Some of these include the following:  
a. Data sharing and data comparability are a centerpiece of federal water monitoring programs, under ACWI and the NWQMC. https://acwi.gov/methods/pubs/over\_pubs/valcomp\_fs.pdf   
b. Federal agencies are already committed to open data. USGS (which operates NWIS and BIODATA) and USEPA (which operates WQX/STORET) collaborate via the Water Quality Portal and the Internet of Water, as well as maintenance of the National Hydrography Dataset and its derivative products, in order to make high quality data available to the scientific community and the general public.   
c. State and Tribal data collected under EPA funding is required to be uploaded to STORET/WQX.  
d. (Side note - the SCAPE model described in this article appears to have been built on StreamCat, an EPA produced, publicly available geospatial dataset. The SCAPE website clearly credits StreamCat; this manuscript probably should as well.)  
*We agree that many of these national-level products that encourage quality and comparability of data were not mentioned.*

*We have added content to describe these products (line 704): “Many national-level data products already exist that embrace openness to invest in the quality and availability of data (e.g., National Wata Quality Monitoring Council* [*initiatives*](https://acwi.gov/methods/pubs/over_pubs/valcomp_fs.pdf)*, US Geological Survey products through* [*NWIS*](https://waterdata.usgs.gov/nwis) *and* [*BioData*](https://aquatic.biodata.usgs.gov/)*, US Environmental Protection Agency through* [*STORET/WQX*](https://www.epa.gov/waterdata/water-quality-data-wqx)*).”*

*Citations for StreamCat and NHD-Plus were also added to line 564: “Using the National Hydrography Dataset (NHD-Plus; McKay et al.* [*2012*](file:///C:\proj\manuscripts\bioassess_opensci\manu_draft.docx#ref-McKay12)*) and watershed predictors (StreamCat; Hill et al.* [*2016*](file:///C:\proj\manuscripts\bioassess_opensci\manu_draft.docx#ref-Hill16)*), the model classifies stream segments as biologically “constrained” or “unconstrained” by landscape alteration.”*

5. Although some thresholds are predictive (for example, 30% impermeable surface), landscape based watershed models show relatively poor correlation to macroinvertebrate assemblage quality, whereas instream habitat characteristics, certain water quality chemistry measures, and riparian corridor characteristics have better predictive value. The authors of the SCAPE model undoubtedly understand this as well as the nuances of natural stream classes, metric development, etc. Is it fair to ask, however, whether even the most thoughtfully designed tool can be misued by someone who does not understand it? Is it possible that the SCAPE tool could lead the novice/layperson user to conclusions or decisions that are distorted or entirely inappropriate? It is a relevant question.

*This comment addresses one of the main concerns we had developing the SCAPE tool – we did not develop the tool to “write-off” sites that are “beyond hope”, rather our intent was to provide a prioritization tool to identify sites where management actions could have intended outcomes. Prior to SCAPE, managers had no context for identifying biointegrity priorities in developed landscapes. In other words, prior to SCAPE, all urban sites were “bad”, but now we can see that not all sites are created equal and there are indeed opportunities at locations where scores were otherwise not as expected. Our intent was to allow managers to use this information to prioritize among the “bad”, as opposed to just doing nothing.*

*We developed SCAPE through close interaction with stakeholders (box 1 in figure 4) and with members of the state water board to communicate our intended use of the model results. Our open process made these interactions possible and in doing so we feel there is greater likelihood that SCAPE will be used as intended. Of course some might abuse products, which has certainly happened in the past, but every effort has been made to communicate intent with those that make decisions that will affect how SCAPE could be implemented. We encourage you to review our full manuscript on SCAPE in FWS when it becomes available (provisionally accepted as of now, pending Editor-in-Chief final review).*

*That being said, much of the section referring to SCAPE has been shortened and only relevant text has been retained. This discussion applies more to our forthcoming article and less-so about this paper.*   
  
6. This manuscript focuses on bioassessment data in particular, but it gives scant attention to the particularly thorny nature of biological data. The authors cite Cao and Hawkins 2011, but they do so in a general discussion of "duplicated effort" and "lack of coordination in the monitoring community." The same paper, in fact, is a good review of the particular difficulties of biological data. This manuscript would benefit from a short discussion of the unique characteristics and problems of biological data that set it apart from other data types, such as nested hierarchy, changing taxonomy, ambiguous taxa, the importance of ancillary information such as ecological and toxicological data, etc. Other papers in this vein are Cuffney et al 2007 (JNABS 26:286), Lenat & Resh 2001 (JNABS 20:287), Chessman et al 2007 (JNABS 26:546) and Stribling 2011 (Chapter 4 in the book "Modern Approaches to Quality Control.")   
*The following was added to the beginning of the section “curating bioassessment data” to provide some context on specific challenges with these data: “After project goals are established, the research team identifies requirements and sources of data that need to be synthesized to meet the research needs. Bioassessment data, or more generally, biological data obtained from field sampling have a unique set of challenges that require added vigilance in data stewardship (Cao and Hawkins* [*2011*](#ref-Cao11)*). Taxonomic resolution requires a tradeoff between specificity with added cost (Lenat and Resh* [*2001*](#ref-Lenat01)*, Chessman et al.* [*2007*](#ref-Chessman07)*) and names change regularly requiring updates to standard taxonomic effort (*[*STE*](http://www.safit.org/Docs/STE_1_March_2011_7MB.pdf)*) tables that are critical for many biological indices. Unidentified or ambiguous individuals or taxa must also be explicitly treated in analysis workflows (Cuffney et al.* [*2007*](#ref-Cuffney07)*), e.g., are they treated as missing values or are they substituted with coarser taxonomic designations? Environmental data that describe physical or chemical conditions are also critical to support development of an assessment index, as well as understanding potential stressors or background condition that could influence biological condition.”*

**Reviewer 3 comments:**

Summary: In this article the authors outline the ways in which open science principles and technologies can be applied to bioassessment to better link science and management. This is done by summarizing open science core concepts, and new and emerging tools for application by researchers and managers. It is further illustrated by describing recent development of a bioassessment products using an open science approach.   
*We greatly appreciate your detailed comments on our manuscript and have made every effort to address them through revision or direct comments herein.*

General Notes: The topic is important, and the article is generally well written. The primary drawbacks were that it seems much longer than is necessary, is repetitive, and does not always make clear how open science approaches will advance bioassessment. It can be "preachy" at times, assuming that end users are very reluctant to adopt these approaches instead of (as I suspect) mainly overburdened and lacking appropriate support. For example, most research projects have 1-2 years of funding; management agencies and their priorities are funded on 2-4 year legislative cycles. In this context, producing a grey literature or peer-reviewed article may be the only/most viable option for communication.

*Your comment suggests the tone of the writing be modified. As noted above in our response to the AE, our writing style was purposeful and included repetition to convince others that open science is a valuable investment of time and resources. Given your comments and those from the AE, we realize this writing style was not very effective. In the revisions throughout, much of the repetitive content has been reduced. We feel this has improved the tone significantly. Also, please see our response to providing “practical solutions” in the “Limitations and opportunities” section.*

In this same vein, who is the target audience(s) - is this article intended to convince funding sponsors and/or legislators holding the purse strings? State bioassessment program mangers? Academic researchers? In my experience, the hurdles may differ among groups. For example, academic researchers may be in a better position to adopt new tools, but have less access to manager/stakeholder input or ability to sustain an interactive website over time. Conversely, state agencies may be in a position to sustain a website over time (maybe!), but have less bandwidth to explore and learn new tools given their management mandates. Collaborations may be an important and critical way to overcome these kinds of institutional limitations for open science.

*The appropriate audience for this manuscript was an early point of discussion among the co-authors. It was our hope that the article would have broad appeal to many in the bioassessment community. For example, we provide detailed descriptions of specific open science tools that the research community can leverage, while we also discuss the benefits of open science from an institutional perspective. We admit that the article is slightly balanced towards the research community (i.e., our repeated use of the term “research team”), but we also wanted to write in an appealing way for managers or funding agencies that use or support research, i.e., investments in open science by these parties will likely have long-term returns. We have clarified this intent in the introduction (line 113): “As such, this paper is written primarily for the research team that develops bioassessment products, but we also write for the funders and users (e.g., regulators and managers) of these products to emphasize the value of investing in open science for the protection of public resources.”*

The article would be stronger if it were shorter and focused less on convincing the reader, and more on encouraging/hand-holding by 1) demonstrating the benefits 2) frankly acknowledging challenges, and 3) presenting open science as a series of "components" that facilitate a more transparent, repeatable, and iterative/engaging process (vs. assessment itself being "open" or "closed').

*We hope that our revisions to shorten some of the sections have strengthened our narrative.*   
  
The specific comments below all stem from the general notes.  
  
Introduction: Is too long. It has good information, but makes the point in multiple ways that bioassessment is uniquely embedded in legislation/management action and could benefit from adoption of open science. For example, the exact words "hundreds of assessment methods" appear in the 1st and 3rd paragraphs, and similar points appear throughout. The challenges presented are accurate, but I have a hard time seeing how adopting open science will necessarily meet all of them. For example, abundance of methods and lack of guidance (Lines 90-93) is a problem, but having these same methods available more openly wouldn't necessarily provide guidance on which ones are most appropriate. Also, the way that challenges are interspersed with how open science provides solutions are muddled and difficult to follow. For example, "Biological indices are typically used to develop post-hoc diagnoses to trigger remediation or restoration actions, or to serve as early warning indicators of environmental change" (Lines 63-64) - but then "discoverability" (Line 67) is presented as the solution to this challenge.  *Changes to the introduction are as follows:*

* *The entire second paragraph was removed (lines 52-70) as most of the content was repetitive.*
* *Removed redundant language, e.g., “hundreds of assessment methods”.*
* *Removed any direct statements that are unsubstantiated, e.g., discoverability will provide guidance on choosing a method. Although we agree that having methods more open does not necessarily help with choosing a bioassessment product, it does directly address repetition by preventing others from reinventing the wheel.*
* *First and third (now first and second) paragraphs were revised in accordance with the flow of ideas outlined in the responses below.*

I think a better approach is to briefly summarize the benefits of open science (either in bioassessment or other fields) and present it as one way to help address the science-management gap that is currently identified in bioassessment, without trying to map out how it will exactly address very specific challenges.

*Please see comments above about our restructuring of the introduction. The flow of ideas in the introduction is structured around 1) bioassessment as an applied tool (paragraph 1), 2) implementation challenges (paragraph 2), 3) open science to address these challenges (paragraph 3), and 4) goals/objectives paragraph.*   
  
Line 56-58: What is "imbalance" here? Seems to need a citation too

*This sentence was removed.*   
  
Lines 108-123: Repeats much of the abstract. Recommend writing this as objectives, and - more importantly - identifying your audience(s) and what they should get from reading the article.  
*This paragraph was shortened to reduce redundancy with the abstract. We have also explicitly indicated the intended audience for this paper. Please see our response above.*

Lines 97-103. I wouldn't call out that bioassessment has or has not embraced open science compared to other disciplines; it's very subjective - and constraints of time, funding, and expertise are the likely culprits. Sustaining management attention can be a big hurdle too for agencies. However, there is a case that bioassessment could benefit somewhat uniquely from these tools, due to the nature of being embedded in legislative mandate/public interest (requiring transparency), being a relatively new mandate/concept (requiring ongoing development), and the need for each state to conduct and report on monitoring (requiring replicability).

*Sentence was revised: “Open science principles that democratize all aspects of the scientific method can help meet these needs and there is a unique opportunity in bioassessment to leverage openness to support public resources.”*  
  
Lines 125-153. I don't think it's necessary to elaborate on the distinction between "conventional" and "open-science" approaches - managers and researchers are pretty aware of the limitations of current approaches; besides it's already covered in the Introduction. Defining what you mean by open science here should be sufficient, without calling out everything that's wrong with non-open science.

*We feel this section provides a good introduction to the issues that open science remedies and we have retained the content (also see AE comments for this same section). Further, the revisions to the introduction have reduced any redundancies with this section.*   
  
Line 154-201: Why is open data not part of the open science principles section? This section also seems very long to make a point that is widely accepted (although one that can be difficult to implement and - more importantly - sustain)

*We want to distinguish open data as a unique component of open science, so we retain the content in its own section. However, we have shortened the content to reduce redundancy and retain only the main points.*   
  
Sections "Applying open science principles to bioassessment" and "Conventional bioassessment" are making the same points, but from an inverted perspective. Example: Lines 255-256 is about accessible data and lines 272-273 are about inaccessible data. Also, lines 261-263 state: "A typical workflow for developing a bioassessment product is not entirely dissimilar from a conventional scientific process" - exactly. So it's not necessary to elaborate on the standard process, it's the one everyone knows. These two sections also repeat the same challenges raised elsewhere.   
*Agreed that there was redundancy between these sections. We have revised the “Applying open science principles to bioassessment section” to serve only as an introduction to the following sections. Also, please see our response to the AE on the same topic (i.e., response to comments on lines 202-258.*

Lines 296-297: they are uncommon in all disciplines - it doesn't seem helpful to call out the bioassessment community

*This sentence was removed based on revisions to this section.*   
  
Lines 309-314: This is fairly redundant with Figure 4 (but doesn't reference it). Also is related to the sections after, but not aligned with them.

*We have removed figure 4.*

Lines 309-492: (Related to above) Coming up with a more streamlined way to refer to the recommended process will help organize the paper, avoid redundancy, and help readers follow along. In other words, I'm not sure what the intended organization is here and in the following sections - is it organized by process or by tools? Make use of the tables and figures whenever possible instead of walking readers through text-based descriptions of tools/packages. Also, I would probably avoid sticking in more justifications for open science approaches (e.g., lines 348-351) in these sections, since (hopefully) the reader has already bought in to the "why" at this point.

*We have shortened and streamlined these sections to improve organization. Specifically, we have removed our example about the “conventional workflow” and consolidated figures and tables where appropriate. We have also specifically removed lines 348-351. Please see our responses to the other comments below for additional explanation of changes.*   
  
Lines 364-492: This section is too long, and walking readers through Table 2. If needed, expand Table 2 with some additional details or columns (e.g., example applications, which bioassessment steps it will help with) and dramatically cut down the text.  
*This section was reduced by nearly two pages.*

Lines 459-468. Suggesting readers can start developing R packages for bioassessment is an off-putting stretch/tangent - if they are able to develop R packages, then they are already experienced in using these tools.

*Our intent of this paragraph was to highlight the benefits of compartmentalizing a bioassessment product in an R package. We have modified the language to highlight the benefits, rather than suggesting that readers actively consider developing their own packages. This speaks to our intended audience for this paper, as noted above. For example, a manager reading this paper might read about the benefits of developing R packages and consider hiring or investing in someone with experience in this area to provide these services.*

Line 493: Suggest subtitle "Open Science in Practice: The SCAPE Project". In this section, be sure to refine and present information that is relevant to open science and/or is not redundant with previous sections. For example, lines 526-537 rehash challenges and the science-management disconnect. Similarly, struggling to see how lines 538-552 relate to open science.

*Subtitle was changed as suggested. Much of this section was also reduced following recommendations herein and from the AE to reduce redundancy. In total, the content was reduced from ten paragraphs down to four.*   
  
Lines 588-631: I refer to this later (Figure 4), but this section is essentially a repackaging of Table 2 and Figure 3. Recommend cutting this and/or finding ways to integrate anything really essential or new into other sections.

*Please see our response to the previous comment.*  
  
Section "Limitations and Opportunities". This is an important section, and the abstract states: "We also discuss technical, sociocultural, and institutional challenges for adopting open science, including practical approaches for overcoming these hurdles in bioassessment applications.". But I didn't find many practical suggestions for overcoming these hurdles in this section. For example, "Many scientists feel they cannot prioritize learning new skills given existing demands on their time" (648-649) and "requires a research team to stay abreast of new technologies as they are developed" (652-653)are big hurdles that won't be overcome by a better appreciation of the benefits of open science. Many of these hurdles are based in overarching constraints on the way science and management are funded and sustained (at the whim of short-term funding and even political cycles). My reading of this section is that it goes after the low-hanging fruit (e.g., scientific culture being closed to new ideas) instead of offering suggestions to counter the more intrinsic hurdles of lack of sustained funding, personnel, and expertise to develop open science models. I think focusing on suggestions that help overcome these types of hurdles will be better received and more reflective of the current challenges faced by research and management groups.  
*Your comment speaks to the core challenge in adopting open science tools, in that there is no easy or simple remedy to ease adoption. Our intent with this section was to highlight some of the main reasons why open science is not more widespread to, at the very least, allow readers to think about their own challenges as a starting point to adoption. Perhaps we were over-zealous in claiming that there are simple and “practical” solutions, but we firmly believe that some of the approaches we have described are the most effective (and practical) ways to promote adoption. In particular, lines 655-675 focus on teaching and creating communities of practice as a powerful approach to overcoming many of the hurdles we describe. Moreover, our broader intent with this paper was to emphasize the value that open science can have and to convince our readers that learning new tools is a valuable use of time (considering other demands).*

*Along these lines, we have added content to provide some more practical solutions (starting on line 675):*

*“…This also encourages the development of a community of practice that shares and learns together to navigate the collection of existing and developing open science tools. Champions of open science should also be vocal proponents that spread awareness of the value of open science tools, particularly to those that make decisions on project resources. Department heads or administrative leaders may not be aware of the value of investing in open science, particularly if the consequences of not doing so are externalized in indirect costs that are not budgeted. A change in mindset may be needed where open science is viewed as a core tool that is critical to maintaining relevance of a research program in the future (Hampton et al. 2017).*

*Many scientists feel they cannot prioritize learning new skills given existing demands on their time, particularly if the benefits of these approaches, such as the value for the research team of sharing their data, are not apparent or immediate. Short-term funding and even political cycles can disincentivize scientists from spending time on anything but contractually obligated deliverables, which as noted above, may not effectively apply science in decision-making. This is an acute concern for early career scientists that have higher demands on establishing reputation and credentials, where investments in open science may be seen as detracting from progress (Allen and Mehler* [*2019*](file:///C:\proj\manuscripts\bioassess_opensci\manu_draft.docx#ref-Allen19)*). As an alternative, a practical solution is to actively encourage the investment in open science within the research team or lab, as opposed to placing the burden on the individual as an isolated researcher (i.e., team science, Cheruvelil and Soranno* [*201*](file:///C:\proj\manuscripts\bioassess_opensci\manu_draft.docx#ref-Cheruvelil19)*8). Laboratory or department heads should allow and encourage research staff to invest time in learning new skills and exploring new ideas, even if this does not immediately benefit the latest project. Over time, small investments in developing new skills will have long-term payoffs, particularly if a growing skillset among the research team encourages networking and peer instruction (Lowndes et al.* [*2017*](file:///C:\proj\manuscripts\bioassess_opensci\manu_draft.docx#ref-Lowndes17)*, Allen and Mehler* [*2019*](file:///C:\proj\manuscripts\bioassess_opensci\manu_draft.docx#ref-Allen19)*). Developing an environment where open science tools are highly valued and encouraged may also increase job satisfaction and benefit recruitment and retention if researchers are allowed the space and time to develop skills beyond the current project.”*

Table and Figures  
  
Figure 2. The "a" section detracts from this figure. I can think of many "conventional" assessments that incorporate some aspect(s) of an open science approach, but fall short of incorporating all aspects of it, due to lack of time/expertise/money etc. This figure would be better presented as "Idealized or potential components of bioassessment based on open science principles" to encourage adoption of different components - piecemeal if needed - vs. an all-or-nothing buyin.  
*We removed the top “conventional” subfigure to reflect the changes that were made to the text*

Figure 4. This type of information is already presented in Table 2 and the text (and to some extent the workflow figure previous) - the large graphical representation seems unnecessary. Some information could be added to Table 2 if needed to replace this (i.e., more explicit explanations or examples of R package applications).

*This figure was removed. We have added information in the SCAPE section to supplement any missing information (e.g., links to examples that are specific to SCAPE).*