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Improving environmental risk assessments of chemicals: Steps towards evidence-based ecotoxicology

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1. Introduction

Few would argue that regulatory decisions related to chemical substances, whether pre-market authorisations, setting of health-based reference values and environmental quality standards, or prioritizing for future testing and management measures, ought to be based on less than all reliable and relevant evidence. Yet opinions on how the use of ecotoxicological and toxicological evidence should be operationalized in regulatory practice can differ considerably (Wagner et al., 2018). Although all regulatory decision-making based on science has some degree of empirical support, we argue here that evidence-based ecotoxicology goes further by systematically collating, classifying and integrating evidence by its epistemological strength, commonly referred to as the weight of evidence (Table 2). The term evidence-based ecotoxicology was selected to mirror developments in medical and clinical practice that are commonly referred to as “evidenced-based medicine”.

As illustrated by recent high profile controversies documented in the peer-reviewed literature, such as the hazards and risks of atrazine, decabromodiphenyl ether, bisphenol A, or glyphosate, the roots of such divergent assessments can often be traced back to different approaches for gathering evidence and the consequent consideration of different sets of studies, or differing interpretations when weighing seemingly ambiguous results (Alcock et al., 2011; Beronius et al., 2010; Boone et al., 2014; Tarazona et al., 2017). One of the major issues under debate concerns the use of non-standardized ecotoxicity and toxicology studies as a basis for decisions. These studies, when included, may alter the conclusions of a regulatory assessment. This has resulted in sometimes tense discussions among academia, industry, public interest groups, and regulatory agencies regarding the reliability of non-standardized tests, or the relevance of different test designs, organisms, and endpoints. Increasingly, the effects of conflicts of interest and publication bias have been raised where the concern is the risk-of-bias of individual studies or entire bodies of evidence (Borgert and Anderson, 2007; Buonsante et al., 2014; Cope and Allison, 2010; Myers et al., 2009; Suter and Cormier, 2016; Tyl, 2009; Vom Saal and Myers, 2010; Wandall et al., 2007).

A wide breadth of expertise is employed to conduct ecotoxicological studies and chemical risk assessments, involving different stakeholders at different stages. Ecotoxicity studies are typically performed by academic institutions, regulatory agencies, or by industry laboratories themselves or contract research organizations funded by industry. In contrast, chemical evaluations are performed either by regulatory agencies, or by industry representatives and then reviewed by regulatory agencies. One prerequisite to the success of these processes is clear communication between stakeholders regarding expectations, possibilities, and limitations within each step. This is particularly important since most stakeholders are not involved at all stages and a lack of mutual understanding may undermine collaboration. For example, a new scientific study or methodology is more likely to be embraced by regulatory authorities if it is accompanied by an explanation of the context in which it may be used, the gap it fills, and how it advances knowledge compared to previously used methods.

To foster such cooperation between stakeholders and promote robust and transparent regulatory decision-making, we have reviewed recent trends and developments in the interpretation of ecotoxicology studies for regulatory environmental risk assessment and offer here a set of recommendations. This was initially discussed during a Society of Environmental Toxicology and Chemistry (SETAC) Pellston Workshop™ titled “Improving the usability of ecotoxicology in regulatory decision-making”. The recommendations are developed based on our own experiences of performing and scrutinizing risk assessments for chemicals within the European, North American, Pacific and Asian regulatory frameworks (Table 1).

2. The recommendations

Some of these recommendations will be easy to implement and could be described as ‘low hanging fruit’, while others will be challenging to implement, as they require structural changes within organizations, but could offer breakthrough advances in decision making.

Table 1
Nine recommendations towards evidence-based ecotoxicology and their principal actor(s).

Recommendation	Principal actor(s)
1. Consider all applicable studies	Risk assessors and regulators
2. Report all findings of experimental studies	Academic and industry scientists, scientific journals, public research funding bodies
3. Make ecotoxicity studies publicly accessible	Academic and industry scientists, scientific journals, public research funding bodies
4. Implement reporting guidelines for publication of ecotoxicity studies	Scientific journals
5. Apply transparent and consistent evaluation criteria to all ecotoxicity studies	Risk assessors and regulators
6. Improve the regulatory guidance for weight-of-evidence evaluations	Regulators
7. Increase collaboration among all stakeholders	All stakeholders
8. Declare interests	All stakeholders
9. Improve training and knowledge transfer between all stakeholders	All stakeholders

Table 2
Example of definitions of key terms.

Key term	Definition	Reference
Reliability Common synonyms: quality, internal validity.	Evaluating the inherent quality of a test report or publication relating to preferably standardized methodology and the way the experimental procedure and results are described to give evidence of the clarity and plausibility of the findings. Reliability of data is closely linked to the reliability of the test method used to generate the data.	ECHA, 2011
	The inherent quality of an effect value in a test report or publication relating to: 1) a clearly described experimental design to allow for the study to be repeated independently, 2) the way the experimental procedures were performed, and 3) the reporting of the results to provide evidence of the reproducibility and accuracy of the findings.	Moermond et al., 2016a
Relevance Common synonym: external validity.	Covering the extent to which data and tests are appropriate for a particular hazard identification or risk characterisation.	ECHA, 2011
Weight of evidence	The process of considering the strengths and weaknesses of various pieces of information in reaching and supporting a conclusion concerning a property of the substance.	ECHA, 2010
	A systematic review method, applied in a manner suited to the nature of the evidence or decision, that uses a pre-established protocol to comprehensively, objectively, transparently, and consistently, identify and evaluate each stream of evidence, including strengths, limitations, and relevance of each study and to integrate evidence as necessary and appropriate based upon strengths, limitations, and relevance.	U.S. EPA, 2017
Systematic review	A systematic review is an overview of existing evidence pertinent to a clearly formulated question, which uses pre-specified and standardized methods to identify and critically appraise relevant research, and to extract, report and analyse data from the studies that are included in the review.	EFSA, 2011

The focus is here on environmental risk assessments, but the recommendations could equally be applied to human health assessments. All recommendations adhere to the principles of the 3Rs (replacement, reduction, and refinement) developed to reduce the use of test animals (William and Burch, 1959). For definition of key terms, see Table 2.

2.1. Consider all applicable studies

A prerequisite of scientific evidence as the basis for sound decision-making is for the body of scientific evidence considered pertinent to be as near complete as possible. The first recommendation therefore challenges the potential a priori exclusion of ecotoxicity studies before further considering their relevance and reliability. The first step towards this aim is the adoption of transparent and reproducible approaches to gathering evidence by methodically attempting "to collate all empirical evidence that fits pre-specified eligibility criteria in order to answer a specific research question" (Higgins and Green, 2011). For this purpose, much can be learned from the systematic review methodology. Systematic review is a rigorous, protocol-driven method, initially developed in the fields of psychology, social science, and health care, and considered a valuable tool for evidence-informed decision-making across many domains. The potential advantages of adapting the methodology to the field of chemical risk assessment have been recognized by multiple research groups and organizations (Whaley et al., 2016) and efforts to apply systematic review methods at least in environmental health regulatory decision-making have commenced (EFSA, 2018; Gundert-Remy et al., 2017; U.S. EPA, 2011, 2018). Typically, a robust methodology includes a well-defined study question, a reproducible and transparent literature-search strategy, and pre-determined inclusion and exclusion criteria (Vandenberg et al., 2016).

2.2. Report all findings of experimental studies

Still, even the most robust systematic review method cannot alone prevent reporting biases, particularly publication bias or outcome reporting bias (Hopewell et al., 2009). There are many potential causes of missing data; whole studies may never have been published or made accessible to risk assessors, studies may have been inappropriately indexed in databases making them difficult to locate, and specific endpoints or data points may have been excluded from reports and/or summary analyses (Higgins and Green, 2011). Missing data are problematic since decisions may then be based on a dataset that does not reflect the totality of the body of knowledge. This is particularly alarming if data are deliberately suppressed or censored.

Publication and outcome reporting biases refer to the publication or non-publication of research findings or the selective reporting of some outcomes but not others, respectively, depending on the nature and direction of the results. There are several possible explanatory factors behind publication bias and selective reporting; positive results are considered to be more interesting (e.g., reporting a response of an environmental species at a lower concentration than previously known), and scientific journals are therefore more likely to publish these. Similarly, as the interest of readers turns into citations and potentially into funding or promotion, researchers themselves may lack incentives to publish negative or less interesting results (Hanson et al., 2018). Finally, financial or other conflicts of interest may deter individual scientists or organizations from fully disclosing research results. In medicine, analyses have shown that clinical trials with positive findings are published sooner and more often than trials with negative findings (Hopewell et al., 2009). Nonetheless, others warn that various conflicts of interest, such as financial incentives or existing accepted paradigms, may work in the direction of censoring or diminishing effects (Ioannidis, 2008). There are, to our knowledge, no systematic analyses of the direction and magnitude of publication bias and selective reporting in ecotoxicology. In the absence of such evidence and in the presence of commercial interests linked to reporting no effects and/or regulatory pressures to report positive effects within a certain time limit, a priori gauging the magnitude and direction of publication bias and selective reporting in ecotoxicology remains speculative and itself prone to bias and conflicts of interest.

Regardless, negative findings are equally informative for regulatory chemical risk assessments and researchers should be encouraged to publish negative results. The acceptance of studies that find "no effect" for publication in peer-reviewed journals should also be promoted. In other disciplines, some journals now devote a section to negative findings (Dirnagl and Lauritzen, 2010) while entire journals dedicated to negative results have also been launched (O'Hara, 2011). Similar initiatives in the field of ecotoxicology are required. Additionally, open repositories offer an additional avenue to make negative results and data publicly accessible.

2.3. Make ecotoxicity studies publicly accessible

Access to scientific literature and databases can be costly and not all regulatory agencies, interest groups, or other stakeholders (e.g., small and medium sized enterprises) can afford it. Peer-reviewed ecotoxicity

studies should therefore preferably be published as open access, or reasonable efforts should also be made to make research data available in any other way. Access to raw data can be crucial for the understanding of study results, as well as for recalculations of data to fit the user's own needs. To facilitate access, supplemental information can be used to share raw data.

Today, numerous general-purpose data repositories, at scales ranging from the institutional (for example, a single university), to open globally-scoped repositories such as FigShare (http://figshare.com), Mendeley Data (https://data.mendeley.com/), or Zenodo (http://zenodo.org/), to cite a few, are available and accept a wide range of data types in a wide variety of formats. This diversity has prompted the formulation of the so-called FAIR Data Principles (Kilkenny et al., 2010) (namely that data should be findable, accessible, interoperable, and reusable), and large-scale initiatives such as the European Open Science Cloud (https://ec.europa.eu/research/openscience/index.cfm?pg=open-science-cloud).

The recommendation to make ecotoxicity studies publicly accessible does not only apply to academic researchers but is equally valid for regulatory and industry scientists. Grey literature (e.g., reports, working papers, and evaluations from government agencies, non-governmental organizations, research institutes, and consultants), are often publicly available, but can be difficult to track and access since they are not included in literature databases in a systematic way. However, their importance for avoiding publication bias has been highlighted in systematic literature reviews in health and medicine (Paez, 2017). A number of topic-focused search engines are now available and can help identify grey literature not listed in databases. Examples include the search engines Environar (https://environar.com/environar/desktop/en/search.html), open access bibliographical databases such as OpenGrey (http://www.opengrey.eu/), which searches grey literature across Europe, or CORE (http://www.core.ac.uk), to search open access items in institutional repositories.

For some industry studies, making studies publicly available is a goal fraught with potential economic and legal complications. Conducting studies constitutes a substantive financial investment, and if the information has commercial value its dissemination has the potential to harm economic interests. Jurisdictions, like the European REACH regulation, therefore have data-sharing agreements where use of a study funded by one company can only be submitted by another company if a compensation agreement has been agreed to (Fleischer, 2007). In these cases, making the data available to the public would not result in a financial burden.

Further, there may be conflicts with existing intellectual property rights or licenses granted by third parties. Still, dissemination should be considered a worthwhile goal as improved transparency could increase the credibility of regulatory processes as well as that of the regulated entity. We recommend seeking means by which confidential business information can be made more accessible while protecting legitimate business interests. One suggestion would be to harmonise data protection agreements that currently exist in some regulatory agencies, allowing the ownership of data to remain protected while data are made publicly available.

2.4. Implement reporting guidelines for the peer reviewed publication of ecotoxicity studies

Studies performed according to standardized methods and Good Laboratory Practice (GLP) follow strict reporting requirements. It is well recognized that meeting such requirements is not necessarily the same as asking the right question or performing best science. However, it promotes thorough reporting of studies which in turn facilitates understanding and evaluation of results. In contrast, the reporting of ecotoxicity studies in peer-reviewed journals is less structured and formalized. Crucial information may be missing and lead to disqualification from consideration in regulatory assessments (Ågerstrand et al., 2013; Harris et al., 2014). Complete and transparent reporting of peer reviewed ecotoxicity studies is not only important to comprehend the credibility of the study, it is a necessity if the study is to be used in a regulatory context. An evaluator needs to be able to appraise whether a study was conducted using a reliable method relevant for the specific regulatory assessment under consideration. However, it may be difficult to differentiate between an unreliable study, i.e., a study performed using a problematic test design (e.g. too few replicates) or careless practices (e.g. contamination in controls), and a reliable study that is just poorly reported. Unless the assessor can gain access to additional information that can help untangle this assessment dilemma, the regulatory implications will be the same for an unreliable study as for a poorly reported reliable study: both would be excluded from further consideration, i.e. waste of valuable research effort and funding (Moermond et al., 2016a,b).

Debates regarding the reproducibility and reliability of published data are not limited to ecotoxicology. Similar discussions have taken place in most if not all other scientific fields (Baker, 2016). A commonly suggested solution is to improve the reporting of studies (Ågerstrand et al., 2013; Baker, 2016). Reporting requirements have been successfully implemented for observational epidemiology studies, in vivo toxicity studies, and for microarray experiments (Glasziou et al., 2014; Miller, 2014; Von Elm et al., 2007). Similar guidelines to help researchers publish reproducible and reliable ecotoxicity studies already exist (Brazma et al., 2001; Kilkenny et al., 2010) and implementing these in relevant journals is not anticipated to present particular challenges. Nevertheless, at the time of writing, only a limited number of journals have adopted specific requirements (such as confirmation of exposure concentrations), the pertinent peer-reviewed journals have yet to fully implement existing reporting guidance (Hanson et al., 2017). Such guidelines could prevent crucial omissions if consulted when designing, conducting, and reporting studies. Furthermore, reporting guidelines also act as an efficient tool for reviewers (Moermond et al., 2016a,b). Funders of scientific studies could require researchers to ensure that studies are of sufficient reliability by stipulating that reporting guidelines should be used (Hanson et al., 2017).

2.5. Apply transparent and consistent evaluation criteria to all ecotoxicity studies

Evaluation of included studies requires the application not only of transparent evaluation criteria, but also, that the same demands should apply to all studies of similar type. In the context of ecotoxicology, that means that evaluation methods that solely base their assessment on whether a study is a standardized study or not, such as the literal application of the Klimisch method (Klimisch et al., 1997), violate core principles of systematic review by introducing a bias. Similarly, while compliance with GLP regulations confers confidence in many aspects of the study (e.g., adherence to a pre-established protocol, independent quality assurance inspection, record-keeping, reporting), this alone does not mean the study is relevant to the assessment question at hand.

Furthermore, evaluation methods should be systematic and sufficiently detailed to guide evaluators into finding possible weaknesses of a study and consequently ensure the consistency, reproducibility, and robustness of the evaluation (Kase et al., 2016). Comparisons of evaluation methods show that care should be given when choosing the method, and that there are noteworthy differences between the various methods (Ågerstrand et al., 2011; Moermond et al., 2016a,b; Roth and Ciffroy, 2016). Characteristics for which differences were found between evaluation methods include: applicability domain, referring to both the environmental compartment and type of study (QSAR, in vivo, in vitro, standardized studies); the amount of guidance provided to interpret each evaluation criterion; the method of weighting of criteria; overall scoring; and previous testing of the evaluation method.

Until recently, available evaluation methods only considered reliability, but the relevance of a study, i.e. the extent to which its results

can be utilized for the assessment question under consideration, is equally important. The relevance aspects considered when assessing the safety of chemicals tend to be limited to comparing treatment levels with expected exposure estimates (Moermond et al., 2016a,b). However, other aspects of study design such as the relevance of the toxicological endpoint, life-stage or representativeness of the test organisms, or the route of exposure to name a few are equally pertinent (Rudén et al., 2017). Whereas reliability is an intrinsic measure of the design, conduct and reporting of a study, its relevance depends on the goal of a given assessment question. As a result, evaluation methods need to be flexible enough to be capable of handling different types of studies and assessment goals. Evaluation methods need to adopt a systematic approach and be sufficiently detailed to facilitate consistency between evaluators. Moreover, to ensure transparency and understanding of regulatory decisions, clear reporting and documentation of the evaluation process is necessary.

2.6. Improve the regulatory guidance for weight-of-evidence evaluations

The need for transparent processes extends to methods and approaches to integrate, synthesise and/or summarize said evidence. In the field of chemical regulation the terms weight-of-evidence (WoE) and systematic review are sometimes used interchangeably to describe the entire assessment procedure from assembling available studies to evaluating, interpreting and integrating the whole body of evidence to reach conclusions, while others use systematic review to describe the method by which studies are gathered and WoE that of the evaluation that occurs afterwards (Ågerstrand and Beronius, 2016). Although the term WoE appears frequently in the scientific literature, it has historically been used in many disciplines encompassing economics, law or medicine and is often poorly and inconsistently defined (Krimsky, 2005; Linkov et al., 2009; Weed, 2005). In its recent guidance document, EFSA lists no less than 22 examples of definitions for WoE (Hardy et al., 2017) and the U.S. EPA has recently provided a definition in its regulations for conducting risk evaluations under the Toxic Substances Control Act (U.S. EPA, 2017). This multiplicity of definitions is matched by the diversity of available methods ranging from those that are largely qualitative in nature to fully quantitative and Bayesian approaches (Martin et al., 2018; Rhomberg et al., 2013; Suter, 2016).

While potential applications may be too diverse to allow for a single dictated WoE method (Hall et al., 2017), within a certain application the goal should be to have common methods for WoE that will decrease the risk of contradicting assessments, and increase the general public's trust in institutional decision-making. A recent critical review by ANSES, the French Agency for Food, Environmental and Occupational Health and Safety, highlights the needs for harmonisation of methods and terminologies (Martin et al., 2018). Multilateral organizations such as the Organisation for Economic Cooperation and Development (OECD) or United Nations institutions have provided platforms to promote harmonisation, e.g., the monographs produced by the WHO/FAO Joint Meeting on Pesticide Residues (JMPR) played an important role in the international harmonisation of acceptable daily intakes for human health assessment (Kortenkamp et al., 2017). All WoE approaches will involve elements of expert-informed judgments, and explicit criteria related to the selection process of expert panels have to date largely been omitted from guidance for WoE approaches (Martin et al., 2018) (this aspect is partially addressed by recommendations 7 and 8). At a minimum, a critical aspect is that the WoE approach be transparent, documented, and fit-for-purpose (Schreider et al., 2010). This should include the development and publication of a priori WoE protocols appropriate for the assessment or application under consideration according to relevant guidelines (Shamseer et al., 2015), preferably in a peer-reviewed journal or alternatively on open platforms (e.g., Zenodo).

It should also be noted that WoE approaches ought to be sufficiently calibrated by ring-testing or by experimental, epidemiological and/or modelling results (Brock et al., 2016; van Wijngaarden et al., 2015). Verifying the consistency of environmental risk assessment decision schemes should be a basic requirement for every guidance document.

2.7. Increase collaboration among all stakeholders

Assessing the risks of chemicals to the environment involves a variety of stakeholders having different perspectives and interests. Partnerships and collaboration can improve the scientific basis of assessments when regulators, industry, academics and non-governmental organizations representing public or specific interests work collaboratively towards shared goals. Where such consensus can be achieved, decision-making processes may be more readily accepted as transparent which in turn renders them more efficient. Platforms such as the Society of Environmental Toxicology and Chemistry (SETAC), where ideas can be exchanged can help foster an increased understanding of other's perspectives and further develop partnerships among academia, regulators, industry and non-governmental organizations.

Nonetheless, participatory processes are delicate balancing acts and collaboration for its own sake does not alone guarantee success. It is therefore essential to pay heed to the lessons learnt by practitioners in other disciplines and recognize that stakeholder participation does not take place in a power vacuum. In any collaborative situations, there are always power and group dynamics at play. These should be recognized and acknowledged rather than ignored as, if inadequately facilitated, they may discourage minority perspectives from being expressed, potentially leading to a “dysfunctional consensus” (Reed, 2008).

2.8. Declare interests

It follows that, in the interest of transparency, collaborative activities as well as the source of their funding, and any other activity or relation with an entity that has a stake in the risk assessment of chemicals, should be duly and publicly declared (Schreider et al., 2010). Not all conflicts of interest can be avoided however, nor are they necessarily harmful. Transparency about interests and potential conflicts should be seen as a strict minimum and should be applied consistently across journals and agencies.

In the management of conflicts of interest, there are obvious tensions between this recommendation and the previous one: because of real or perceived conflicts of interests, some stakeholders may be excluded from collaborations. Typically, the onus is on the declarant to foresee and manage such conflicts. However, attitudes as to which situations are perceived as so conflicting they ought to forbid participation in a decision-making process are diverse. The ideal of value-free science dictates that science-based decision be purely rational and devoid of any value-laden or moral judgement, and in turn, evidence of any such judgement or expressed opinion could be construed as a conflict of interest or ‘bad science’. This view is however not universally accepted and is argued to be not only unrealistic but ultimately undesirable (Lekka-Kowalik, 2010). With its stated protection goals, the use of science in chemical regulation is value-laden from its inception and its inherently normative nature should be acknowledged. Science should be used to encourage an informed societal debate rather than stir fruitless disputes between experts that run the risk of undermining the public's trust in scientific results. Rather, to foster both openness and participation, emphasis should be focused on transparency with regards to public declaration of interests, appropriate representation of different or opposing values, and the careful facilitation of power and group dynamics in participatory processes, as previously mentioned.

2.9. Improve training and knowledge transfer between all stakeholders

The successful implementation of all the other recommendations depends on a substantial effort to exchange knowledge and build capacity (Harris et al., 2017). While some endeavours to include

toxicology in chemistry and specifically green chemistry curricula are ongoing (Cannon et al., 2017), the norm remains that chemistry students, as well as other natural science students, graduate with little understanding of the concepts necessary for chemical risk assessment. Including green and sustainable chemistry principles in education and practice will require commitment and support from all stakeholder groups, including academic institutions, chemical societies, Ministries of Education, and the private sector. Furthermore, existing national, regional and global networks should be used to disseminate and exchange best practices (UNEP, 2019). This predicament is rendered more acute by the rapid development of the in vitro, in silico, and other high-throughput methods necessary to meet the requirements of the 3Rs and the fundamental biological knowledge necessary to appraise the advantages and limitations of various experimental models. The overhaul of current toxicity testing methods and tools for interpretation of test results hailed by 21st century toxicology needs to be matched by significant revision of the curricula currently used to train students for careers in ecotoxicology and environmental chemistry, as well as opportunities for continuing professional development. This is especially important for what is now referred to as translational toxicology, which focuses on how test results and interpretive tools are used to make environmental risk management decisions regarding hazardous chemicals (Andersen and Krewski, 2009). This discipline intersects with biology, ecology, and environmental economics and environmental decision-making and requires the design and delivery of interdisciplinary educational and professional development courses.

3. Concluding remarks

Implementing the recommendations above will require concerted and sustained efforts from a variety of sectors and stakeholders, including industry, environmental interest groups, regulators, risk managers, policy makers, scientists, publishers, and educators. Whereas some of the recommendations are more readily achievable, and indeed progress has already been made on some, others require a shift from a more narrowly defined disciplinary focus to a more holistic interdisciplinary understanding of environmental decision-making. Ultimately, it is the authors' belief that better evidence will lead to better decisions, which in the end leads to sustainable innovation and a healthier environment.

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Disclaimer

This paper is the work of the authors and the opinions herein are those of the authors alone and do not necessarily reflect the view or opinions of their institutions or SETAC.

Declaration of interests

Amy Beasley, Scott Belanger, Roger L. Breton, Malyka Galay Burgos, John Green, Tilghman Hall, Duane Huggett, Marion Junghans, Grace Panter, Veronique Poulsen, Christian E. Schlekat, Ilse Schoeters, Jane Staveley, Randall Wentsel, and James R. Wheeler are, or were at the time of the Pellston workshop, employed by companies that are to be regulated or employed by companies that perform services for regulated industries and regulatory authorities.

Ryszard Laskowski and Theo Brock were members of the EFSA Panel on Plant Protection Products and their Residues when the Pellston workshop took place. Keith Solomon has participated in and published several Weight of Evidence assessments for industrial clients prior to and since the SETAC Pellston workshop took place. Mark Hanson has conducted research and data assessments for Syngenta LLC. Michael Warne has assessed the toxicity of hypersaline brine discharge for several Australian desalination plants. The remaining authors have no conflict of interests to declare.

Authors contributions

Martin and Ågerstrand drafted the manuscript. All authors contributed to discussions during the workshop, read, commented on and approved the final manuscript. All data are available in the manuscript.

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