Table 1. Comparison of Common Resources (Zenodo, Figshare, Dryad Digital Repository, PANGAEA Data Publisher, GitHub, and Bitbucket) Used for Archiving Code and Data[a]

	Zenodo	Figshare	Dryad	PANGAEA	GitHub and Bitbucket	Supplementary Material
Default License	Flexible	MIT	CC0	CC-BY	Flexible	None
Long-term	Yes[b]	Yes [b]	Yes [b]	Yes [b]	No	Yes [b]
Assigns DOI	Yes	Yes	Yes	Yes	No	No
Code Search Option	Yes	Yes	No	No	Yes	No
Upload from GitHub	Yes	No	No	No	–	No
Cost to Author	None	None	Possible	None	None	None

[a]For the default licenses: flexible means that multiple license options are available from a menu, MIT is the Massachusetts Institute of Technology License, CC0 is the Creative Commons Zero License, and CC-BY is the Creative Commons Attribution License. DOI, digital object identifier. Zenodo, Figshare, Dryad, and PANGAEA are good options for archiving because they provide licenses, are long-term, and are citable. The cost to authors assumes that the code is publicly available. Note that the information in this table is subject to change.

[b]Long-term availability depends on continued government funding or the success of the companies involved.

license or license options, making it easy to add a license when code is submitted. Archives need to be long-term, assuring continuous availability ([14], https://caseybergman.wordpress.com/2012/11/08/on-the-preservation-of-published-bioinformatics-code-on-github/). All of the resources in Table 1 store submissions for the long-term except for GitHub and Bitbucket. Some of the archives assign code submissions a digital object identifier (DOI), which makes code straightforward to cite in scientific publications. Other considerations are whether it is possible to search specifically for code within the archive, the process for uploading code, and the cost of archiving code. Most of the archives host code for free if the code is made publicly available. Overall, Zenodo, Figshare, Dryad, and PANGAEA are good options for archiving because they provide licenses, are long-term, and are easily citable (Table 1).

Journals can have a significant impact on increasing the value of code within the ecology community. We believe that broad adoption of the suggestions to increase visibility and discoverability of code, require archiving of code, and increase citation incentives for doing so, will motivate more authors to release both analysis code and scientific software. By fostering reproducibility and reuse, more available code can improve the quality and accelerate the rate of research in ecology.

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Science & Society

Communication of Science Advice to Government

Jeffrey A. Hutchings[1,2,3,*] and Nils Chr. Stenseth[2,4,5]

There are various ways to construct good processes for soliciting and understanding science. Our critique of advisory models finds that a well-supported chief science advisor (CSA) best ensures the

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Trends

We critique advisory models for the communication of science to government.

Above all, we favour a well-supported, well-connected Office of Chief Science Advisor.

The ideal model provides deliberative, informal, and emergency advice, absent of vested interests.

Advocacy, particularly harmful when unacknowledged, hinders science communication and advice.

provision of deliberative, informal, and emergency advice to government. Alternatively, bias, increasingly manifest as science-based advocacy, can hinder communication, diminish credibility, and distort scientific evidence.

Motivation

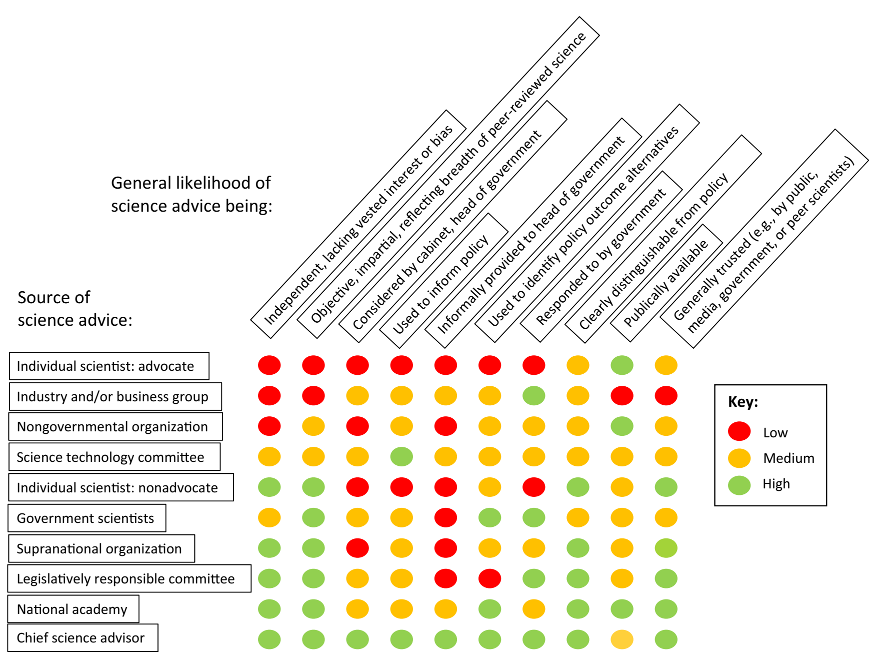
Science provides one of only a few impartial lenses on the world. It offers factually defensible explanations of the natural, technological, and socioeconomic realms, and of the potential consequences of using these to better the human condition. To realize the latter, decision-makers have made use of scientific knowledge to guide general regulatory and policy development and to evaluate the potential outcomes of alternative decision options [1–3]. The extent to which governments seek science advice, and the means by which they do so, varies considerably. Social scientists have long grappled with matters pertaining to the communication of science [2–5], natural scientists less so [6–8]. However, motivated by threats that human-induced change pose for the integrity of the natural systems of the Earth, many researchers have become increasingly engaged in how science is communicated to, and used by, decision-makers.

Based on our 40-plus years of advisory experience (formal and informal) on two continents, our primary objective here is to critique existing models for how science is communicated to government. In so doing, we hope to better inform ecologists and evolutionary biologists who wish to strengthen links between their areas of expertise and related areas of government decision-making. Our secondary goal is to contribute to the nascent discussion of science-based advocacy, a practice to which many are increasingly drawn (www.aaas.org/report/workshop-advocacy-science).

Science Advice Versus Science-Based Advocacy

To be of greatest utility, expert science advice should have a high probability of achieving several ideal outcomes (Figure 1). Among these are impartiality, independence from vested interests, and communication with the levels of government at which authority to make a binding decision rests. Given particular levels of consensus and uncertainty, such advice should contribute to objective, informed evaluations of the implications of policy options from a science perspective [1–7]. The benefits of such advice are many. For decision-makers, a strong evidentiary basis for a particular policy will strengthen and broaden support, help buttress contrary positions from interest groups, and be less likely to cause political harm or embarrassment. Ministers can (ideally) be confident that the advice is based on rigorous, objective assessments of the best available evidence. The public can be hopeful that government is using the evidentiary nature of science in the best interests of society; if decisions are made that are inconsistent with or do not appropriately account for scientific evidence, this needs to be clearly communicated.

In our opinion, credible advice emerges from discourse continually subject to comment and criticism by peers. Peer review can be anonymous (commonly associated with papers in scientific journals and expert-panel reports) or not (such as an open, collective review by a committee of 'peers', common with some forms of government-department advice). Peer review underpins the confidence that decision-makers and the public have in science advice. Peer review allows government and society to benefit from clarity



Trends in Ecology & Evolution

Figure 1. Models for the Communication of Science Advice, Ranked in Ascending Order of Subjective Likelihoods of Achieving Desirable Outcomes.

about the weight of evidence that supports or does not support a particular policy. Peer review can also distinguish objective advice from value-based opinion and vested interests.

Science-based advocacy differs from science advice. Advocacy reflects the interests of those providing information at the expense of the breadth of peer-reviewed science on which the information is based [7]. Advocates selectively frame or shape advice with the intention of favouring one policy outcome over another. Although the advocate might base their perspective on science, that perspective is affected by how the advice might be used by decision-makers. Advocacy is not always readily detectable and, in many cases, individuals are not as vigilant as they should be as to whether they are science-based advocates. Industry, business, and many non-governmental organizations (NGOs) are commonly identified as overt advocates. Less well appreciated is the growing number of academics whose impartiality has been questioned.

We acknowledge the role that science-based advocacy has in society. For a variety of personal reasons, individuals will wish to advocate for particular decisions and outcomes. However, such scientists, often well intentioned, must clearly acknowledge their advocacy role. A 'responsible advocate' is one who communicates their values fairly and truthfully, makes explicit how their values are linked to their policy choices, and clarifies that their personal conclusions might differ from the scientific consensus [9]. In our view, many individuals are negligent in communicating these biases, leading to the 'irresponsible advocacy' [9] that we disparage.

At its core, advocacy reflects elements of personal value systems: social ideology, cultural tradition, employment experience, religious beliefs, education, and family upbringing. The personal value systems of scientists have no intrinsically greater merit than those of the decision-makers whom they advise or the citizenry who might be affected by the advice. Government decisions will always be political; politicians will often conflate facts and values. To establish and maintain societal trust, scientists proffering advice to government should do neither.

Models of Advice: A Typology

Notwithstanding the ideals, science advisory models differ considerably in practice. This variability need not necessarily affect the quality of the advice (although this is certainly possible), but differences in how advice is communicated to decision-makers clearly has tangible effect on the likelihood that government will integrate the information within its decision-making process (Table 1, Figure 1).

Models for the provision of science advice differ in several key aspects. One of these, as noted previously, is the degree of bias. Advice from vested interests, although readily available, is infrequently heeded by government (unless there is political benefit in doing so). Perception of bias can be as problematic as real bias. Science and technology advisory committees (STACs) advise many governments on technological innovation and development of perceived economic value. However, STACs have the potential to produce advice influenced by vested interests, depending on committee membership. The STAC in Canada (members are appointed by a government minister) is dominated by business, industry, and government sectors (www.stic-csti.ca/eic/site/stic-csti.nsf/eng/h_00008.html); by contrast, individuals from academia, national academies, and research councils comprise the majority of the STAC in the UK (members are appointed by the Prime Minister; www.gov.uk/government/organisations/council-for-science-and-technology/about/membership).

Most advisory models do not allow for advice to be directly communicated to national cabinets and heads of government [10]. Government scientists, STACs, and national academies formally advise at ministerial or subministerial levels. By contrast, CSAs directly advise government heads [11,12]. Indirectly, supranational organizations (e.g., Intergovernmental Panel on Climate Change) can achieve the same. By eclipsing national borders and transcending national politics, their advice can provide justification for governments to supersede ideologically narrow national considerations in favour of broader global concerns.

Among science-communication models, few constitute legally responsible advisory bodies (LRABs) that provide advice to which government is required, by statute, to respond. Two prominent examples concern the listing of threatened species: Committee on the Status of Endangered Wildlife in Canada (COSEWIC; established by the Species at Risk Act) [13] and the Threatened Species Scientific Committee in Australia (established by the Environment Protection and Biodiversity Protection Act).

Office of Chief Science Advisor

In our view, a well-supported CSA offers a highly defensible, potentially optimal, means of strengthening the evidential basis of, and societal benefits accruing from, science advice to government. A growing number of countries have established the position and a considerable part of the natural and financial resources of the world is governed by jurisdictions advised by a CSA [3,10,14]. Globally, 14% of the land and fresh water on Earth (https://en.wikipedia.org/wiki/List_of_countries_and_dependencies_by_area) is encompassed by countries advised by a CSA (the percentage was 20% from 2004 to 2008 before Canada rescinded its CSA position, the only country to have done so). In 2015, CSA-advised countries accounted for approximately 31% of the global gross domestic product (https://en.wikipedia.org/wiki/List_of_countries_by_GDP_%28nominal%29).

Table 1. Highlighted Strengths and Weaknesses of Science Advisory Models[a]

Science Advisory Model	Strengths	Weaknesses
Advocates: NGOs, industry, business, and individual scientists	Considerable potential to communicate with broad sectors of society; ability to increase public and/or political awareness	Real or perceived bias, vested interests; vulnerable to criticism that science-based information is selectively provided and/or not peer-reviewed; increased probability of being excluded from meaningful government science advisory roles
Science and technology advisory committee	Ready access by government to advice on technological innovation and development; evidence-based reporting of national progress against international competitors	Remit is comparatively narrow, lacking scientific breadth; potential for real or perceived bias, depending on committee membership; often lack of clear separation between science and policy
Government scientists	Ministers have ready and rapid access to advice germane to their portfolios; advice is highly relevant to legislative and regulatory responsibilities	Not always readily publically available; interactions between scientists and public can be highly restricted or controlled; lack of clear separation between science and policy
Supranational organizations (e.g., IPCC, WHO, or IUCN)	Generally perceived to lack bias or vested interests; advice transcends national politics and ideology; clear separation between science and national government policies	Usually no legal or convention-based requirement for governments to heed advice; limited ability to provide informal advice or to respond to emergencies; priorities of such bodies cannot easily be directed by national priorities
Legislatively responsible advisory body (e.g., COSEWIC or TSSC)	Tight link between science advice and governmental statutory responsibilities; objective advice provided independently of the consequences of the advice; government legally required to respond to the advice	Remit is narrow, restricted to that specified by legislation; unable to formally provide or evaluate policy-outcome alternatives
National Academies (e.g., UK Royal Society, Leopoldina[b], or US National Academy of Sciences)	Offer breadth of expertise across natural, medical, and social sciences; capacity to undertake in-depth interdisciplinary research on longstanding issues	Usually unable to provide advice promptly, depending on the academy; limited ability to provide informal advice or to respond effectively to emergencies
Office of CSA	Provides deliberative or informal advice, analysis, and opinion on any aspect of science; advises head of government and cabinet, rather than a single minister or bureaucrat; provides advice in emergency situations; communicates with public to enhance societal confidence in science and technology	Unable to fulfil responsibilities when government support and confidence is inadequate; best suited to national rather than multinational jurisdictions

[a]Abbreviations: COSEWIC, Committee on the Status of Endangered Wildlife in Canada; IPCC, Intergovernmental Panel on Climate Change; IUCN, International Union for the Conservation of Nature; TSSC, Threatened Species Scientific Committee; WHO, World Health Organisation.
[b]The National Academy of Sciences in Germany.

The remit of CSAs is typically broad [1,3,11,12,14]. Foremost is to provide, to the head of government, deliberative and informal advice, analysis, and opinion on any aspect of science (particularly novel issues when scientific progress entails opportunity or threat). CSAs do not act in isolation. Rather, they serve as the primary conduit of advice from all sources, including STACs. CSAs have a responsibility to communicate science with elected representatives and the public. Nonetheless, despite a broad mandate to generally inform policy, it is not the purview of a CSA to provide unsolicited advice on science policy or matters related to science funding. Doing so places the office in the real or perceived position of being an advocate, compromising the ability of the CSA to sustain trust.

Evidence suggests that appointment of a CSA from outside government improves the use of science across ministries and assists in developing clear science-related strategies within government [15]. The UK, the first to establish the office (in 1964), has used it to considerable effect, having appointed a CSA to each of its government departments. In addition, to deal with emergencies, the UK Government CSA chairs the scientific advisory group (www.gov.uk/government/groups/scientific-advisory-group-for-emergencies-sage) responsible for advising government on science issues with potential influence on UK citizens, such as the 2014 Ebola outbreak, the 2011 Japan nuclear incident, and the 2010 Icelandic volcanic ash cloud.

Despite its theoretical and practical advantages, barriers to the office of CSA remain. Reasons for this can be related to the evolution of national governance structures, particularly within multinational jurisdictions where a single CSA (especially if not well supported) might find it difficult to reflect a diversity of political and decision-making cultures. Testament to this challenge is the 2014 termination of CSA to the President of the 28-nation European Commission (EC). The EC has replaced the individual-based CSA model with a seven-member 'high level group' of scientific advisors (https://ec.europa.eu/research/sam/index.cfm?pg=hlg) whose effectiveness has yet to be determined. Politics and advocacy can also have a role. The closure by Canada of its CSA office coincided with a strong ideological shift in the national government, although a recently elected government has promised to re-instate the position (http://pm.gc.ca/eng/minister-science-mandate-letter). The EC decision to rescind the position was preceded, and arguably heavily influenced by, advocacy-based, lobbying efforts [3]. Discontent by vested interests with independent scientific advice is not uncommon, challenges to the listing advice from COSEWIC on polar bear (*Ursus maritimus*) providing one illustrative example [16].

Concluding Remarks

The compelling argument has been made that science advisory systems should comprise three fundamental components: deliberative advice; informal advice; and advice in emergencies [1,11,12]. Deliberative or formal advice can be provided, albeit not coordinated, by a combination of some of the models considered here. Informal advice can also be requested of, and provided by, a subset of advisory models; having chaired an LRAB (J.A.H.) and a national academy (N.C.S.), we can attest to the value that decision-makers place on such advice. However, in addition to other deficiencies (Figure 1, Table 1), none of these models provides for regular and direct communications between those providing the advice and national heads of government and their cabinets. We feel that such a connection is vital.

We conclude that a well-supported CSA, with strong links to the advisory capacities of government departments (possibly through their own CSA offices, as in the UK), STACs, national academies, and supranational bodies is optimal for ensuring the integrity of science advice throughout the decision-making system of a government, and for providing informal advice when necessary, especially during emergencies.

To fully realize the benefits of societal investments in science, it is self-evident that governments should fully utilize the ultimate product of science (evidence) to strengthen policy and better inform decision-making. Societies invest a great deal to generate peer-reviewed scientific evidence; it can also cost a great deal not to use it wisely and not to communicate it responsibly. It need not, and should not, be wasted.

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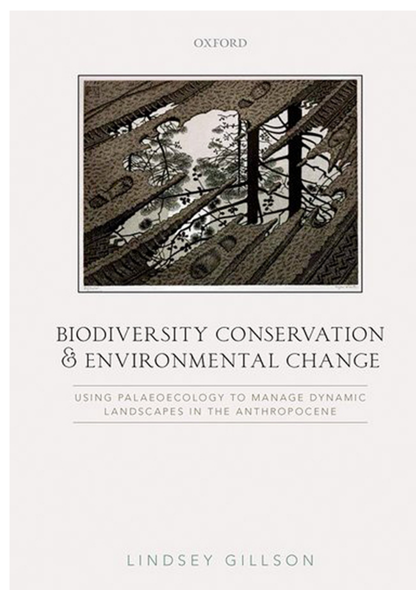
Book Review

Looking Back to Look Forward

Althea Davies[1,*]



Although palaeoecologists have published papers on the relevance of long-term data to conservation for over 20 years [1,2], an accessible book that brings examples together and relates