ICES Journal of Marine Science

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science (2012), 69(1), 3–7. doi:10.1093/icesjms/fsr179

Food for Thought

Advice under uncertainty in the marine system

Dorothy J. Dankel[1]*, Robert Aps[2], Gurpreet Padda[3], Christine Röckmann[4], Jeroen P. van der Sluijs[5], Douglas C. Wilson[6], and Poul Degnbol[7]

[1]Institute of Marine Research, PO Box 1870, N-5817 Bergen, Norway
[2]Estonian Marine Institute, 14 Mäealuse Street, EE-126 18 Tallinn, Estonia
[3]Department for Environment, Food and Rural Affairs, Nobel House, Area 2D, 17 Smith Square, SW1P 3JR London, UK
[4]Wageningen IMARES, PO Box 68, NL-1970 AB IJmuiden, The Netherlands
[5]Utrecht University, PO Box 80125, NL-3508 TC Utrecht, The Netherlands
[6]Department of Development and Planning, Innovative Fisheries Management, Aalborg University, Fibigerstræde 13, DK-9220 Aalborg Ø, Denmark
[7]ICES, H.C. Andersens Boulevard 44-46, DK-1553 Copenhagen V, Denmark

*Corresponding Author: tel: +47 55 23 85 56; fax: +47 55 23 86 87; e-mail: dorothy@imr.no

Dankel, D. J., Aps, R., Padda, G., Röckmann, C., van der Sluijs, J. P., Wilson, D. C., and Degnbol, P. 2012. Advice under uncertainty in the marine system. – ICES Journal of Marine Science, 69: 3–7.

Received 4 February 2011; accepted 10 October 2011; advance access publication 22 November 2011.

There is some uncertainty in the fisheries science–policy interface. Although progress has been made towards more transparency and participation in fisheries science in ICES Areas, routine use of state-of-the-art quantitative and qualitative tools to address uncertainty systematically is still lacking. Fisheries science that gives advice to policy-making is plagued by uncertainties; the stakes of the policies are high and value-laden and need therefore to be treated as an example of "post-normal science" (PNS). To achieve robust governance, understanding of the characteristics and implications of the scientific uncertainties for management strategies need to come to the centre of the table. This can be achieved using state-of-the-art tools such as pedigree matrices and uncertainty matrices, as developed by PNS scholars and used in similar science–policy arenas on other complex issues. An explicit extension of the peer community within maritime systems will be required to put these new tools in place. These new competences become even more important as many countries within the ICES Area are now embarking on new policies.

Keywords: fisheries advice, fishery system, maritime system, pedigree matrix, post-normal science, uncertainty.

Introduction

The Working Group on Fisheries Systems (WGFS) was established by the International Council for the Exploration of the Sea (ICES) 10 years ago, *inter alia* "to develop a framework and methodology for the analysis of fishery system performance" and "propose … interdisciplinary research which will advance ICES future capability in fishery systems analysis" (ICES, 2000).

The WGFS created a forum to bring social scientists into ICES to help describe the socio-ecological system around fisheries and to use this perspective to intensify ICES' effectiveness in marine science advice for policy. The main conclusions from 10 years of interdisciplinary WGFS work/expertise are that many interests should be represented when science and policy meet and that an understanding of the characteristics and the implications of scientific uncertainty (including data quality) need to be placed at the centre of the discussion (ICES, 2008b). The latter is seen as the key to governance in the science–policy interface of complex issues. Others have argued, for good reason, that overemphasizing uncertainty in fisheries advice can lead to policy paralysis (Rosenberg, 2007). However, broader experience in science and policy indicates that underemphasizing uncertainty is even more dangerous, because it can do lasting damage to the credibility of the science (Keepin and Wynne, 1984; Kloprogge and van der Sluijs, 2006; van der Sluijs, 2007; van der Sluijs *et al.*, 2008). An effective approach for dealing with science in situations of high stakes and high systems uncertainty is through "post-normal science" (PNS), as developed by Funtowicz and Ravetz (1993). Succinctly, the concept of PNS—as opposed to "normal science"—suggests that in situations of high uncertainty and high stakes, imperfect (and sometimes subjective) knowledge needs to be used in providing advice to policy-makers. An important pillar of PNS is the inclusion of an extended peer community

(EPC), including stakeholders with different types of expertise. These EPCs need to acknowledge, analyse, and communicate uncertainty and quality in science for policy in the extended peer-review process (Funtowicz and Ravetz, 1990, 1993; van der Sluijs, 2002; Kloprogge and van der Sluijs, 2006; Petersen, 2008). Hence, the EPCs need to become the foundation for credible, legitimate, and salient science for policy advice. Cash *et al.* (2003) found these three variables to have the most influence on the extent to which a scientific result will be incorporated in policy. The PNS approach characterizes a method of enquiry for situations in which decisions need to be made before conclusive scientific evidence is available (Funtowicz and Ravetz, 1990, 1993). Often, in fact, a single scientific answer will never be available for complex systems such as fisheries. In such cases, more research does not lead to less uncertainty, but can lead instead to unforeseen complexities (van der Sluijs *et al.*, 2005, 2010; Trenberth, 2010). Concurrently, the potential impacts of decisions based on uncertain science have very large consequences (biological and/or social), so values are in dispute.

We highlight two examples from outside fisheries science to illustrate the importance of advancing uncertainty early and in a transparent manner. The first is the recent "Climategate" controversy from late 2009 (van der Sluijs *et al.*, 2010), which originated at the Climatic Research Unit at the University of East Anglia (UK), after a hacker published e-mails and files from CRU scientists on the Internet. The media coverage that followed instigated an independent review panel of the CRU (Oxburgh *et al.*, 2010). The e-mail leak exposed the decision by some climate scientists to exclude a specific (tree ring) dataset from the historical climate reconstruction presented in the latest IPCC report. Although there are good scientific reasons not to include the data post-1960 (Briffa *et al.*, 1998), and although these reasons are widely accepted as valid in the scientific community working on temperature reconstructions from the past, this was not made clear in the final report of the IPCC, nor did the report mention that these data were excluded from the climate reconstructions presented. This prompted climate sceptics to question the credibility and legitimacy of the report, which is based on scientific consensus within the IPCC. Consecutive independent reviews of both the science (Oxburg *et al.*, 2010) and the process (Russell, 2010) concluded that the scientific approach had been justified, proper scientific process such as peer review had been in place, but the problem had been elsewhere, because "there has been a consistent pattern of failing to display the proper degree of openness" (Russell, 2010). The case demonstrates how overselling certainty creates vulnerability in the credibility and legitimacy of the scientific basis for policy. Such vulnerabilities can and will be exploited easily, to obstruct and delay policy intervention (van der Sluijs *et al.*, 2010).

An example of a severe scientific credibility crisis of advice for policy support is the controversy originated by a whistle-blower at the Netherlands Environmental Assessment Agency in early 1999 (van der Sluijs, 2002). The media was the last way out for senior statistician de Kwaadsteniet who decried his institution for using poorly validated computer models as the scientific basis for advice given to the Dutch government for far-reaching environmental policy decisions. De Kwaadsteniet was also critical that the agency's advice was presented as point values, with spurious precision and opaque uncertainties (van der Sluijs, 2002). A 6-month credibility-ravaging media storm fuelled vehement debate in parliament on the credibility and validity of environmental numbers that form the basis of Dutch environmental policy. It ultimately resulted in rigorous reforms of the quality-control procedures inside the Netherlands Environmental Assessment Agency and in how scientific evidence is analysed, reviewed, and communicated in their assessments, and a new focus that copes with uncertainty (van der Sluijs *et al.*, 2003; Beck, 2007; Petersen *et al.*, 2011).

These dangers from overselling certainty are relevant to ICES, because ICES also communicates results from uncertain and imperfect data. Most ICES assessment scientists have experienced being asked to find certainty that is not really there: the achievable state of knowledge does not allow one to deliver the degree of certainty that policy-makers seem to expect from science (Wilson, 2009; Kraak *et al.*, 2010). Even when the uncertainties in science are presented through caveats in the advice, policy-makers have little choice but to take and use the uncertain numbers. Under the current Common Fisheries Policy (CFP), policies do neglect uncertainties surrounding problem-framing, model structures, assumptions, system boundaries, indeterminacies, and the extent to which a policy is value- (or theory-) laden (Hauge, 2010; van der Sluijs *et al.*, 2010).

Tools to address uncertainty

One tool to address unquantifiable uncertainties is the numeral unit spread assessment pedigree (NUSAP) analytical and notational system (van der Sluijs *et al.*, 2005). It extends the classic notational system for quantitative scientific information (usually provided as a number, a unit, and a standard deviation) with two additional qualifiers: expert judgement of the reliability (the assessment) and a multicriteria characterization reflecting the origin and status of the information (the pedigree). The classical notational system does not reveal the distinction between nearly perfect information (such as the speed of light) and highly imperfect information (such as the size of a marine fish stock). The two additional qualifiers, assessment and pedigree, attempt to remedy this problem. The pedigree analysis is a qualitative structural process to clarify the knowledge base on which scientists and stakeholders frame their perceptions of a problem, by appraising the information underpinning the numbers and theories that form the basis of scientific advice, often model-derived. In PNS, the traditional search for robust scientific findings, ideally based on scientific consensus, is replaced by a search for robust policy strategies, which are useful regardless of which of the diverging scientific interpretations of the knowledge is correct (van der Sluijs *et al.*, 2010). The qualitative approach of pedigree analysis helps to assess different aspects of the knowledge base, such as its empirical basis, the level of theoretical understanding, the rigour of the scientific methods used, the extent to which the findings have been validated, and the extent of scientific consensus among peers and among the wider scientific and stakeholder communities (van der Sluijs *et al.*, 2005). An example of a pedigree matrix is presented in Table 1. Results from sensitivity analysis and pedigree analysis can be combined in a so-called diagnostic diagram that aims to reveal the weakest, i.e. the most uncertain, elements of a scientific assessment or a model (van der Sluijs, 2005). It is based on the notion that neither sensitivity alone nor pedigree alone is a sufficient measure for whether uncertainty is critical for the outcome of an assessment. For example, if the spread in a model parameter has a negligible effect on model output (low sensitivity), the robustness of model output to parameter uncertainties could be good even if uncertainty around that parameter

Table 1. Pedigree matrix of the knowledge status of key biological parameters for a fish stock.

Pedigree score	Stock–recruitment	Growth	Natural mortality (M)	State of stock (input in long-term management plan simulations)	Impact of climate change
4	Clear visual and functional relationship	Well sampled and causes of fluctuations are well understood	Reliable estimates of M	*High-quality assessment with uncertainty estimates*	Well-understood consequences of temperature fluctuations experienced
3	Possible relationship	*Well sampled, but causes of fluctuations poorly understood*	Reliable estimates of M, but not at early life stages	High-quality assessment, but limited focus on uncertainty estimates	Known impact on growth or recruitment or distribution
2	*No clear relationship, recent average used*	Poor sampling and environmental effects on growth poorly understood	Poor estimates of M	Rather low-quality assessment	*Limited knowledge and not accounted for in modelling*
1	Unknown	Unknown	*Unknown predation by cod and other top predators of the ecosystem*	Inadequate data and knowledge in assessment	No knowledge of temperature effects on stock

Pedigree refers to the categorical quality of a dataset for the biological parameters, and 4 is the highest score. The rows include the descriptions of each of the pedigree scores from 1 to 4 for each of the biological parameters. The western Baltic herring pedigree score for each parameter is in italics (from Ulrich *et al.*, 2010).

is high. In that situation, ignorance of the true value of the parameter has no immediate consequence. Alternatively, model outputs can be robust against parameter spread even if its relative contribution to the total spread in the model is high (high sensitivity), provided the pedigree score is also high. In the latter case, the high uncertainty in the model outcome adequately reflects the inherent and irreducible uncertainty in the complex system represented by the model. Uncertainty is then a property of the modelled system and does not stem from imperfect knowledge of that system. The policy response chosen needs then to be robust against these uncertainties. Mapping components of the knowledge base in a diagnostic diagram therefore reveals the weakest elements of an assessment, helps in the setting of priorities for improvement, and assists in the choice of adequate policy strategies to cope with uncertainty. A further development has been to include societal dimensions of uncertainty in pedigree analysis (Corral Quintana, 2000; Craye *et al.*, 2005).

Another tool available to address uncertainty is the uncertainty matrix (Walker *et al.*, 2003), which allows analysts to typify and characterize the various sources of uncertainty for a given case following an application of quantitative methodology. The benefit of this tool is that it provides a specific overview where there are policy-relevant uncertainties, and it assists the analyst to identify types and sources of uncertainty that require additional analysis as well as to select the appropriate tools. The uncertainty matrix demonstrates transparency by clearly communicating to policy-makers the uncertainties playing key roles in the assessment process. The uncertainty matrix has become part of a standardized methodology adopted in 2003 by the Netherlands Environmental Assessment Agency, where aspects of the knowledge production and use are systematically scrutinized by a knowledge quality checklist (Petersen, 2008; van der Sluijs *et al.*, 2008). The matrix classifies uncertainty according to location (where it occurs), level (statistical, scenario, or ignorant levels of uncertainty), nature (whether uncertainty stems from knowledge or inherent variability), qualification of the knowledge base (strong and weak components of the process), and choices burdened by values identifying the biases that shape the knowledge base (Petersen, 2008; van der Sluijs *et al.*, 2008).

These tools go hand in hand with other, over-reaching, hierarchical types of risk assessment. An example of this is the ecological risk assessment for the effects of fishing (ERAEF) described by Hobday *et al.* (2011), which evaluate risk and the vulnerability of different ecosystem components. As we see it, uncertainty matrices and the NUSAP analysis of data sources could be used within the ERAEF framework (Hobday *et al.*, 2011) along with effective tools leading to a facilitation strategy between scientists and stakeholders, as outlined by Hanssen *et al.* (2009).

Extending the peer community

The WGFS has documented a number of examples of a post-normal approach to fisheries management (ICES, 2008b). An important step in PNS is the identification and establishment of EPCs. EFIMAS was the earliest project to address such communities (Wilson and Pascoe, 2006); the project carried out extensive consultation with stakeholders about the use and abuse of management models (Degnbol *et al.*, 2008) as well as participatory modelling exercises for Baltic cod, North Sea flatfish, and Mediterranean swordfish (EFIMAS, 2008). The work was constructed in the SAFMAMS (Hegland and Wilson, 2009; Wilson, 2009) and JAKFISH projects, where scientists built EPCs particularly through regional advisory councils (RACs), comprising industry, non-governmental organizations, managers, administrators, and other scientists.

The first step in such a collaborative/participatory approach is to define the research question jointly. This process can be initiated by both scientists and industry. JAKFISH used pedigree and uncertainty matrices to facilitate the communication of model complexities, critical assumptions, and uncertainties. Feedback from collective learning and the entire participatory process was collated in focus groups and from questionnaires. In terms of usefulness and applicability of science, a major benefit of the collaboration within the EPCs was that industry priorities were explicitly included in JAKFISH investigations. The participants in the EPCs recognized the potential of the modelling approach for demonstrating and raising awareness of the complexity of fisheries management; they found the collaborative modelling approach useful in developing a common framework for complex issues (Wilson and Pascoe, 2006; ICES, 2008b; Hegland and Wilson, 2009; Ulrich *et al.*, 2010).

In PNS, it is important to communicate quantitative and qualitative risk assessment to policy-makers. Apart from WGFS, the Study Group on Risk Assessment and Management Advice (ICES, 2009) and the Study Group on Management Strategies (ICES, 2008a) are two ICES Study Groups that dealt specifically with the challenges of high uncertainties and risks in fisheries advice and management. Participatory modelling is now gaining broader acceptance and is also delivering the knowledge and experience gained in the ICES expert groups (Ulrich *et al.*, 2010; Röckmann *et al.*, 2011).

The problem of validation and verification

As with any other practice of science, PNS is faced with validation and verification of its results. From a science-to-policy perspective, PNS aims to answer the questions “are we addressing the right issue” and “are we doing it the right way”. This is the process of establishing evidence that the scientific results actually fit reality. This challenge is not trivial, because policy issues that require a PNS approach characterize the fact that truth (e.g. the true size of a fish stock) cannot be known immediately when the policy decision needs to be made and subsequently cannot be a substantial aspect of the issue. In practice, however, validation is impossible (Oreskes *et al.*, 1994; Beck, 2002). In PNS, therefore, the unachievable task of validation is replaced by a task of rigorous quality control of the knowledge-production process. Discipline is maintained by controlling model assumptions and other assessment tools, and maintaining good practice in their development and application (Kraak *et al.*, 2010). Tools for knowledge quality assessment provide a form of heuristic that encourages systematic self-evaluation and reflexivity on pitfalls in the assessment process.

Of course, PNS provides a complementary approach to conventional science approaches (i.e. statistical analyses) by making the assessment of knowledge quality a key task in the science–policy interface. Popper (2002) asserts that “probability estimates are not falsifiable. Neither, of course, are they verifiable…” Therefore, the challenge is to demonstrate that the subjective decisions based on PNS advice are objectively better than those based on other grounds.

The way forward

Interdisciplinary advice will be needed more in the future than in the past. In fact, the ICES Science Plan states that the “success of ICES science in the future depends on strengthening the links between environmental science, physical and biological oceanography, fishery science, and socio-economic sciences, and in developing integrated programmes”. Today, the ICES community is approaching a new integrated maritime policy (IMP) in the European Union (EC, 2007), and especially the environmental pillar of the IMP, the Marine Strategy Framework Directive (EC, 2008), which enshrines an ecosystem approach to marine management across economic sectors.

The legitimacy, credibility, and salience of results determine the impact of science on policy and can be increased when the peer community is extended to include stakeholders in a PNS–policy context. The WGFS has been active in outlining these issues, but the concern now is to put theory into practice. We therefore propose a move towards understanding how human societies relate to and manage their interactions with marine ecosystems. This broader understanding should aid ICES in providing advice that is credible, legitimate, and salient, including effective communication of uncertainty within an EPC (Kraak *et al.*, 2010). This is a key to useful advice under uncertainty in the marine system.

Does that mean that ICES should stop providing fisheries advice (currently still by far the bulk of ICES advice)? We think that this is unlikely to happen or even advisable—even integrated policies will require advice on specific issues on sectors, including fisheries, and fisheries will remain a sector where there is a need to manage human interactions with the marine ecosystems. What this means is that ICES advice needs to progress in two dimensions simultaneously: (i) towards advice that increasingly incorporates consideration of human interactions with marine ecosystems in all economic sectors in an integrated way, and (ii) towards new modes of advice development and advice delivery that are more interactive and include an extended peer-review community. These two dimensions are closely linked, because advice with a wider societal scope also inevitably depends on dialogue on societal choices. Choices that cannot originate from within the science community itself need to be developed through extended dialogue and exploration of options, uncertainties, and risks with the extended peer-review community.

Acknowledgements

We thank colleagues and participants of ICES WGFS meetings over the past 10 years who helped inspire and contribute to the progress of systems understanding in fisheries, and Kjellrun Hiis Hauge and Martin Pastoors for their probing comments on an earlier version of this manuscript.

References

Beck, M. B. 2002. Model evaluation and performance. *In* Encyclopedia of Environmetrics, 3, pp. 1275–1279. Ed. by A. H. S. Shaarawi, and A. W. Piegorsch. John Wiley & Sons, New York.

Beck, M. B. 2007. Environment: how best to look forward? Science, 316: 202–203.

Briffa, K. R., Schweingruber, F. H., Jones, P. D., Osborn, T. J., Shiyatov, S. G., and Vaganov, E. A. 1998. Reduced sensitivity of recent tree-growth to temperature at high northern latitudes. Nature, 391: 678–682.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Jäger, J., *et al.* 2003. Knowledge systems for sustainable development. Proceedings of the National Academy of Sciences of the USA, 100: 8086–8091.

Corral Quintana, S. 2000. Una metodología integrada de exploración de los procesos de elaboración de políticas públicas. Universidad de La Laguna, Tenerife, and EC, Ispra, Italy, EUR 19724 ES.

Craye, M., van Der Sluijs, J. P., and Funtowicz, S. O. 2005. A reflexive approach to dealing with uncertainties in environmental health risk science and policy. International Journal for Risk Assessment and Management, 5: 216–236.

Degnbol, P., Eustace, B., Frangoudes, K., Hatchard, J., Hegland, T., Pitchon, A., and Jacobsen, R. 2008. Stakeholder perspectives on fisheries science and modelling—focus group discussions in Spain, Greece, UK, Denmark, and Ireland. Focus Group Report, Work Package 5, EFIMAS (Operational Evaluation Tools for Fisheries Management Options) EU 6th Framework Programme Specific Targeted Research Project, SSP8-CT-2003-502516. 184 pp. http://vbn.aau.dk/files/16350587/Stakeholders_Perspective.pdf.

EC. 2007. An integrated maritime policy for the European Union. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. 16 pp.

EC. 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008: establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019:0040:EN:PDF.

EFIMAS. 2008. EFIMAS (Operational Evaluation Tools for Fisheries Management Options) Policy Brief, 2008. Specific Targeted Research Project under the 6th Framework Programme, Project SSP8-CT-2003-502516. 6 pp.

Funtowicz, S. O., and Ravetz, J. R. 1990. Uncertainty and Quality in Science for Policy. Kluwer, Dordrecht. 220 pp.

Funtowicz, S. O., and Ravetz, J. R. 1993. Science for the post-normal age. Futures, 25: 735–755.

Hanssen, L., Rouwette, E., and van Katwaijk, M. 2009. The role of ecological science in environmental policy making: from a Pacification toward a Facilitation Strategy. Ecology and Society, 14(1). http://www.ecologyandsociety.org/vol14/iss1/art43/.

Hauge, K. H. 2010. Uncertainty and hyper-precision in fisheries science and policy. Futures, doi:10.1016/j.futures.2010.10.006.

Hegland, T. J., and Wilson, D. C. 2009. Participatory modelling in EU fisheries management: western horse mackerel and the pelagic RAC. Maritime Studies, 8: 75–96.

Hobday, A. J., Smith, A. D. M., Stobutzki, I. C., Bulman, C., Daley, R., Dambacher, J. M., Deng, R. A., *et al.* 2011. Ecological risk assessment for the effects of fishing. Fisheries Research, 108: 372–384.

ICES. 2000. Report of the Working Group on Fishery Systems. ICES Document ICES CM 2000/D: 02. 44 pp.

ICES. 2008a. Report of the Study Group on Management Strategies (SGMAS). ICES Document CM 2008/ACOM: 24.

ICES. 2008b. Report of the Working Group on Fishery Systems (WGFS). ICES Document CM 2008/RMC: 07. 49 pp.

ICES. 2009. Report of the Study Group on Risk Assessment and Management Advice (SGRAMA). ICES Document CM 2009/RMC: 14.

Keepin, B., and Wynne, B. 1984. Technical analysis of IIASA energy scenarios. Nature, 312: 691–695.

Kloprogge, P., and van der Sluijs, J. P. 2006. The inclusion of stakeholder knowledge and perspectives in integrated assessment of climate change. Climatic Change, 75: 359–389.

Kraak, S., Kelly, C., Codling, E., and Rogan, E. 2010. On scientists' discomfort in fisheries advisory science: the example of simulation-based fisheries management-strategy evaluations. Fish and Fisheries, 11: 119–132.

Oreskes, N., Shrader-Frechette, K., and Belitz, K. 1994. Verification, validation, and conformation of numerical models in the Earth sciences. Science, 263: 641–646.

Oxburgh, R., Davies, H., Emanuel, K., Graumlich, L., Hand, D., Huppert, H., and Kelly, M. 2010. Report of the International Panel set up by the University of East Anglia to examine the research of the Climatic Research Unit. 9 pp. http://www.uea.ac.uk/mac/comm/media/press/CRUstatements/SAP.

Petersen, A. 2008. Stakeholder participation guidance for the Netherlands Environmental Assessment Agency. 23 pp. http://www.rivm.nl/bibliotheek/rapporten/550032007.pdf.

Petersen, A., Cath, A., Hage, M., Kunseler, E., and van der Sluijs, J. 2011. Post-normal science in practice at the Netherlands Environmental Assessment Agency. Science Technology and Human Values, 36: 362–388.

Popper, K. 2002. The Logic of Scientific Discovery, Routledge Classics, London.

Rosenberg, A. A. 2007. Fishing for certainty. Nature, 449: 989.

Röckmann, C., Bell, E., Haapasaari, P., Mäntyniemi, S., Tserpses, G., and Ulrich, C. 2011. Workshop reports and evaluation of case studies management strategy evaluation. JAKFISH Deliverable 4.2. 15 pp. https://www.surfgroepen.nl/sites/jakfish/Publications/JAKFISH%20D4.2%20Workshop%20reports%20and%20evaluation%20of%20case%20studies%20MSE.pdf.

Russell, M. 2010. The independent climate change emails review. University of Eastern Anglia, Norwich. http://www.cce-review.org/pdf/FINAL%20REPORT.pdf.

Trenberth, K. 2010. More knowledge, less certainty. Nature Reports Climate Change, 4: 20–21. doi:10.1038/climate.2010.06.

Ulrich, C., Coers, A., Hauge, K. H., Clausen, L. W., Olesen, C., Fisher, L., Johansson, R., *et al.* 2010. Improving complex governance schemes around western Baltic herring, through the development of a long-term management plan in an iterative process between stakeholders and scientists. ICES Document ICES CM 2010/P: 07. 28 pp.

van der Sluijs, J. P. 2002. A way out of the credibility crisis of models used in integrated environmental assessment. Futures, 34: 133–146.

van der Sluijs, J. P. 2005. Uncertainty as a monster in the science policy interface: four coping strategies. Water Science and Technology, 52: 87–92.

van der Sluijs, J. P. 2007. Uncertainty and precaution in environmental management: insights from the UPEM conference. Environmental Modelling and Software, 22: 590–598.

van der Sluijs, J. P., Craye, M., Funtowicz, S. O., Kloprogge, P., Ravetz, J. R., and Risbey, J. S. 2005. Combining quantitative and qualitative measures of uncertainties in model based environmental assessment: the NUSAP system. Risk Analysis, 25: 481–492.

van der Sluijs, J. P., Petersen, A. C., Janssen, P. H. M., Risbey, J. S., and Ravetz, J. R. 2008. Exploring the quality of evidence for complex and contested policy decisions. Environmental Research Letters, 3: 024008. doi:10.1088/1748-9326/3/2/024008.

van der Sluijs, J. P., Risbey, J. S., Kloprogge, P., Ravetz, J. R., Funtowicz, S. O., Corral Quintana, S., Guimarães Pereira, Â., *et al.* 2003. RIVM/MNP Guidance for Uncertainty Assessment and Communication: Detailed Guidance, 3. Utrecht University, Utrecht. 71 pp.

van der Sluijs, J. P., van Est, R., and Riphagen, M. 2010. Beyond consensus: reflections from a democratic perspective on the interaction between climate politics and science. Current Opinion in Environmental Sustainability, 2: 409–415.

Walker, W. E., Harremoës, P., van der Sluijs, J. P., van Asselt, M. B. A., Janssen, P., and Krayer von Krauss, M. P. 2003. Defining uncertainty: a conceptual basis for uncertainty management in model-based decision support. Integrated Assessment, 4: 5–7.

Wilson, D. C. 2009. The Paradoxes of Transparency: Science and the Ecosystem Approach to Fisheries Management in Europe. University of Amsterdam Press, Amsterdam. 303 pp.

Wilson, D. C., and Pascoe, S. 2006. Delivering complex scientific advice to multiple stakeholders. *In* The Knowledge Base for Fisheries Management. Developments in Aquaculture and Fisheries Science Series, pp. 329–353. Ed. by L. Motos, and D. C. Wilson. Elsevier, Amsterdam.

Handling editor: Verena Trenkel