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Contribution to the Themed Section: 'Risk Assessment'

Introduction

Risk assessment and risk management: a primer for marine scientists

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Risk assessment is the management approach or framework of choice in many disciplines, including health care and research, engineering design, and particularly the insurance sector which relies on the best available forward projections of natural hazards and accidents. The marine management community, which includes researchers, practitioners, and resource managers responsible for individual targeted stocks, aquaculture activities, and the marine environment in general, has been slower to take up quantitative risk assessment approaches. Whilst there are prominent examples where risk assessment and management approaches have been applied, they are relatively few. This article theme set presents examples of such and identifies tools and approaches that can be applied to coastal and oceanic marine systems worldwide. The methods developed and the lessons learned from these studies can be used to guide researchers, practitioners, and resource managers. It is hoped that this article theme set will provide an overview of the current state of risk assessment as applied to marine resource management, and stimulate new thinking on how risk assessment approaches can be applied.

Keywords: ecological risk assessment, environmental impact assessment, expert elicitation, marine and coastal risk assessment.

An overview of approaches to risk assessment

The prominent sociologist Ulrick Beck has linked the modernization of many nations over the last century with the development of the "Risk Society" in which governments, communities, organizations, and individuals focus much of their day-to-day efforts managing risk and, where possible, transfer risk onto others. Beck (1992) argues that this fixation on managing and transferring risk is a defining attribute of our post-modern society, particularly in industrialized nations. Consistent with this view, a number of scientific, public health, sociological disciplines, and technical practices have adopted strong risk management approaches and frameworks (e.g. EFSA, 2012, 2013, 2014, and see Mao *et al.*, 2010). A topical, but unpopular example would be the finance sector whose well-evolved risk management processes are arguably advantageous to particular parts of the finance sector, but less helpful to the remainder of the international investment community (e.g. Moshirian, 2011).

Policy and regulations in the health sector are increasingly risk-based. Health policy is now commonly assessed in terms of indicators that focus on risk to life expectancy, or average number of years forgone or added as a result of proposed policy instruments (Yokota and Thompson, 2004). Risk to remaining years of life is often monetized and directly compared with the cost of healthcare to assess the efficiency and effectiveness of health policy. These approaches are explicitly risk-based as they seek to understand the risks to human lives, or the risks that are mitigated by policy initiatives. Similarly, the engineering design of infrastructure is also increasingly risk-based (e.g. Dai *et al.*, 2002). Structural design needs to balance the likelihood of failure against construction cost, especially in zones where natural hazards such as floods, earthquakes, or tornadoes can occur (Cornell *et al.*, 2002). In such locations, it is generally economically inefficient to have all structures completely immune to all *possible* hazards and, therefore, infrastructure is commonly built to be immune to *probable* hazards. Assessing the difference between *possible* and *probable* requires a probabilistic analysis and the results of such risk analyses are often formalized in building standards and codes. For example, the Australian Building Codes now account for very low likelihood extreme cyclone events (known as hurricanes or typhoons in the northern hemisphere) for some parts of Australia. These Codes, which apply to all structures, were developed based on the estimated risk to a range of locations across the north of Australia (Standards Australia, 2006). As a further example, road tunnels in many nations must now conform to safety levels that are several orders of magnitude safer than the likelihood of loss of life on the adjacent sections of highways (Miclea *et al*., 2007). This increased level of immunity or safety reflects road users' preferences for road tunnels to be safer than the conjoining open highway (Standards Australia, 2011). This risk standard is then used to define what safety equipment is installed in tunnels. Once again, major management decisions are based on the results of risk assessments.

The engineering risk assessment approach is also enshrined in many national and international standards, most recently the ISO 31000 series. ISO 31000 defines the risk assessment process as consisting of determining the risk context, identifying, analysing and evaluating, and then treating risks. Similarly, risk-based approaches have been proposed that incorporate future uncertainties associated with climate change (Jones, 2001).

The insurance sector is the stalwart of risk management. Insurers are highly leveraged around quantitative estimates of the risk of natural and industrial hazards (e.g. Santomero and Babbel, 1997). This is because insurance companies, and especially re-insurance companies, tread a fine balance between earning income from premiums and financial outlays following catastrophic events. As premiums are collected before hazard events, and outlays redeemed following them, insurers seek to set premium levels so that enough revenue can be earned over the long term. These quantitative estimates or predictions of future hazard events are generated through the application of actuarial techniques, which can be regarded as at the forefront of quantitative risk assessment (Embrechts *et al*., 1999).

In contrast, risk assessments are not commonly applied to the management of natural systems and environments. It can be argued that, at present, ecological risk assessment is a term that is narrowly used for the assessment of impacts of chemical contaminants to the environment, that is, in ecotoxicology. This is although, both globally and regionally, the largest threat or hazard to ecological systems and processes is mostly loss or physical alteration of habitat, invasive species, or direct exploitation (as for targeted species), and not chemical contamination. Therefore, it follows that ecological risk assessment, perhaps the most powerful framework for assessing anthropogenic changes to the environment, is not currently being directed towards assessing and managing the greatest threats facing natural systems. One of the reasons for this is the widespread use of environmental impact assessments (EIAs).

For decades, EIAs have been one of the primary policy instruments for environmental management and have become a globally consistent approach to managing impacts of human activities, including in the coastal and marine environment (e.g. Tullos, 2009, although see the caveats raised by Hedgpeth, 1973). However, much of the advice generated by coastal and marine science practitioners, through the generation of EIAs and similar assessments, are *implicitly* risk-based but often do not *explicitly* follow risk assessment methodologies. This can sometimes be a substantial limitation in environmental assessment methods, but can also sometimes be an opportunity to improve EIAs. The reason this can become problematic is that governing agencies and natural resource managers often operate within explicit risk management frameworks and, therefore, are at times forced to apply quasi-risk assessments in the form of EIAs to formal administrative processes that are expected to be risk-based. It follows, therefore, that embracing a risk assessment approach could lead to increased uptake of scientific advice by natural resource managers, and ultimately lead to better environmental management outcomes. In any case, in the light of the importance of the likelihood of possible consequences occurring, it would be helpful if we moved away from EIAs that contain a comprehensive identification of the possible sources of hazard and consequences but have cursory treatment of the likelihood of the hazards occurring. To illustrate this, Table 1 presents a generalized comparison of the information contained in a typical coastal or marine EIA with information contained in a risk assessment. Despite areas of commonality, there are key differences in the requirements.

Fisheries science and management practitioners have recently begun to apply formal risk management processes to fishing activities (e.g. Hobday *et al*., 2011). In many ways, this has been a natural extension of quantitative stock modelling and assessment as these approaches already involve the application of statistical approaches for parameter estimation. The uptake of formal risk assessment by fisheries practitioners has presumably been accompanied by an upskilling of individuals and teams. Ideally, this upskilling would have involved consideration of the plethora of literature and guidelines detailing best-practice risk assessment methodologies. However, having said this, a particular characteristic of the discipline of risk assessment is that the terminology and methodologies are often applied in a loose manner—it seems that everyone is a risk assessor. This may be a consequence of Beck's Risk Society where it could be argued that everyone is in fact by default, a risk assessor and manager. However, it does not follow that despite our universal pre-occupation with risk assessment and transference, that we all follow formal and defensible methodologies for achieving these outcomes.

Risk is most often defined as the product of the likelihood or probability of an event occurring, and the consequences of the event if it were to occur. Alternative definitions have been proposed; for example, the influential risk communicator Peter Sandman (www.psandman.com) defines risk as:

$$\text{Risk} = \text{hazard} + \text{outrage},$$

as opposed to the more formal definition of risk as:

$$\text{Risk} = \text{likelihood} \times \text{consequence}.$$

Table 1. Comparison of the characteristics of EIAs and risk assessments.

	Context identified	Risk identification	Risk analysis	Risk evaluation	Risk treatment
Risk assessment	✓	✓	✓	✓	✓
EIA	✓	✓	?	?	✓

The Sandman definition has developed from the perspective of public relations management of industrial accidents whereby the key outcome to be avoided is public outrage. The classical definition, commonly attributed to Blaise Pascal in the 17th century (Bernstein, 1996), defines risk as directly and simultaneously dependent on both the likelihood (commonly expressed as a probability) and the consequence of the hazard occurring.

It is also important to note that risk perception in humans is a psychological process through which an individual digests, correlates, and assesses information about a hazard (Shackleton *et al.*, 2011). Decisions about the perceived severity of the risk are based on, for example, an individual's circumstances, their knowledge of the risk, their personal experiences and beliefs, social norms, and a consideration of the possible impacts that action or inaction may have. Importantly, a scientific assessment of risk may not always be the primary source of information in the risk perception process, either at the individual or societal levels, particularly if this information is not communicated in an appropriate manner. For example, a study of coastal communities vulnerable to flooding found that information from family, friends and local community groups was perceived as more important in assessing flood risk than information from media reports or government agencies (Harvatt *et al.*, 2011). It is vitally important, therefore, that risk assessment procedures include stakeholders in the process and that outcomes are communicated in a clear and intuitive manner.

Despite the long-standing origins of probabilistic risk assessment, it can be argued that many scientific disciplines followed the trail blazed by classical physicists and chemists (underpinned by Newtonian deterministic views of cause and effect) for much of the twentieth century. This dominance acted to downplay the relevance and importance of more statistical-based or probabilistic methodologies for understanding cause and effect such as risk assessment. Having said this, the rise of quantum mechanics as a means of explaining shortfalls in Newtonian physics has helped to promote the application of more probabilistic approaches such as risk assessment. A consequence of this focus on deterministic mechanisms was also that Bayesian statistical approaches, arguably the most appropriate framework for risk assessment, were also rarely applied until relatively recently (e.g. Siu and Kelly, 1998). As highlighted above, the approach of assessing risk in terms of likelihood and consequence is the foundation of a number of risk management disciplines, including financial, emergency, asset, and business continuity management. However, despite the long and distinguished history of risk assessment, its uptake in coastal and marine applications has lagged behind its overall uptake by at least a decade (compare Figure 1 with Figure 1 in Mao *et al.*, 2010).

The core quantitative tasks in risk assessment are the estimation of the likelihood and consequences of a source of risk. The first step in a risk assessment is generally to identify the possible consequences, ranging from immediate and obvious to more far-field and cumulative. The identification of possible cascading consequences is generally a tractable task. This is especially the case where numerical models are able to simulate possible consequences. This can also be achieved through engaging technical specialists to identify potential sources of risk. However, this process of expert elicitation needs to be undertaken with care as being a technical specialist is not a sufficient condition for being risk-intelligent (see, for example, http://www.projectionpoint.com for details on risk intelligence, and see EFSA, 2014). In other words, many technical specialists are clearly experts in their discipline, but can be poor at estimating the likelihood of future events or conditions occurring.

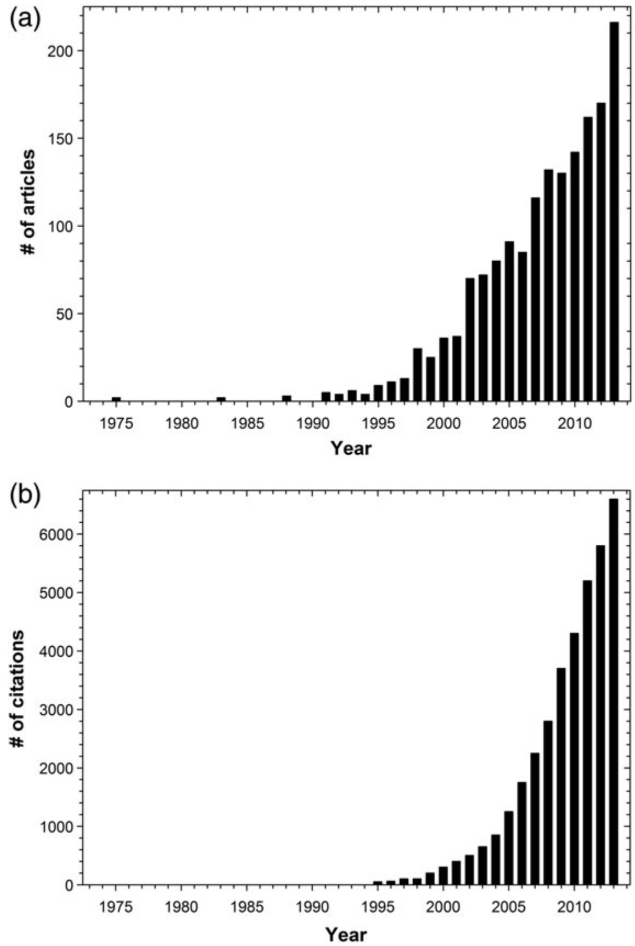

Figure 1. Absolute number of articles (a) and citations (b) during the period 1945–2013 that are returned by a search for the string "risk assessment" and "marine" in the Thomson–Reuters Web of Science database. The *x*-axis begins at 1975 because the numbers were zero before then. The search was conducted on 18 August 2014.

Therefore, developing a list of *possible* consequences is a relatively straightforward task. For example, anyone who has been involved with high profile or controversial coastal or marine infrastructure development proposals or natural resource exploitation proposals will have found that opponents to, for example, coastal developments or increases in fisheries allowable catches are very capable of generating long lists of *possible* future impacts. Furthermore, such opponents often then jump to advocating for the precautionary principle (Lauck *et al.*, 1998) to be applied as a justification for not approving projects under the argument that there are so many possible impacts that the risk will be unacceptable. This is a misapplication of risk assessment (and the precautionary principle) since, in such cases, there is no defensible investigation of the likelihood of the impacts occurring and, therefore, no distinction between *possible* and *probable* impacts. In other words, it is relatively easy to come up with a long list of all possible consequences or impacts of a proposal. However, this alone can be somewhat unhelpful unless the corresponding estimate of the likelihood is provided so that *possible* impacts can be distinguished from the *probable* impacts. This does not mean to say that low likelihood but possible impacts need to be ignored; rather it recognizes that estimates of risk require consideration of both the consequence and the likelihood.

Estimating the likelihood of particular consequences is often problematic. This is especially the case for low likelihood, high consequence events. For high likelihood, low consequence events, there are often considerable data and time-series available for analysis. Hence, while low likelihood/high consequence risks are quantitatively the same risk as high likelihood/low consequence risks, the latter are generally easier to assess and hence our confidence in these risk predictions is often greater as we typically have direct personal experience with these events. This fact also means that even subject matter experts can implicitly bias risk assessments towards more frequent and better-known events. For example, there can widespread differences in opinion, even among experts, over the frequency of natural hazards such as earthquakes (e.g. Shearer and Stark, 2012).

There are four general approaches for estimating the likelihood of specified impacts occurring: (i) estimates based on the measured impacts of similar activities in similar environments or contexts, (ii) estimates based on results validated numerically, semi-empirically, or using empirical models, (iii) estimates based on accepted theory of cause–effect mechanisms, and (iv) expert elicitation and opinion of one or more individuals. The robustness or defensibility of estimates of the likelihood of impacts occurring will be maximized if more than one of these methods is applied. For example, if expert opinion alone is used, then this opinion should be developed from the basis of theory, previously applied models, and/or similar examples presented in the scientific literature (see EFSA, 2014).

In effect, the assessment of the likelihood of future events occurring is a prediction. While the basis of the prediction may be at least partly developed from previous occurrences of the impacts or consequences under investigation, fundamentally it is a future-looking prediction and, therefore, subject to the well-documented difficulties that humans have in predicting future events, especially those that occur infrequently (Gregory *et al*., 1996). It is, therefore, critical that the basis for any prediction be systematic, methodologically sound, and well documented. Such systematic methodology is at the core of formal risk assessment methodologies, and this highlights the criticality that risk assessment practitioners have a deep understanding of these processes. For example, while workshops may be a good approach to elucidating the possible consequences of projects, or changes to regulations, workshops alone may not be suitable for generating estimates of the likelihood of consequences occurring. That is because workshop participants may not be well equipped to compare very low and very high likelihood future events without bias (Yang *et al*., 2009).

As a result of the difficulties in assessing likelihood, the most robust approach is to follow the prioritization presented above. However, in some cases, detailed previous examples may be absent and, for ecological systems, numerical or even empirical or analytical models may also be unavailable. For physical processes, the movement of water in aquatic environments is well described by the Navier–Stokes equations of motion that can be adequately encapsulated in numerical hydrodynamic models. The same cannot be said for ecological systems as they cannot be fully described by a single set of coupled partial-differential equations. It is this inconsistent approach to assessing likelihood that is a key difference between formal risk assessment and EIA.

A clear benefit in applying risk-based approaches is that the identification of *probable* impacts can be differentiated from a long list of *possible* impacts. However, perhaps one of the most valuable outcomes of a risk assessment exercise is in the identification of gaps in the knowledge/data required to quantify the risk. Thus, even if the exercise cannot adequately quantify the risk *per se*, it will almost always result in a ranked list of research questions that must be pursued to support the risk assessment process.

An article theme set: Risk assessment and risk management in the marine sciences

In the context of the above, and given the widespread adoption of formal risk assessment frameworks in many disciplines, we thought it timely to assess the uptake and application of quantitative risk assessment and risk management approaches in marine and coastal resource and environmental management. To this end, this article theme set presents eight case studies in which risk assessment has been applied to inform and guide the management of coastal and marine systems.

Taranger *et al.* (2015) provide details of the development and implementation of a quantitative risk assessment approach for investigating multiple risks associated with Norwegian aquaculture activities. The results of these analyses provide valuable knowledge for the ongoing management of the aquaculture sector in Norway.

Stelzenmueller *et al.* (2015) applied risk assessment approaches, including the use of Bayesian belief network models, to develop spatially explicit information to underpin marine spatial planning. This approach was able to incorporate impacts and recovery potential for different fishing fleets with different vessel and gear characteristics.

Fletcher (2015) provides a personal view and lessons learned from applying risk assessments to the management of several key stocks and ecosystems. Key lessons learned include the importance of engaging and empowering stakeholders through assessment approaches that are more intuitive so that they can actively understand and participate in the risk assessment process. Similarly, Cortés *et al.* (2015) detail the results of an investigation into how risk frameworks can be applied to the analysis of population dynamics of cartilaginous fish populations. The results of a comparative assessment of different approaches applied to the same stock are provided.

Azmi *et al.* (2015a, b) provide two reports based on a series of biosecurity and pest invasion studies. The global marine biosecurity research and management community have recognized that directing resources to manage incursions is most effective if resources are deployed according to risk. However, this can only be effectively achieved if the assessment of the risk is accurate. These two studies provide examples of how this can be achieved.

Risk screening is commonly applied as the first step in quantitative risk assessments. Cotter *et al.* (2015) undertook an ecological risk screening exercise for fisheries off the Southwest coast of England. This involved extensive stakeholder workshop tasks to both elicit information, and ensure engagement with key stakeholders. The ecological risk screening approach was effective in eliciting and integrating disparate information that can then be used to prioritize management resources.

Knights *et al.* (2015) provide a demonstration of how causal pressure-state linkage approaches can be incorporated into a risk management framework. This approach can be used to investigate the relative magnitude of different impact pathways and thereby identify ecosystem components most at-risk. Finally, Astles (2015) highlights the importance of addressing multiple scales and risk pathways in both the ecological system and the human system, and the need for risk communication throughout both the assessment and management processes. This study provides an approach for transitioning from effective risk assessment to risk management, demonstrated through a case study of an urban estuary.

All of these case studies demonstrate the considerable advantages and utility that risk-based approaches offer. It follows, therefore, that there is considerable potential and scope for risk-based approaches to be applied to the management of marine fisheries, aquaculture, spatial planning, and other activities that occur in coastal and marine systems, in coordination with the direct management of living resources and habitats.

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References

Astles, K. L. 2015. Linking risk factors to risk treatment in ecological risk assessment of marine biodiversity. ICES Journal of Marine Science, 72: 1116–1132.

Azmi, F., Hewitt, C. L., and Campbell, M. L. 2015a. A hub and spoke network model to analyse the secondary dispersal of introduced marine species in Indonesia. ICES Journal of Marine Science, 72: 1069–1077.

Azmi, F., Primo, C., Hewitt, C. L., and Cambell, M. L. 2015b. Assessing marine biosecurity risks when data is limited: bioregion pathway and species-based exposure analyses. ICES Journal of Marine Science, 72: 1078–1091.

Beck, U. 1992. Risk Society: Towards a New Modernity. Sage, New Delhi.

Bernstein, P. L. 1996. Against the Gods: The Remarkable Story of Risk. John Wiley and Sons, New York. ISBN 0-471-12104-5

Cornell, C., Jalayer, F., Hamburger, R., and Foutch, D. 2002. Probabilistic Basis for 2000 SAC Federal Emergency Management Agency Steel Moment Frame Guidelines. Journal of Structural Engineering, 128: 526–533.

Cortés, E., Brooks, E. N., and Shertzer, K. W. 2015. Risk assessment of cartilaginous fish populations. ICES Journal of Marine Science, 72: 1057–1068.

Cotter, J., Lart, W., de Rozarieux, N., Kingston, A., Caslake, R., Le Quesne, W., Jennings, S., *et al.* 2015. A development of ecological risk screening with an application to fisheries off SW England. ICES Journal of Marine Science, 72: 1092–1104.

Dai, F. C., Lee, C. F., and Ngai, Y. Y. 2002. Landslide risk assessment and management: an overview. Engineering Geology, 64: 65–87.

EFSA Panel on Animal Health and Welfare (AHAW). 2012. Guidance on risk assessment for animal welfare. EFSA Journal, 10: 2513. 30 pp. doi:10.2903/j.efsa.2012.2513.

EFSA SC (EFSA Scientific Committee). 2013. Scientific opinion on priority topics for the development of risk assessment guidance by EFSA's Scientific Committee. EFSA Journal, 11: 3345. 20 pp. doi:10.2903/j.efsa.2013.3345

EFSA (European Food Safety Authority). 2014. Guidance on expert knowledge elicitation in food and feed safety risk assessment. EFSA Journal, 12: 3734. 278 pp. doi:10.2903/j.efsa.2014.3734.

Embrechts, P., Resnick, S. I., and Samorodnitsky, G. 1999. Extreme value theory as a risk management tool. North American Actuarial Journal, 3: 30–41.

Fletcher, W. J. 2015. Review and refinement of an existing qualitative risk assessment method for application within an ecosystem-based management framework. ICES Journal of Marine Science, 72: 1043–1056.

Gregory, R., Slovic, P., and Flynn, J. 1996. Risk perception, stigma, and health policy. Health and Place, 2: 213–220.

Harvatt, J., Petts, J., and Chilvers, J. 2011. Understanding householder responses to natural hazards: flooding and sea-level rise comparisons. Journal of Risk Research, 14: 63–83.

Hedgpeth, J. W. 1973. The impact of impact studies. Helgoläander wissenschaftliche Meeresuntersuchungen, 24: 436–445.

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: 2–3.

Jones, R. N. 2001. An environmental risk assessment/management framework for climate change impact assessments. Natural Hazards, 23: 1997–1230.

Knights, A. M., Piet, G., Jongbloed, R. H., Tamis, J. E., White, L., Akoglu, E., Boicenco, L., *et al.* 2015. An exposure-effect approach for evaluating ecosystem-wide risks from human activities. ICES Journal of Marine Science, 72: 1105–1115.

Lauck, T., Clark, C. W., Mangel, M., and Munro, G. R. 1998. Implementing the precautionary principle in fisheries management through marine reserves. Ecological Applications, 8: S72–S78.

Mao, N., Wang, M-H., and Ho, Y. S. 2010. A bibliometric study of the trend in articles related to risk assessment published in Science Citation Index. Human and Ecological Risk Assessment, 16: 801–824.

Miclea, P. C., Chow, W. K., Shen-Wen, C., Junmei, L., Kashef, A., and Kang, K. 2007. International tunnel fire-safety design practices. ASHRAE Journal, 49: 50–60.

Moshirian, F. 2011. The global financial crisis and the evolution of markets, institutions and regulation. Journal of Banking and Finance, 35: 502–511.

Santomero, A., and Babbel, D. F. 1997. Financial risk management by insurers: an analysis of the process. The Journal of Risk and Insurance, 64: 231–270.

Shackleton, E. C. R., Potts, J., and Carter, B. 2011. Residents' perceptions of coastal flood risk and its management through Coastal Defence Strategies at Emsworth, United Kingdom. Littoral 2010. Royal Geographical Society, London. http://dx.doi.org/10.1051/litt/201113001

Siu, N. O., and Kelly, D. L. 1998. Bayesian parameter estimation in probabilistic risk assessment. Reliability Engineering and System Safety, 62: 89–116.

Shearer, P. M., and Stark, P. B. 2012. Global risk of big earthquakes has not recently increased. Proceedings of the National Academy of Sciences of the United States of America, 109: 717–721.

Standards Australia. 2006. Australian Standard AS 4055–2006, Wind loads for housing. Sydney (Australia).

Standards Australia. 2011. Australian Standard AS 4825–2011, Tunnel fire safety. Sydney (Australia).

Stelzenmüller, V., Fock, H. O., Gimpel, A., Rambo, H., Diekmann, R., Probst, W. N., Callies, U., *et al.* 2015. Quantitative environmental risk assessments in the context of marine spatial management: current approaches and some perspectives. ICES Journal of Marine Science, 72: 1022–1042.

Taranger, G. L., Karlsen, Ø., Bannister, R. J., Glover, K. A., Husa, V., Karlsbakk, E., Kvamme, B. O., *et al.* 2015. Risk assessment of the environmental impact of Norwegian Atlantic salmon farming. ICES Journal of Marine Science, 72: 997–1021.

Tullos, D. 2009. Assessing the influence of environmental impact assessments on science and policy: an analysis of the Three Gorges Project. Journal of Environmental Management, 90: S208–S223.

Yang, Z., Coble, K. H., and Hudson, M. D. 2009. The role of individual personality type in subjective risk elicitation outcomes. Journal of Risk Research, 12: 209–222.

Yokota, F., and Thompson, K. M. 2004. Value of information analysis in environmental health risk management decisions: past, present, and future. Risk Analysis, 24: 635–650.