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Session IPM 007: Statistics, Environmental Health & Risk Assessment

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I wish to commence by thanking all three speakers for their interesting, stimulating, and timely presentations on the role of statistics in assessing environmental health and formal risk assessments. The paper by David Brillinger advocates the use of simple, intuitive yet informative devices such as box-plots to support more comprehensive risk assessments. Louise Ryan correctly acknowledges that risk assessment is more than just statistical uncertainty associated with parameter estimation while David Marker provided us with a concrete example to emphasise the importance of proper design and sampling protocols for assessing risk. Interestingly, all three presenters had their own working definition of 'risk', although this was not explicitly defined in any of the talks. No doubt it embraced the concept of probability or likelihood of some adverse outcome. This lack of transparency is a common feature of many quantitative risk assessments and continues to undermine the credibility of the RA paradigm. The indeterminacy, vagueness, and ambiguity of language (or what Burgman 2005 refers to as "linguistic uncertainty") are also stumbling blocks. Interestingly, we still grapple with a universal definition of 'risk' and at times struggle to understand what actually constitutes a 'risk assessment'. My comments on the three papers we have just heard focus on the following five areas:

1. Risk – definitional problems
2. Risk metrics
3. Risk calculus
4. Risk communication
5. Role of statistics and statisticians

Definition & Genesis

Environmental risk assessment is not new. Indeed its earliest application can be found in the setting of permissible occupational exposure limits for chemicals in the workplace back in the 1930s (Eduljee 2000). David Marker's paper illustrates the continuing focus on human health issues and the risks associated with our home environments. Rachael Carson's *Silent Spring* was a wake-up call that kick-started the environmental movement of the 1970s and led to the establishment of EPAs whose focus was on 'end of pipe' regulation and compliance. However, this 'command and control' approach did little to elevate our understanding of the ecosystem and resulted in data rich – information poor agencies that were ill-equipped to make more comprehensive and holistic assessments of the environment. The 1980s saw the emergence of risk assessment as a regulatory paradigm although the ensuing decade was dogged by a lack of agreement on what constituted a risk assessment, a confused lexicon, and inconsistent methodologies. In particular, many quantitative risk assessments were little more than an assignment of subjective probabilities to various adverse outcomes which were manipulated by an often-times dubious and concealed calculus. Risk assessments became the purview of the technical elite and agencies tended to adopt what has been referred to as the DAD approach – decide, announce, and defend (Kwiatkowski 1998). By the late 1980s and early 1990s, concerns were being expressed with the risk assessment approach. Common complaints centred on the highly technical nature of the methods employed, the specious use of outputs, and the lack of an inclusive process. Even today, we still don't have agreement on many aspects of risk assessment – not least of which is a definition of risk. Ecotoxicologists have defined risk as the product of hazard and exposure and indeed the terms 'risk' and 'hazard' are often confused and used interchangeably. The Boeing Corporation has a definition of risk that is the product of 'likelihood', 'severity', and 'detectability'. Statistician Frank Duckworth on the other hand claims that risk is a qualitative term that cannot be measured. He argues that risk is *not* synonymous with probability but rather "to take a risk is to allow or cause exposure to the danger" (Duckworth 1998). My own definition of risk is that it is the chance, within a specified time-frame, of an adverse event with specific (negative) consequences. This definition acknowledges the important concepts of: uncertainty; time bounded; defined events; and consequences. As noted by Louise Ryan, an essential ingredient of risk is *uncertainty*. Burgman (2005) distinguishes between *epistemic uncertainty* and *linguistic uncertainty*. Epistemic uncertainty characterises the fact that we don't know what we don't know! It is a consequence of: incomplete knowledge; systematic error; natural variation; model uncertainty; and subjective judgement. In her presentation, Louise Ryan gave a further breakdown of sources of systematic uncertainty. Linguistic uncertainty on the other hand arises from the imprecision of our language (what is, after all a "moderate" or "high" risk? What's the difference?).

Risk Metrics

In his June 1996 presidential address to the Royal Statistical Society, Adrian Smith suggested that the public needed some simple measure of risk to alleviate the irrational behaviour associated with individuals' perception of risk. He coined the term 'riskometer' and campaigned for the development of a one-dimensional risk scale in a spirit similar to the Fujita scale for tornadoes, the Richter scale for earthquakes, the Beaufort scale for winds and the decibel scale for sound intensity. Statistician Frank Duckworth (co-developer of the Duckworth/Lewis method for cricket scoring) took up the challenge and devised a 'risk number' (Duckworth, 1998) although evidence of subsequent uptake is minimal, if not entirely non-existent. Whether or not Adrian Smith's vision will ever be realised is uncertain and perhaps risk is not reducible to a simple number. The lack of agreement over what actually constitutes a risk assessment may help explain the lack of progress towards the establishment of an agreed index of risk. Any attempt at achieving unification and harmonisation of environmental risk assessments will need to be cognisant of the desire of many individuals and organisations to construct 'tailor-made' risk metrics. A major challenge therefore is risk education and risk communication.

Risk Calculus

The treatment of quantitative risk is either via deterministic models (such as *hazard* x *exposure*) or traditional modes of statistical estimation and inference. As noted by David Brillinger, the latter mode of analysis embodies both classical (frequentist) and Bayesian statistical methods although these are not without their problems. As noted by Root (2003), the difficulty with the frequentist approach is that environmental protection agencies adopt the logic of the courtroom in making environmental decisions but that “the logic of the courtroom operates under the handicap of working with non-repeatable events”. Bayesian methods are currently experiencing a resurgence in popularity among natural resource managers (see for example Clark 2005). I attribute this to increased levels of frustration with a purely data analytic approach that precludes treatment of knowledge in the form of expert opinion/belief coupled with computational advances and associated tools such as WinBugs which make accessible more sophisticated models. While the Bayesian approach provides a logical and consistent method for melding prior probabilities with evidence in the form of data, the old questions concerning choice of priors and parameterisation of complex hierarchical models are resurfacing in this new debate (Bier 1999). Another difficulty is perception bias – Bayesian methods are seen by some as being highly technical and complex and thus too hard to understand and implement. As reported in *The Times* (3 November 1997), the London Court of Appeal asserted its position on the role of probability and statistics in assessing weight of evidence cases:

> “Introducing Bayes Theorem, or any similar method, into a criminal trial plunges the jury into inappropriate and unnecessary realms of complexity, deflecting them from their proper task.”

While the difficulties are acknowledged, I suggest that arguments such as this are little more than a smoke-screen designed to keep statisticians at arms length from the judicial process. The challenge for Statisticians is to communicate more effectively (see next section). Judges, juries, and lawyers are increasingly required to grapple with highly technical issues and rely on expert scientific evidence and testimony. Surely the Statistician has a legitimate and rightful place in this context? Nevertheless, as we seek to refine existing risk paradigms and develop new ones, there are some clear take-home messages that need to be heeded if the environmental risk assessment tools are to find a prominent place in the natural resource manager’s toolkit.

Risk Communication

Mathematicians and Statisticians need to become more sophisticated in their interactions with others outside their professional domain and simultaneously more engaged in the application and development of risk tools. David Brillinger’s talk on the beginnings of EDA to support ERA is most timely. The Royal Statistical Society devoted the June 2003 issue of *Statistics in Society* (JRSS series A) to a collection of short papers on the communication of risk. In his foreword, Adrian Smith asks rhetorically “What are we doing wrong?” (Smith, 2003). A partial answer is provided when he later comments “In some cases, it is surely our own fault for not being sufficiently aware of the communication problem and not being sufficiently creative in finding forms of communication that bridge the gap between the language of the professional statistician and an intended audience”. As stated by Rosenbaum and

Culshaw (2003) “communication of risk is all about the communication of uncertainty”. To this end, the Science Media Centre has provided some tips to assist scientists convey risk concepts to the lay person (www.ScienceMediaCentr.org). In addition to effective risk communication, managers need strategies to prioritise and manage risks or more precisely, the threats, the exposure, and activities. Inasmuch as this relates to environmental management, a number of ‘principles’ or ‘concepts’ have been devised. As an expression of environmental risk management, the Precautionary Principle is a ‘better to be safe than sorry’ dictum that says "where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental degradation". The Australian Academy of Technological Sciences and Engineering (ATSE) argues that, while politically correct, the precautionary principle has been misapplied and has stifled innovation and application of science and technology to future development. Sunstein (2002) notes that “the precautionary principle, taken for all that it is worth, is literally paralysing. It bans every imaginable step, including inaction itself”. He further notes that the concept of sustainable development “has had an extraordinary influence in the international environmental debates, so much as that it now serves as a kind of symbol for any serious commitment to environmental protection”.

The Role of Statistics and Statisticians

David Brillinger is on the right track. His message is clear – ‘keep it simple’. Mother Nature does not readily yield to designed experimentation. Lack of randomness and true ‘controls’, over-dispersion, confounding in time and space, non-stationarity and a paucity of data are common characteristics of many environmental risk assessment exercises. I have previously referred to the ‘green’ and ‘brown’ statistical paradigms (Fox 2001) to reflect the schism between industrial and environmental statistics and have argued that there should be a greater degree of cross-talk between these two areas. It is almost always true that risk assessments deal with rare and infrequent events. As statisticians our focus is drawn to the tails of the ‘risk distribution’. So why do so many quantitative risk assessments borrow so heavily from classical modes of mean-based inference? Just as engineers design structures to cope with the 1-in-100 year storm rather than the average storm, environmental and human health risk analysts need to place greater emphasis on extreme percentiles. In addition to the box-plots advocated by David Brillinger, I suggest more use needs to be made of: control charts; matrix plots; robust smoothers; and, as advocated by David Marker, more rigorous design of experiments. These all need to be supported by an increased emphasis on *monitoring* – not of the routine, data collection that supports model construction/validation but monitoring that is an integral part of the ERA process and which specifically addresses the “how well did we do?” question. As noted by Suter and others, this type of monitoring is rarely done.

Conclusion

Today’s presentations have provided valuable insights into the opportunities that exist for statisticians to become seriously engaged with three key activities underpinning risk assessment: effective exploratory data analysis; robust quantification of uncertainty; and rigorous design and analysis of data collection activities. The presentations have, for me, highlighted areas of ERA that still require clarification and further development by statisticians. Truly effective risk assessment and risk communication cannot occur until the language, the methods, and the metrics are rationalised and made accessible to the broader community. It is impossible to effectively communicate a concept that is vague, ill-defined, and ambiguous – no matter how polished the presentation. Risk analysts and the public need a universally accepted index of risk that is easily understood and whose interpretation is unaffected by contextual setting. Thus, a risk of *x* should engender the same degree of concern whether it relates to human health, the environment, the financial market, or a failure of an O-ring in the space shuttle. Only then will the public have the same general appreciation of risk as they do a force 10 gale, a 9.6 tsunami, or a 15odb rock concert. Thank you.

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