Putting Perspective on Uncertainty
November 3/4 2005
Kananaskis Field Station
Workshop Notes

"Unacknowledged uncertainty leads to optimistic expectations that cannot be satisfied to the misdirection of scarce conservation resources, and to actions that are blind to substantial qualitative and quantitative uncertainties that, if they were apparent, would lead to different decisions" (Burgman et al. 2005).



MIISTAKIS INSTITUTE FOR THE ROCKIES

Participants

Organizing Committee

Roger Creasey	Shell Canada, Miistakis Institute
Paul Paquet	University of Calgary, Miistakis Institute
Danah Duke	Miistakis Institute
Mike Quinn	University of Calgary, Miistakis Institute

Participants

Shelley Alexander	University of Calgary, Miistakis Institute
Clayton Apps	University of Calgary
Bette Beswick	Golder Associates
Stan Boutin	University of Alberta
Kent Brown	Terrestrial and Aquatic Environmental Management
Steve Donelon	Alberta Community Parks and Protected Areas
Carol Engstromm	Husky Energy
Lisa Brygidyr	Shell Canada
Cormack Gates	University of Calgary
Mike Gibeau	Parks Canada
Mike Gillingham	University of Northern British Columbia
Randall Glaholt	Tera Environmental
Jeremy Hall	Haskayne School of Business, University of Calgary
Martin Jalkotzy	Golder Associates
Petr Komers	Axys Environmental
Kevin Lloyd	Axys Environmental
Stelvia Matos	Haskayne, University of Calgary
Marco Musiani	University of Calgary
Jim Pissot	Defenders of Wildlife – Canada
Rob Powell	Natural Resources Conservation Board
Bill Ross	University of Calgary
Gordon Stenhouse	Foothill Model Forest
Mary-Ellen Tyler	University of Calgary
Cliff White	Parks Canada, Banff

The workshop and report were sponsored by Shell Canada. The workshop was conducted and the report compiled by the Miistakis Institute

Foreword



The debates that surround the status of wildlife and habitat exemplify the difficulties of making decisions in the face of scientific uncertainty and socioeconomic pressures. Researchers are unable to agree on the exact response of wildlife to disturbance, or the larger question of how long populations will persist. With so many conflicting opinions, everyone - scientists, the corporate sector, the public, NGO's and government regulators – has been understandably confused about just what the experts know, and how certain they really are.

In the winter of 2005, Paul Paquet and I found ourselves on opposite sides of a difficult issue. The issue involved a proposal to build a road to connect new gas wellsites with existing infrastructure in the Carbondale area of SW Alberta, and the effects of that road were open for debate at a public hearing. Central to this debate was how to deal with uncertainty associated with wildlife and habitat modeling and how to reconcile that uncertainty with the decision making process.

Paul and I considered our respective evidence and decided that debate on the issue would be more effective if we could bring a number of wildlife biologists and decision makers together to discuss the many facets associated with uncertainty.

This report provides a summary of a two-day workshop that brought together a diverse group of biologists, (Environmental Assessment) EA practitioners and decision makers that focused on a general discussion of uncertainty from several aspects. The workshop included presentations, the examination of a case study with associated break out groups and facilitated discussions.

The two day workshop was a brief but significant first step in the discussion surrounding uncertainty. This report is a compilation of those discussions and demonstrates the importance of bringing together the varied perspectives involved with uncertainty to exchange knowledge and experience. .

Roger Creasey and Paul Paquet

Topics Covered



The following section summarizes presentations that were included as part of the workshop. Full presentation materials are included in Appendix 1.

UNCERTAINTY IN WILDLIFE MODELING – WHAT IS IT? HOW DO WE CALCULATE IT? HOW DO WE PRESENT IT?

Mary Ellen Tyler and Mike Quinn
Uncertainty in Wildlife Modeling-What is it, How do we calculate it, How do we present it..pdf
The workshop began by identifying that uncertainty is found in both ecological modeling and in multi-criteria decision-making. The players in each area (biologists and decision makers) are seen to act separately. However, there is a need for them to come together. Conventional science strives for objective certainty but science must work in a social and economic context and that is often unrecognized. Model uncertainty cannot be controlled. Decision-making uncertainty is based on the assumption that objectivity is grounded in fact. However, probability is not completely objective but also belief based, as is the interpretation of data. Risk assessment is also not objective but examines the full extent of possibilities (real vs. perceived). Technical analyses have not been successful. Actual decisions depend less on analytical tools and more on understanding and reason. There is a need to find an integrated approach and introduce cross reference methodology into both groups probably by coming at it from both sides. We need to ask if what is being addressed is what decision makers need to know and vice versa. Language and definitions are important.

CONSIDERING UNCERTAINTY IN WILDLIFE MODELING

Mike Gillingham
Considering Uncertainty in Wildlife Modeling.pdf
In wildlife modeling four considerations are important: 1) Contrast to Sensitivity – determining which input has the biggest effect (recognizing that our outputs may become someone else's inputs), 2) Uncertainty Analysis – depicting the range of what our answers are, 3) Sensitivity Analysis – identifying the model component with the

greatest influence on the variation in predictions, and 4) Validation – error assessment relating model predictions to truth.

If planning occurs one area at a time there is the possibility to learn from each for subsequent planning. However, when this is not possible one must rely on modeling and computer driven predictions. The data sources all have variation or uncertainty but they are not all easy to document. How do you document variation from expert source data or work with uncertainty across GIS layers (prepared in different models)? Other issues that arise include: 1) the building of average models for average animal (Is there such a thing?), 2) the need to be explicit about the scale of model interpretation and 3) exporting models to other locations. Models are not static but are developed in a static way. We need to know estimates of errors of all or at least the significant parameters and validation is necessary. From a spatial context, it is important to convey reliability and present the uncertainty associated with predictions.

APPLICATION AND CHALLENGES OF UNCERTAINTY IN ENVIRONMENTAL ASSESSMENT

Kevin Lloyd

All have a responsibility to be mindful of the future and well-being of those living in the community when communicating uncertainty. We need to use uncertainty up front in land use decisions, stating assumptions while also framing uncertainty in a reassuring way when it can be. The use of traditional knowledge can augment western science.

Martin Jalkotzy

In a risk assessment consultants look at the joint probability of three things interacting (1. critters, 2. area where may be and 3. disturbance to the site) and their likelihood of having an effect. Typically, data are obtained from one year of ground work and past work in the area. Because the best local data are usually insufficient, they often rely on regional data as this information is more abundant. The data are used to produce a model and subsequently used to measure the effect of a disturbance on a species. Model testing is done at the regional level due to insufficient local data. Habitat Index Suitability (HIS) modeling is the primary approach taken. The model is only as good as the input data and often the input data are not local and not current. Also, the HIS model has its own error, which is not quantified and does not express the propagation of errors. This uncertainty is dealt with through confidence intervals. However, because of the scale of the analysis, regional dilution results, often indicating no effect from a disturbance. In addition, the determined threshold for sign of impact is arbitrary and the size of the region to determine this does not include the mine site (or site of interest), so again no impact is shown. Operational effects are also only beginning to be considered in Environmental Impact Assessments (EIAs) and practitioners are not, but should be, obligated by regulators to state cumulative effects (a clear consistent

definition needs to be applied). Quantitative is not necessarily better, the best assessment addresses the needs of decision-making.

Bill Ross

Uncertainty Workshop.pdf

A well calibrated model implies credibility and how it will stand up to scrutiny is important. Such models are more easily accepted by a decision panel. Follow up studies are also a useful tool for dealing with uncertainty. Follow up studies to cover information gaps are essential for decision-making. A follow up study should include monitoring, evaluation and management and should be designed for action to manage impacts (adaptive environmental management). It can work when impacts are important and uncertain however, is limiting when an impact cannot be identified in time or if the cost is an issue. In the latter case, a decision should be made now. Also, important to a follow up study is to have an independent overseer to ensure the follow up is done well and to provide credibility. It can be good in dealing with uncertainty and in dealing with the link between results and decision-making. Follow up studies also provide knowledge for future EIAs. Consultants can make recommendations and in some cases are in a position to convince both the regulators and the company. Collaboration is very effective in making decisions. Recommendations for follow-up should state "Conditions of approval that follow up studies are carried out and management responses are required." Monitoring without evaluation and management is inadequate.

CASE STUDY

Roger Creasey and Paul Paquet

Both presented the background that led to this workshop. See Foreword. The case involved establishing a new drill site and assessing the environmental impacts of a new road, and the mitigative potential of gating the road from public motorized access. Although the issue of access roads and wildlife impacts have been discussed since the 1970s not much research has been carried out in this area. Industry is frequently charged with assessing the effects of roads, but little empirical research exists. As this kind of study is long term most people would not invest in it. This is an excellent case where adaptive management would work well to reduce uncertainty. Monitor and see in five years who is right. Work from first principles – why roads would affect animals, what would the biology say? This is a classical follow up study, needing detailed examination including monitoring, evaluation, management alternatives if there is a problem and a good independent oversight group to provide credibility to the community and regulators.

BREAK OUT GROUPS –

Decision Makers /EA Perspective

Sticking to a story gives a false impression that one has the whole story. It does not help the decision maker and if there is uncertainty it should be brought to the attention of decision makers. Consultants not communicating uncertainty ought to recognize this as it may affect their credibility. Consultants act to provide information not advocate.

Each side could present strong arguments regarding modelling to a panel but both would be jousting over things that are arbitrary and so uncertain. Instead of arguing position, why not look at the common interests. However, the judicial system is set up to argue facts, not uncertainty, nor common interests. We argue development and wildlife because it is not valid to argue other societal values and issues such as quality of life. Grizzlies may be the true concern but may also be a mask for these other issues. How do we argue public interest versus personal interests in such cases?

To get a decision maker to make a good decision one needs to help them understand the impact and ask SO WHAT – what does it depend on and what should the conditions be? Decision makers work with worst case or best judgment to decide. Regulators do not use precautionary principle. If they do not know what to use then they can go ahead and manage until we can decide on an approach to take. If their approach is too cautious, than they often do not know what is working. Let it become a problem so that can learn rather than hide without determining. Panelists may also lack expertise in specific areas and are dealing with economic, social, and other issues so they need experts supporting them in relevant areas. Decision makers use information that presenters give, asking is it credible and do they understand it. Uncertainty is not always required in EI assessments; hence there are gaps in knowledge and in the consequences of the impact. Decision makers need a clearer interpretation of uncertainty in EIs. The responsible approach is to be honest and give a frank appraisal of uncertainty, stating the process that was taken to arrive at the conclusions. It is also important to state which information is certain.

The linear process does not serve well because there is no feedback process. Need to make decision recommendations that are implemented including follow-up processes.

Modeling Perspective

Models are kept as scientific as possible but when reporting the results of models the social components are integrated. In EAs, the Terms of Reference (TOR) gives strict limits on what is to be included with no allowances for further inquiry if needed. This makes a considerable difference in how models are approached.

Modelers need to know how decision makers assess risk. Are they concerned with common responses or extremes? This will influence how models are constructed. There should also be a requirement on both parties to define uncertainty. Once uncertainty is defined, one needs to define thresholds of acceptable uncertainty, which requires

accurate data. This will result in a range of possibilities presented that allows common ground to be explored. The sources of uncertainty must be identified, whether it is scientific evidence, parameters, outcomes, predictions, mechanisms etc. Included in the process should be mechanisms to confirm the assumptions included in the decision. Monitoring should be focused on the parameters that are most sensitive.

Social Perspective

The public is becoming more sophisticated. Science is refutable. Understanding the interactions trumps good science. Methodologies – require a systematic approach to understanding values – value functions. Need something more rigorous than media reporting. There is a need to understand the difference between social values and stakeholder values. There is also a need to distinguish between political position and social values. The process has become more input focused than outcome. There seems to be more focus on what we do not want with much more disagreement about what is bad than good.

DECISION MAKING AND UNCERTAINTY

Rob Powell

The Report of the Plausible.pdf

Rob presented three case studies to demonstrate the difficult forms of uncertainty that decision makers see and what they do with it. Challenges that decision makers face include vague un-testable predictions, the data to test predictions and not gathered, unwarranted inferences, too many assumptions, overwhelming complexity, obsolete predictions due to design changes, and the transfer of science from one location to another, which is not necessarily scientific. The case studies also identified issues of follow up where the linear process for decision-making does not provide opportunities for follow up on a decision should changes arise with a project. Some of these problems could be solved by tracking after the fact.

Generally, how do decision makers deal with uncertainty? Ideally the panels understand the uncertainty in what they are presented. They then weigh the evidence in support of the predictions to assess uncertainty. Evidence may include scientific, anecdotal, as well as examining mathematical calculations, how many assumptions and are the models well established. Panels avoid irreversible decisions if there is a great deal of uncertainty.

Jeremy Hall

Jeremy presented numerous case studies of oil and gas companies and the factors contributing to their success in establishing international projects. These companies succeeded because they addressed not only the below ground risks (technical aspect)

but also the above ground risks (political and social aspects). The companies become involved in the communities they entered and this involvement provided them with information. As a result, stakeholder ambiguity issues (where an unknown entity suddenly arises with opposition to a project) did not arise. Building a skill set in stakeholder ambiguity has allowed smaller companies to succeed where larger companies have been unsuccessful. In the cases presented companies still needed to work with government. However, with the support of stakeholders they were more successful.

Mike Quinn

Ecosystem Based Management Uncertainty.pdf

Ecosystem-based management (EBM) is the dominant emerging philosophy of natural resource management. EBM embraces uncertainty and explicitly calls for understanding, mitigating and communicating uncertainty in planning and management. The focus of EBM is on the long-term sustainability of complex biosocial systems rather than on resource outputs. EBM at its best is practiced within the context of environmental decision-making for complex problems. The field of "post-normal science" offers valuable insight and methods for the role of science and uncertainty in EBM. A central tenet of EBM is adaptive management, which provides a mechanism for managing in the face of uncertainty. Decisions are framed by the "precautionary principle" such that the probability of serious or irreplaceable environmental damage is minimized. Adaptive management is requires a commitment to a continuous improvement cycle and is not a license to apply single solutions across large landscapes.

Discussion Points and Comments




The following highlights the main discussion points as well as direct comments that resulted from the two day workshop.

IMPORTANCE OF ADDRESSING UNCERTAINTY UPFRONT

- Language is used to obscure problems; therefore, clarity of language is very important
- Need to explicitly define terms. For example, uncertainty as used by Jeremy Hall differs from uncertainty used by Mike Gillingham
- Consultants not communicating uncertainty should recognize that it might affect their credibility.
- It is important to state which information is certain and which is uncertain. .Otherwise uncertainty may be extended to all information.
- It is important to state the bounds of uncertainty and the factors influencing uncertainty
- Need first to determine the decision making objectives and the implications of being wrong. Do the questions posed by decision makers include a level of uncertainty? We need to know from the outset how decision makers assess risk
- If documentation of uncertainty is lacking and not presented, the proponent may be forced to take extreme opposing views. If uncertainty on both sides is presented they may find consensus.
- All models are wrong but useful
- Models are representations of reality
- Need to be careful of the link between uncertainty and credibility
- It would be beneficial to define agreements with respect to uncertainty at the outset of projects, need to have buy in from all parties, this reduces the risk that only one player is addressing uncertainty
- By addressing uncertainty upfront you may present options that eliminate the need for a hearing

IMPORTANCE OF LANGUAGE AND DEFINITIONS

- Decision makers and biologists need to come together and determine how each makes decisions and how to come together with a common framework
- Need to make a distinction between information and knowledge

- Distinction between uncertainty and sensitivity – sensitivity includes inputs, uncertainty includes outputs
- There should be a requirement on both parties to define uncertainty. Once uncertainty is defined you also need to define thresholds of acceptable uncertainty, which requires accurate data. This will result in a range of possibilities presented that allow common ground to be explored
- However, it is important not to keep re-defining works to satisfy everyone's needs

RECOMMENDED CHANGES FOR EIA

- Need to include operational effects
- Inclusion of indirect effects – even if they cannot be quantified they need to be included
- Inclusion of impacts from global warming
- Obligation to assess cumulative effects with the recognition that managing those effects may not be possible.
    - A project's cumulative effects should feed into regional level planning and regional level planning should feed back into each project.
- Importance of follow up reports/monitoring
    - Follow up studies can be used to address uncertainty – need to monitor for information to improve projects
    - Follow up studies need to be robust and credible and use adaptive management principles.
- Uncertainty needs more explicit recognition in EA processes. Responsibility for this falls with: 1) regulators (to demand it), 2) scientists (to provide it), 3) industry/proponents (who design and implement), and 4) public (who need to understand it).
- EIAs often include lots of information that has little relevance to the issues and lots of money is wasted – this needs to be revised
- Adaptive Environmental Management
    - Needs to be clearly defined
    - Is a tool for dealing with uncertainty – it can link the impacts with decision making
    - Conditions of approval need to include evaluation of monitoring, and a requirement to manage identified impacts - not just monitoring as monitoring only includes the collection of data, not its interpretation and not the environmental management needs.
    - Adaptive management can be effective when there is a reasonable assumption that monitoring will determine impacts in time for something to be done

IMPORTANCE OF SOCIAL DYNAMICS

- There may be a well defined method, explicit criteria and measurement of how decisions are made but each problem needs to be clearly identified and the values/world view of each person needs to be identified
- The importance of Traditional Knowledge

SCALE

- Scale of model interpretation needs to be explicit – need to state the temporal and spatial extent to which they are valid

OTHER IMPORTANT POINTS

- There are also differences in expert opinions. More experts need to be identified so that the distribution of these expert opinions can be defined
- Need to examine the difference between uncertainty and scientific subjectivity – we all carry our own biases, this in itself adds to/masks uncertainty
- Uncertainty is not an obstacle in a flawless process, it is one aspect we deal with (in addition to opinions, subjectivity etc.)
- Need to conduct sensitivity analysis of the role that uncertainty has played in decision making

ARE WE GETTING ANYWHERE?

- Compared with 30 years ago when EIAs were not conducted routinely we now do have deliberate processes in place to address many of these issues before decisions are made. EIAs are not perfect but, in theory, they allow the best information to be brought forward and encourage public involvement
- All of this is good, but does it address the problem of environmental degradation or has it just slowed it down?
- We are better at documenting the losses – we need to get better at defining the future we want
- By addressing uncertainty are we unmasking other aspects that we use to hide behind?
- We need eternal vigilance – if uncertainty is properly addressed and it does improve decision making there will be something else that people use to reach their goals
- The question should not be are we doing anything better than 30 years ago but are companies addressing uncertainty better than other jurisdictions.

NEXT STEPS

- Follow up meeting and discussions that includes a broader range of participants (regulators and professional practice organizations).

Selected Reference Materials

Adriaenssens, V., B. De Baets, et al. 2004. Fuzzy rule-based models for decision support in ecosystem management. Science of the Total Environment 319(1-3): 1-12.

Alverson, D. L. 2004. Searching for ecosystem reality-terms and concepts. Bulletin of Marine Science 74(3): 639-652.

Berling-Wolff, S. and J. Wu. 2004. Modeling urban landscape dynamics: A case study in Phoenix, USA. Urban ecosystems 7: 215-240.

Burgman, M. A., Lindenmayer, D. B., and J. Elith. 2005. Managing landscapes for conservation under uncertainty. Ecology 86(8): 2007-2017.

Burns, C.E., Johnston, K. M. and O. J. Schmitz. 2003. Global climate change and mammalian species diversity in U.S. national parks. PNAS. 100 (20): 11474-11477.

Caldwell, L. K. 1995. Science assumptions and misplaced certainty in natural resources and environmental problem solving. Scientific uncertainty and environmental problem solving. J. Lemons. Cambridge, Mass, Blackwell Science: 394-421.

Carpenter, R. A. 1995. Uncertainty in managing ecosystem sustainability. Scientific uncertainty and environmental problem solving. J. Lemons. Cambridge, Mass, Blackwell Science: 118-159.

Clark, J. S. 2005. Why environmental scientists are becoming Bayesians. Ecology Letters 8(1): 2-14.

Clevenger, A. P., J. Wierzchowski, B. Chruszcz and K Gunson. 2002. GIS-Generated, Expert-Based Models for Identifying Wildlife Habitat Linkages and Planning Mitigation Passages. Conservation Biology 16 (2), p. 503-514.

Crosetto, M. and S. Tarantola. 2001. Uncertainty and sensitivity analysis: tools for GIS-based model implementation. International Journal of Geographical Information Science. 15(5): 415-437.

De Genst, W., F. Canters, et al. 2001. Uncertainty modeling in buffer operations applied to connectivity analysis. Transactions in GIS 5(4): 305-326.

deFur, P. L. and M. Kaszuba. 2002. Implementing the precautionary principle. Science of the Total Environment 288(1-2): 155-165.

Eastman, J.R. 2001. Uncertainty Management in GIS: Decision Support Tools for Effective Use of Spatial Data Resources. In Spatial Uncertainty in Ecology: Implications for Remote Sensing and GIS Applications, eds. C.T. Hunsaker, M.F. Goodchild, M.A.

Eastman, J. R., H. Jiang, and James Toledano, 1998. Multi-criteria and multi-objective decision making for land allocation using GIS. In Multicriteria Analysis for Land-Use Management, eds. E. Beinat and P. Nijkamp (Dordrecht: Kluwer Academic Publishers) p. 227-252.

R. S. Etienne. 2003. Ecological Impact Assessment in Data-Poor Systems: A case study on metapopulation persistence. Environmental Management. 32(6): 760-777.

Fieberg, J. and K. J. Jenkins. 2005. Assessing uncertainty in ecological systems using global sensitivity analyses: a case example of simulated wolf reintroduction effects on elk. Ecological Modelling 187: 259-280.

Gaines, W. L., P. H. Singleton, et al. 2003. Assessing the cumulative effects of linear recreation routes on wildlife habitats on the Okanogan and Wenatchee National Forests. General Technical Report PNW-GTR-586. Portland, OR, USDA Forest Service, Pacific Northwest Research Station.

Gustavson, K. R. 2003. Applying the precautionary principle in environmental assessment: the case of reviews in British Columbia. Journal of Environmental Planning and Management 46(3): 365-379.

Hall, J. and H. Vredenburg. Stakeholder Ambiguity and Corporate Risk Strategies. Calgary Management Review (submitted).

Handmer, J. W., T. W. Norton, et al., Eds. 2001. Ecology, uncertainty and policy: managing ecosystems for sustainability. Harlow, UK, Pearson Education Limited.

Harremoes, P., D. Gee, et al. 2001. Late lessons from early warnings: the precautionary principle 1896–2000. Copenhagen, Denmark, European Environment Agency.

Johnson, C. J. and M. P. Gillingham. 2004. Mapping uncertainty: sensitivity of wildlife habitat ratings to expert opinion. Journal of Applied Ecology. 41: 1032-1041.

Jolma, A. and J. Norton 2005. Methods of uncertainty treatment in environmental models. Environmental Modelling & Software 20: 979-980.

Jordan, C. F. and C. Miller. 1995. Scientific uncertainty as a constraint to environmental problem solving: large-scale ecosystems. Scientific uncertainty and environmental problem solving. J. Lemons. Cambridge, Mass, Blackwell Science: 91-117.

Kingsley, L. 1999. Implementing cumulative effects assessment: a framework and approach for Canada's national parks. Ottawa, ON, Carleton University.

Lackey, R. T. 2005. Economic growth and salmon recovery: an irreconcilable conflict? Fisheries 30(3): 30-32.

Lahdelma, R., Salminen, P. and J. Hokkanen. 2000. Using multicriteria methods in environmental planning and management. Environmental Management. 26(6): 595-605.

Lemons, J. 1995. The conservation of biodiversity: scientific uncertainty and the burden of proof. Scientific uncertainty and environmental problem solving. J. Lemons. Cambridge, Mass, Blackwell Science: 206-232.

Lemons, J. 1995. Scientific uncertainty and environmental problem solving. Cambridge, Mass, Blackwell Science.

Longstaff, H. A. 2005. Frankenfish, monsatan, and killer canola: making good decisions in the midst of environmental controversy. Journal of Environmental Infomatics 6(1): 33-45.

MacDonald, L. H. 2000. Evaluating and managing cumulative effects: process and constraints. Environmental Management 26(3): 299-315.

Martin, T. G., P. M. Kuhnert, et al. 2005. The power of expert opinion in ecological models using Bayesian methods: Impact of grazing on birds. Ecological Applications 15(1): 266-280.

Matos, S. and J. Hall. Integrated sustainable development in the extended value chain: The case of life cycle assessment in the oil and gas and agricultural biotechnology industries. Journal of Operations Management (submitted).

Matsuda, H. 2003. Challenges posed by the precautionary principle and accountability in ecological risk assessment. Environmetrics 14(2): 245-254.

McCarthy, M. A. and P. Masters. 2005. Profiting from prior information in Bayesian analyses of ecological data. Journal of Applied Ecology 42: 1012-1019.

McKelvey, K.S. and B. R. Noon, 2001, Incorporating Uncertainties in Animal Location and Map Classification into Habitat Relationships Modeling. In Spatial Uncertainty in Ecology: Implications for Remote Sensing and GIS Applications, eds. C.T. Hunsaker, M.F. Goodchild, M.A. Friedl, and T.J. Case, (Springer: New York) p. 72-90.

Miller, K. K. and C. T. K. McGee. 2001. Toward incorporating human dimensions information into wildlife management decision-making. Human Dimensions of Wildlife 6(3): 205-221.

Newman, L. 2005. Uncertainty, innovation, and dynamic sustainable development. Sustainability: Science, Practice, & Policy 1(2): 25-31.

Pallottino, S., G. M. Sechi, et al. 2005. A DSS for water resources management under uncertainty by scenario analysis. Environmental Modelling & Software 20: 1031-1042.

Piper, J. M. 2001. Barriers to implementation of cumulative effects assessment. Journal of Environmental Assessment Policy and Management 3(4): 465-481.

Popper, Steven W., Robert J. Lempert and Steven C. Bankes. 2005. Shaping the Future: Scientific uncertainty often becomes an excuse to ignore long-term problems, such as climate change. It doesn't have to be so. Scientific American 292(4):66-71.

Post, J. R., C. Mushens, et al. 2003. Assessment of alternative harvest regulations for sustaining recreational fisheries: Model development and application to bull trout. North American Journal of Fisheries Management 23(1): 22-34.

Regan, H. M., Ben-Haim, Y., Langford, B., Wilson, W. G., Lundberg, P., Andelman, S. J., and M. A. Burgman. Ecological Applications (in press).

Rigg, C. M. 2001. Orchestrating ecosystem management: challenges and lessons from Sequoia National Forest. Conservation Biology 15(1): 78-90.

Sarewitz, D. 2004. How science makes environmental controversies worse. Environmental Science and Policy 7: 385-403.

Sethi, G., C. Costello, et al. 2005. Fishery management under multiple uncertainty. Journal of Environmental Economics and Management 50: 300-318.

Shoemaker, D. J. 1995. Cumulative environmental effects: managing aggregate resource extraction in southern Ontario. Waterloo, ON, University of Waterloo.

Shrader-Frechette, K. 1995. Methodological rules for four classes of scientific uncertainty. Scientific uncertainty and environmental problem solving. J. Lemons. Cambridge, Mass, Blackwell Science: 12-39.

Smith, W. and Y. S. Son. 2005. Can the desire to conserve our natural resources be self-defeating? Journal of Environmental Economics and Management 49(1): 52-67.

Thuiller, W., M. B. Araujo, et al. 2004. Biodiversity conservation: uncertainty in predictions of extinction risk. Nature 430(6995).

van Bodegom, P., C. Bakker, et al. 2004. Identifying key issues in environmental wetland research using scale and uncertainty analysis. Regional Environmental Change 4(2-3): 100-106.

Vredenburg, H. and J. Hall. 2003. The challenges of innovating from sustainable development. MIT Sloan Management Review. Fall 2003: 61-68.

Waltner-Toews, D., J. J. Kay, et al. (2003). Perspective changes everything: managing ecosystem from the inside out. Frontiers in Ecology and the Environment 1(1): 23-30.

Web Sites

Clark Labs – IDRISI
http://www.clarklabs.org/

Institute of Environmental Systems Research
http://www.usf.uos.de/root.en.html

The International Institute for Applied Systems Analysis (IIASA)
http://www.iiasa.ac.at/

Integrated Assessment Society
http://www.tias-web.info/

POST-NORMAL SCIENCE - Environmental Policy under Conditions of Complexity
http://www.nusap.net/sections.php?op=viewarticle&artid=13

Rachel's Environment and Health Weekly
http://www.mindfully.org/Precaution/Scientific-Uncertainty-Rachels.htm

Stockholm Environment Institute
http://www.sei.se/

UK Parliamentary Office of Science and Technology
http://www.parliament.uk/documents/upload/POSTpn220.pdf

UNESCO – Ethics and Science
http://www.unesco.org/science/wcs/background/ethics_uncertainty.htm

APPENDIX

AGENDA

Putting Perspective on Uncertainty

November 3-4, 2005
Kananaskis Field Station
Agenda

November 3

10am	Welcome/background (Paul Paquet/Roger Creasey)
10:20 – 11:30	Uncertainty in wildlife modeling – What is it/how do we calculate it/how do we present it?

- Mary-Ellen Tyler (University of Calgary)
- Mike Gillingham (University of Northern British Columbia)

11:30 – 12:30	Application and challenges of uncertainty in Environmental Assessment

- Kevin Lloyd (Axys Environmental Consulting Ltd.)
- Martin Jalkotzy (Golder Associates)
- Bill Ross (University of Calgary)

12:30 – 1:30	Lunch
1:30 – 3:00	Case Study - Break out sessions

A case study will be presented by Paul Paquet and Roger Creasey focused on roads and wildlife. This will be followed by breakout groups that will address the following questions related to the case study. Questions may include:

- How do we determine uncertainty?
- How do we determine acceptable levels of uncertainty?
- How do we reduce uncertainty?
- How do we clearly state uncertainty?
- What information can decision makers use reliably?

3:00 – 3:15	Break
3:15 – 4:00	Break out groups report back
4:00 – 5:00	Plenary discussion – results from break out session. Preparation for Day 2.

6:00 – 7:00 Dinner

Evening – casual social

November 4

8:30 Decision Making and Uncertainty

- Rob Powell (NRCB)
- Jeremy Hall (Haskayne School of Business, U of C)

9:30 Ecosystem Management approaches

- Mike Quinn (University of Calgary)

10:00 – 10:15 Break

10:15 – 11:45 Facilitated discussion

Options for discussion:

- Recommendations for practitioners on how to present and integrate uncertainty in decision making
- Identification of research needs
- Identification of successful approaches

11:45 – 12:15 Conclusions