Both begin with a B

Bayesian networks or Bayesian hierarchical modelling for ecological risk assessment

SETAC North America 2020

Ullrika Sahlin and Dmytro Perepolkin
Lund University, Sweden

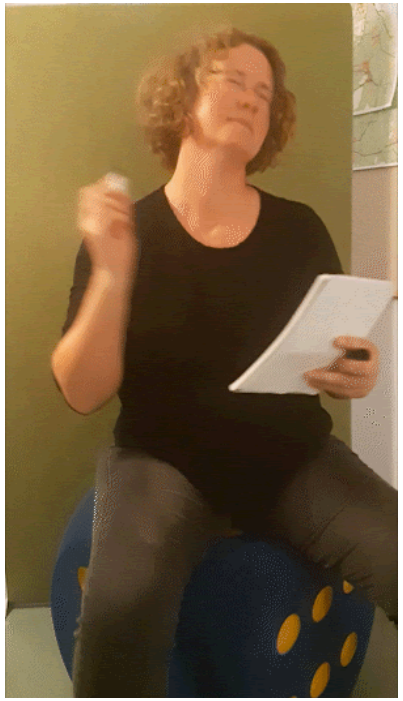
2020-11-19

"Uncertainty is an uncomfortable position. But certainty is an absurd one."

Voltaire 1694 - 1778

Uncertainty in risk assessment

- Uncertainty arise from limitations in knowledge
- Uncertainty is personal. *Someone* is uncertain



Uncertainty in risk assessment

- Uncertainty arise from limitations in knowledge
- Uncertainty is personal. *Someone* is uncertain
- Epistemic uncertainty (from Ancient Greek: ***ἐπιστήμη***, epistēmē, 'knowledge')
    - uncertainty about the model (including parameters), lack of scientific consensus, small sample sizes, bias or low quality in experimental studies, observation or measurement errors, ambiguous terms, misunderstandings
- Aleatory uncertainty (from Latin: *āleă*, dice):
    - inherent randomness in real world systems, heterogeneity, variability, between study variability, chance outcomes
- Ontological uncertainty
    - uncertainty about the future, in which our current objectives, management alternatives and understanding of the world (models) are made obsolete by change.

Tuxedo fallacy

"Treating all decisions as if they took place under epistemic conditions analogous to gambling at the roulette table."

Hansson (2009)

Communicate uncertainty

- Communicating uncertainty to decision makers is important

> "Unless uncertainty is known a decision maker can place too much confidence in experts and face unexpected problems or a decision maker can place too little confidence in experts and miss opportunities and resources to collect information has been waisted.
> In some situations it can be motivated to hide one's uncertainty, but in scientific assessments honesty is the only option"
>
> — Fischhoff and Davis (2014)

- Uncertainty analysis is an integral part of risk assessment
  - EFSA (2018) The principles and methods behind EFSA's guidance on uncertainty analysis in scientific assessment.
  - SAPEA and EC (2019) Scientific Advice to European Policy in a Complex World
  - Institute of Medicine (2013) Environmental decisions in the face of uncertainty

Expressing epistemic uncertainty

Direct uncertainty (about facts, numbers and scientific models)

- Verbal statements
- Intervals
- Probability

Indirect uncertainty (strength in knowledge)

- List of caveats
- Judged error or risk of different biases

van der Bles van der Linden, et al. (2019)

Expressing epistemic uncertainty

Direct uncertainty (about facts, numbers and scientific models)

- Verbal statements
- Intervals
- Probability - a *precise way* to express epistemic uncertainty

Indirect uncertainty (strength in knowledge)

- List of caveats
- Judged error or risk of different biases

van der Bles van der Linden, et al. (2019)

B as in Bayesian

Bayesian methods

1. Subjective probability to quantify uncertainty
2. Bayes rule for inference
3. Rule for Bayes optimal decisions

$$P(A|E) = \frac{P(E|A)P(A)}{P(E)}$$

$$d^* = \min_{d \in D} P(A|E \,\&\, d)$$

Bayesian methods

1. Subjective probability to quantify uncertainty
2. Bayes rule for inference
3. Rule for Bayes optimal decisions

$$P(A|E) = \frac{P(E|A)P(A)}{P(E)}$$

$$d^* = \min_{d \in D} P(A|E \,\&\, d)$$

These can, but don't have to be used together.

Questions

- In what way are Bayesian Networks related to these three pillars of Bayesian methods?
- What is required to treat uncertainty when BNs are used for ecological risk assessment?

Uncertainty about the model structure and parameters within models is not handled by BNs by default.

Bayesian networks

1. Handle categorical, discrete and discretized continuous variables.
2. Parameters (PTs and CPTs) are fixed and can be assigned by expert judgement or case learning
3. Bayesian inference to revise the network conditional on a configuration of nodes.

Aleatory Bayesian Networks

- Assessment variables modeled with probability distributions (variability)

Epistemic Bayesian Networks

- State nodes are modeled with probability distributions (uncertainty)
- Data nodes are modeled with probability distributions (likelihood)

> Statistical models which explicitly address uncertainty can support parametric inference and uncertainty analysis in ERA.

Sahlin Helle, et al. (2020)

BHM for uncertainty analysis of a BN

A BN can be "wrapped" into a hierarchical model and Bayesian inference can be used to quantify uncertainty in parameters for probabilistic uncertainty analysis.

Hierarchical Models (HM) attribute variation to different groups, e.g. random mixed effect models.

A Bayesian HM is a joint probability distribution of parameters, variables and data.

Gelman Carlin, et al. (2013); Kadane (2011)

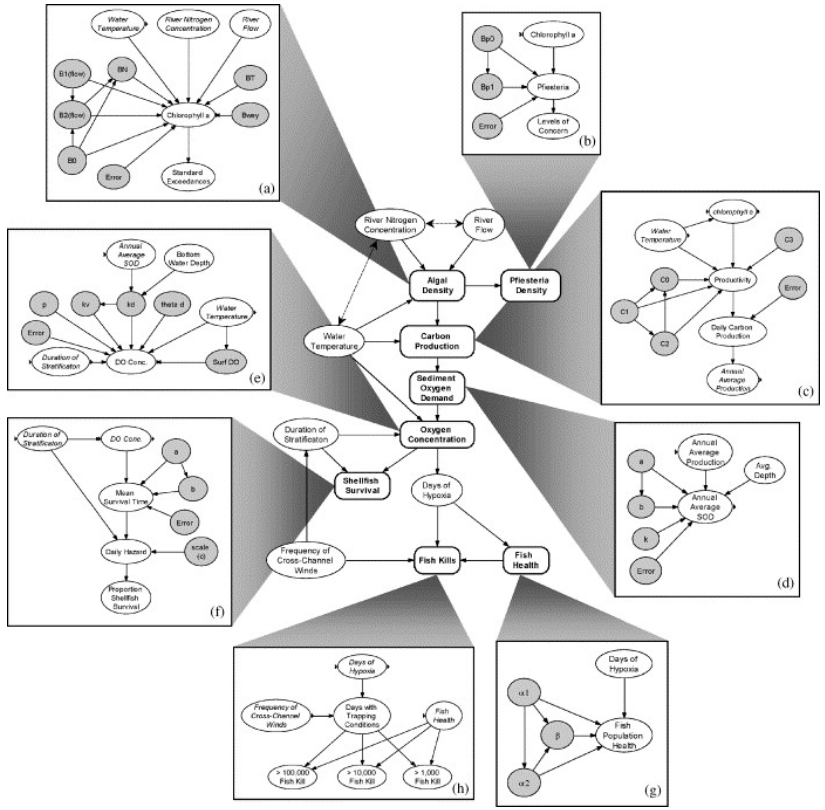
BHM for uncertainty analysis of a BN

A BN can be "wrapped" into a hierarchical model and Bayesian inference can be used to quantify uncertainty in parameters for probabilistic uncertainty analysis.

Hierarchical Models (HM) attribute variation to different groups, e.g. random mixed effect models.

A Bayesian HM is a joint probability distribution of parameters, variables and data.

> Variables from several BHMs can be combined into an aleatory BN



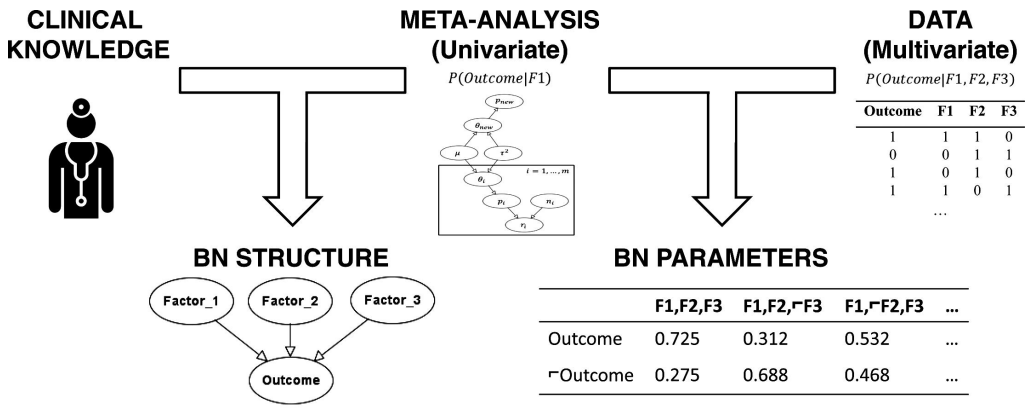
Gelman Carlin, et al. (2013); Kadane (2011)

Borsuk Stow, et al. (2004)

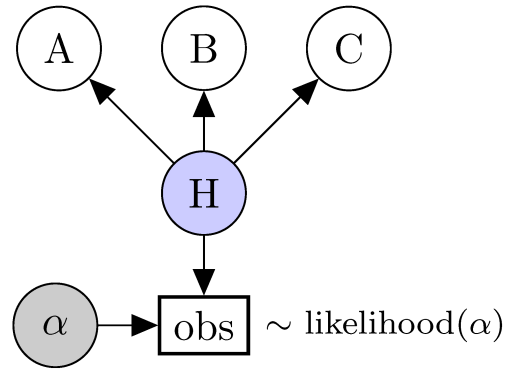
BHM for uncertainty analysis of a BN

BHMs can combine multiple and different sources of studies to inform BNs

-Combine multiple sources of evidence using meta-analysis considering variability and error in data.



-Consider measurement error or partial observability when building Epistemic BNs such as Bayes naive classifiers.



Hu O'Connor, et al. (2020); Yet Perkins, et al. (2014); Hamilton Pollino, et al. (2015)

A way forward

Both Bayesian networks and Bayesian hierarchical modeling should be used for ecological risk assessment.

BHM for parametric inference combined with

- Aleatory BNs to build integrated assessment models to assess probability of adverse events or impacts
- Epistemic BNs for probabilistic reasoning about uncertain quantities based on multiple and different sources of evidence

Thanks!

ullrika.sahlin@cec.lu.se
dmytro.perepolking@cec.lu.se

Acknowledgments

FORMAS
Swedish research council for sustainable development

Slides created via the R package xaringan

Slides including references:

bit.ly/BNboth

References

Borsuk, M. E., C. A. Stow, et al. (2004). "A Bayesian Network of Eutrophication Models for Synthesis, Prediction, and Uncertainty Analysis". In: *Ecological Modelling* 173.2-3, pp. 219-239. DOI: 10/fn728t. URL: https://linkinghub.elsevier.com/retrieve/pii/S0304380003003958 (visited on Sep. 15, 2020).

der Bles, A. M. van, S. van der Linden, et al. (2019). "Communicating Uncertainty about Facts, Numbers and Science". In: *Royal Society Open Science* 6.5, p. 181870. DOI: 10/gf2g9j. URL: https://royalsocietypublishing.org/doi/10.1098/rsos.181870 (visited on Aug. 26, 2019).

EFSA (2018). "The Principles and Methods behind EFSA's Guidance on Uncertainty Analysis in Scientific Assessment". In: *EFSA Journal* 16.1. DOI: 10/ghhdx2. URL: https://data.europa.eu/doi/10.2903/j.efsa.2018.5122 (visited on Sep. 15, 2020).

Fischhoff, B. and A. L. Davis (2014). "Communicating Scientific Uncertainty". In: *Proceedings of the National Academy of Sciences* 111 (Supplement 4), pp. 13664-13671. DOI: 10/f6gwcg. pmid: pmid. URL: https://www.pnas.org/content/111/Supplement_4/13664 (visited on Dec. 05, 2019).

Gelman, A., J. B. Carlin, et al. (2013). *Bayesian Data Analysis*. CRC press.

References

Hamilton, S. H., C. A. Pollino, et al. (2015). "Habitat Suitability Modelling of Rare Species Using Bayesian Networks: Model Evaluation under Limited Data". In: *Ecological Modelling* 299, pp. 64-78. ISSN: 0304-3800. DOI: 10.1016/j.ecolmodel.2014.12.004.

Hansson, S. O. (2009). "From the Casino to the Jungle". In: *Synthese* 168.3, pp. 423-432. URL: https://doi.org/10.1007/s11229-008-9444-1 (visited on Sep. 15, 2020).

Hu, D., A. M. O'Connor, et al. (2020). "How to Conduct a Bayesian Network Meta-Analysis". In: *Frontiers in Veterinary Science* 7. URL: https://www.frontiersin.org/article/10.3389/fvets.2020.00271/full (visited on Nov. 04, 2020).

Institute of Medicine (2013). *Environmental Decisions in the Face of Uncertainty*. Washington, D.C.: National Academies Press, p. 12568. ISBN: 978-0-309-13034-9. DOI: 10.17226/12568. URL: http://www.nap.edu/catalog/12568 (visited on May. 03, 2020).

Kadane, J. B. (2011). *Principles of uncertainty*. Chapman & Hall/CRC texts in statistical science series: 92.

References

Sahlin, U., I. Helle, et al. (2020). "'This is what we don't know' â€ Treating epistemic uncertainty in Bayesian networks for risk assessment". In: *Integrated Environmental Assessment and Management*, p. ieam.4367. ISSN: 1551-3777, 1551-3793. DOI: 10.1002/ieam.4367.

SAPEA and EC (2019). *Scientific Advice to European Policy in a Complex World*. LU: Publications Office. URL: https://data.europa.eu/doi/10.2777/68120 (visited on Nov. 04, 2020).

Yet, B., Z. B. Perkins, et al. (2014). "Combining Data and Meta-Analysis to Build Bayesian Networks for Clinical Decision Support". In: *Journal of Biomedical Informatics* 52, pp. 373-385. ISSN: 1532-0464. DOI: 10.1016/j.jbi.2014.07.018.