Reflections on Bayesian analysis to support landscape ecological risk assessment in the Upper Grande Ronde Watershed of INLAS

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Fire is more than a local impact

The sun in the middle of the afternoon near Burlington Washington—smoke from hundreds of miles away and last several days.

Being on the boarder we get it from California, Oregon, Alaska, British Columbia and occasionally from Asia.
Our application of Bayesian Networks grew out of a program funded by Joint Venture Agreement No. PNW 06-JV-11261900–070 with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Terry Shaw facilitated the program and when we said that we wanted to start using Bayesian Networks-he said that this guy down the hall uses them all the time so ok. Of course, that person was Bruce G. Marcot and my research took a different path.....
Forestry Management has multiple management goals and fire is only one of them.

Bayesian networks allow a number of questions about “current states” and then a number of “what if” questions and management alternatives.

The methods in this talk have now been applied for the cleanup of toxic sites, disease prediction, synthetic biology, invasive species and other types of questions.
Short Introduction....

Conventional Relative Risk Model

A Pilot Application of Regional Scale Risk Assessment to the Forestry Management of the Upper Grande Ronde Watershed, Oregon

Suzanne M. Anderson and Wayne G. Landis
Institute of Environmental Toxicology, Huxley College of the Environment, Western Washington University, Bellingham, WA, USA

A Bayesian Approach to Landscape Ecological Risk Assessment Applied to the Upper Grande Ronde Watershed, Oregon

Kimberley K. Ayre and Wayne G. Landis
Institute of Environmental Toxicology, Huxley College of the Environment, Western Washington University, Bellingham, WA, USA

Our first application of Bayesian networks
The study area........
Risk Assessment Structure and Causal Pathway

Figure 1. Diagram of the fundamental RRM conceptual model for regional risk assessment.

Anderson and Landis 2012
Risk Assessment Structure and Causal Pathway

- Directed Acyclic graph
- Nodes
- Lines of influence
- Categorical
- Probabilistic

**Figure 4.** Conceptual model. Complete pathways are indicated with connecting lines. The same model is used for each risk region although the ranks and filters are altered specifically for each calculation.
Bayesian Network Structure

• Nodes represent variables
  • Parent node has no input variables
  • Child node has input from other variables

• Variables are assigned discrete states
  • Zero, low, medium, and high
  • Similar to treatment with relative risk model

• Structure reflects causality
  • Based on conceptual model developed by Suzanne Anderson
Bayesian Network Relative Risk Model

The methods have been published for other sites and a variety of stressors:

<table>
<thead>
<tr>
<th>Parent Nodes</th>
<th>Child Node</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stressor A</strong></td>
<td><strong>Condition 1</strong></td>
</tr>
<tr>
<td>zero</td>
<td>4.04 ± 1.5</td>
</tr>
<tr>
<td>low</td>
<td>16.0</td>
</tr>
<tr>
<td>med</td>
<td>54.0</td>
</tr>
<tr>
<td>high</td>
<td>26.0</td>
</tr>
</tbody>
</table>

| **Stressor B** | **States** |
| zero           | 12.0       |
| low            | 27.0       |
| med            | 43.0       |
| high           | 18.0       |

<table>
<thead>
<tr>
<th><strong>Conditional Probability Table</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stressor A</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>zero</td>
</tr>
<tr>
<td>low</td>
</tr>
<tr>
<td>med</td>
</tr>
<tr>
<td>high</td>
</tr>
</tbody>
</table>
Conditional Probabilities

• Link parent and child nodes
• Value of child node is dependent upon the likelihood of states for all parent nodes
• Conditional probabilities established through spatial analysis of GIS data for all parent node variables
Why Bayesian Networks?

1. Combine different types of data including model predictions and expert judgment
2. Uncertainty is inherently reflected in the probability distributions
3. Updateable when new information or knowledge comes available
4. Can be used to predict both input and output variable states
The Bayesian network for UGR watershed of INLAS

A slight rearrangement.

The inputs are now on the top row, the outcomes (impacts) are on the bottom-

Parameterized using the extensive datasets and expert knowledge of the USFS.

Figure 3. Bayesian network model developed for the analysis of ecological risk from landscape disturbances in the upper Grande Ronde watershed in northeastern Oregon. The top parameter nodes in the diagram repre-

Ayre and Landis 2012
The Bayesian network in Netica for UGR watershed of INLAS
The Bayesian network in Netica for UGR watershed of INLAS

Disturbances

Note the distributions….the inputs have been incorporated into the Parent Nodes
The Bayesian network in Netica for UGR watershed of INLAS

Habitats/Locations

Note the even distributions….model is not yet compiled. Left out in the examples to come.
Endpoints-to be managed

Note the even distributions….model is not yet compiled.

HRV-Historic Range of Variation
Interesting criterion in the time of climate change
## GIS Data Used to Develop CPTs

<table>
<thead>
<tr>
<th>Variable</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insect Outbreaks</td>
<td>2007 Insect &amp; Disease Aerial Survey Data online at <a href="http://www.fs.fed.us/r6/nr/fid/as/r6id2007e00.zip">http://www.fs.fed.us/r6/nr/fid/as/r6id2007e00.zip</a></td>
</tr>
<tr>
<td>Wildfire</td>
<td>Consequences of Wildfires on the W-W NF online at <a href="http://www.fs.fed.us/r6/data-library/gis/wallowa-whitman/data/cons.zip">http://www.fs.fed.us/r6/data-library/gis/wallowa-whitman/data/cons.zip</a></td>
</tr>
</tbody>
</table>
Conditional Probability Table

Real distributions….model is compiled.
Risk Ranks

• Risk rankings calculated as the mean state of the probability distribution

• Expressed ± standard deviation for the probability distribution—but note that they do not look like Gaussian distributions, but many seem to like seeing them.

• Output represents the likely range of risk ranks
Risk Ranks initial risk assessment

Range of risk values - note the the distributions
Solving the Model “Backwards”

- Set endpoint risk values to desired risk level
- Model automatically updates values of parent parameters need to achieve desired risk level
- Can the parameters be managed in such a pattern?
- Which endpoint has a priority, what if questions.
Low Risk for each endpoint....

Low risk each endpoint

Grazing has the largest change

Initial conditions

Low risk each endpoint-Grazing has the largest change
Zero Risk for HRV fire....

Initial conditions

Zero risk Fire

- Forest Mgmt
  - Zero: 0.10
  - Low: 37.1
  - Med: 36.9
  - High: 59.7
  - Mean: 4.14 ± 1.1

- Grazing
  - Zero: 9.11
  - Low: 35.0
  - Med: 33.6
  - High: 22.3
  - Mean: 3.38 ± 1.8

- Insects
  - Zero: 91.8
  - Low: 0.88
  - Med: 3.97
  - High: 3.47
  - Mean: 0.381 ± 1.3

- Wildfire
  - Zero: 0
  - Low: 0.93
  - Med: 98.9
  - High: 3.07
  - Mean: 4.04 ± 0.4

- Timber Resources
  - Zero: 13.7
  - Low: 16.6
  - Med: 32.9
  - High: 36.6
  - Mean: 3.85 ± 2.1

- GrazingLand
  - Zero: 13.5
  - Low: 20.2
  - Med: 29.9
  - High: 45.4
  - Mean: 3.97 ± 2.2

- Recreation
  - Zero: 9.17
  - Low: 16.4
  - Med: 33.5
  - High: 49.8
  - Mean: 4.12 ± 1.9

- HRVFire
  - Zero: 100
  - Low: 0
  - Med: 0
  - High: 0
  - Mean: 0

- HRVInsects
  - Zero: 40.9
  - Low: 24.5
  - Med: 35.7
  - High: 5.44
  - Mean: 1.76 ± 1.8

- HRVInvasives
  - Zero: 15.8
  - Low: 24.5
  - Med: 39.1
  - High: 20.7
  - Mean: 3.29 ± 2.2

- HRVFishHabitat
  - Zero: 5.97
  - Low: 8.41
  - Med: 19.4
  - High: 66.2
  - Mean: 4.92 ± 1.8
Zero Risk for HRV Fish....

Low risk Fish

Initial conditions
Low risk Recreation - all other risks reduced to even lower than focusing on fish...

Low risk Fish - all other risks are also reduced...

Comparison of Scenarios

Initial conditions - state as of 2012
Why do all this analysis? OODA Loops

Observe, Orient, Decide and Act—Loop

Unfolding Events → Observe → Orient → Decide → Act → Observe

"OODA.Boyd" by Patrick Edwin Moran - Own work. Licensed under CC BY 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:OODA.Boyd.svg#/media/File:OODA.Boyd.svg
Adaptive management—Landis 2017

Social goals (economic, cultural, well-being) that correspond to the multiple resources at a site.

Ecological risk assessment: Designed to accommodate the multiple management goals in a site-specific manner.

Management and remediation options: Methods are evaluated using risk assessment and evaluated by monitoring that incorporates multiple stressors and multiple endpoints.

Estimates of risk to multiple endpoints across the management region.

Inputs describing the potential outcomes from the remediation options and the data from ongoing monitoring.

Constraints due to economic resources, benefits, social concerns, and legislation and the importance of the remediation goals.

Derivation of the endpoints considered in the risk assessment and the criteria to be met in a spatially explicit context.

Public Engagement and Governance

Decision making: Can be at different levels including local stakeholders, responsible parties, local, regional, national, and international agencies.

Research, Engineering, Risk Assessment and Management

Change in Externalities: Alterations in environmental conditions outside the management loop such as climate change, population growth, economics, technology.

Just another OODA loop with the externalities included.
Ecological risk assessment: Designed to accommodate the multiple management goals in a site specific manner.

Evaluation of management and remediation options: Estimates of risk to multiple endpoints across the management region.

Inputs describing the outcomes from the remediation options and the data from ongoing monitoring.

Decision making
Why Bayesian networks?....

• Adaptable—Fire and lots more
• Multiple stressors are normal and can be calculated
• Interactions of management methods can be evaluated
• Pictures and numbers...
• Warning—risks do not always go down together like in this example.
Thanks for your time.....