REFRESH WP5

London November 2013

Bayesian-based conceptual model for macroinvertebrate diversity in lowland streams

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Some WP5 REFRESH Objectives

- to develop and improve the performance of integrated catchment models for simulating the ecological response of freshwater ecosystems to climate, land-use/management and pollution change;

- to use the models to explore the ecological and cost-effectiveness of alternative adaptation, mitigation and restoration strategies at the catchment scale, to ensure long-term sustainable management.

So we need a set of ecological models!

Ecological Model Requirements

They should:

Work at a catchment scale

To be able to respond to changes in aquatic systems due to:

- Climate
- Land use
- Nutrients
- Management interventions

Produce outputs which relate to European legislation, e.g.
the Water Framework Directive

Produce outputs which are comprehensible to water managers

Be fairly easily transferable to sites other than
the demonstration sites

The Solution?

Bayesian Networks!!!??

- But what is a Bayesian network?

Bayesian Statistics

Named after the Reverend Thomas Bayes, who published a posthumous paper in 1763

Bayesian probability is a measure of an individual's *degree of belief* in an event or hypothesis.

Prior + New data —model→ Posterior

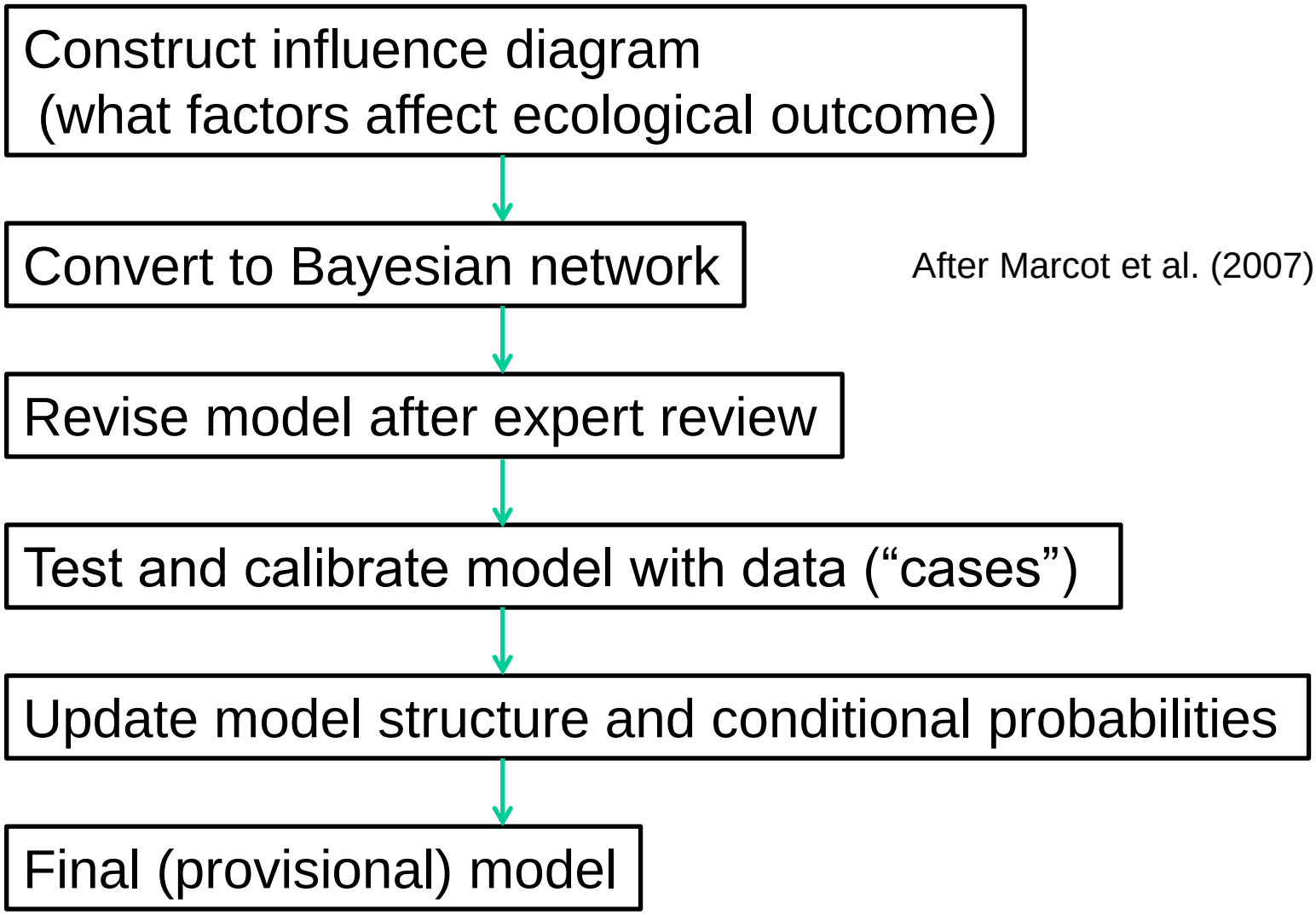
Current knowledge (prior) is updated with new data using a model to give improved knowledge (posterior).

Bayesian Network

So a Bayesian network is a network of relationships, expressing degrees of belief in a set of propositions, which can be updated with new knowledge.

What relationships and probabilities do we have for stream macroinvertebrates? Specific focus is forested streams in The Netherlands

How to Construct an Ecological BBN



After Marcot et al. (2007)

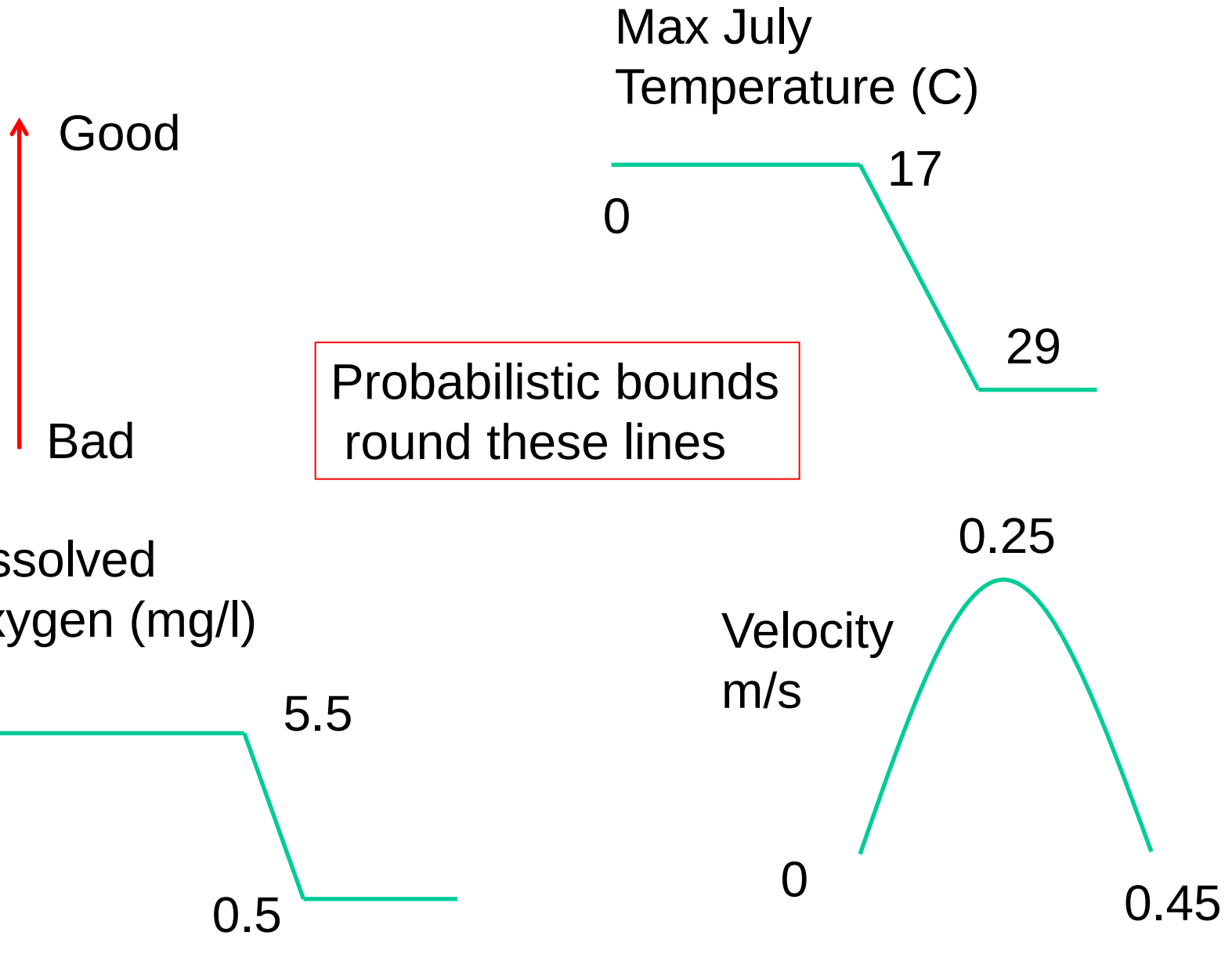
What affects stream macroinvertebrates?

Immediate drivers:

- Stream temperature
- Dissolved oxygen
- Stream velocity
- Food quality
- Substrate quality

Questions:
How do these variables affect macroinvertebrates?
How do they interact with each other?
How are they driven by environmental variables, in particular climate and land use?

Functional Relationships



Functional Relationships (2)

Substrate:

Interaction between coarse particulate organic matter (CPOM) and silt%

Food Quality:

Interaction between CPOM, algae and macrophytes

These are expressed as conditional probability tables

These relationships are all derived from data, literature sources, and expert judgement

Calculating the driving variables

Some examples:

1. Temperature

Climate simulations produce air temperature.

USGS Energy Balance Model SSTEMP is pre-run for different combinations of July air temperature, shading, and various stream characteristics.

This is converted into a regression equation ($r^2 > 0.99$), and then into a conditional probability table.

Groundwater is then mixed in.

Thus we can simulate the macroinvertebrate response to water temperature as a function of air temperature, shading, and groundwater input

Calculating the driving variables (2)

Some examples:

2. Dissolved Oxygen

Maximum dissolved oxygen decreases with temperature.

Standard empirical relationship is converted to a regression equation ($r^2 > 0.99$).

Oxygen is then subtracted from the maximum value due to consumption by BOD and respiration of primary production

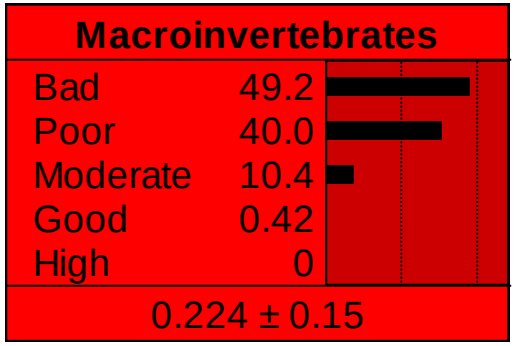
Oxygen is then added as a function of velocity (all literature relationships) and macrophyte presence.

This is then converted into a (rather complex) CPT

Thus we can simulate the macroinvertebrate response to oxygen as a function of air temperature, shading, BOD, groundwater, etc.

Output

In WFD classes as a probability (“belief bar”)



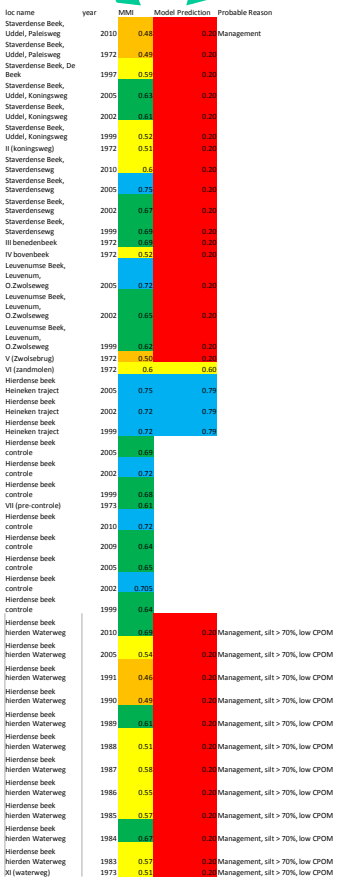
Doesn’t need to be.
Could be indicator scores or even communities

Testing

42 long-term monitored streams in the The Netherlands

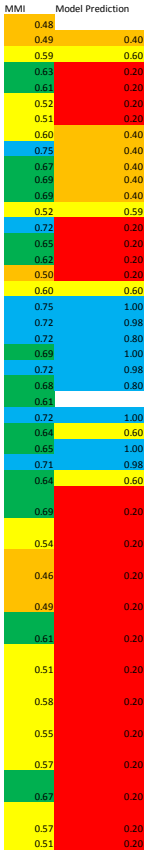
First

Observed Modelled



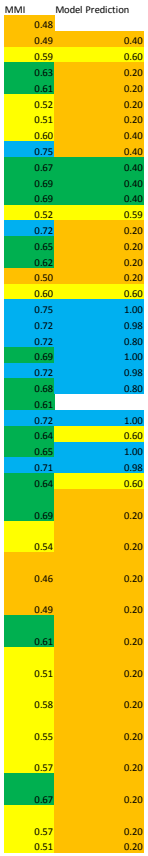
loc name	year	MMI	Model Prediction	Probable Reason
Staverdense Beek, Uddel, Paleisweg	2010	0.48	0.20	Management
Staverdense Beek, Uddel, Paleisweg	1972	0.49	0.20	
Staverdense Beek, De Beek	1997	0.59	0.20	
Staverdense Beek, Uddel, Koningsweg	2005	0.63	0.20	
Staverdense Beek, Uddel, Koningsweg	2002	0.61	0.20	
Staverdense Beek, Uddel, Koningsweg	1999	0.52	0.20	
II (koningsweg)	1972	0.51	0.20	
Staverdense Beek, Staverdensewg	2010	0.6	0.20	
Staverdense Beek, Staverdensewg	2005	0.75	0.20	
Staverdense Beek, Staverdensewg	2002	0.67	0.20	
Staverdense Beek, Staverdensewg	1999	0.69	0.20	
III benedenbeek	1972	0.69	0.20	
IV bovenbeek	1972	0.52	0.20	
Leuvenumse Beek, Leuvenum, O.Zwolseweg	2005	0.72	0.20	
Leuvenumse Beek, Leuvenum, O.Zwolseweg	2002	0.65	0.20	
Leuvenumse Beek, Leuvenum, O.Zwolseweg	1999	0.62	0.20	
V (Zwolsebrug)	1972	0.50	0.20	
VI (zandmolen)	1972	0.6	0.60	
Hierdense beek Heineken traject	2005	0.75	0.79	
Hierdense beek Heineken traject	2002	0.72	0.79	
Hierdense beek Heineken traject	1999	0.72	0.79	
Hierdense beek controle	2005	0.69		
Hierdense beek controle	2002	0.72		
Hierdense beek controle	1999	0.68		
VII (pre-controle)	1973	0.61		
Hierdense beek controle	2010	0.72		
Hierdense beek controle	2009	0.64		
Hierdense beek controle	2005	0.65		
Hierdense beek controle	2002	0.705		
Hierdense beek controle	1999	0.64		
Hierdense beek hierden Waterweg	2010	0.69	0.20	Management, silt > 70%, low CPOM
Hierdense beek hierden Waterweg	2005	0.54	0.20	Management, silt > 70%, low CPOM
Hierdense beek hierden Waterweg	1991	0.46	0.20	Management, silt > 70%, low CPOM
Hierdense beek hierden Waterweg	1990	0.49	0.20	Management, silt > 70%, low CPOM
Hierdense beek hierden Waterweg	1989	0.61	0.20	Management, silt > 70%, low CPOM
Hierdense beek hierden Waterweg	1988	0.51	0.20	Management, silt > 70%, low CPOM
Hierdense beek hierden Waterweg	1987	0.58	0.20	Management, silt > 70%, low CPOM
Hierdense beek hierden Waterweg	1986	0.55	0.20	Management, silt > 70%, low CPOM
Hierdense beek hierden Waterweg	1985	0.57	0.20	Management, silt > 70%, low CPOM
Hierdense beek hierden Waterweg	1984	0.67	0.20	Management, silt > 70%, low CPOM
Hierdense beek hierden Waterweg	1983	0.57	0.20	Management, silt > 70%, low CPOM
XI (waterweg)	1973	0.51	0.20	Management, silt > 70%, low CPOM

Second



MMI	Model Prediction
0.48	
0.49	0.40
0.59	0.60
0.63	0.20
0.61	0.20
0.52	0.20
0.51	0.20
0.60	0.40
0.75	0.40
0.67	0.40
0.69	0.40
0.69	0.40
0.52	0.59
0.72	0.20
0.65	0.20
0.62	0.20
0.50	0.20
0.60	0.60
0.75	1.00
0.72	0.98
0.72	0.80
0.69	1.00
0.72	0.98
0.68	0.80
0.61	
0.72	1.00
0.64	0.60
0.65	1.00
0.71	0.98
0.64	0.60
0.69	0.20
0.54	0.20
0.46	0.20
0.49	0.20
0.61	0.20
0.51	0.20
0.58	0.20
0.55	0.20
0.57	0.20
0.67	0.20
0.57	0.20
0.51	0.20

Third



MMI	Model Prediction
0.48	
0.49	0.40
0.59	0.60
0.63	0.20
0.61	0.20
0.52	0.20
0.51	0.20
0.60	0.40
0.75	0.40
0.67	0.40
0.69	0.40
0.69	0.40
0.52	0.59
0.72	0.20
0.65	0.20
0.62	0.20
0.50	0.20
0.60	0.60
0.75	1.00
0.72	0.98
0.72	0.80
0.69	1.00
0.72	0.98
0.68	0.80
0.61	
0.72	1.00
0.64	0.60
0.65	1.00
0.71	0.98
0.64	0.60
0.69	0.20
0.54	0.20
0.46	0.20
0.49	0.20
0.61	0.20
0.51	0.20
0.58	0.20
0.55	0.20
0.57	0.20
0.67	0.20
0.57	0.20
0.51	0.20

Testing (2)

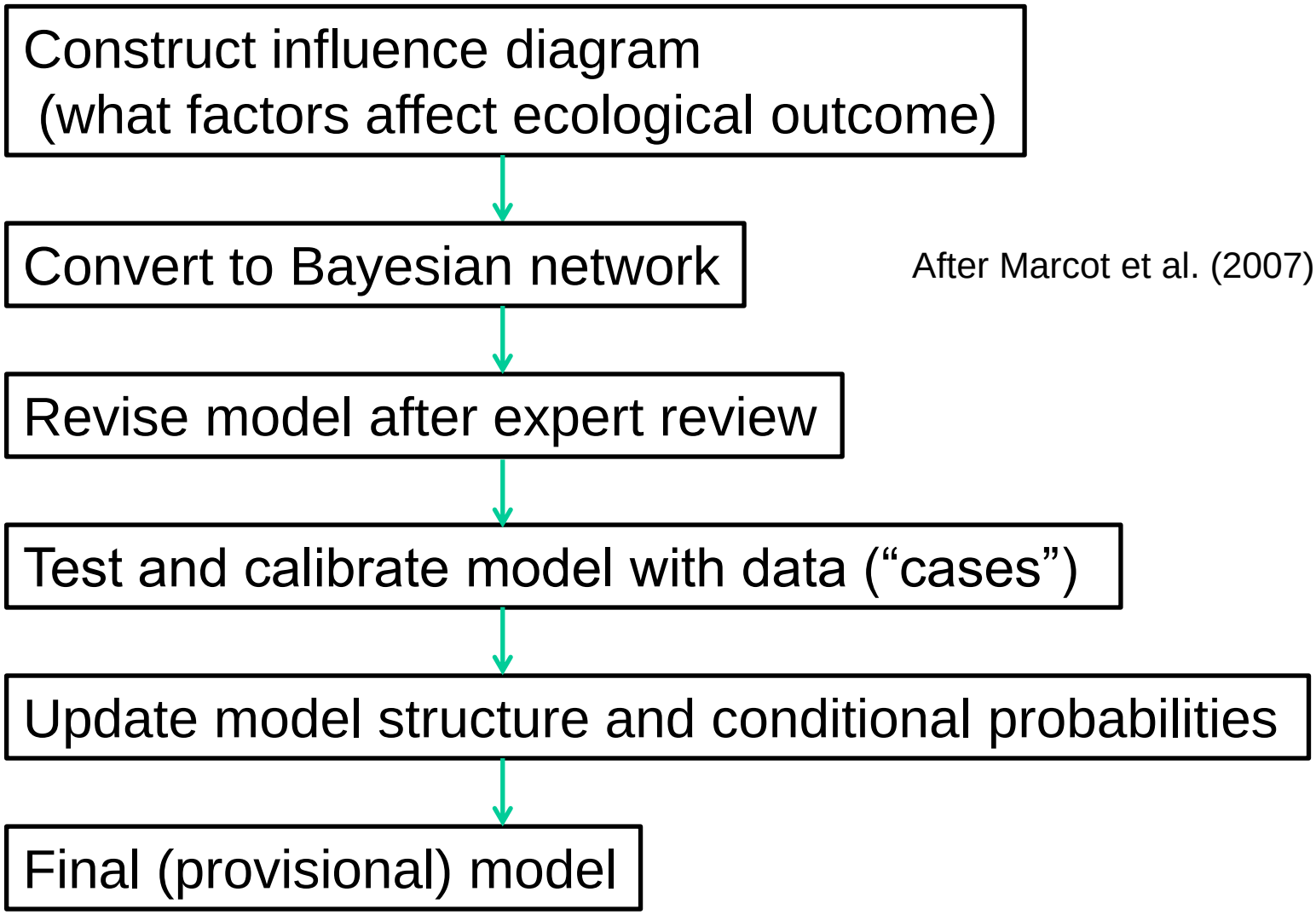
Model still a bit too stringent, particularly with CPOM

Problem may lie in interactions

Many model nodes interact – but the final 5 only interact in the sense that the model takes the worst case for every WFD class.

Maybe a good score on some attributes should compensate for a poor score in others – to some extent

Where Are We?



After Marcot et al. (2007)

Interactions

Interactions occur within the model.

The final 5 variables only interact in the sense that the model takes the worst WFD class for each one.

BBNs in REFRESH

Norway - See poster by Jannicke Moe;
Riparian wetlands in the UK;
Aquatic macrophytes in the Louros River, Greece;
Aquatic macroinvertebrates in Dutch forest streams.

Next Steps

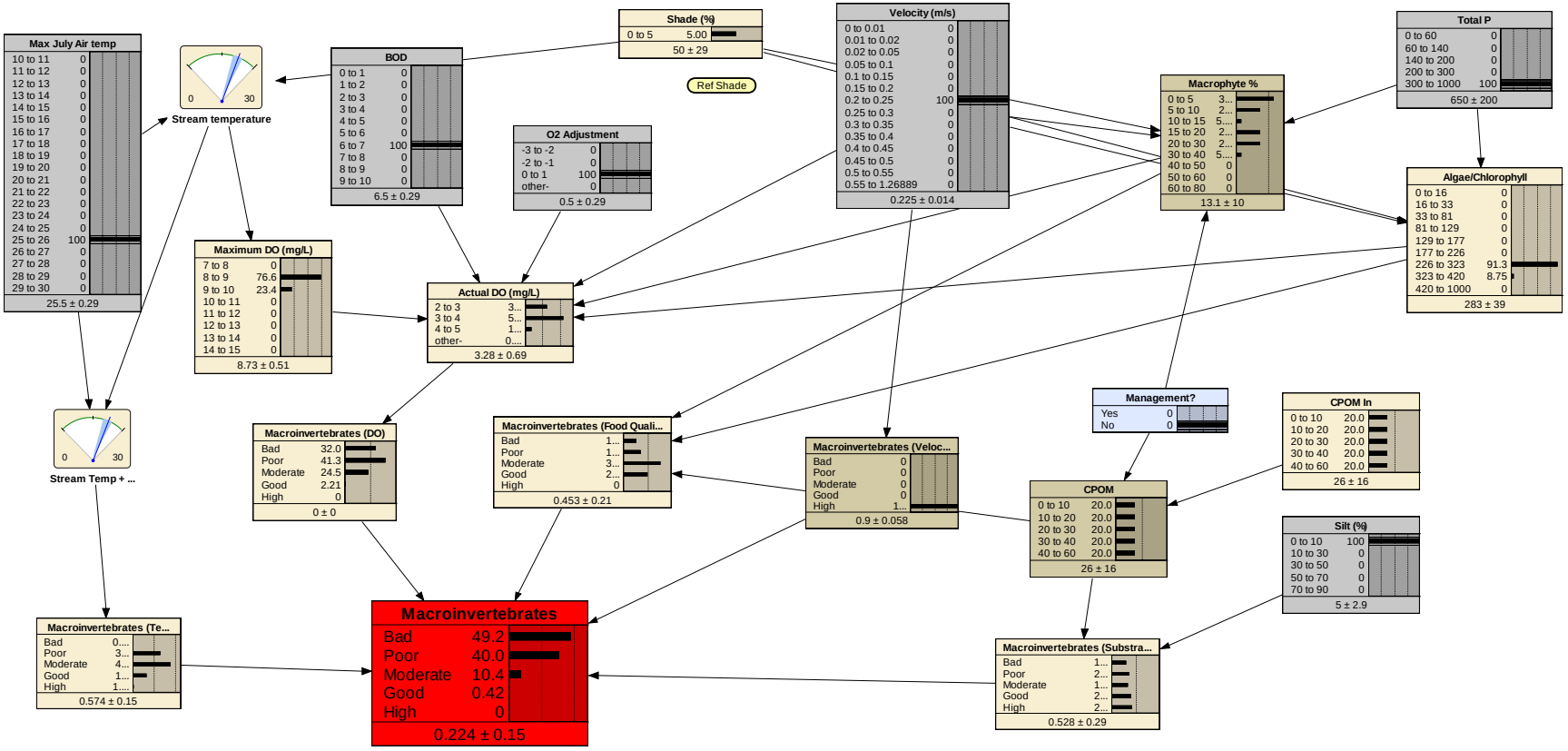
The network produces some intuitively reasonable answers

So far, it is not particularly “Bayesian”

Once a bit happier with the structure – perform a Bayesian updating using the data – i.e. Let the model “learn”.

Then looking to apply elsewhere.

Example Net


Max July Air temp
10 to 11 0
11 to 12 0
12 to 13 0
13 to 14 0
14 to 15 0
15 to 16 0
16 to 17 0
17 to 18 0
18 to 19 0
19 to 20 0
20 to 21 0
21 to 22 0
22 to 23 0
23 to 24 0
24 to 25 0
25 to 26 100
26 to 27 0
27 to 28 0
28 to 29 0
29 to 30 0
25.5 ± 0.29
Stream temperature
0
30
BOD
0 to 1 0
1 to 2 0
2 to 3 0
3 to 4 0
4 to 5 0
5 to 6 0
6 to 7 100
7 to 8 0
8 to 9 0
9 to 10 0
6.5 ± 0.29
Shade (%)
0 to 5 5.00
50 ± 29
Ref Shade
O2 Adjustment
-3 to -2 0
-2 to -1 0
0 to 1 100
other- 0
0.5 ± 0.29
Velocity (m/s)
0 to 0.01 0
0.01 to 0.02 0
0.02 to 0.05 0
0.05 to 0.1 0
0.1 to 0.15 0
0.15 to 0.2 0
0.2 to 0.25 100
0.25 to 0.3 0
0.3 to 0.35 0
0.35 to 0.4 0
0.4 to 0.45 0
0.45 to 0.5 0
0.5 to 0.55 0
0.55 to 1.26889 0
0.225 ± 0.014
Macrophyte %
0 to 5 3...
5 to 10 2...
10 to 15 5...
15 to 20 2...
20 to 30 2...
30 to 40 5...
40 to 50 0
50 to 60 0
60 to 80 0
13.1 ± 10
Total P
0 to 60 0
60 to 140 0
140 to 200 0
200 to 300 0
300 to 1000 100
650 ± 200
Algae/Chlorophyll
0 to 16 0
16 to 33 0
33 to 81 0
81 to 129 0
129 to 177 0
177 to 226 0
226 to 323 91.3
323 to 420 8.75
420 to 1000 0
283 ± 39
Maximum DO (mg/L)
7 to 8 0
8 to 9 76.6
9 to 10 23.4
10 to 11 0
11 to 12 0
12 to 13 0
13 to 14 0
14 to 15 0
8.73 ± 0.51
Actual DO (mg/L)
2 to 3 3...
3 to 4 5...
4 to 5 1...
other- 0...
3.28 ± 0.69
Stream Temp + ...
0
30
Macroinvertebrates (DO)
Bad 32.0
Poor 41.3
Moderate 24.5
Good 2.21
High 0
0 ± 0
Macroinvertebrates (Food Quali...
Bad 1...
Poor 1...
Moderate 3...
Good 2...
High 0
0.453 ± 0.21
Macroinvertebrates (Veloc...
Bad 0
Poor 0
Moderate 0
Good 0
High 1...
0.9 ± 0.058
Management?
Yes 0
No 0
CPOM In
0 to 10 20.0
10 to 20 20.0
20 to 30 20.0
30 to 40 20.0
40 to 60 20.0
26 ± 16
CPOM
0 to 10 20.0
10 to 20 20.0
20 to 30 20.0
30 to 40 20.0
40 to 60 20.0
26 ± 16
Silt (%)
0 to 10 100
10 to 30 0
30 to 50 0
50 to 70 0
70 to 90 0
5 ± 2.9
Macroinvertebrates (Te...
Bad 0....
Poor 3...
Moderate 4...
Good 1...
High 1....
0.574 ± 0.15
Macroinvertebrates
Bad 49.2
Poor 40.0
Moderate 10.4
Good 0.42
High 0
0.224 ± 0.15
Macroinvertebrates (Substra...
Bad 1...
Poor 2...
Moderate 1...
Good 2...
High 2...
0.528 ± 0.29

What affects stream macroinvertebrates?