INTEGRATING DIVERSE DATA IN A WHOLE-OF-SYSTEMS MODEL

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Complex Systems

Many different parts

Complex interactions and emergent behaviour

Uncertainty and surprises

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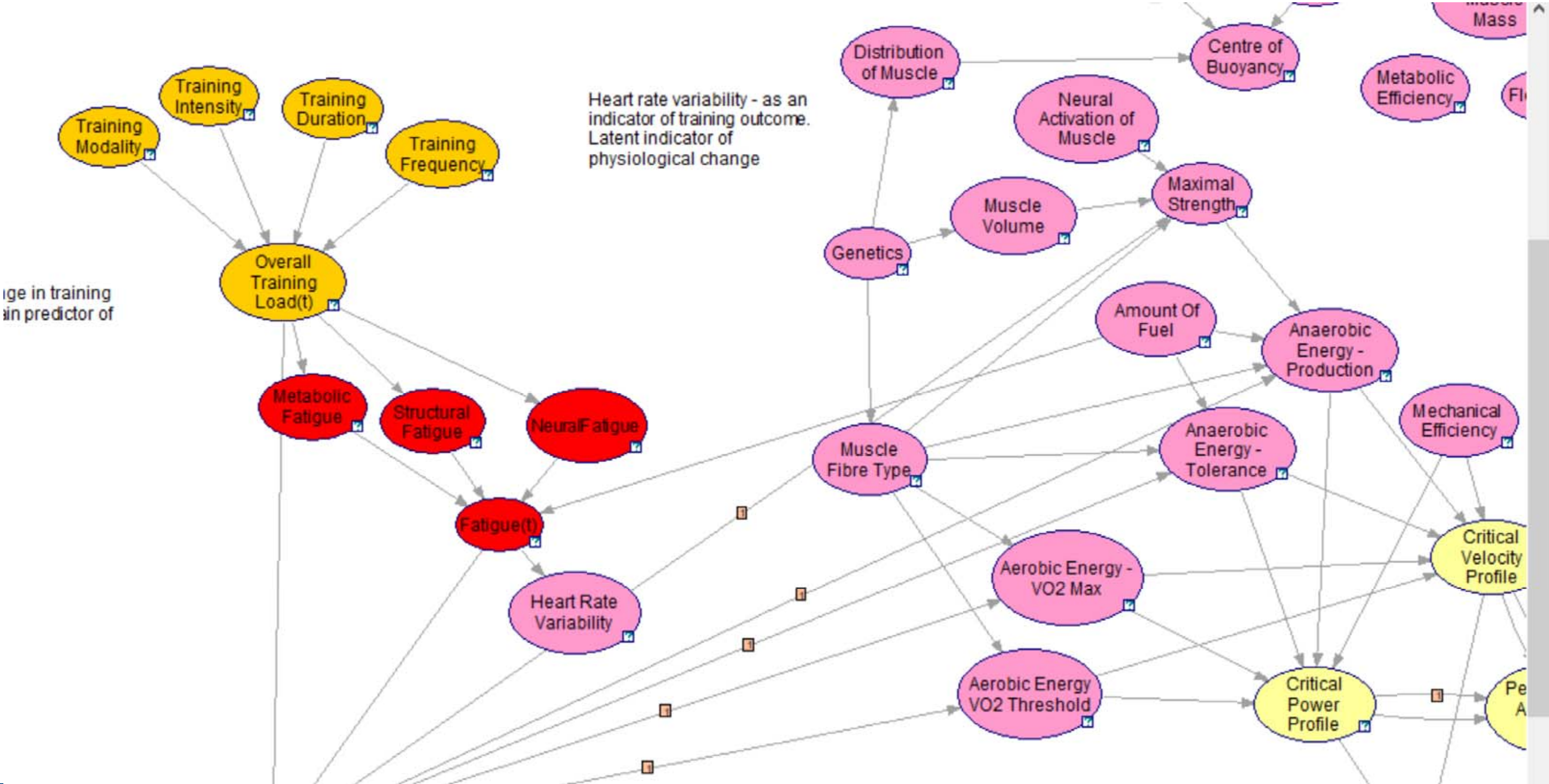
How Do We Make a Whole-of-System Model?



Available Sources of Data

- Types of Data
  - Experimental studies
  - Observational studies
  - Expert knowledge
- Scales of data
  - Spatial scales
  - Time scales

Hierarchical Models

- Response – shoot density, biomass, growth, physiological status
  - Covariates of: level of stress (light shading), duration of stress, time of season, time since stress
  - Multinomial response of high, moderate, low, zero states
  - Modelled using Bayesian framework

Learning Components of the Model

$$\log(Y_{i,j}) \sim \mathcal{M}(p_{i,j}, n_i)$$

$$p_{i,j} = \frac{b_{i,j}}{\sum_j b_{i,j}}$$

$$b_{i,j} = \beta_{0j} + \beta_{1j} t_s + t_d \left(\beta_{2j} x_m w_3 + \beta_{3j} x_m w_6 + \beta_{4j} x_h w_9\right) +$$

$$\beta_{5j} x_m w_6 + \beta_{6j} w_6 + \beta_{7j} w_9$$

$$\beta_{kj} \sim \mathcal{N}(\mu_{\beta_k}, \sigma^2_{\beta_k}), k = 0, 1, ..., 7. j = 1, 2$$

$$\beta_{k4} = 0, k = 0, 1, ..., 7$$

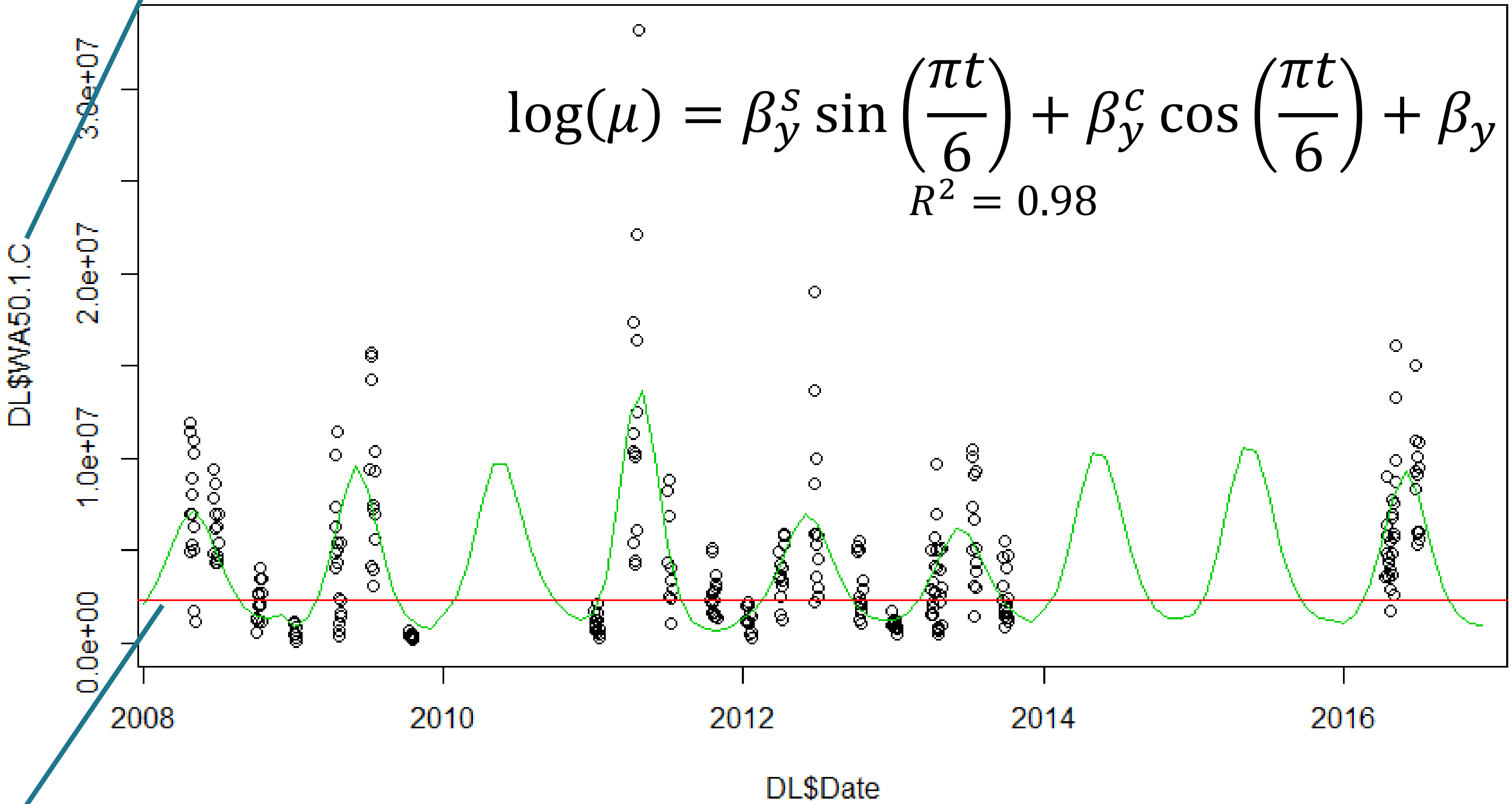
$$\beta_{k3} \sim \mathcal{N}(0, 0.001), k = 0, 1, ..., 7$$

$$\mu_{\beta_k} \sim \mathcal{N}(0, 0.001), k = 0, 1, ..., 7$$

$$\sigma_{\beta_k} \sim \mathcal{U}(0, 100), k = 0, 1, ..., 7$$

Light

Log(Mols of photons/m2/day)

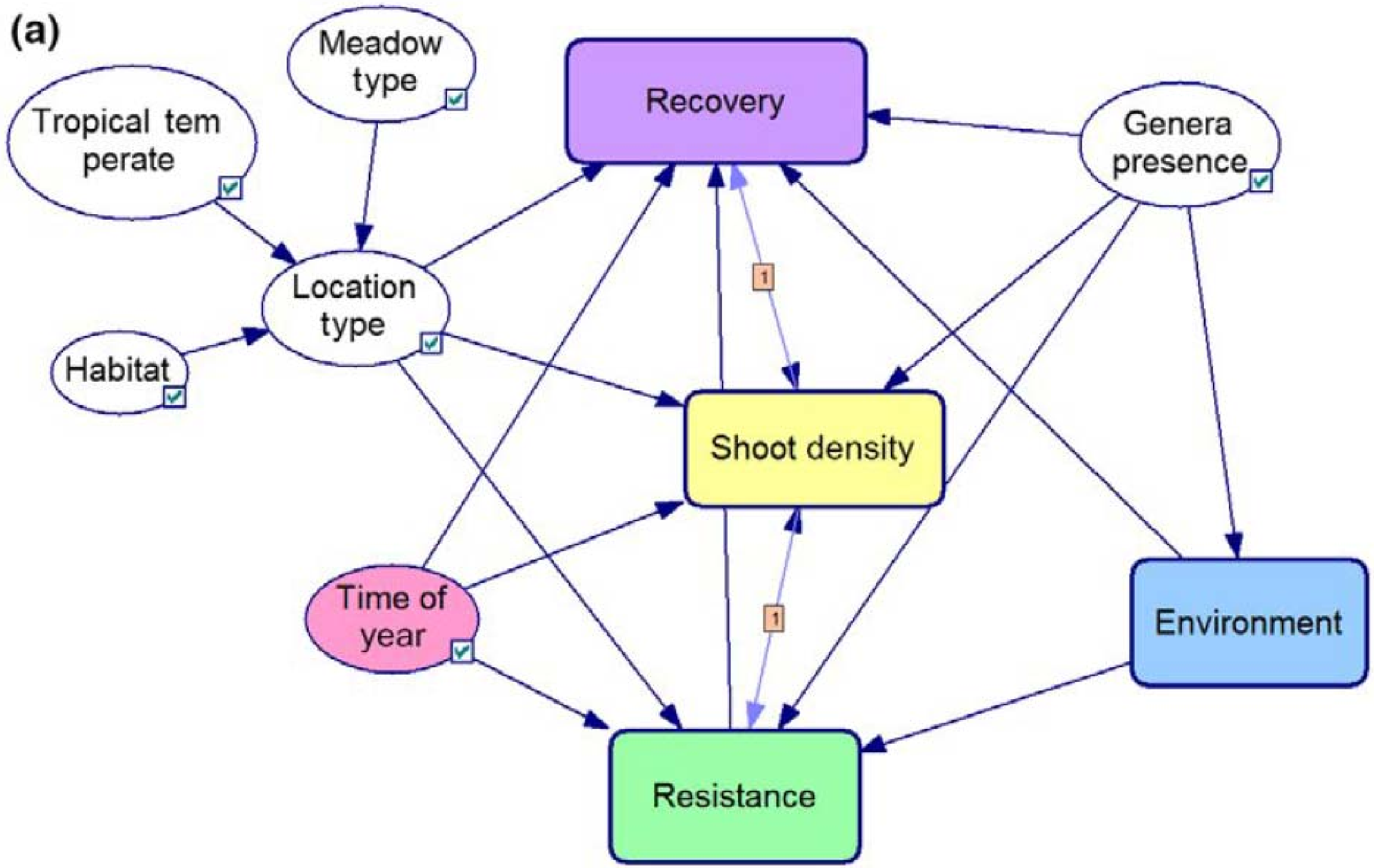


$$\log(\mu) = \beta_y^s \sin\left(\frac{\pi t}{6}\right) + \beta_y^c \cos\left(\frac{\pi t}{6}\right) + \beta_y$$

$R^2 = 0.98$

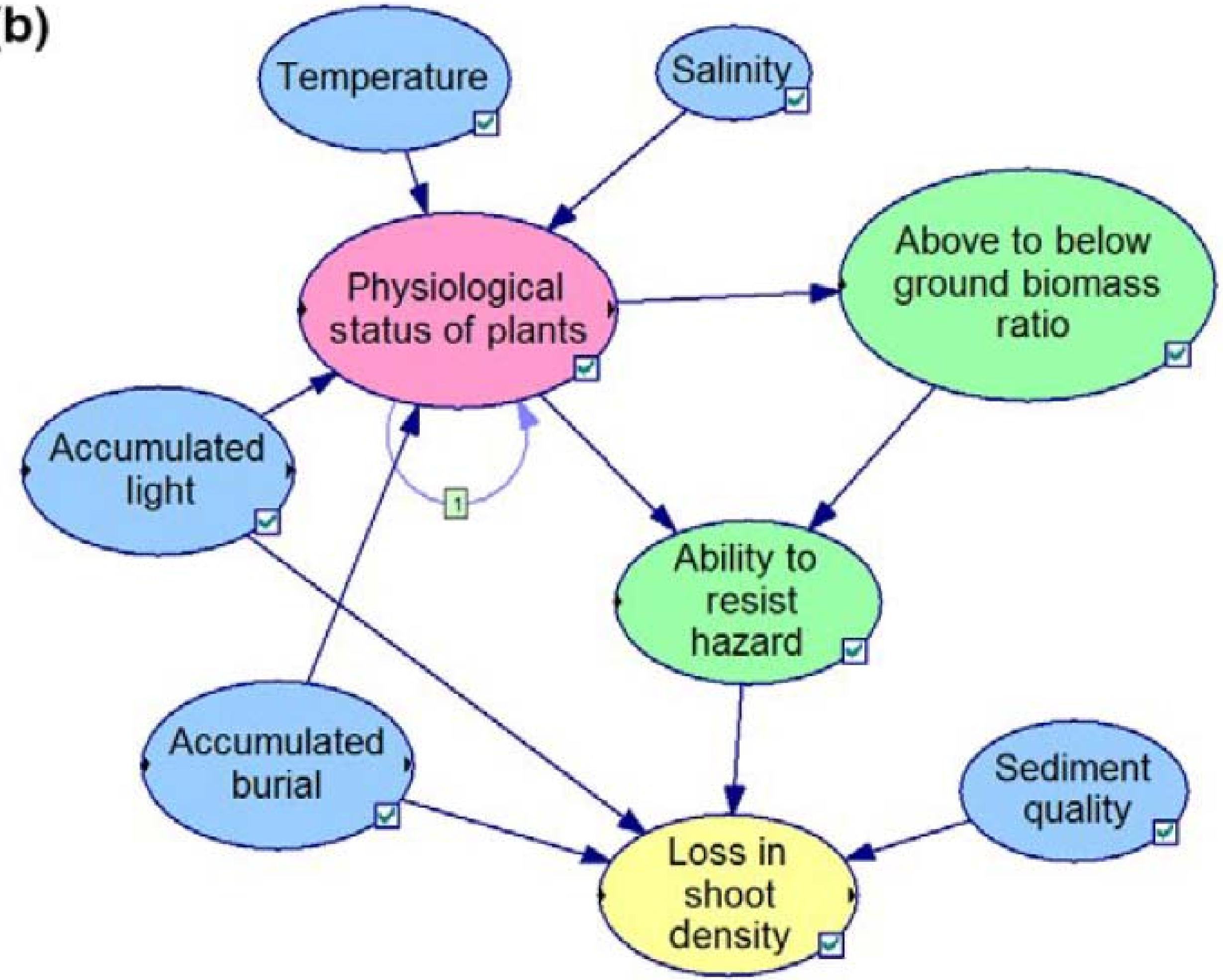
Saturation threshold

Bringing It Together

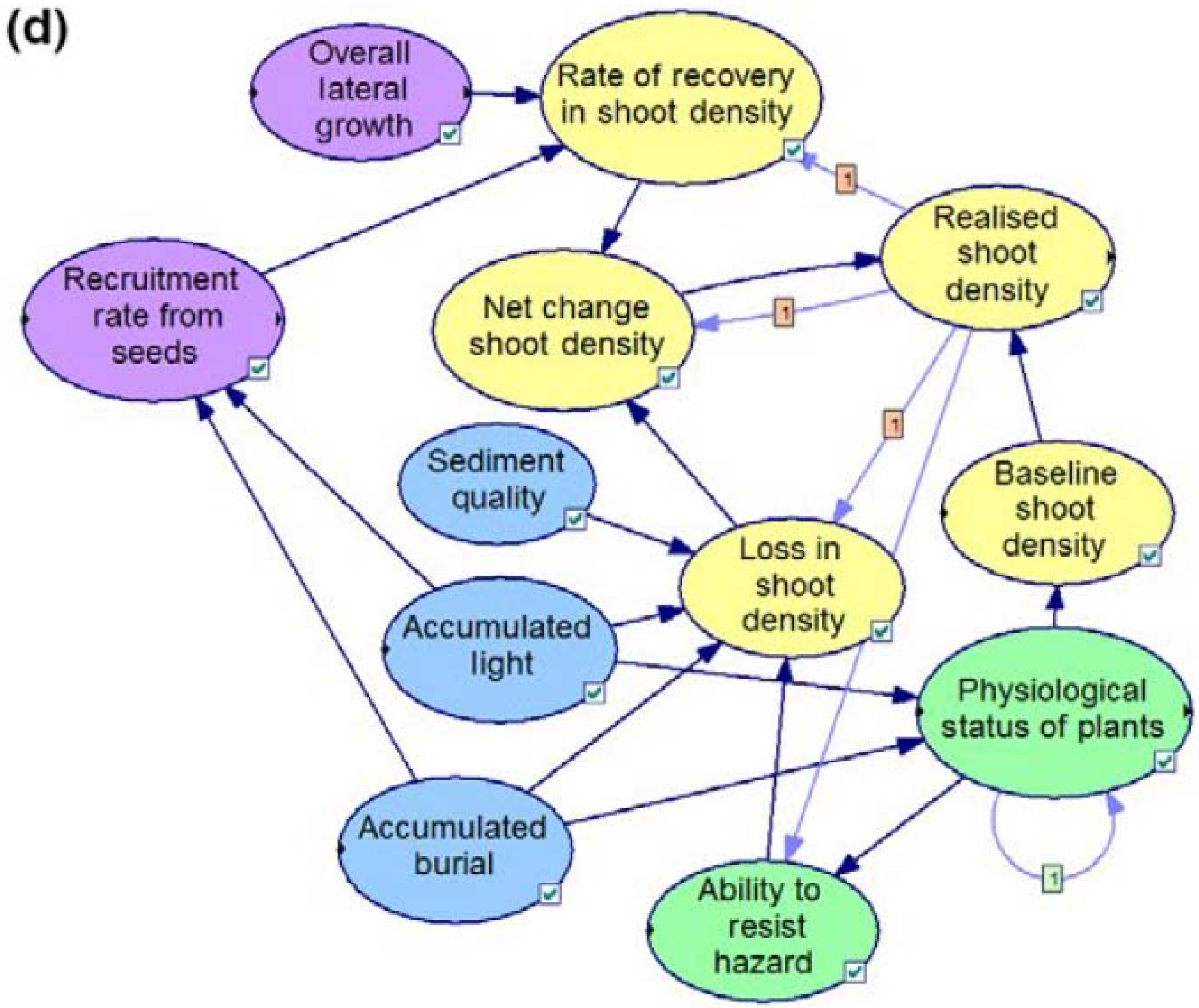


Bringing It Together

(b)



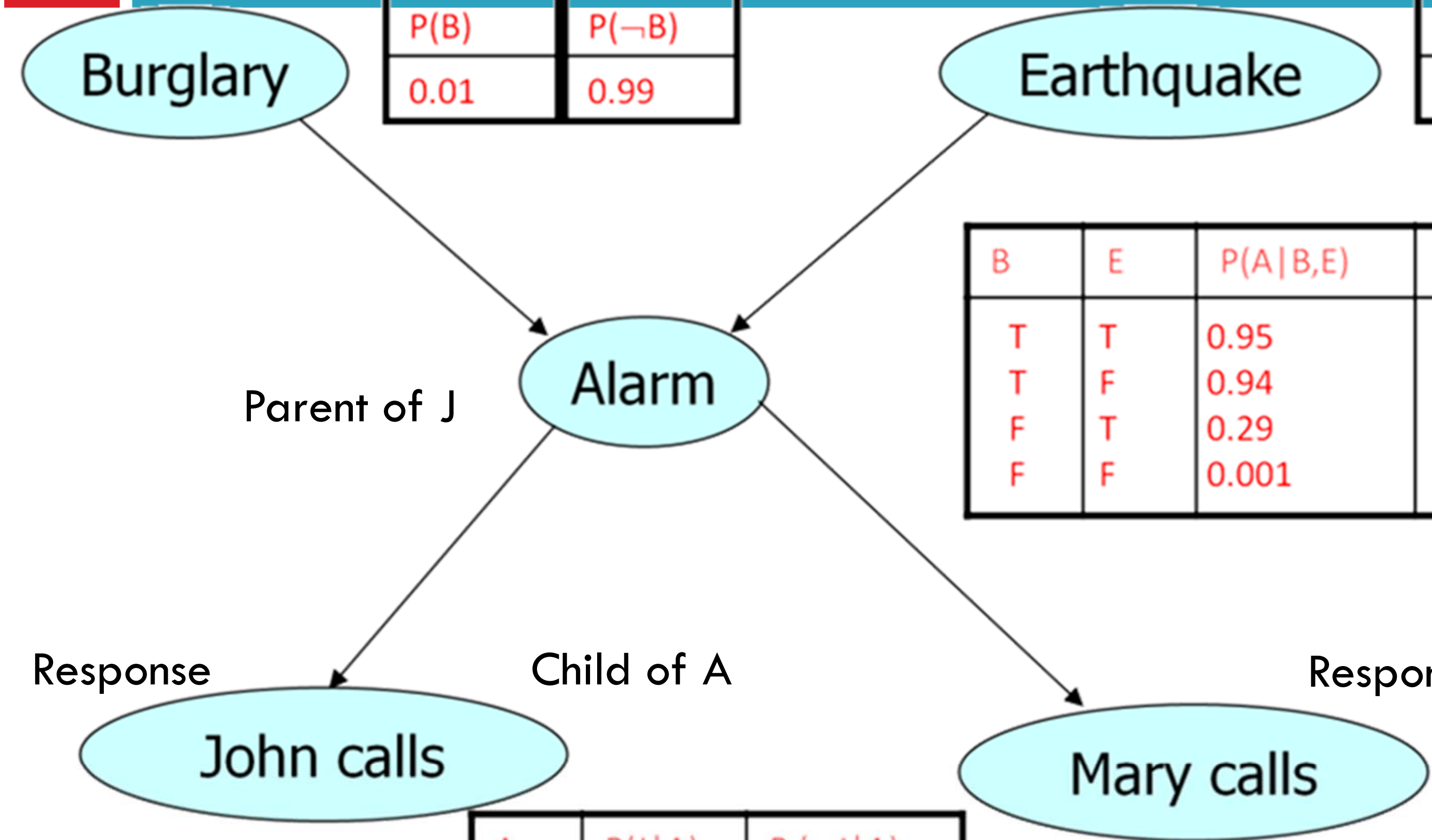
Bringing It Together



Dynamic Bayesian Networks

- Generalised form of Hidden Markov Models (HMMs), Kalman filters
- Model complex systems
- Parameterised by nodes = variables and their parents, node states, and conditional probabilities = relationship between nodes

BN Inference



P(B)	P(¬B)
0.01	0.99

P(E)	P(¬E)
0.02	0.98

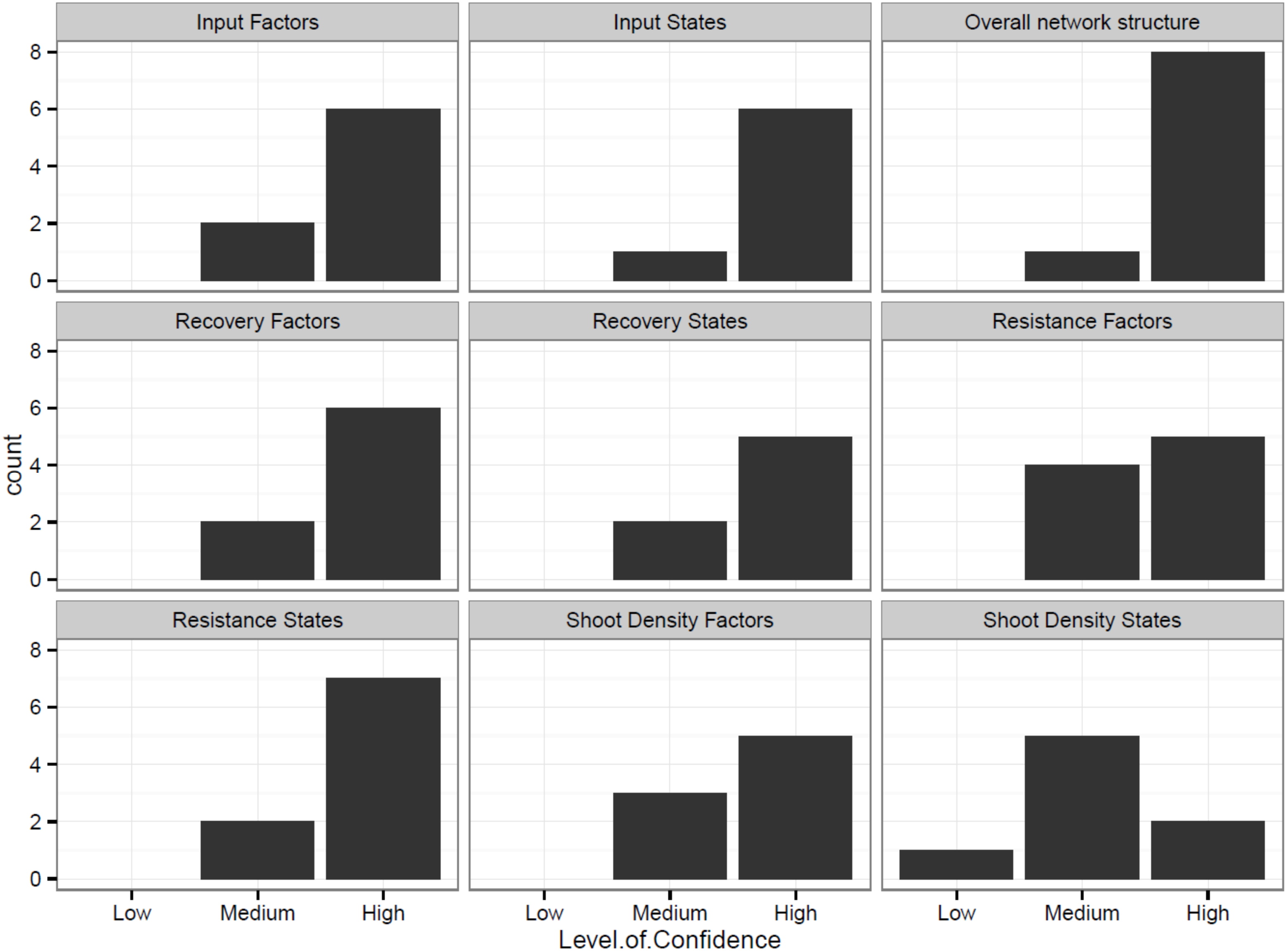
B	E	P(A|B,E)	P (¬A |B,E)
T	T	0.95	0.05
T	F	0.94	0.06
F	T	0.29	0.71
F	F	0.001	0.999

A	P(J|A)	P (¬J|A)
T	0.90	0.10
F	0.05	0.95

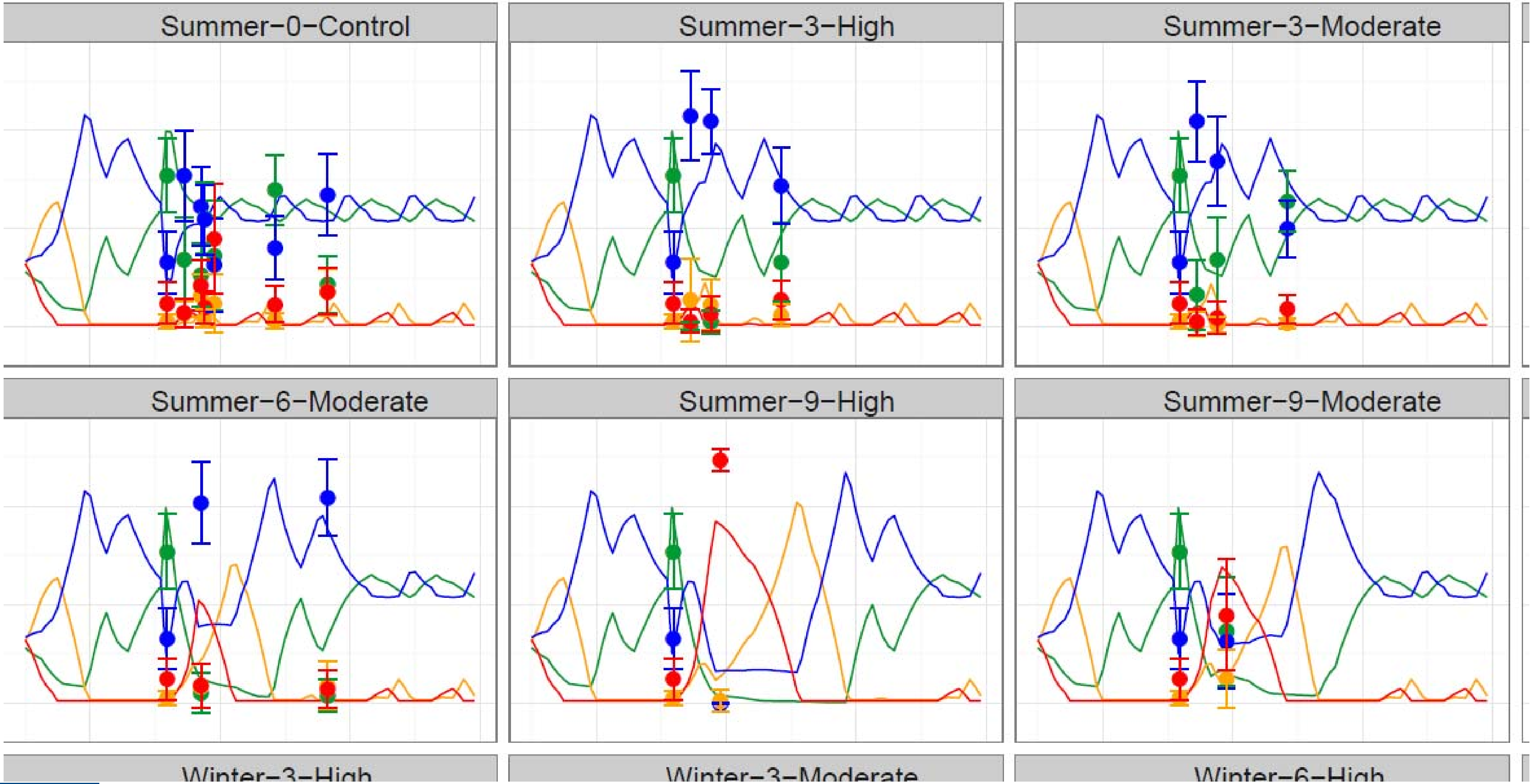
A	P(M|A)	P (¬M|A)
T	0.70	0.30
F	0.01	0.99

Forwards and backwards!

Expert Validation



Experimental Validation



Seagrass Empirical Validation

	Mean Squared Error in State Probability			
Site	**Shoot Density**	**Biomass**	**Growth**	**Physiological Status**
Jurien Bay, Amphibolis (McMahon, 2011)	0.02	0.04	0.016	0.05
Hay Point, Halophila, (York, 2015)	NA	0.004	NA	NA
Salt River Canyon, Halophila, (Williams, 1988)	NA	0.059	NA	NA
Gladstone, Zostera, (Chartrand, 2016)	NA	0.03	0.026	NA
Akkeshi Bay, Zostera, (Watanabe, 2005)	0.033	NA	0.032	NA
Puget Sound, *Zostera*, (Jeffrey Gaeckle)	0.055	NA	NA	NA

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Whole-of-Systems Modelling

- Complex systems
  - E.g. biology, ecology, the Internet, critical infrastructure
  - Characterised by:
    - Complex interactions and interdepencies
    - Large #components
    - Multi-stakeholder, social and regulatory