Society for Risk Analysis Conference

Australia and New Zealand Chapters

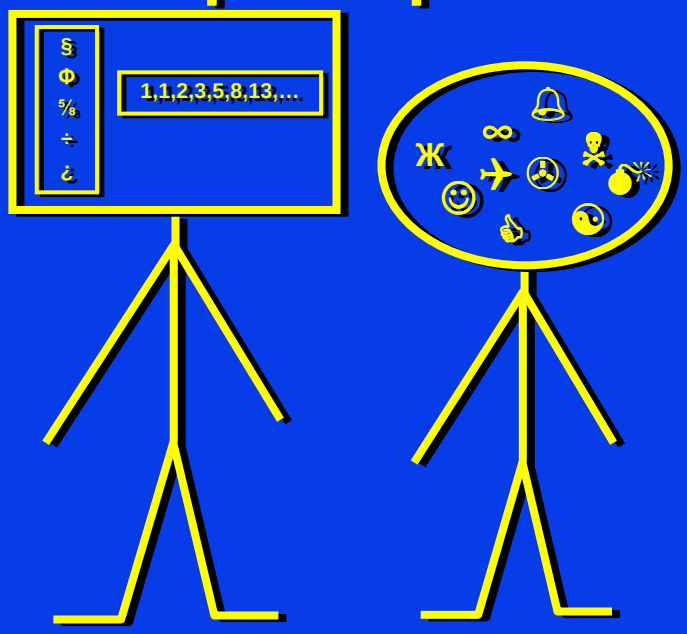
July 19, 2006 University of Melbourne

Qualitative Modelling of Complex Biological and Social Systems

Jeffrey Dambacher
Geoff Hosack
Keith Hayes

Marine and Atmospheric Research

Expert Opinion



[Model]

[Parameters]

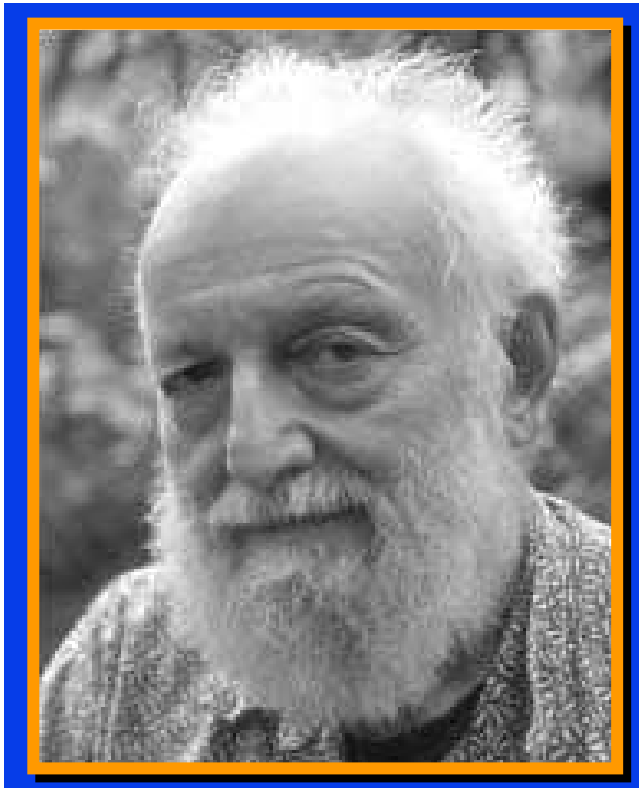
Experts

Stakeholders

Risk = [Probability] x Consequence

Uncertainty

- parametric emphasis
- conceptual framework of experts
- model structure largely ignored
- stakeholder participation and trust



"...our truth is the intersection of independent lies."

Richard Levins

QUALITATIVE MODELS

PRECISION

GENERALITY REALISM

PRECISION

GENERALITY REALISM

PRECISION

GENERALITY REALISM

STATISTICAL MODELS

MECHANISTIC MODELS

LEVINS 1966

$$\frac{dN_1}{dt} \equiv N_1\left(\text{birth} - \alpha_{1,2} N_2\right)$$

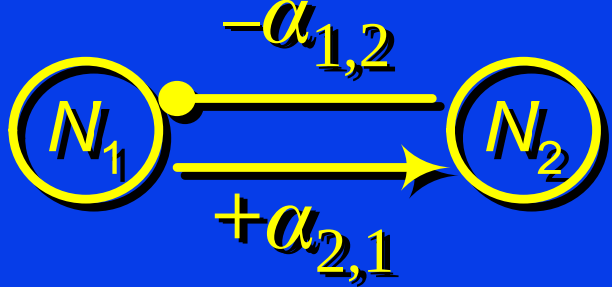
$$\frac{dN_2}{dt} \equiv N_2\left(+\alpha_{2,1} N_1 - \text{death}\right)$$

COMMUNITY MATRIX

$$\begin{bmatrix} 0 & -\alpha_{1,2} \\ +\alpha_{2,1} & 0 \end{bmatrix}$$

***LEVINS* 1968**

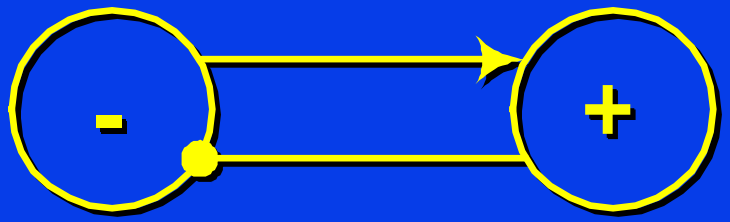
SIGNED DIGRAPH



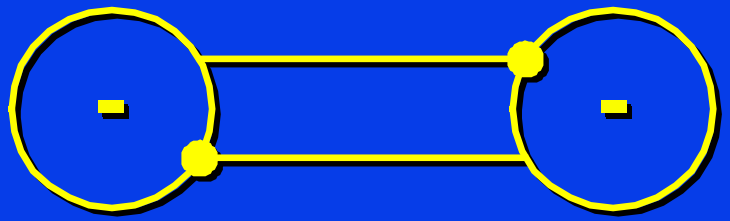
***LEVINS* 1974**

Signed Digraphs

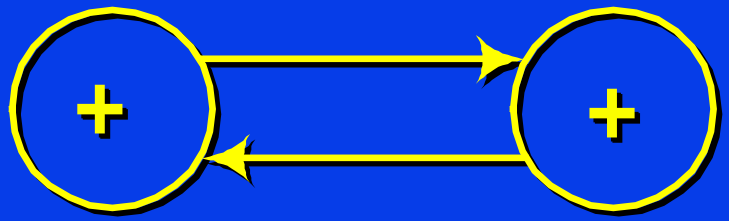
Predator-Prey



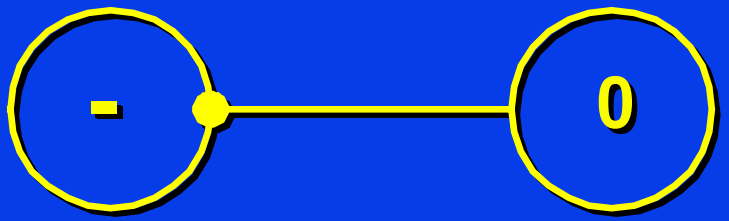
Competition



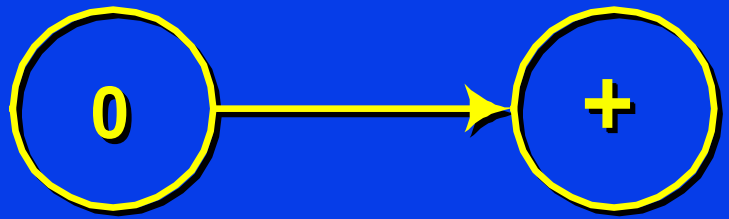
Mutualism



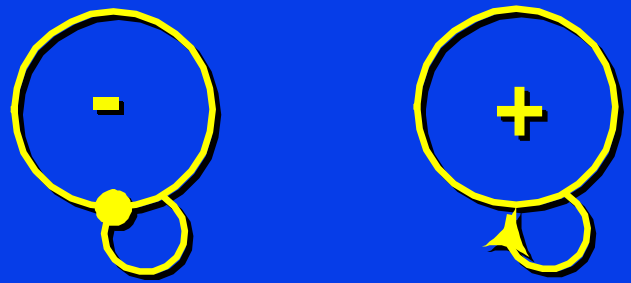
Amensalism



Commensalism



Self-effect



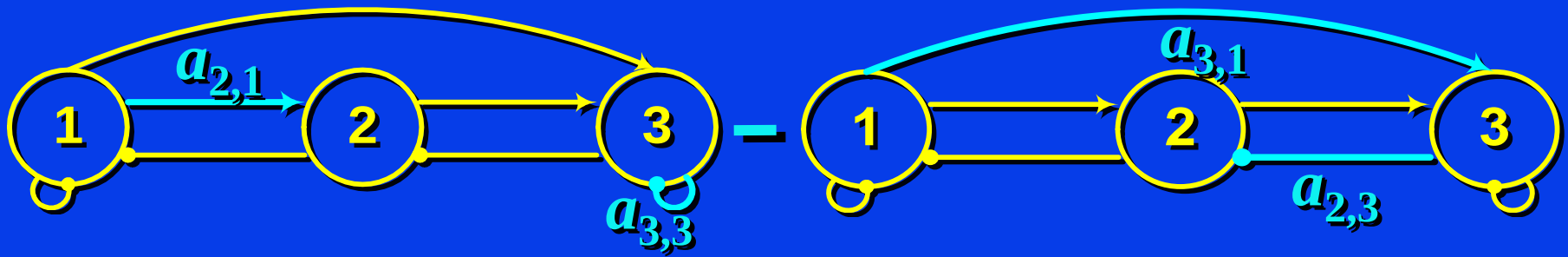
Press Perturbations

$$\frac{\mathrm{d}N_i}{\mathrm{d}t} = N_i\left(\sum_j \alpha_{ij} N_j + \beta_i - \delta_i + \iota_i - \varepsilon_i\right) \qquad (i = 1, \ldots, n)$$

$$\frac{d\mathbf{N}^*}{dp_h} = -\mathbf{A}^{-1}\frac{\partial\left(\frac{d\mathbf{N}}{dt}\right)}{\partial p_h}$$

$$-\mathbf{A}^{-1} = \frac{\text{adjoint}(-\mathbf{A})}{\text{determinant}(-\mathbf{A})} = \frac{\begin{bmatrix} a_{2,3}\,a_{3,2} & -a_{1,2}\,a_{3,3} & a_{1,2}\,a_{2,3} \\ a_{2,1}\,a_{3,3} - a_{2,3}\,a_{3,1} & a_{1,1}\,a_{3,3} & -a_{1,1}\,a_{2,3} \\ a_{2,1}\,a_{3,2} & a_{1,1}\,a_{3,2} - a_{1,2}\,a_{3,1} & a_{1,2}\,a_{2,1} \end{bmatrix}}{+a_{1,1}\,a_{2,3}\,a_{3,2} + a_{3,3}\,a_{1,2}\,a_{2,1} - a_{1,2}\,a_{2,3}\,a_{3,1}}$$

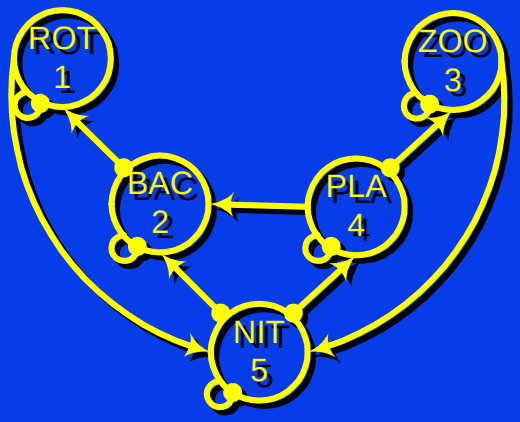
Effect to 2 from positive input to 1



$$+ a_{1,1}\,a_{2,3}\,a_{3,2} + a_{3,3}\,a_{1,2}\,a_{2,1} - a_{1,2}\,a_{2,3}\,a_{3,1}$$

Plankton community model

STONE 1990



Plausible interaction strengths

$$\mathbf{A} = \begin{pmatrix} -1 & .6 & 0 & 0 & 0 \\ -.6 & -1 & 0 & .1 & .6 \\ 0 & 0 & -1 & .2 & 0 \\ 0 & 0 & -.2 & -1 & .5 \\ .6 & -.6 & .2 & -.5 & -1 \end{pmatrix}$$

Quantitative prediction

$$-\mathbf{A}^{-1} = \begin{pmatrix} 0.9 & 0.4 & 0.05 & -0.06 & 0.2 \\ -0.2 & 0.7 & 0.09 & -0.09 & 0.4 \\ 0.05 & -0.01 & 1.0 & 0.2 & 0.07 \\ 0.2 & -0.06 & -0.09 & 0.8 & 0.4 \\ 0.5 & -0.1 & 0.2 & -0.3 & 0.7 \end{pmatrix}$$

Qualitative prediction

$$\text{adjoint}(-\mathbf{A}) = \begin{pmatrix} 5 & 2 & 2 & 1 & 3 \\ 1 & 2 & 2 & 1 & 3 \\ 2 & 0 & 4 & 2 & 2 \\ 2 & 0 & 0 & 2 & 2 \\ 4 & 0 & 4 & 0 & 4 \end{pmatrix}$$

$$+\alpha_{22}\alpha_{33}\alpha_{44}\alpha_{55}+\alpha_{22}\alpha_{33}\alpha_{45}\alpha_{54}+\alpha_{22}\alpha_{43}\alpha_{34}\alpha_{55}+\alpha_{52}\alpha_{33}\alpha_{24}\alpha_{45}+\alpha_{52}\alpha_{33}\alpha_{25}\alpha_{44}+\alpha_{52}\alpha_{43}\alpha_{25}\alpha_{34}-\alpha_{22}\alpha_{53}\alpha_{34}\alpha_{45}$$

$$+\alpha_{21}\alpha_{53}\alpha_{34}\alpha_{45}+\alpha_{51}\alpha_{33}\alpha_{24}\alpha_{45}+\alpha_{51}\alpha_{33}\alpha_{25}\alpha_{44}+\alpha_{51}\alpha_{43}\alpha_{25}\alpha_{34}-\alpha_{21}\alpha_{33}\alpha_{44}\alpha_{55}-\alpha_{21}\alpha_{33}\alpha_{45}\alpha_{54}-\alpha_{21}\alpha_{43}\alpha_{34}\alpha_{55}$$

$$+\alpha_{21}\alpha_{52}\alpha_{34}\alpha_{45}+\alpha_{51}\alpha_{22}\alpha_{34}\alpha_{45}$$

$$+\alpha_{21}\alpha_{52}\alpha_{33}\alpha_{45}+\alpha_{51}\alpha_{22}\alpha_{33}\alpha_{45}$$

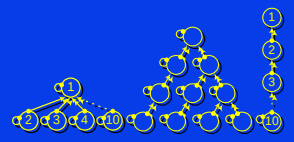
$$+\alpha_{21}\alpha_{52}\alpha_{33}\alpha_{44}+\alpha_{21}\alpha_{52}\alpha_{43}\alpha_{34}+\alpha_{51}\alpha_{22}\alpha_{33}\alpha_{44}+\alpha_{51}\alpha_{22}\alpha_{43}\alpha_{34}$$

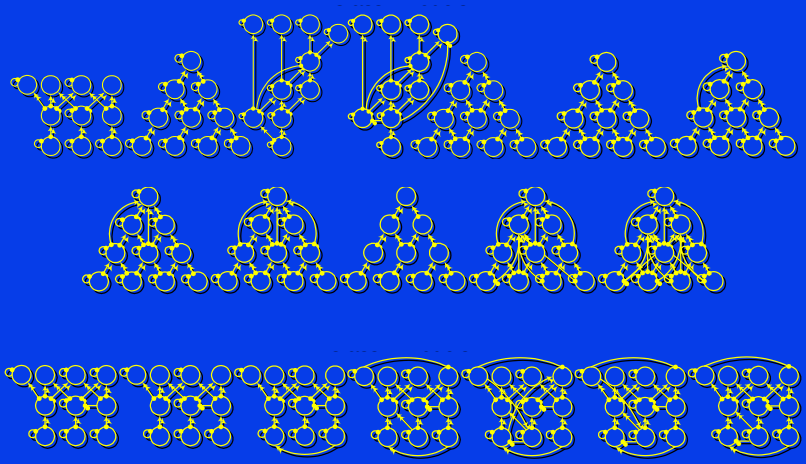
Adjoint matrix						Total Feedback Matrix						Weighted Predictions Matrix				
5	2	2	1	3	÷	7	4	4	3	3	=	0.7	0.5	0.5	0.3	1
1	2	2	1	3		7	4	4	3	3		0.1	0.5	0.5	0.3	1
2	0	4	2	2		2	2	8	4	2		1	0	0.50	0.5	1
2	0	0	2	2		2	2	6	4	2		1	0	0	0.5	1
4	0	4	0	4		4	4	6	6	4		1	0	0.7	0	1

Dambacher et al., 2002

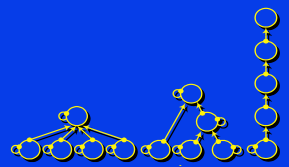
Simulation testing of prediction weights

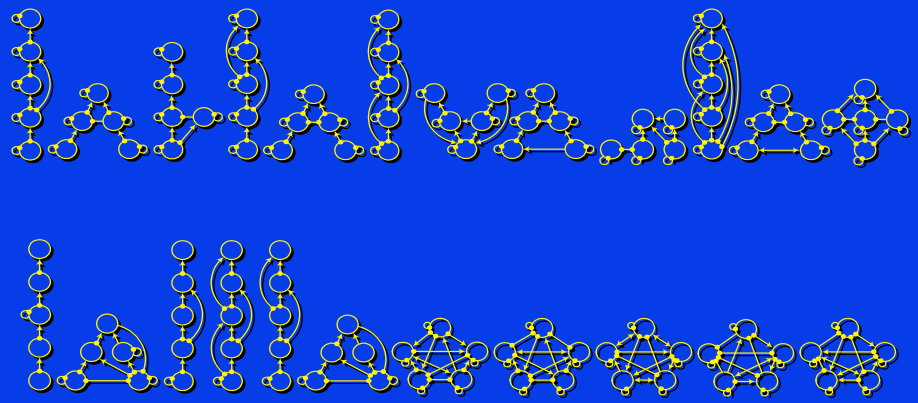
10-variable models



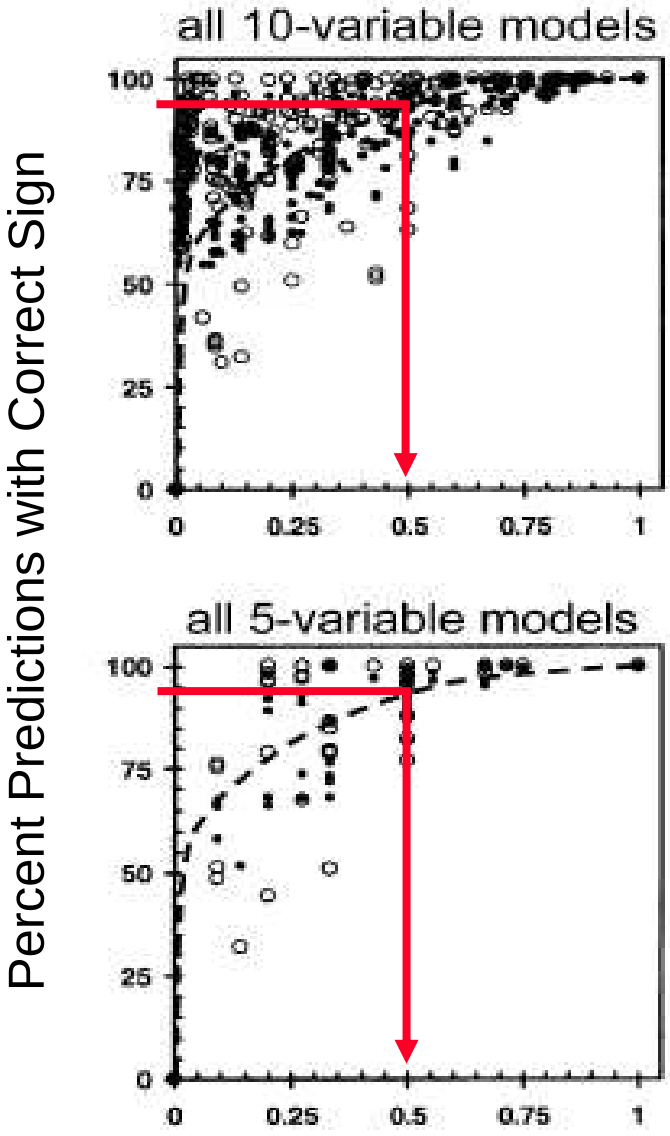


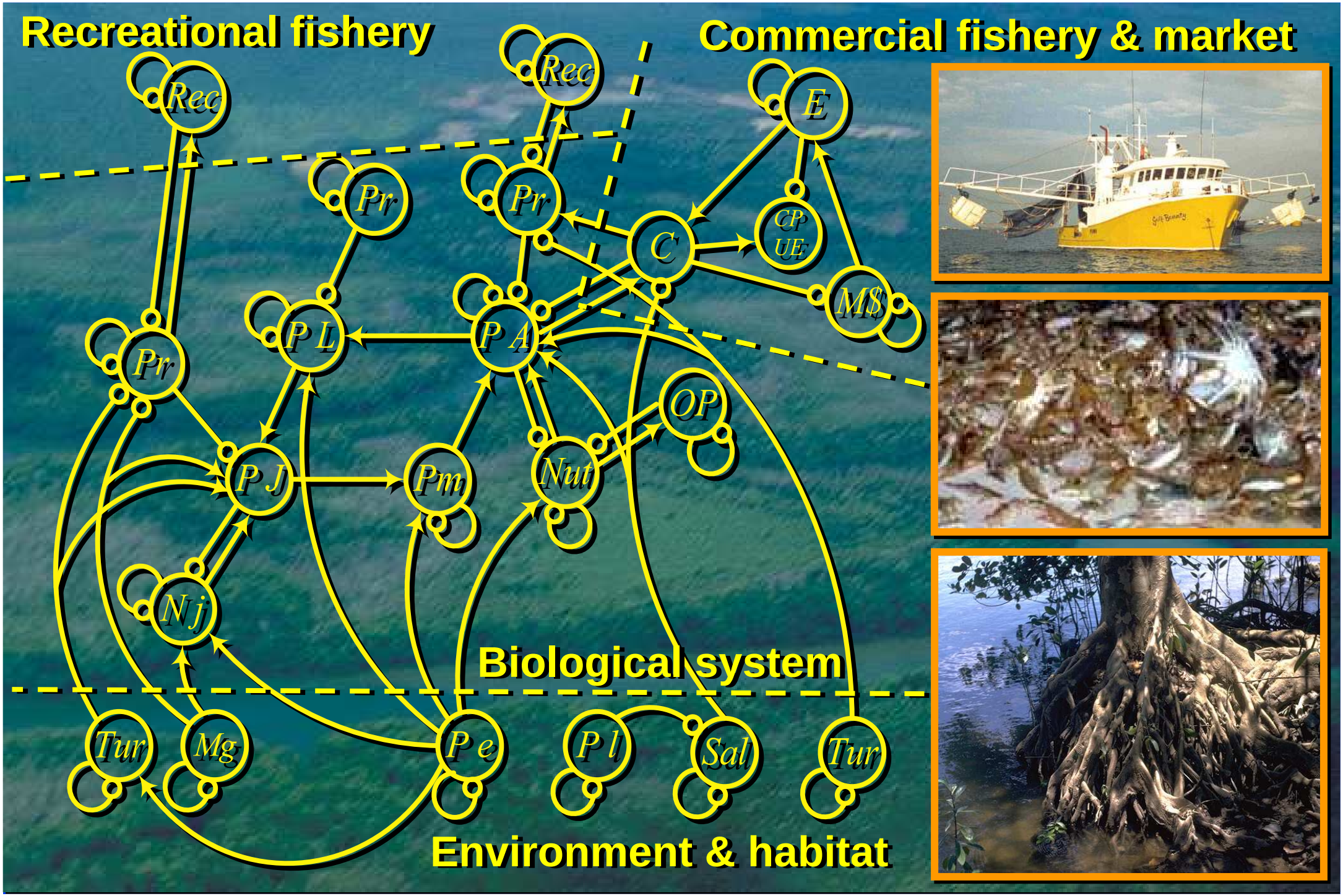
5-variable models





DAMBACHER ET AL. 2003




Recreational fishery
Commercial fishery & market
Rec
Rec
Pr
Pr
Pr
E
C
CP
UE
MS
P L
P A
Pr
OP
P J
Pm
Nut
Nj
Biological system
Tur
Mg
P e
P l
Sal
Tur
Environment & habitat

Qualitative models

- Rapid and inexpensive to develop
- Includes immeasurable variables & parameters
- Counterintuitive effects of system feedbacks.
- Elicitation of alternative causalities...
  via emphasis on model structure...
  therefore ideal for addressing model uncertainty.

Benguela Ecosystem: Effects of seal cull on hakes

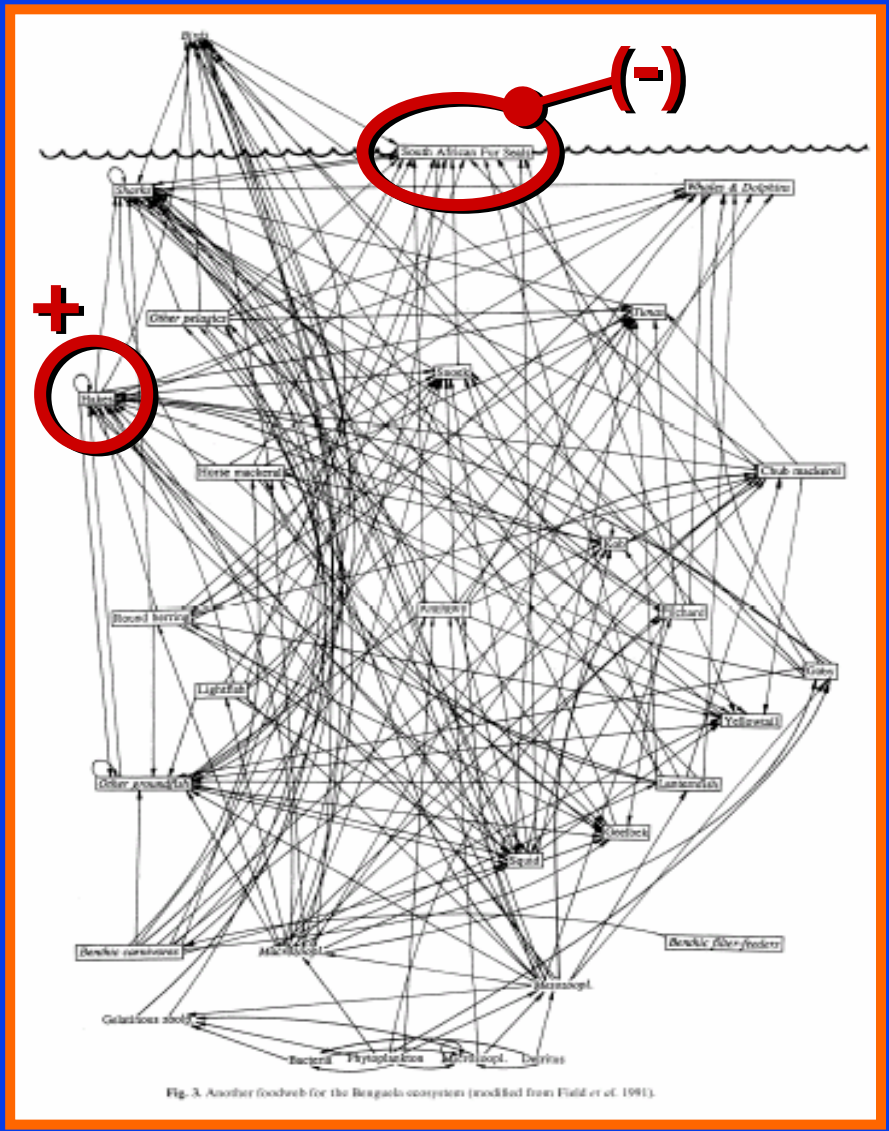
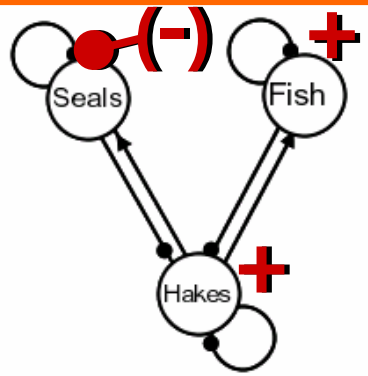


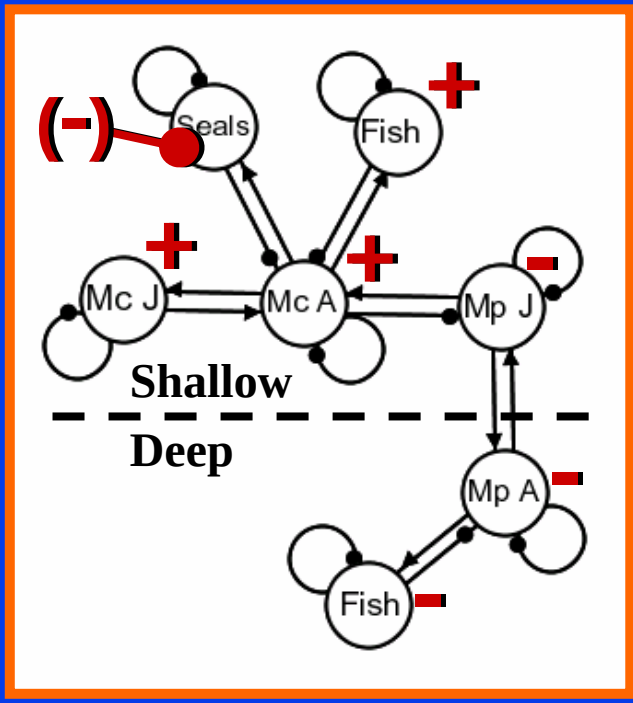
Fig. 3. Another foodweb for the Benguela ecosystem (modified from Field *et al.* 1991).

YODZIS 1998

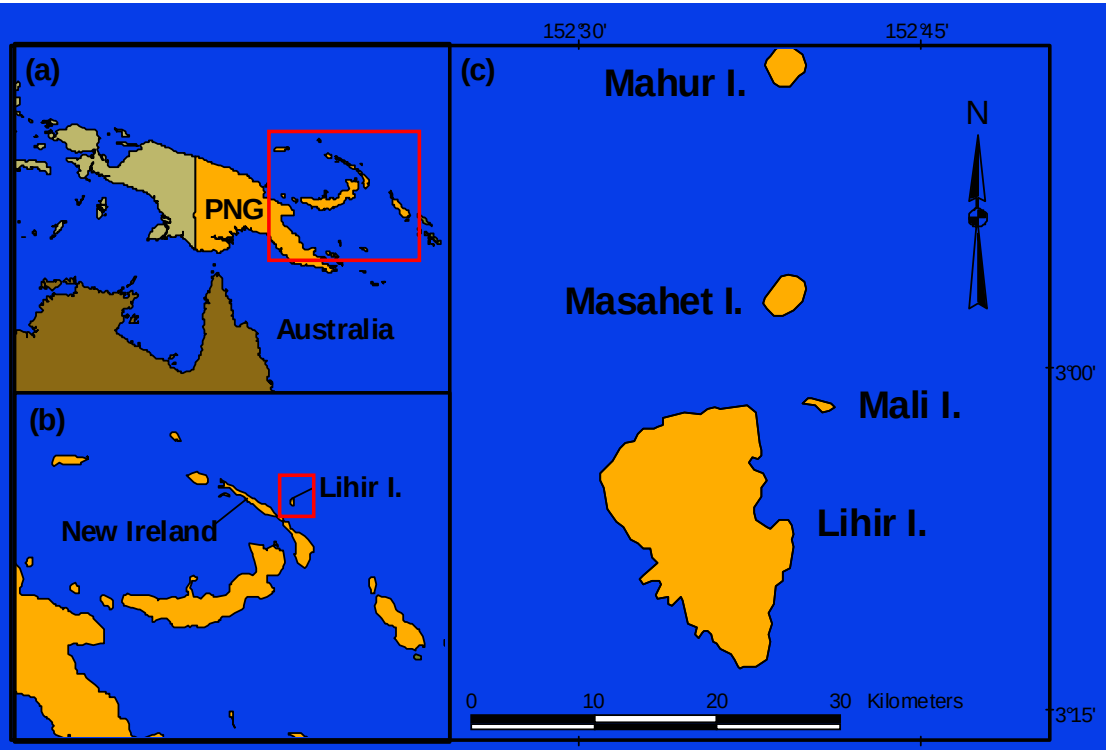
Hakes model

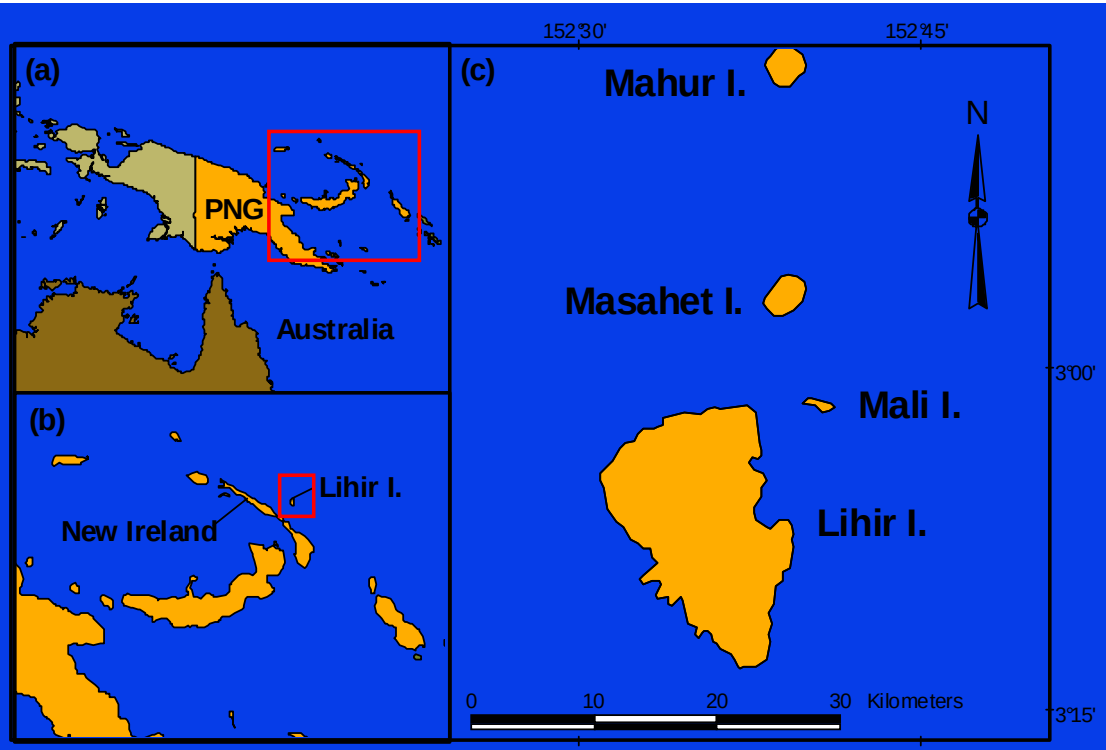


Merluccius capensis & M. paradoxus model



PUNT 1997


(a)
PNG
Australia
(b)
Lihir I.
New Ireland
(c)
152°30'
152°45'
Mahur I.
N
Masahet I.
3°00'
Mali I.
Lihir I.
0
10
20
30
Kilometers
3°15'


(a)
PNG
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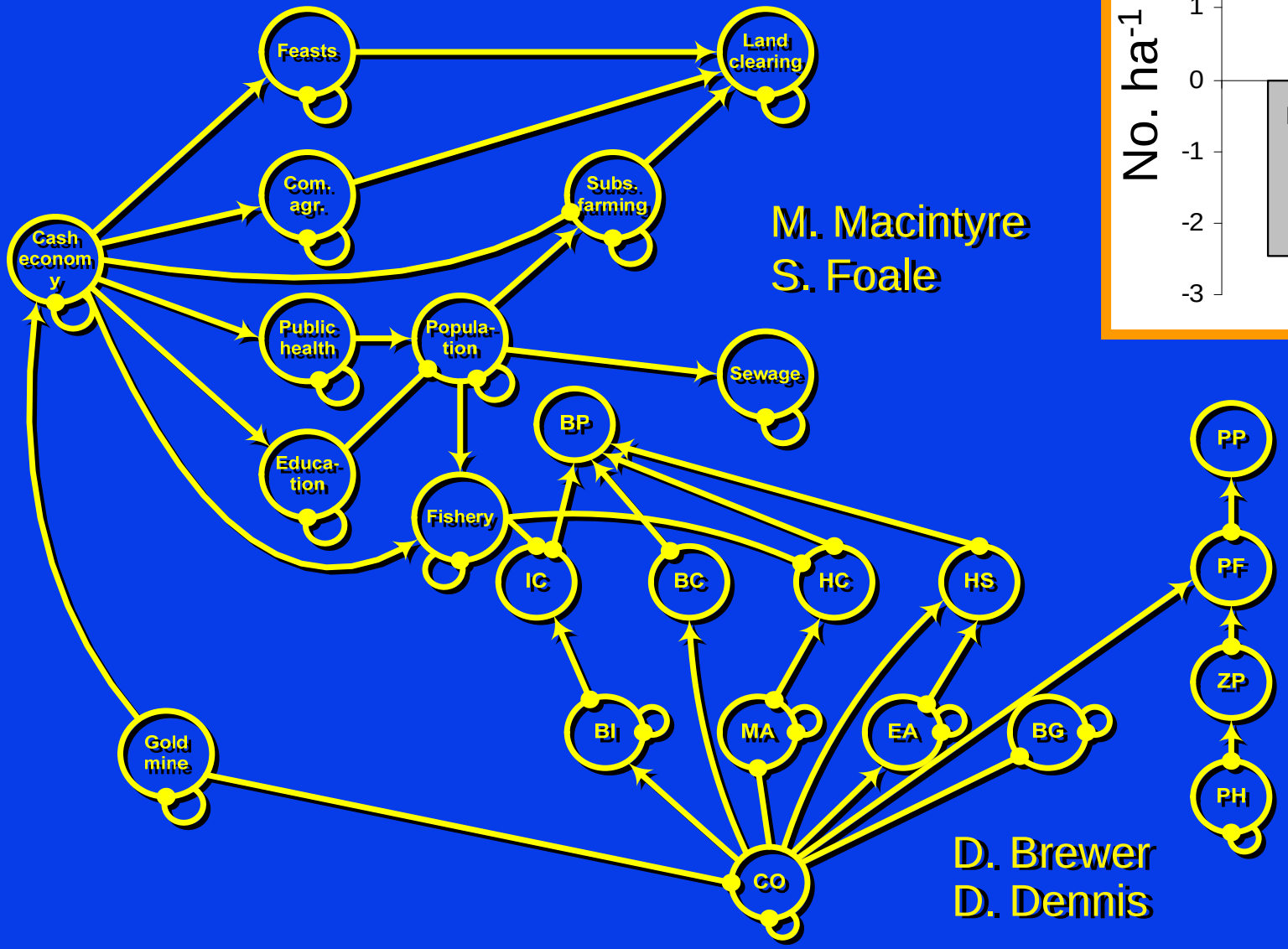
152°30'
152°45'
Mahur I.
N
Masahet I.
3°00'
Mali I.
Lihir I.
0
10
20
30 Kilometers
3°15'

Gold mine impacts on Lihir Island's socio-economic system and reef edge fish community



M. Macintyre
S. Foale

D. Brewer
D. Dennis