

Alternative states in ecological communities: exploring phase shifts on Tasmanian rocky-reefs using loop analysis



Martin Marzloff,
Jeffrey M. Dambacher,
Rich Little,
Stewart Frusher,
Craig R. Johnson



Context: modelling the dynamics of Tasmanian subtidal rocky-reefs

- Abalone  and rock lobster 
= 2 most valuable commercial species in Tasmania

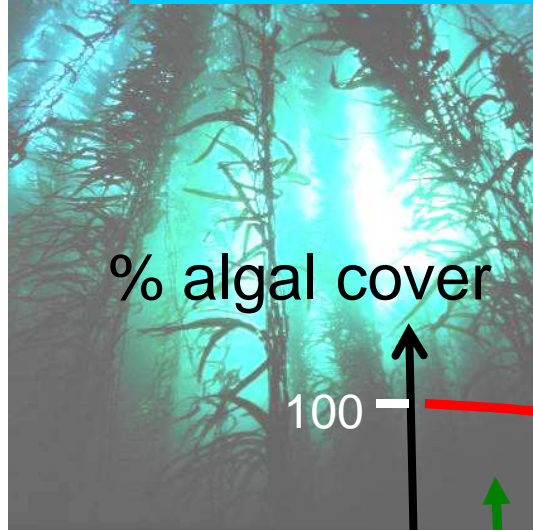
- Development of a network of urchin 'barrens' on the east coast of the state, a threat to subtidal inshore fisheries on the east coast of the state



Centrostephanus rodgersii



An example of hysteresis

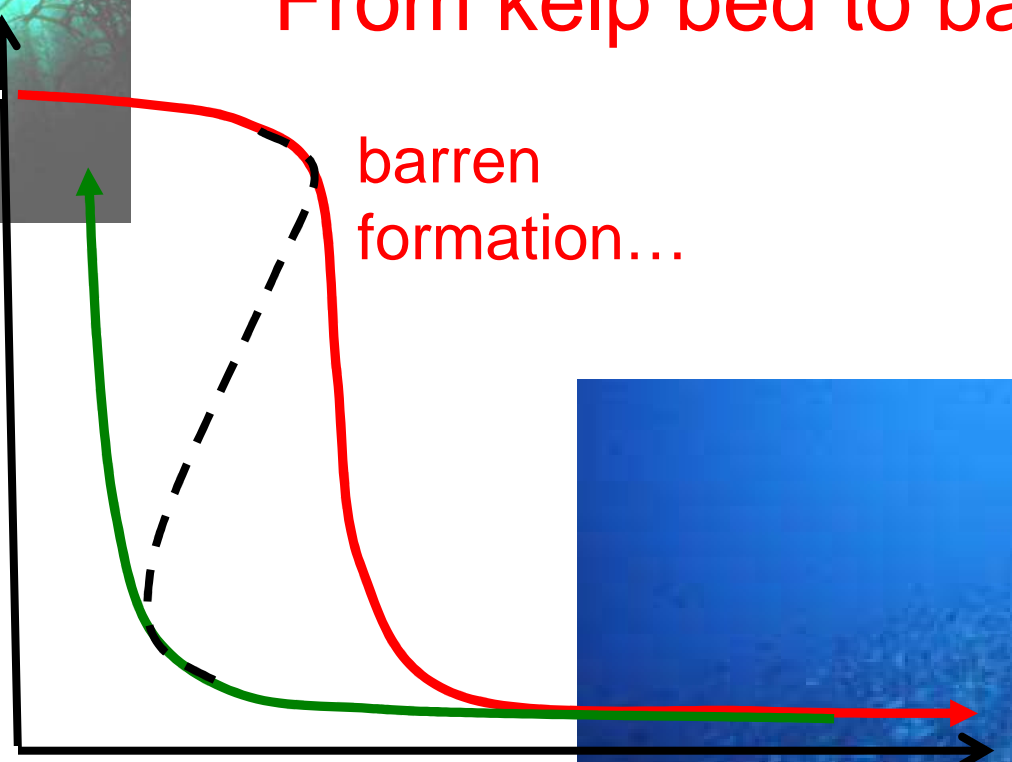
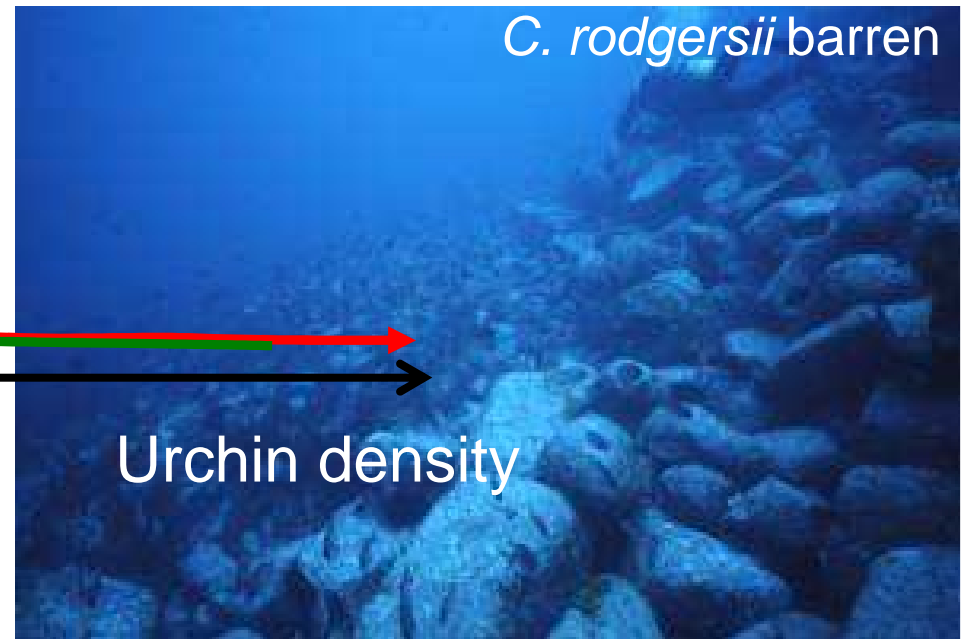


From kelp bed to barren...

barren formation...

... and recovery

...And back



Using loop analysis to model alternative states of the reefs

- Loop analysis = adequate to qualitatively explore the mechanisms of phase shifts in Tasmanian reefs
- Association of positive feedbacks with alternative persistent states (APS) in literature
- Adequacy of loop analysis to explore the potential for APS and phase shifts in ecosystems?
 1. **Existence of APS?**
 2. **Mechanisms of phase shift?**
 3. **To help to manage resilience of ecosystem in their original state or restore degraded system to a desirable APS?**

Alternative states of the Tasmanian rocky-reefs



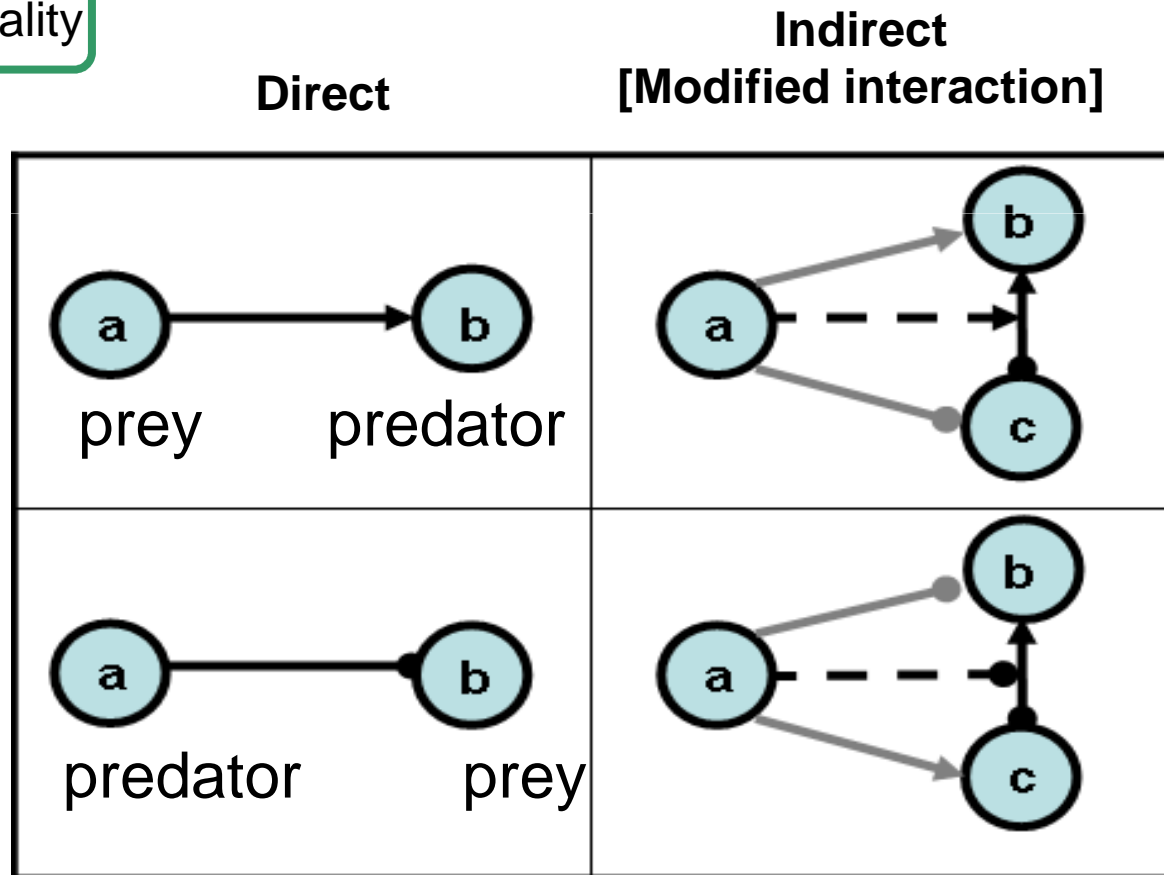
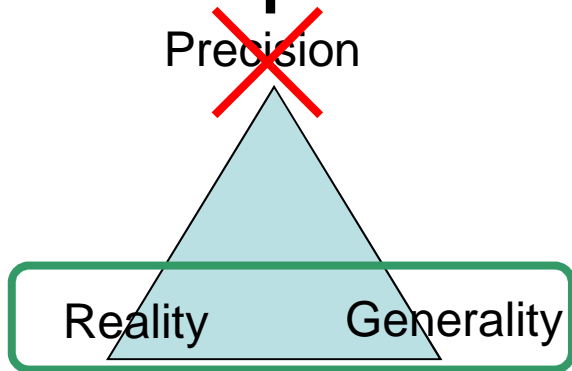
1.
Overstorey
dynamics



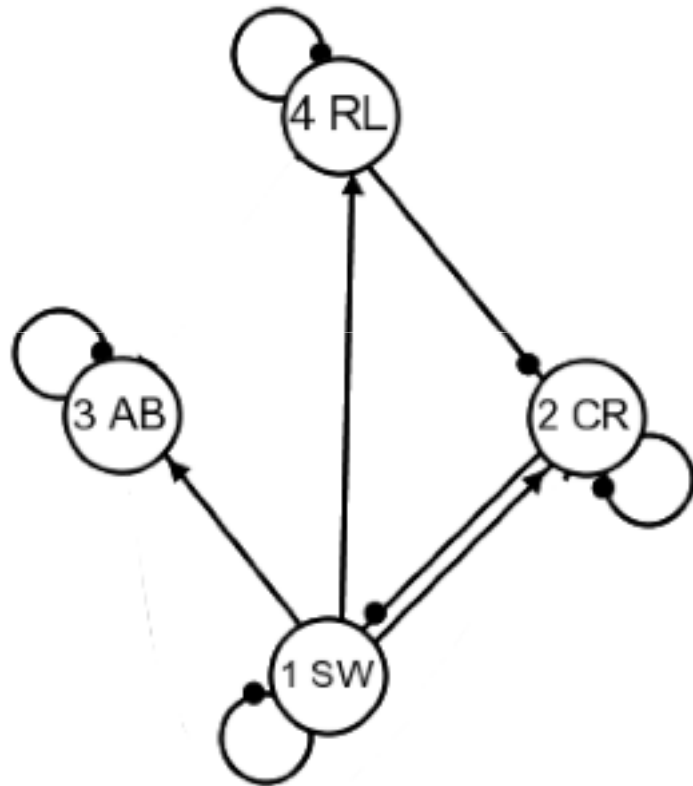
2. Benthic
dynamics
under the
canopy



A qualitative modelling approach: Loop analysis



Qualitative predictions using loop analysis



1= SW, seaweed bed
 2= CR, sea urchin *C. rodgersii*
 3= AB, abalone
 4= RL, rock lobster

Qualitative community matrix

Effects of:

	SW	CR	AB	RL
SW	-1	-1	0	0
On: CR	1	-1	0	-1
AB	1	0	-1	0
RL	1	0	0	-1

Qualitative prediction matrix

Effect of a positive input in the abundance of:

	SW	CR	AB	RL
SW	1	-1	0	1
On: CR	?	1	0	-1
AB	1	-1	1	1
RL	1	-1	0	2

or

+	-	0	+
?	+	0	-
+	-	+	+
+	-	0	+

Overstorey dynamics

Positive input in...

CR ↓ RL ↓

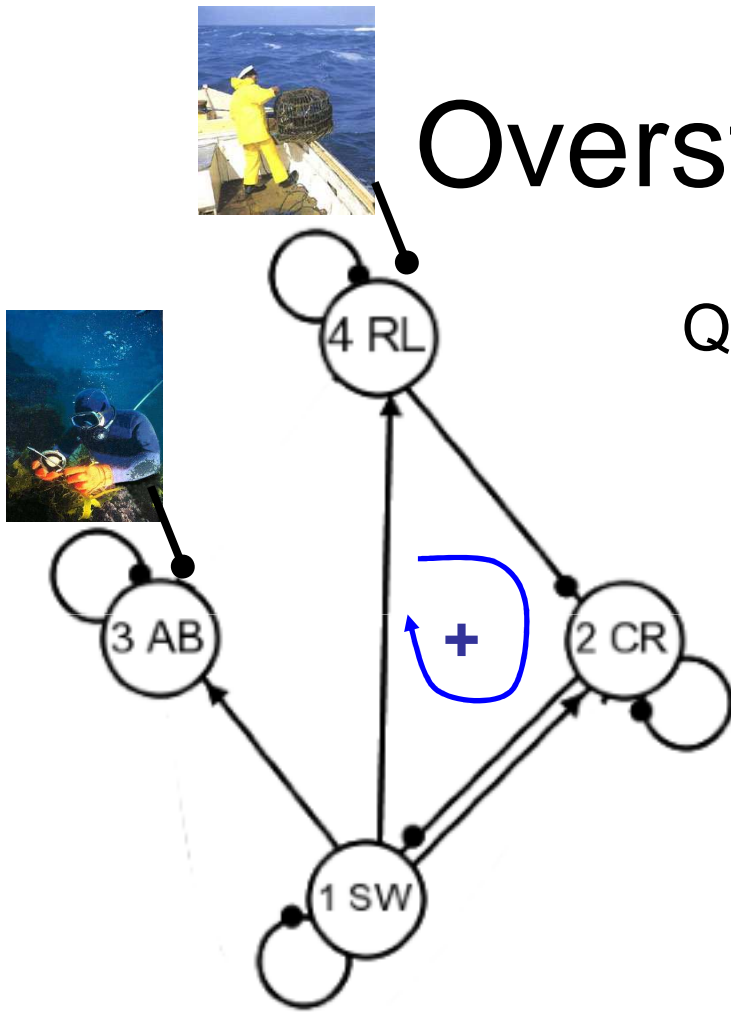
SW	+	-	0	+
CR	?	+	0	-
AB	+	-	+	+
RL	+	-	0	+

Qualitative predictions for:

- Patterns of correlation in species abundances in response to perturbations ~ 2 alternative states

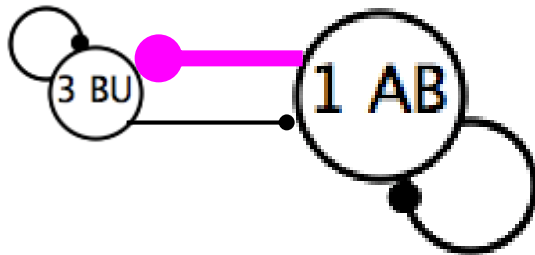
- Perturbations push the community towards:

- **State I**: productive seaweed bed
- **State II**: low productivity and high urchin abundance

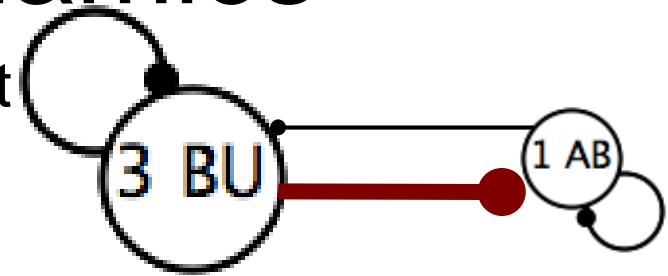


1= SW, seaweed bed
 2= CR, sea urchin *C. rodgersii*
 3= AB, abalone
 4= RL, rock lobster

Understorey dynamics



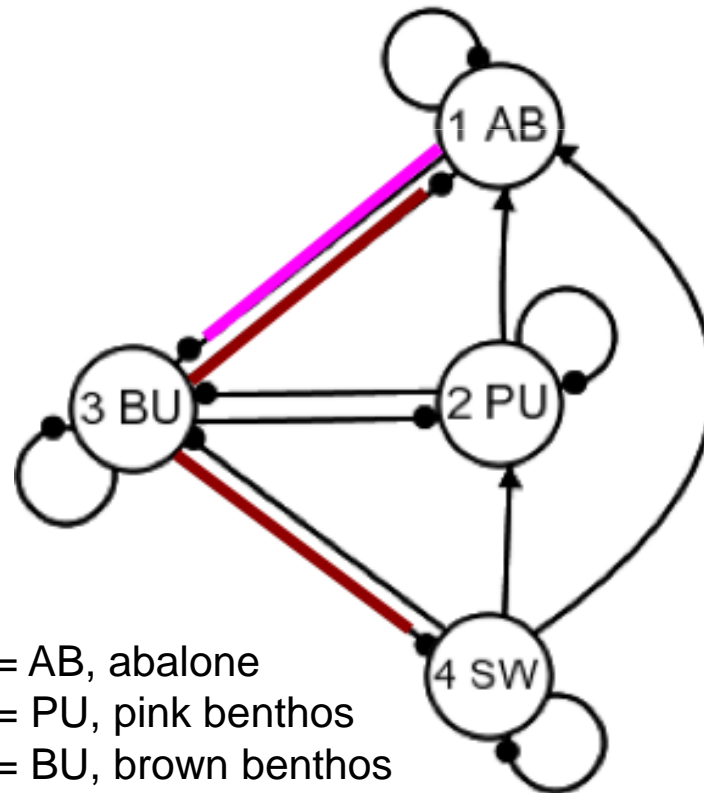
Changes in dominant interactions driving the dynamics



'AB → BU'
Pink state



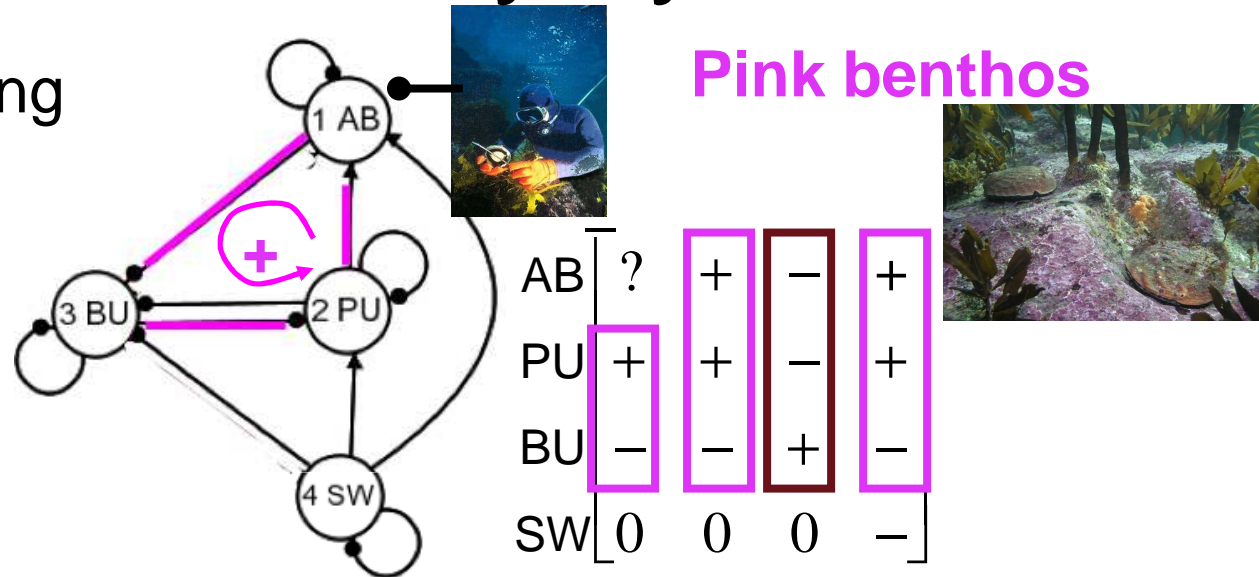
'BU → AB'
Brown state



- 1= AB, abalone
- 2= PU, pink benthos
- 3= BU, brown benthos
- 4= SW, seaweed bed

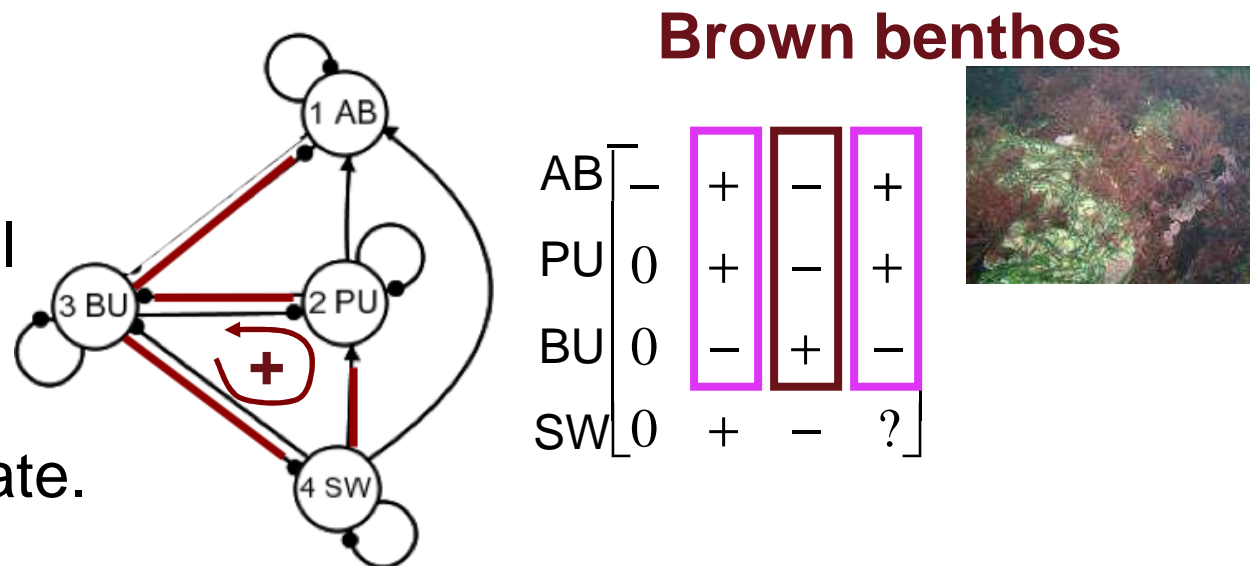
Understorey dynamics

Abalone grazing maintains the pink state.



- 1= AB, abalone
- 2= PU, pink benthos
- 3= BU, brown benthos
- 4= SW, seaweed bed

No more control of abalone on the dynamics of the brown state.

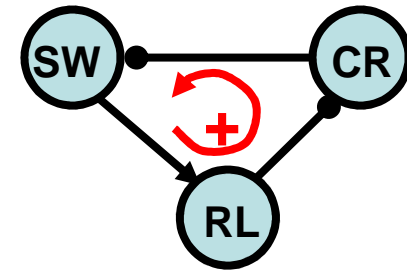
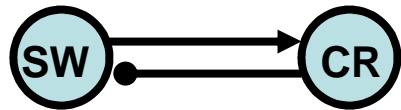


Qualitative dynamics of the Tasmanian reefs

- Indirect consequences of fishing abalone and lobster on the state of the benthic community
- Correlation in variable abundance in the prediction matrix
 - ~ propensity for 2 alternative states
- Changes in interaction patterns in the understorey
 - ~ 2 different basins of attraction in the pink and the brown states, respectively

1. Can loop analysis detect systems with APS?

- Qualitative predictions sum up all the feedbacks in a community



⇒ Useful to identify the propensity of an ecosystem for APS from its feedback properties

- Good support to design further manipulative experiments to test for APS

2. Can loop analysis help to study phase shifts?

- **To explore the mechanisms facilitating phase shift?**

YES,

e.g. indirect effects of fishing



- **To predict the qualitative effects of phase shifts?**

YES,

through a general causal understanding of system dynamics...

But limited to act as a definitive management tool for specific instantiations

3. Can loop analysis support the management of ecosystem with APS?

- To maintain resilience of ecosystems in their original state? Or to restore degraded systems into a most desirable state?

YES

-> Basis for a multi-species criteria to monitor the evolution of ecosystem state

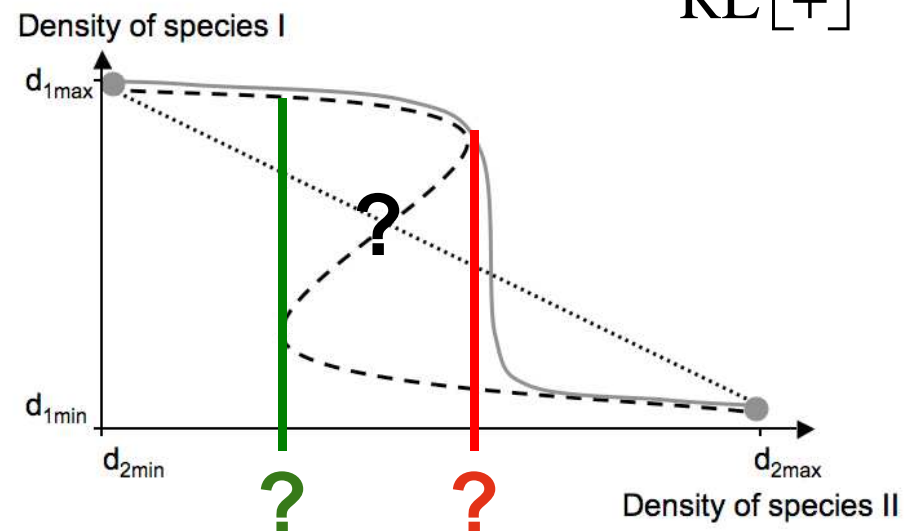
- To identify key thresholds in system dynamics?

NO

- To characterize the nature of a phase shift?

NO

$$\begin{matrix} SW \\ CR \\ AB \\ RL \end{matrix} \begin{bmatrix} + \\ - \\ + \\ + \end{bmatrix}$$

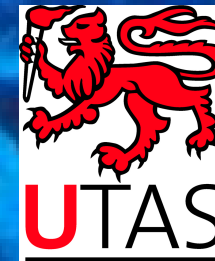
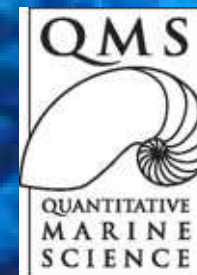


Conclusions

- Loop analysis, APS and phase shifts:
 - Causal understanding of ecosystem dynamics and potential for APS
 - Good framework to design further manipulative experiments to test for APS
 - Design of a multi-species criteria
- In the scope of my Ph.D. project, interest of loop analysis to test for model structure uncertainty before further quantitative modelling

Thanks for
your attention....

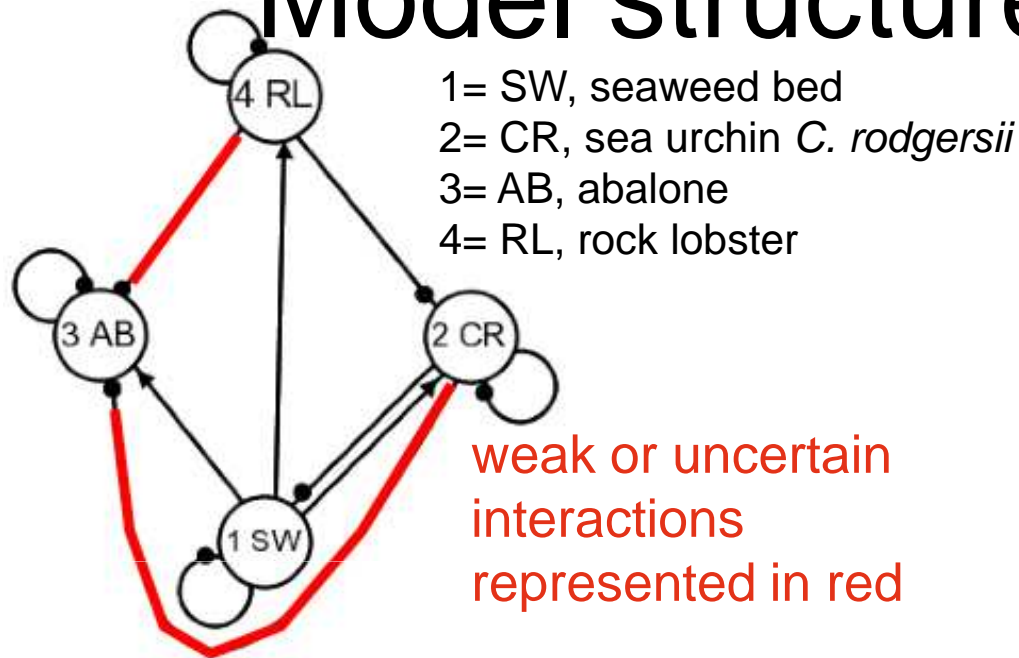
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Model structure uncertainty



- Consistent model structure!
 Only abalone dynamics is affected by the inclusion of weak/uncertain interactions
- Effects on qualitative predictions (for abalone):
 - more ambiguity
 - reversed sign of prediction

Qualitative predictions

Model A	$\begin{bmatrix} 1 & -1 & 0 & 1 \\ ? & 1 & 0 & -1 \\ 1 & -1 & I & 1 \\ 1 & -1 & 0 & 2 \end{bmatrix}$
Model B RL \rightarrow AB	$[? \quad ? \quad I \quad -I]$
Model C CR \rightarrow AB	$[I \quad -2 \quad I \quad 2]$
Model D RL \rightarrow AB CR \rightarrow AB	$[? \quad -I \quad I \quad ?]$

Understorey dynamics (epilithic benthos) with uncertain interactions

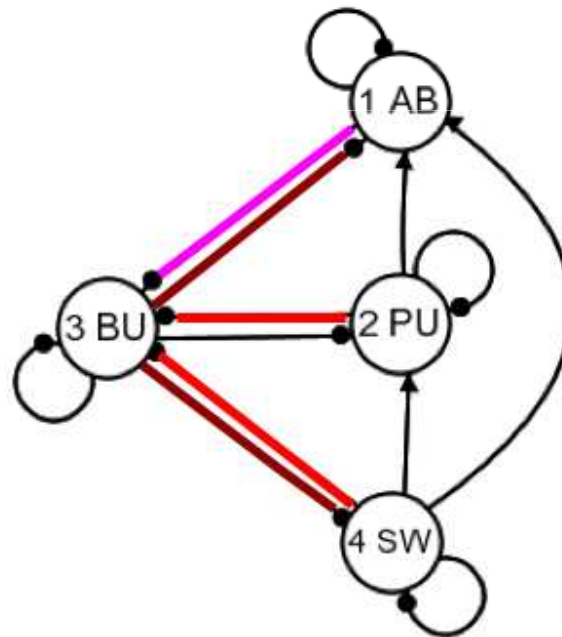
Pink state

'AB → BU' = dominant



Brown state

'BU → AB' |
'BU → SW' = dominant



- 1= AB, abalone
- 2= PU, pink benthos
- 3= BU, brown benthos
- 4= SW, seaweed bed

Note: weak/variable interactions represented in red.