Ecological impacts of species range-shifts: identifying the good, the bad and the uncertain

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Biological changes well documented for south-east Australia…..

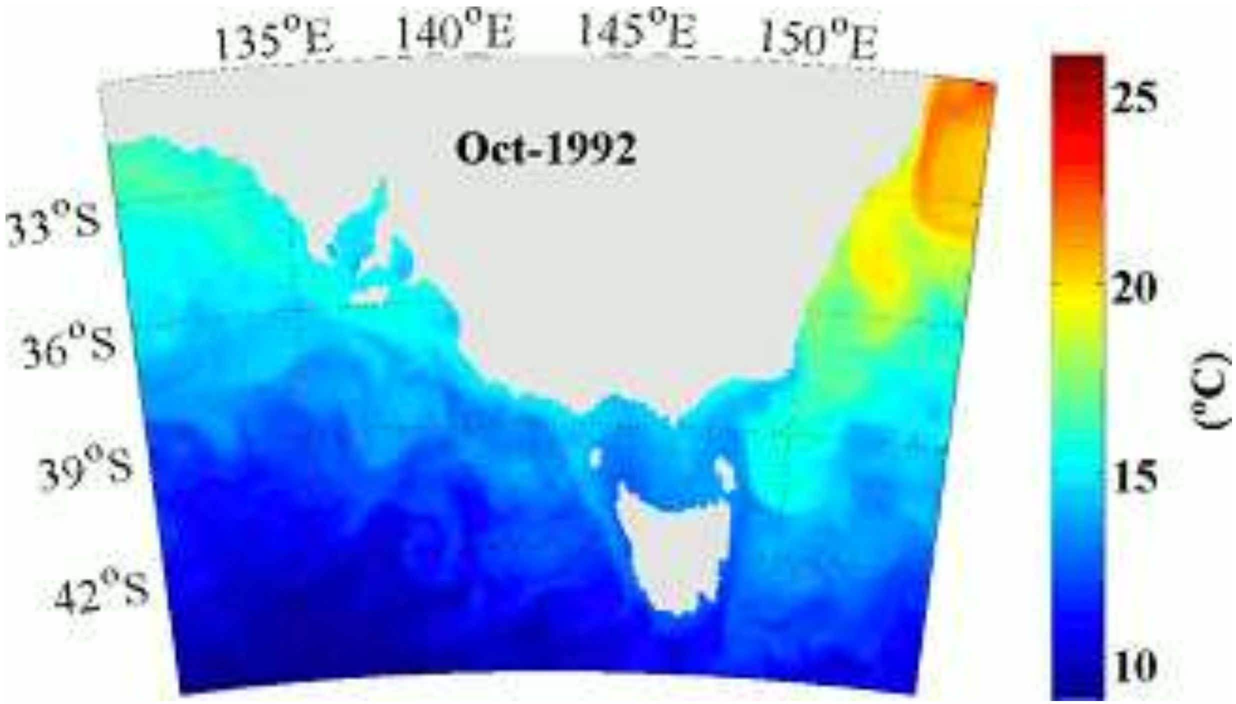
'New' octopus species, first recorded in 2006 and now 13% of commercial fishery (Ramos et al 2014a, b & submitted)

50% intertidal species monitored have moved poleward in Tasmania over last 50 years *(Pitt et al 2010)*

Over 45 coastal fish species exhibited major distributional changes in Tasmania *(Last et al 2011, Robinson et al 2015)*

85% of seaweeds found further poleward on east coast from 1940 *(Wernberg et al 2011)*

East Australian Current (EAC) pushing further south & persisting for longer



Westerly winds south of Australia are intensifying & 'spinning up' the anticlockwise circulation around the South Pacific.

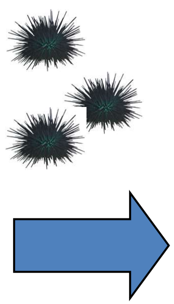
One of the fastest warming regions globally and will likely remain so in the future.

Animation courtesy of CSIRO

From kelp forest to urchin barren

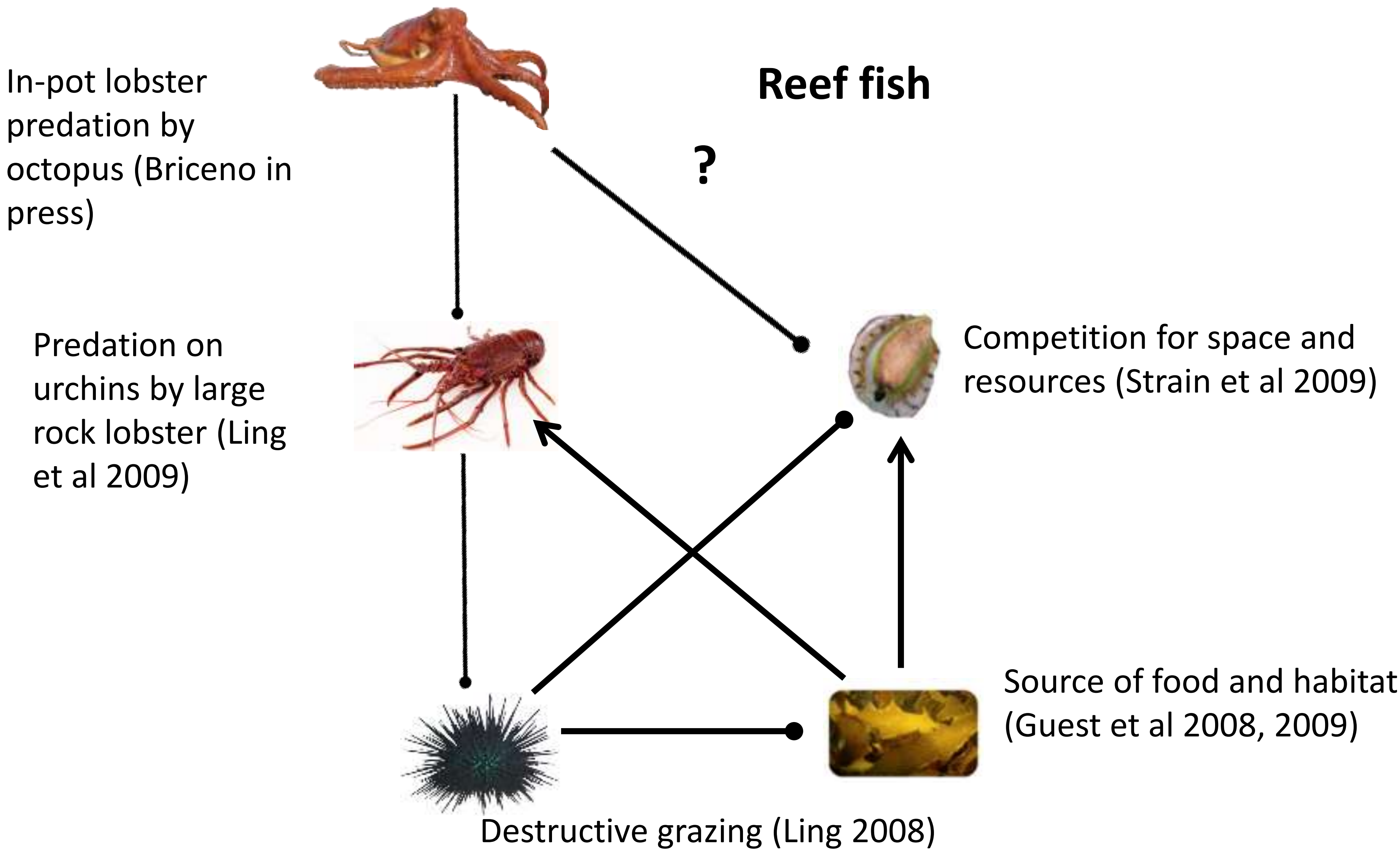
- Arrival and spread of the long spine sea urchin *Centrostephanus rodgersii*

- Destructive grazing and formation of 'barrens' habitat
  - loss of seaweeds / invertebrates
  - loss of production
  - crash in key fisheries (rock lobster and abalone)
  - difficult to reverse



Johnson CR et al. (2005); Ling S. (2008)

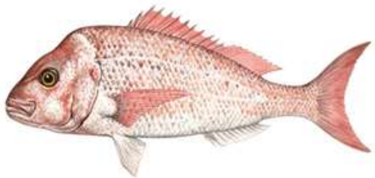
Dynamics of formation, prevention and remediation of urchin barrens



$10m spent understanding 4 'key players'

Urchin is not the only range-shifter

Extending into Tasmania



Snapper (*Pagrus auratus*)

Eastern rock lobster (*Sagmariasus verreauxi*)

Gloomy octopus (*Octopus tetricus*)

Contractions/declines at the north of Tasmania?

Greenlip and blacklip abalone

Southern rock lobster (*Jasus edwardsii*)

Consequences of range shifts?

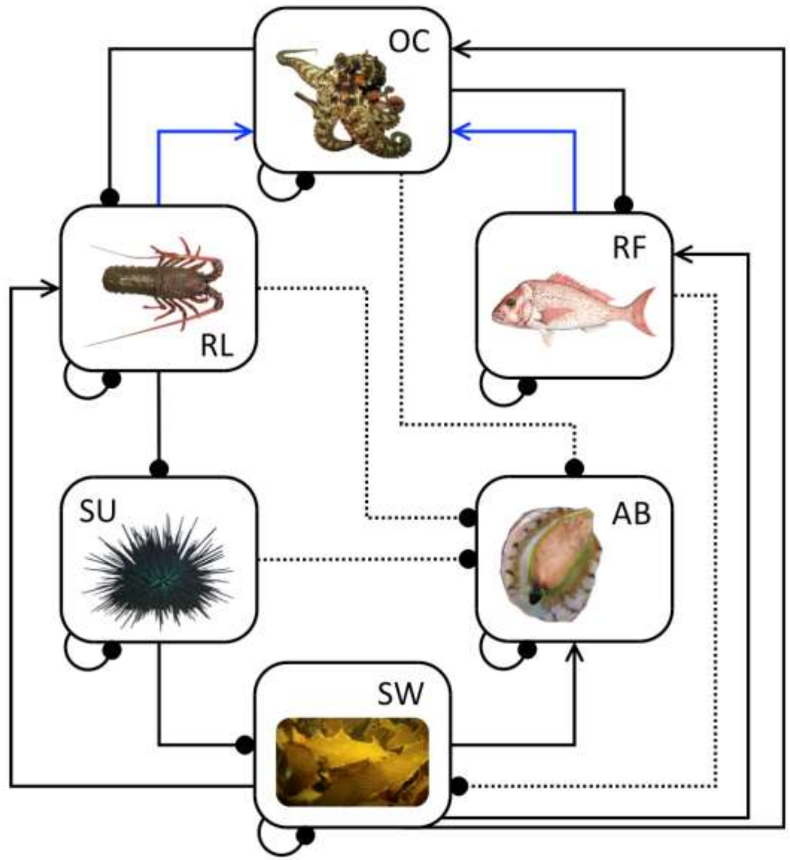
- Direct and indirect effects of species redistribution on ecosystem dynamics and coastal industries poorly characterised
- Ecological, economic and social consequences of range shifts can be large
- Current research focusses on individual species rather than collective impacts of multiple shifters

Consequences of multiple range shifts??

Predictive framework - modelling ecosystem feedback

Requires only qualitative knowledge about community structure and species redistribution

Positive and negative feedback, stability & self-regulation



Model groups:

OC: octopus

RL: rock lobster

RF: reef fishes

SU: sea urchin

AB: abalone

SW: seaweed bed

Interactions:

Positive

Negative

Alternative models

Model i

Model ii

Model iii

Mathematically, the analysis of network models is built on graph theory and matrix algebra; specifically, analysis of the community matrix

Marzloff *et al.* (in review)

Qualitative network model predictions

- Holistically capture general dynamics of reef communities in eastern Tasmania
- Generate qualitative predictions under alternative scenarios
  - Range shifts of individual species
  - Multiple range shifts occurring simultaneously
  - Management interventions – prevent barrens formation by the urchin
- Discriminate between:
  - Range shifters with marginal effects on reef structure and function
  - Those that can induce large community-wide impacts
- Qualitative predictions derived:
  - Symbolically
  - Simulation-based approach where we report probabilities of model groups responding negatively (ie declining in abundance)

Symbolic predictions

Questions/caveats about model stability

Positive input in the abundance of:

Long-term effects on:

	SU	SW	AB	RL	OC	RF
SU	+	–[1]	0	–	+	0
SW	–	+	0	+	–	0
AB	–	+	+[2]	+	–	0
RL	–[1]	+[1]	0	+	–	0
OC	–	+	0	+	–[2]	0
RF	–[3]	+[3]	0	+[3]	–[2]	+[2]

$10m (SU)

$0m (OC)

Conditions:

- **Direct effects > indirect effects**

1: $a_{RL,SW}\, a_{OC,OC} > a_{OC,SW}\, a_{RL,OC}$
2: $a_{RF,SW}\, a_{OC,OC} > a_{OC,SW}\, a_{RF,OC}$

- **Model stability**
(negative feedback > positive feedback)

3: $a_{SU,SU}\, a_{SW,SW}\, a_{RL,RL} > a_{SU,RL}\, a_{RL,SW}\, a_{SW,SU}$

where $a_{i,j}$ is the effect of variable *j* on variable *i*.

Model groups:
SU: sea urchin
SW: seaweed bed
AB: abalone
RL: rock lobster
OC: octopus
RF: reef fishes

Marzloff *et al.* (in review)

Simulation-based approach, probabilities of model groups responding negatively

- Modelling negative and positive system feedback
- Generate 5000 sets of parameters for each interaction
- All matrices are checked for stability
- We know how urchin and lobster respond – so outcomes checked against these
- Bayesian framework for interpreting uncertainty
- Response for each species is positive or negative, summed, probabilities generated

Ecological Monographs, November, Vol. 82, No. 4 : 505-519

Comprehensive evaluation of model uncertainty in qualitative network analyses
J. Melbourne-Thomas, S. Wotherspoon, B. Raymond, and A. Constable
(doi: 10.1890/12-0207.1)

Simulation-based approach, examine several scenarios

Single range shifts
+ range extension to Tas.
-- range contraction in Tas.

Multiple range contractions

Multiple range extensions

All shifts (contractions and extensions)

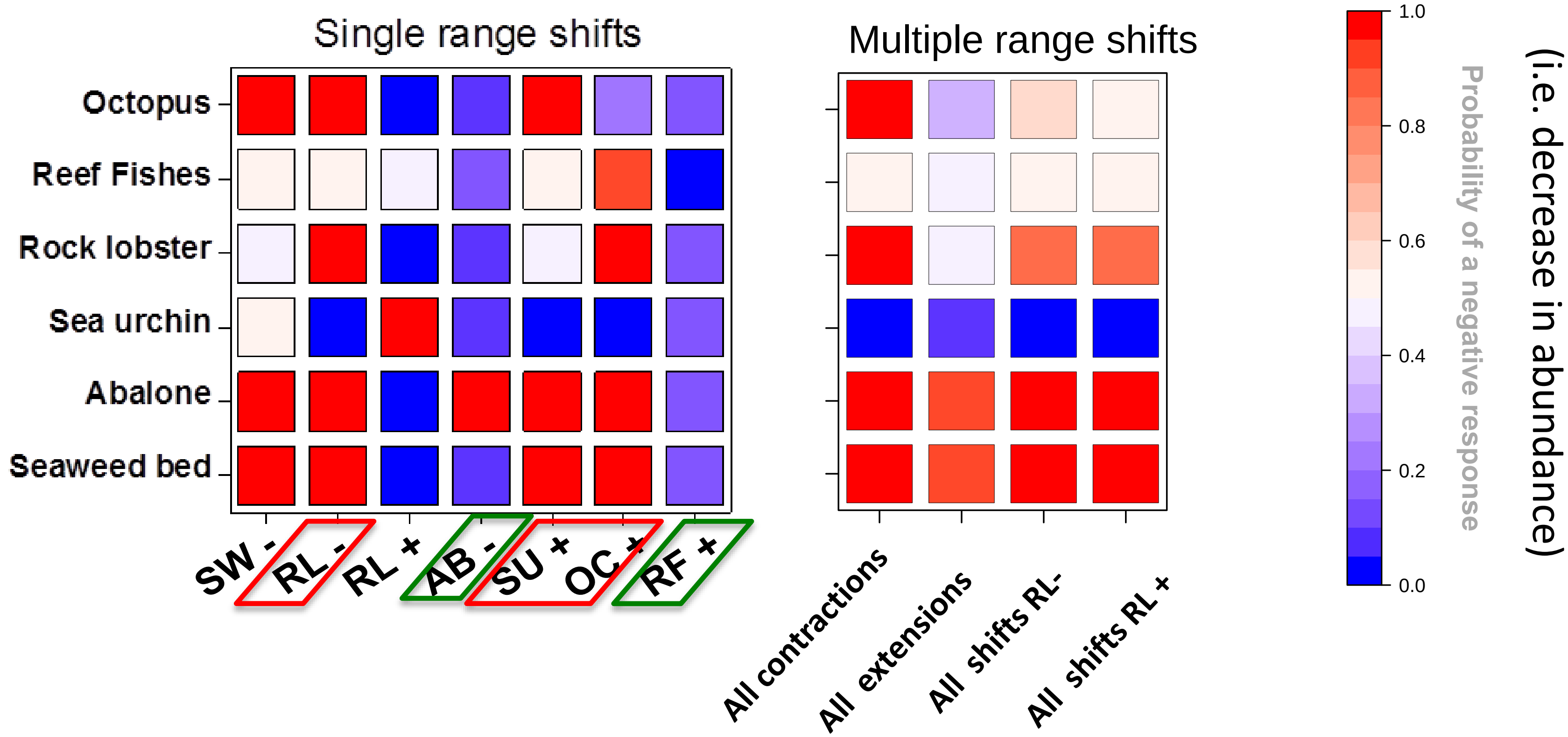
- Net DECLINE in rock lobster biomass (southern rock lobster contracts and is NOT replaced by eastern)

- Net INCREASE in rock lobster biomass (i.e. eastern rock lobster replaces southern rock lobster)

Eastern - extending

Southern - contracting

Similar functional role – large lobsters eat urchins



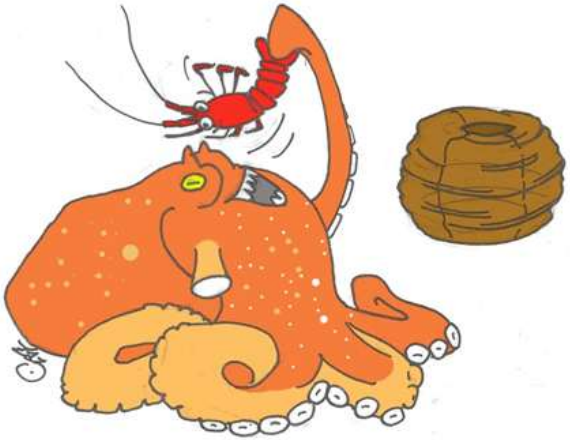
NEGATIVE ECOSYSTEM OUTCOME

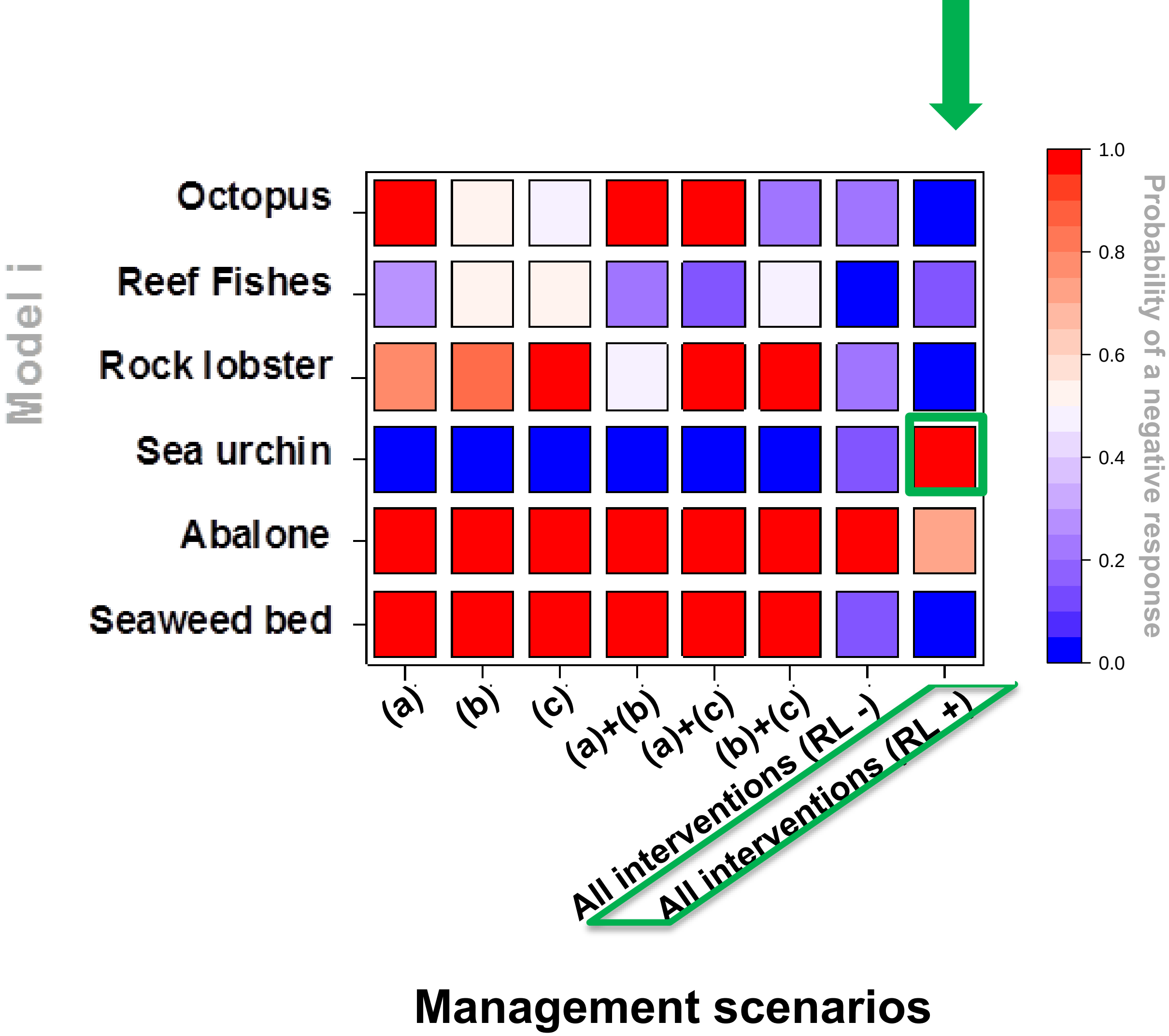
- **LOW probability of NEGATIVE response in urchin (BLUE) - abundance has ↑ or stayed same**
- **HIGH probability of NEGATIVE response in other groups (RED) – abundance has ↓**

- ↓ in southern rock lobster, ↑ in urchin or ↑ in octopus - negative ecosystem impacts
- ↑ in eastern rock lobster – positive ecosystem impacts
- ↑ Reef fish or ↓ abalone – marginal impacts on ecosystem structure
- All shifts – NEGATIVE ECOSYSTEM OUTCOME

Management interventions

- Solely focussed on preventing barrens formation
  - Rock lobster stock rebuilding via reduction in fishing pressure or translocation
  - Sea urchin control through culling/harvesting
  - Octopus control through culling/harvesting





Management interventions:

a: octopus harvesting
b: lobster stock rebuilding
c: sea urchin culling /harvesting

Scenarios:
- 'RL -': lobster biomass decline
- 'RL +': eastern rock lobster replaces southern rock lobster

What we want:

HIGH probability of NEGATIVE response in urchin (RED)

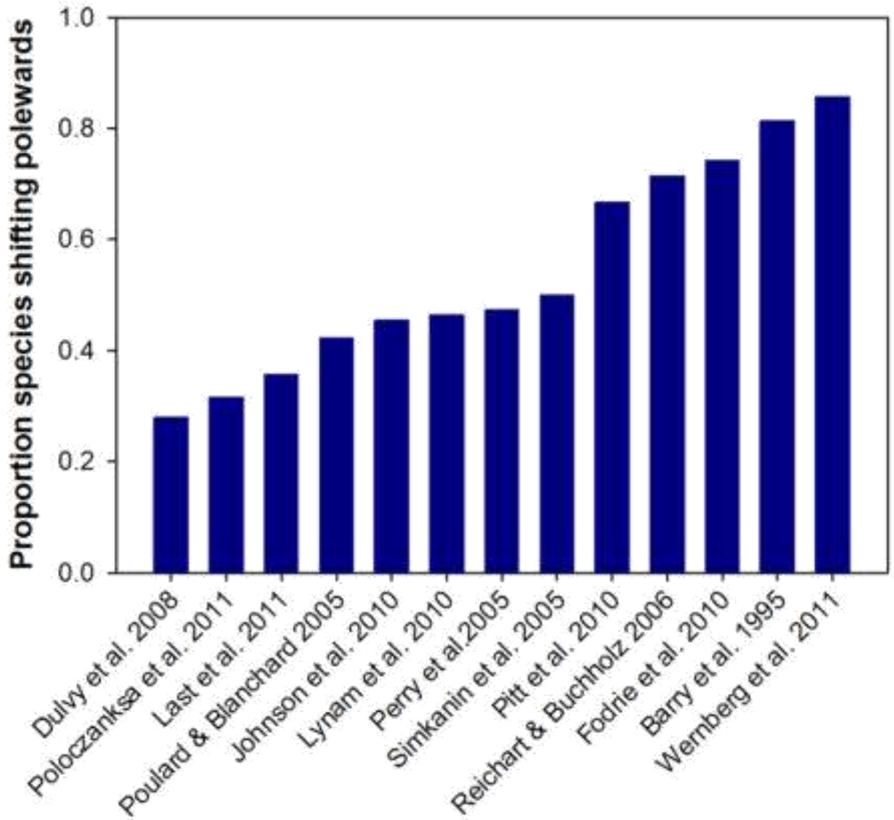
LOW probability of NEGATIVE response in other groups (BLUE)

To prevent barrens formation its unlikely that single interventions will be sufficient

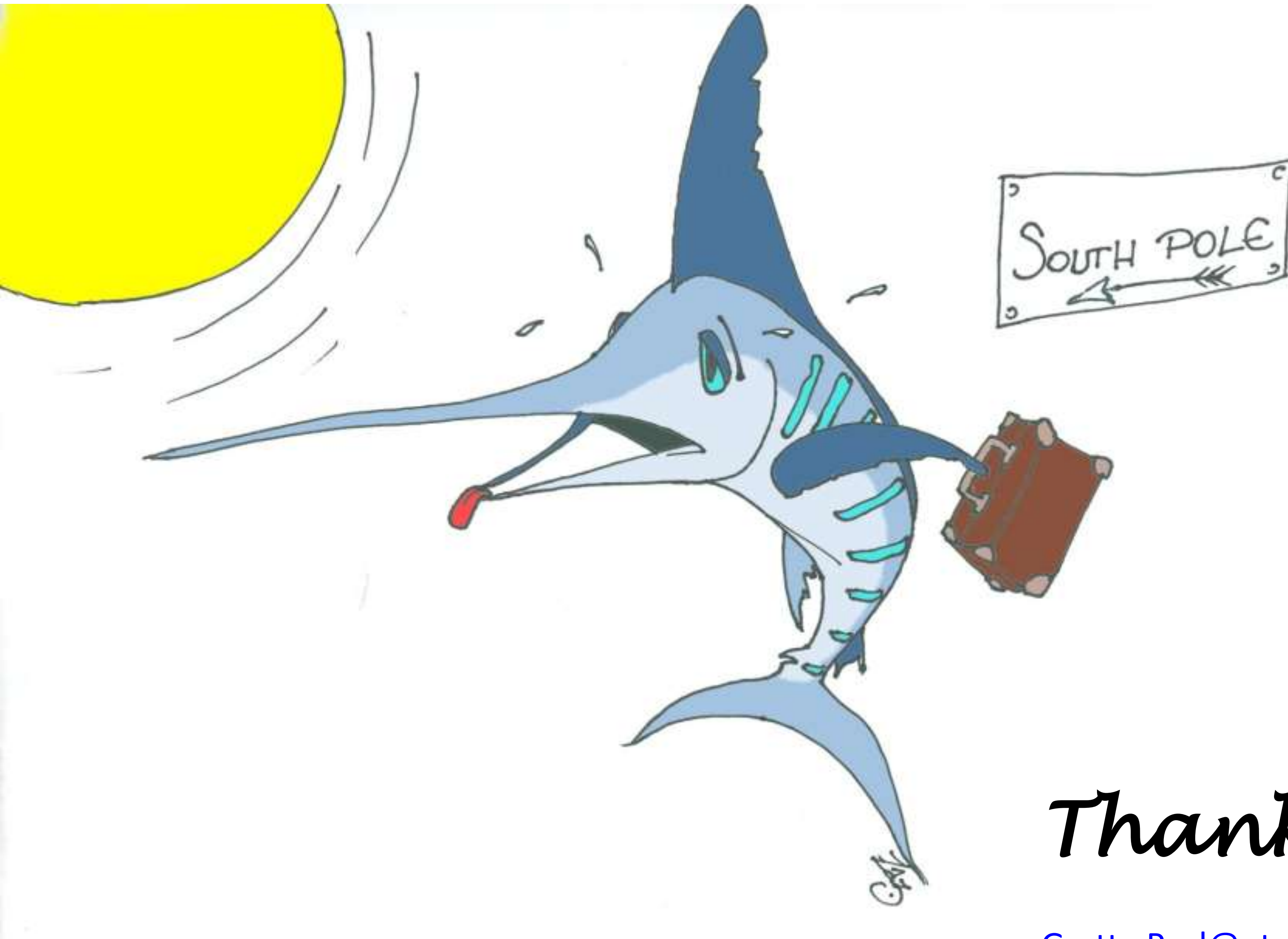
Marzloff *et al.* (in review)

Take home messages

- Multiple range shifts may amplify individual negative ecological impacts
    - Concentrating on the urchin but the octopus is a facilitator
- Combining management interventions for multiple species may be necessary to prevent undesirable consequences
- Modelling system feedback using qualitative information about ecosystem structure
  - Predict ecological consequences of multiple shifts
  - Identify shifters with marginal effects on structure and function vs large community-wide impacts
  - Guide for ecosystem-based adaptation to climate change
  - Prioritise future research and monitoring



Between 25-85% of animals monitored are shifting where they live



Thanks!

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(Image by Elsa Gärtner)

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