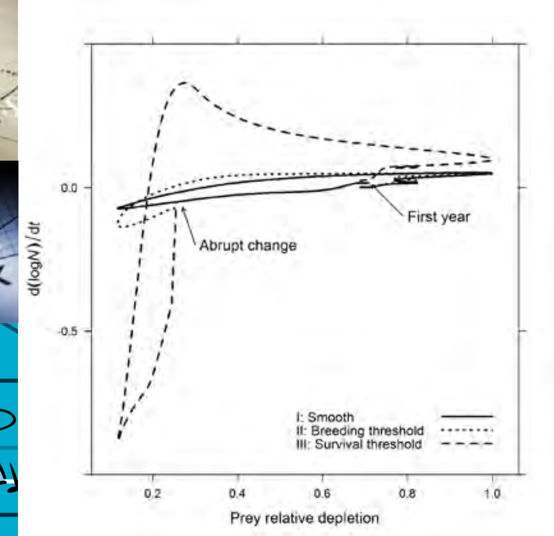


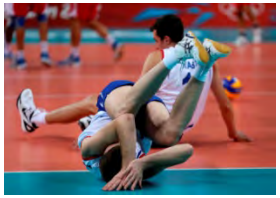
Modelling ecological tipping points and road-testing management strategies for increasing marine ecosystem resilience

Éva Plagányi, Tim Skewes, Alistair Hobday CSIRO, Brisbane, Australia

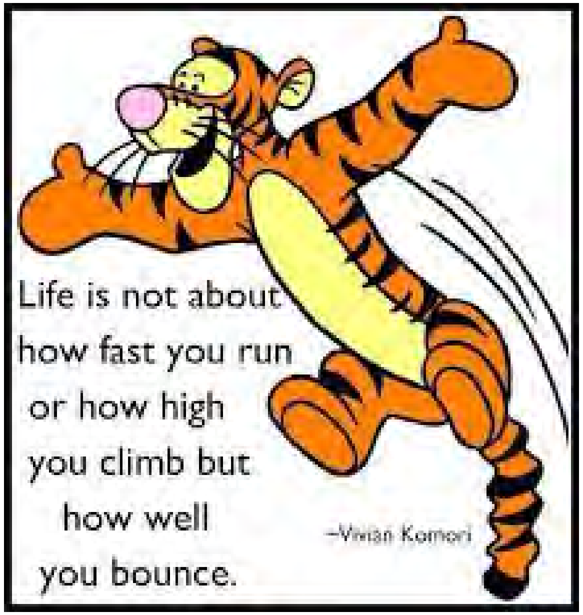
and Laura Blamey, William Robinson University of Cape Town

OCEANS & ATMOSPHERE FLAGSHIP
www.csiro.au

3rd International Symposium on the Effects of Climate Change on the World's Oceans,
Santos, Brazil 2015



‘EXTREME EVENT’ RESILIENCE’:
If a system is perturbed, will it bounce back or fall over?



‘PERMANENT PRESS’ RESILIENCE’:
If a system is subjected to multiple stresses, can we design climate-smart strategies to build resilience and reduce the risk of collapse?

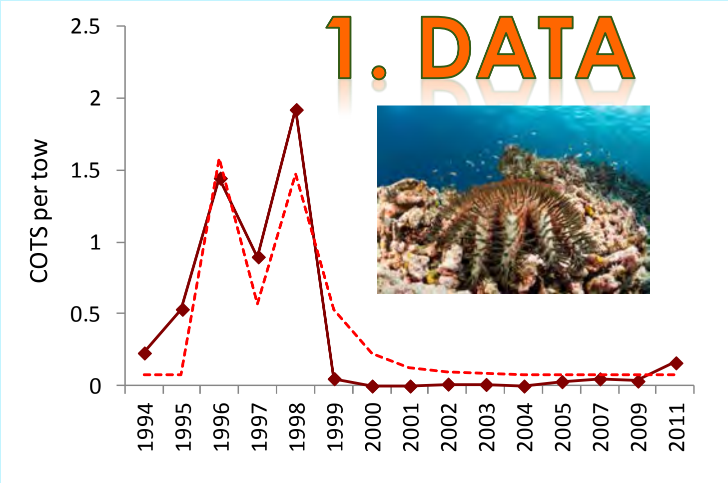
OUTLINE

1. Examples of the use of multispecies models to advance our ability to anticipate or deal with major ecosystem shifts
   - **Impacts of perturbations on populations (e.g. Recovery time, change in state)**
   - **Methods to detect ecological tipping points**

2. Examples of how the outputs can be used to inform monitoring and management
3. Examples of the use of management strategy evaluation (MSE) to test the performance of alternative marine monitoring and management strategies to detect and respond to ecological changes caused by climate change

TOOLBOX

1. DATA

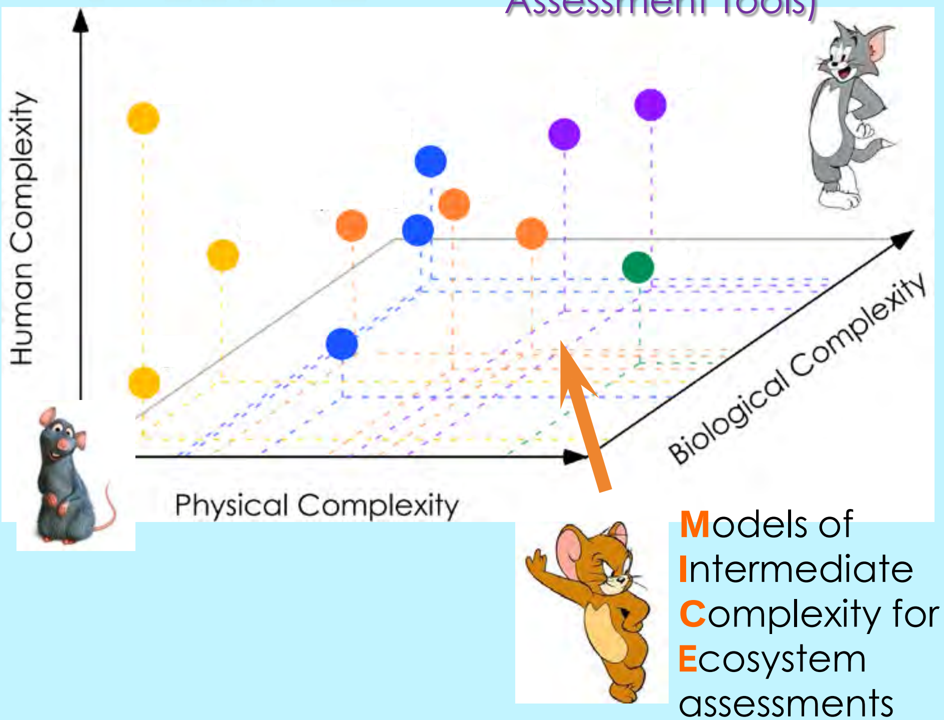


Courtesy: AIMS

2. MICE

CATS (Complex Assessment Tools)

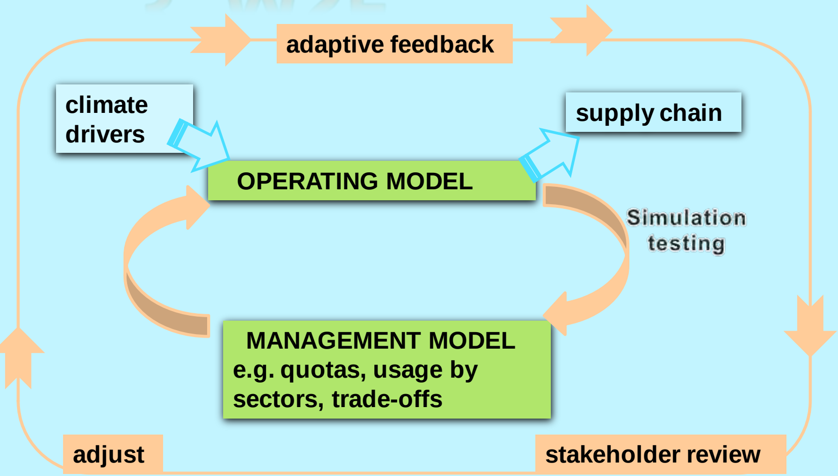
Plaganyi et al 2011 *Mar. Freshw. Res.*



Models of **I**ntermediate **C**omplexity for **E**cosystem assessments

3. MSE

Management **S**trategy **E**valuation



Spatial Multi-species Operating Model (SMOM), Scotia Sea

KRILL FISHERY

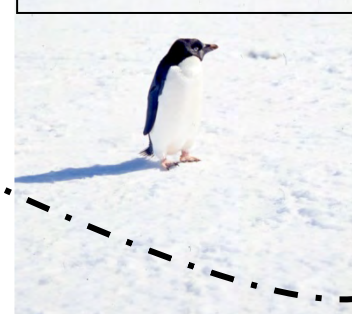
FISHERY

KRILL

WHALES
Blue
Fin
Minke
Humpback

SEALS
Antarctic fur seal

PENGUINS
Adélie
Chinstrap
Gentoo
Macaroni

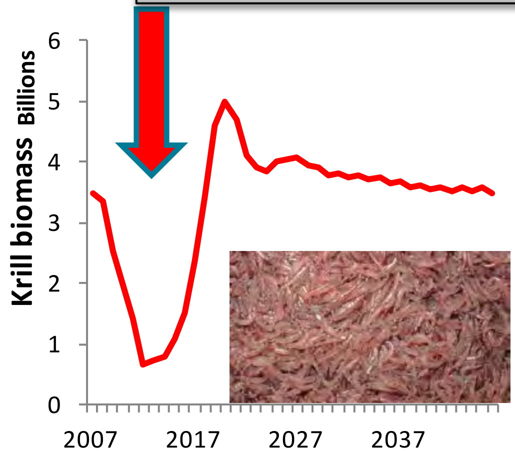


FISH
Myctophids and
Perciforms

Delay difference equations with seasonal time-step

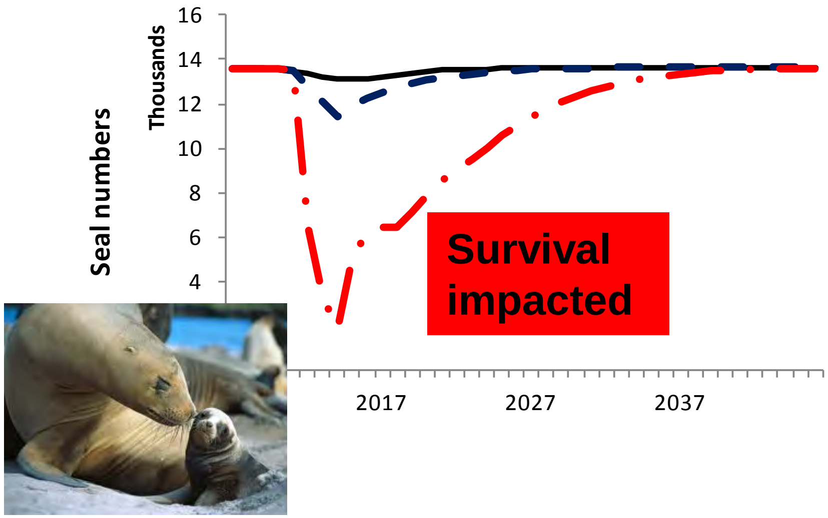
Plagányi & Butterworth 2012 Ecol. Appl.

PERTURBATION

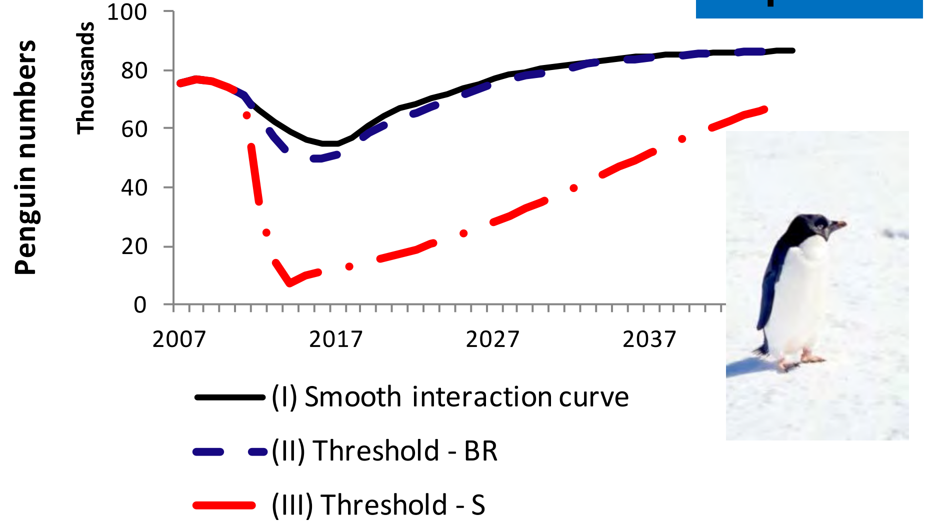


How does variability in one part of system propagate through ecosystem?

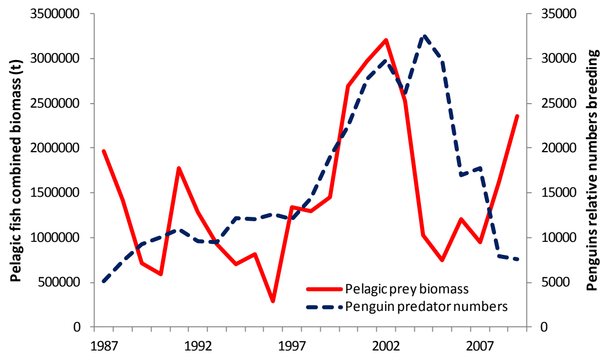
Resilience ?
Response?
Recovery ?



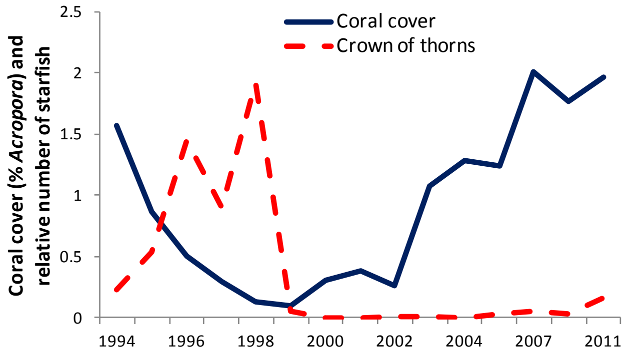
Breeding success impacted



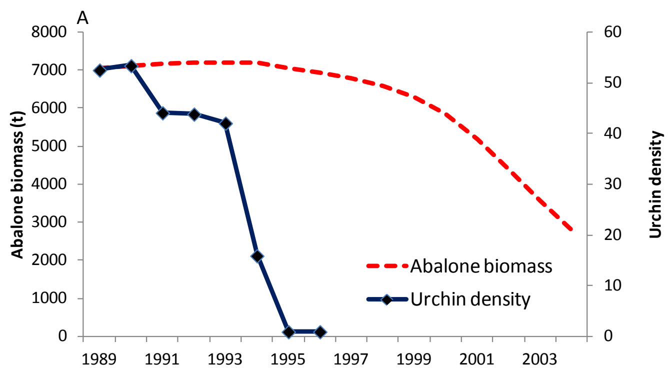
(A) African penguin - sardine



(B) Crown of Thorns Starfish (COTS) - coral



(C) Abalone – urchins (shelter)

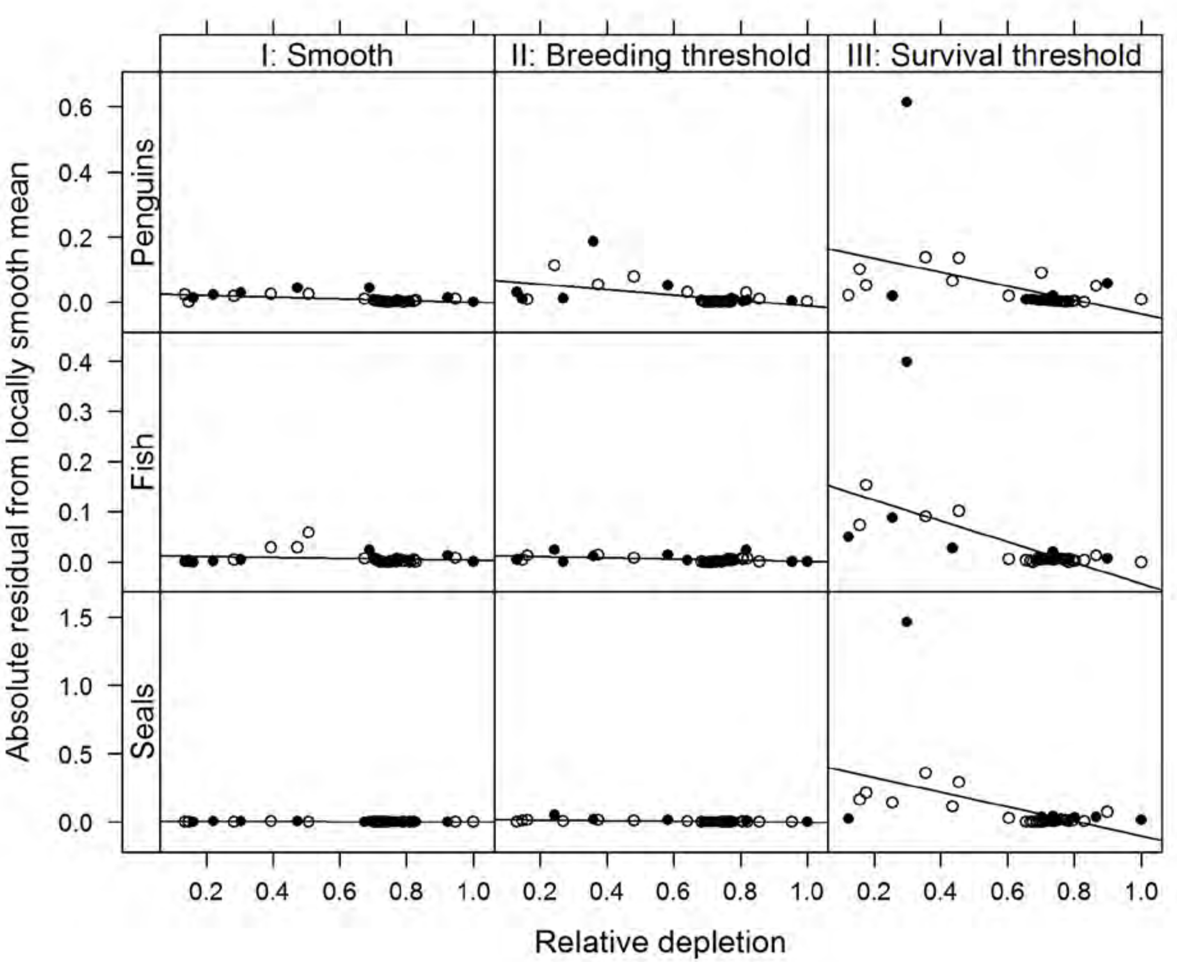


OBSERVED CHANGES BEST EXPLAINED* BY **(III) ABRUPT CHANGE IN SURVIVAL**

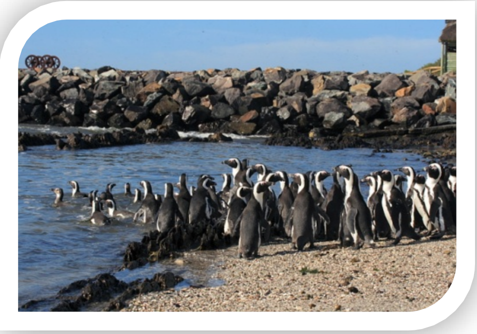
*AIC Model selection criterion – alternative multispecies models fitted to data

Source: Plaganyi et al (2014) MEPS; Robinson et al. (2015) IJMS

Absolute residuals (penguins) versus relative depletion (sardine) using model output: *early warning signal*



There is an increase in the variance as the penguin population starts to decline substantially



Positive residuals: filled circles; negative residuals: open circles

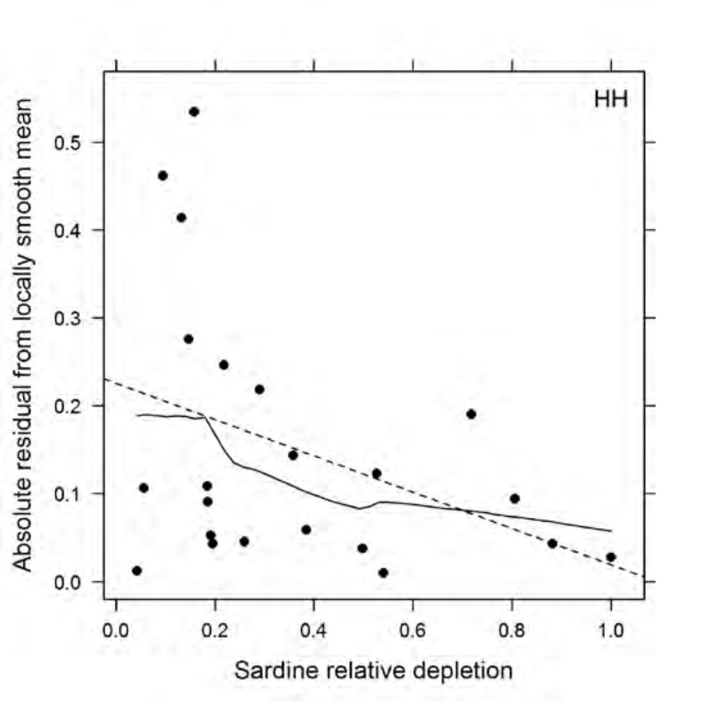
Source: Plaganyi et al (2014) MEPS

In a nutshell

Abrupt changes in some populations can more readily be ascribed to a threshold-like response of adult survival to changing conditions, rather than breeding success or a recruitment collapse

Non-linear changes in population parameters (such as survival rate) below critical prey thresholds may be contributing to the responses of predators to changes in their prey

Increasing variation in population numbers (such as in response to a decline in prey) may be a useful indicator that a system is approaching a tipping point



Plagányi et al. 2014

OUTLINE

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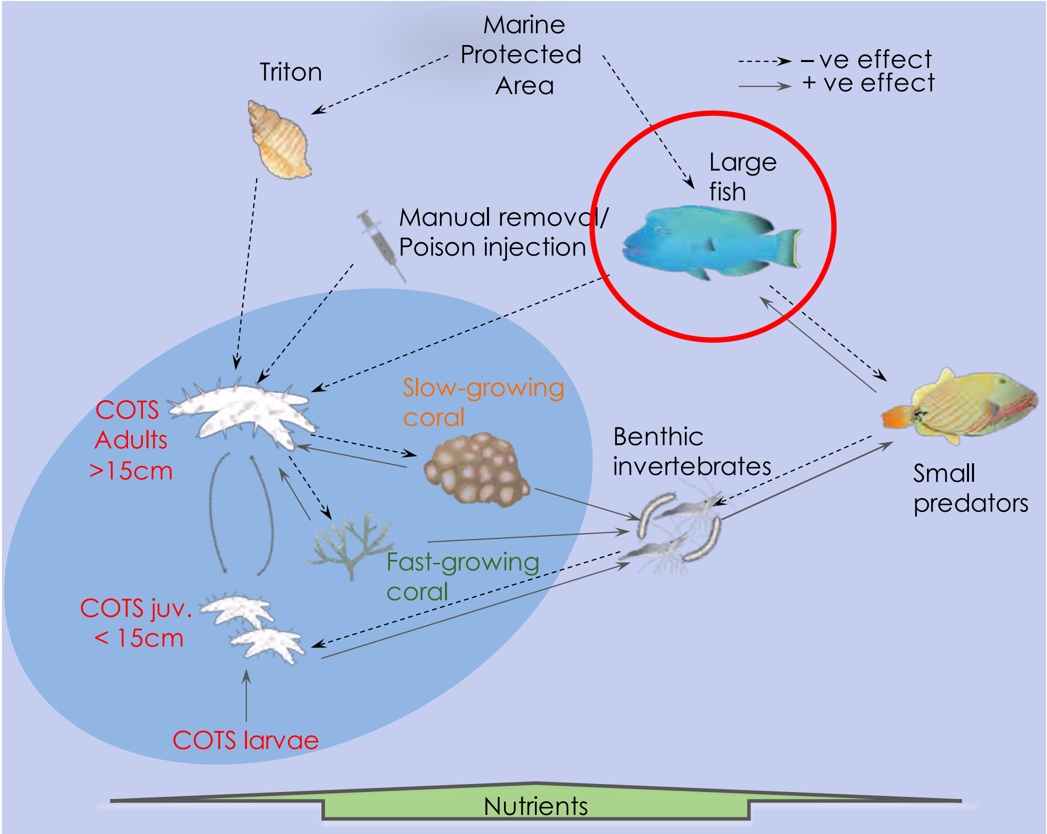
EXAMPLE 1 – CROWN OF THORNS STARFISH (COTS)

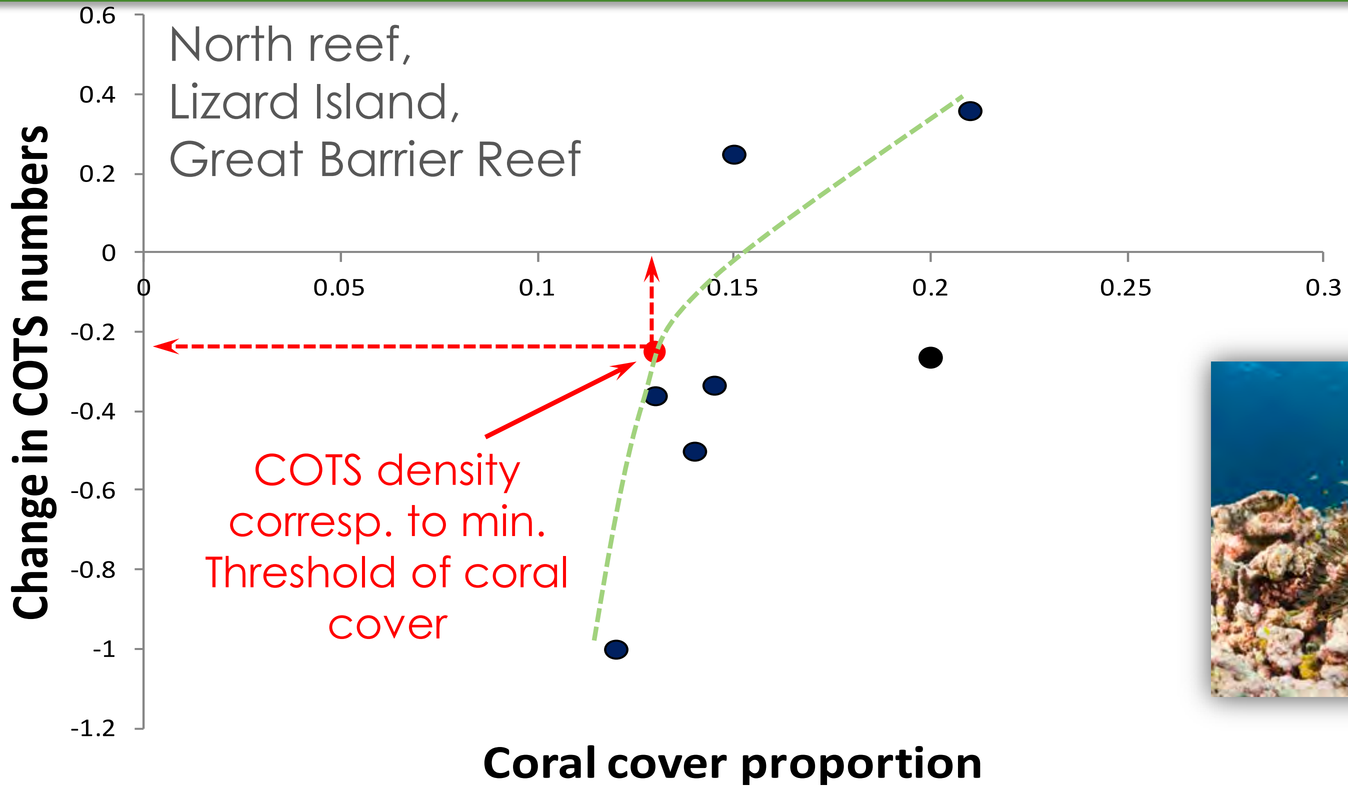
(B) Crown of Thorns Starfish (COTS) - coral



1. Model resilience of alternative ecosystem structures
2. Tipping points to inform field management controls

Source: Morello et al (2014) MEPS

Estimate an ecological threshold for COTS populations



Average threshold COTS density:

7.1 (± 2.3) adult COTS ha^{-1} ≡

0.028 (± 0.01) adult COTS min^{-1} ≡

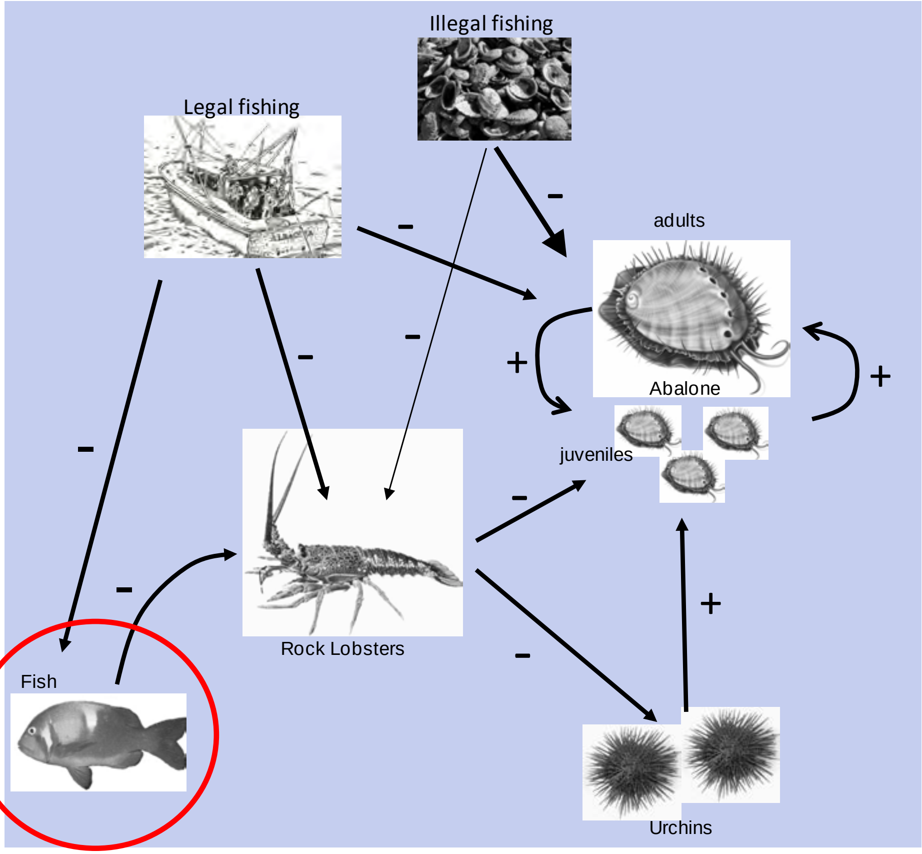
Coral cover of ~14%

Data from Lizard Is. (Pratchett, 2005, 2010)

Source: Plaganyi et al (2014) MEPS

EXAMPLE 2 – ABALONE-URCHIN-LOBSTER

(C) Abalone – urchins (shelter)

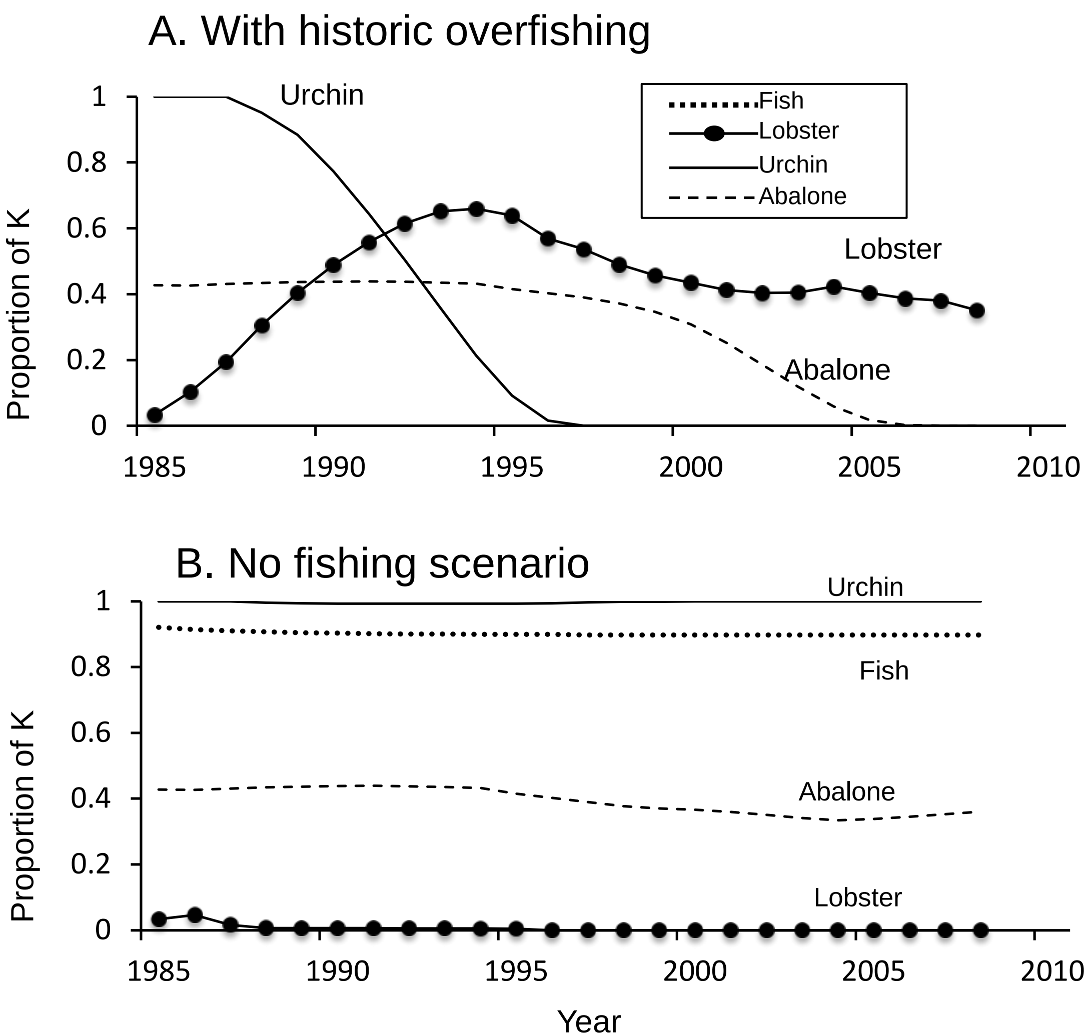


1. Model resilience of alternative ecosystem structures:

   Has overfishing altered the system resilience?

Source: Blamey et al (2014) Ecol. Mod.

Resilience to climate change



Overfishing scenario:

Lobsters invade range of abalone, deplete urchins, change benthos and crash abalone population

Sustainable fishing scenario:

Lobsters invade range of abalone, but are kept in check by fish hence system resilient to changes

From Blamey, Plaganyi, Branch 2014. Ecol. Mod.

OUTLINE

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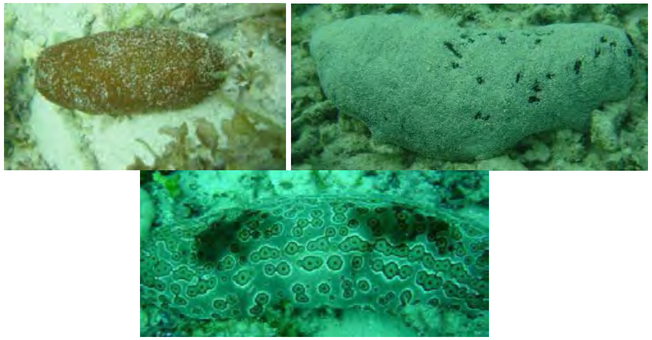
CLIMATE-SMART STRATEGIES

Sea cucumber / bêche-de-mer
Testing alternative management strategies: resource impacted by fishing and climate

- **Fishery:** 8 bêche-de-mer species on 27 reef units (in 8 zones) in the Torres Strait, NE Australia, fished by indigenous fishers
- **Medium term: 2011-2030**
- **Attribution**. Climate change identifiable as separate from other impacts (fishery exploitation)

Dry sandfish
>$200 kg

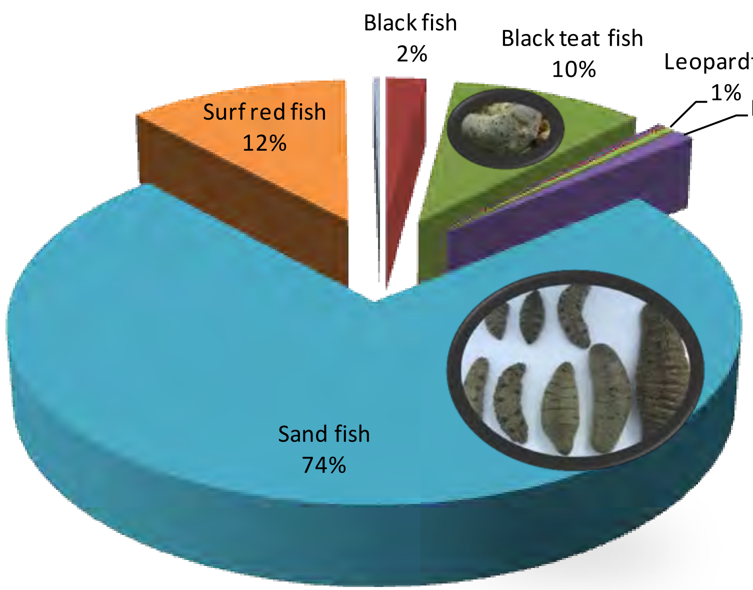


SEA CUCUMBER SPATIAL MULTISPECIES MODEL

- **Data-poor – uncertainty re biological understanding and parameters**

8 zones / areas

Torres Straits, Catch composition, 1993 - 2007



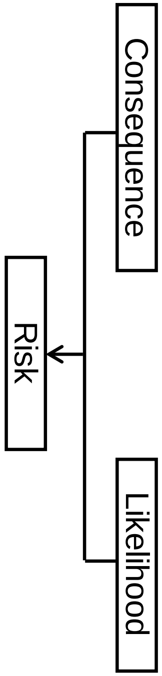
Location choice modelled as a simple function describing utility by zone

8 species

SEA CUCUMBER SPATIAL MULTISPECIES MODEL

- Data-poor – uncertainty re biological understanding
- Uncertainty re risks of climate change
- Uncertainty re impact of climate change on population

2030	Impact	Climate change component								
Life stage	Component	SST	Acidification	SL	Currents, Torres Strait	Storms and Cyclones	Rainfall	Phytoplankton productivity	Seagrass	Coral Reef
Juvenile	Growth	H	L	N	N	N	N	L	L	N
	Mortality	H	L	N	N	L	N	N	M	N
	Carrying cap.	N	N	M	N	L	N	N	L	N
Adults	Growth	H	N	N	N	N	N	N	N	N
	Mortality	H	N	N	N	L	N	N	N	N
	Carrying cap.	N	N	M	N	N	N	N	N	N
	Reproduction	H	N	N	N	N	N	N	N	N
Larvae	Growth	H	L	N	N	N	N	M	N	N
	Mortality	H	L	N	N	N	N	M	N	N
	Advection	N	N	N	N	N	N	N	N	N



RISK MANAGEMENT NEEDS TO ACCOUNT FOR MULTI-DIMENSIONAL UNCERTAINTIES

'PERMANENT PRESS' RESILIENCE

BIOLOGICAL	CLIMATE VARIABLES (and downscaling)	LIKELIHOOD OF CLIMATE IMPACTS (HIGH, MEDIUM, LOW RISK)	SEVERITY OF POTENTIAL CONSEQUENCES
Monitoring data	SST & sea level rise fairly certain	High risk predictions most plausible	Growth first increases then decreases with increasing temperature
Population dynamics model	Ocean pH (acidification, bleaching, coral reef habitat)	Consider cumulative effects of high and medium risk predictions	Positive and negative effects on recruitment and larval survival
Fishing behaviour	Storms & cyclone increases in intensity		Complex contributors to overall mortality rates
Future markets	Phytoplankton productivity		Effect of changes in habitat
Implementation and control	Ocean currents		Multispecies and ecosystem effects

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RISK MANAGEMENT NEEDS TO ACCOUNT FOR MULTI-DIMENSIONAL UNCERTAINTIES

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	Storms & cyclone increases in intensity		Co… o ov…
Future markets	Phytoplankton productivity		Effect of changes in habitat
Implementation and control	Ocean currents		Multispecies and ecosystem effects

M1 – ave *M*
M2 – low *M*
H1 – *h*=0.7
H2 – *h*=0.5

R1 – High risk only
R2 – High+Medium risk

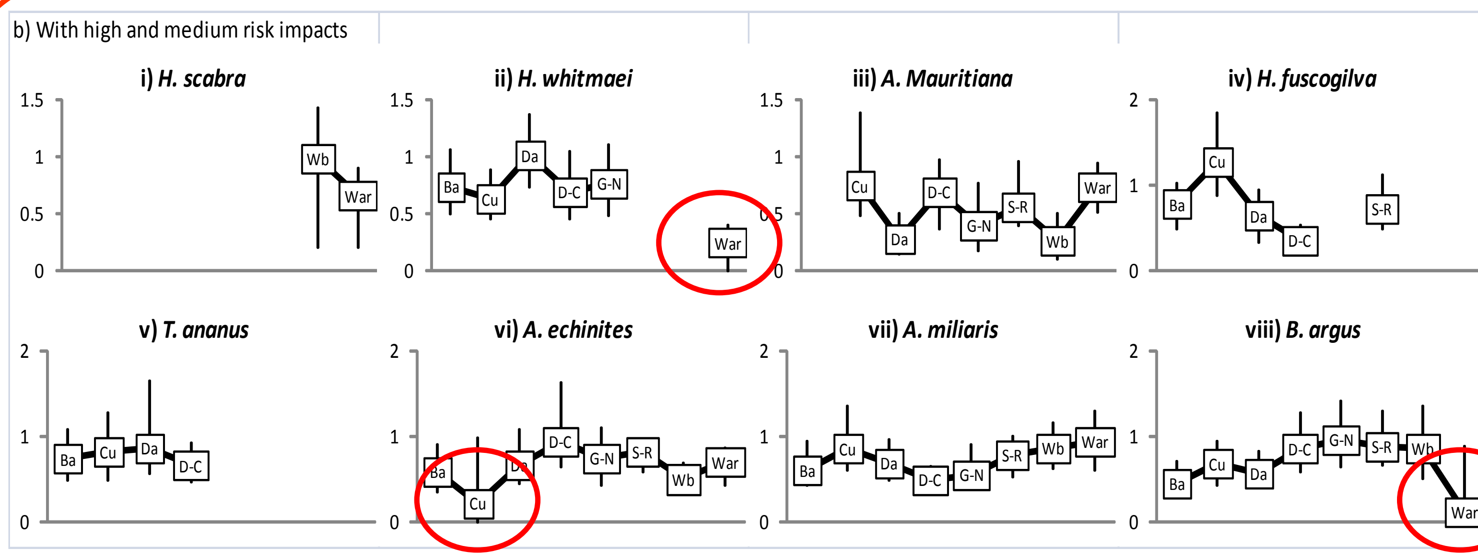
I1 – base
I2 – double severity of impacts

*Outside scope of study – could use multiple climate models; emission scenarios

Results: local depletion per zone and species

Quantify risk (and associated uncertainty) to all 8 species in each of the 8 zones

DEPLETION (Bsp) RELATIVE TO NO FISHING & NO CLIMATE CHANGE



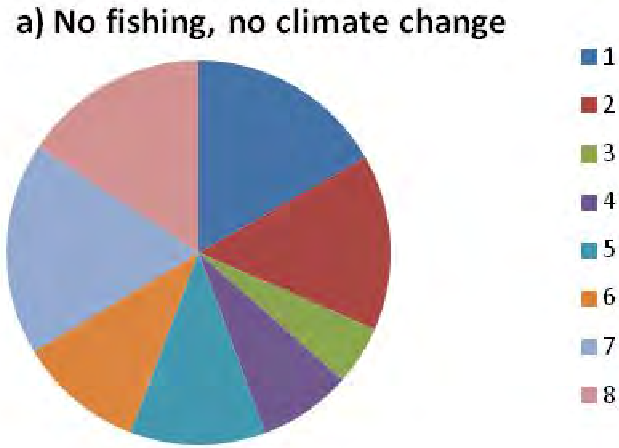
Increased risk under climate change

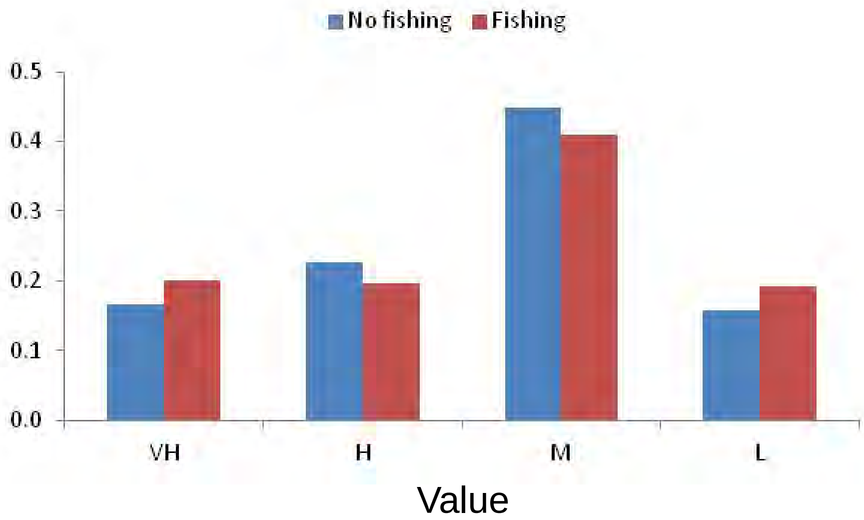
Performance Summary - Harvest Strategies

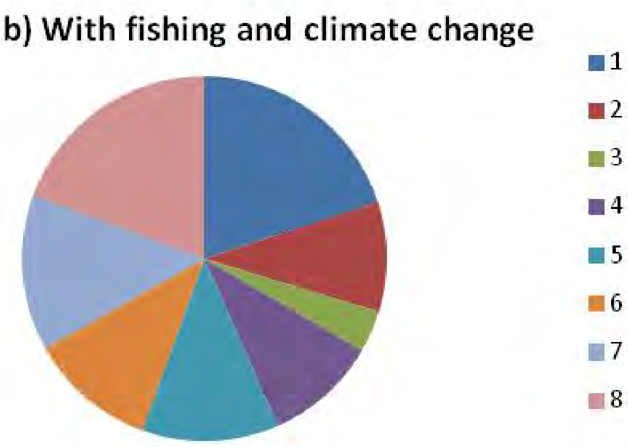
Harvest strategy	Risk of suboptimal management	Risk of depletion below Blim	Risk of local depletion	Average annual profit (US$ million)
A. Current catch(status quo)	**50**	**13**	**12**	**5.31**
B. No monitoring:				
Double catches	75	25	23	10.6
Profit maximisation	50	13	12	5.31
Location choice based on area and distance	50	13	16	5.31
Spatial rotation (3 yr)	25	13	5	3.35
Closed areas/sensitive species (Warrior, Sand	13	13	9	2.72
Multi-species catch composition	13	13	6	3.08
C. Adaptive feedback/monitoring:				
Hockey stick	38	13	9	3.65
Hockey stick with spatial management	13	13	1	5.31
Spatial closure (Single species in Zone) (30%K	38	13	8	5.11
Spatial closure (Entire Zone) (30%K trigger)	13	13	5	3.19
Spatial closure (Entire Zone) (20%K trigger)	13	13	7	4.09

- Risk of sub-optimal management: the percentage of species for which the median 2030 spawning biomass level was less than Btarg (0.48K)
- Risk of depletion below Blim: percentage of species for which the lower 90% confidence limit of the 2030 RS projections was less than Blim

Changes in Species Composition / Mixed harvest bag







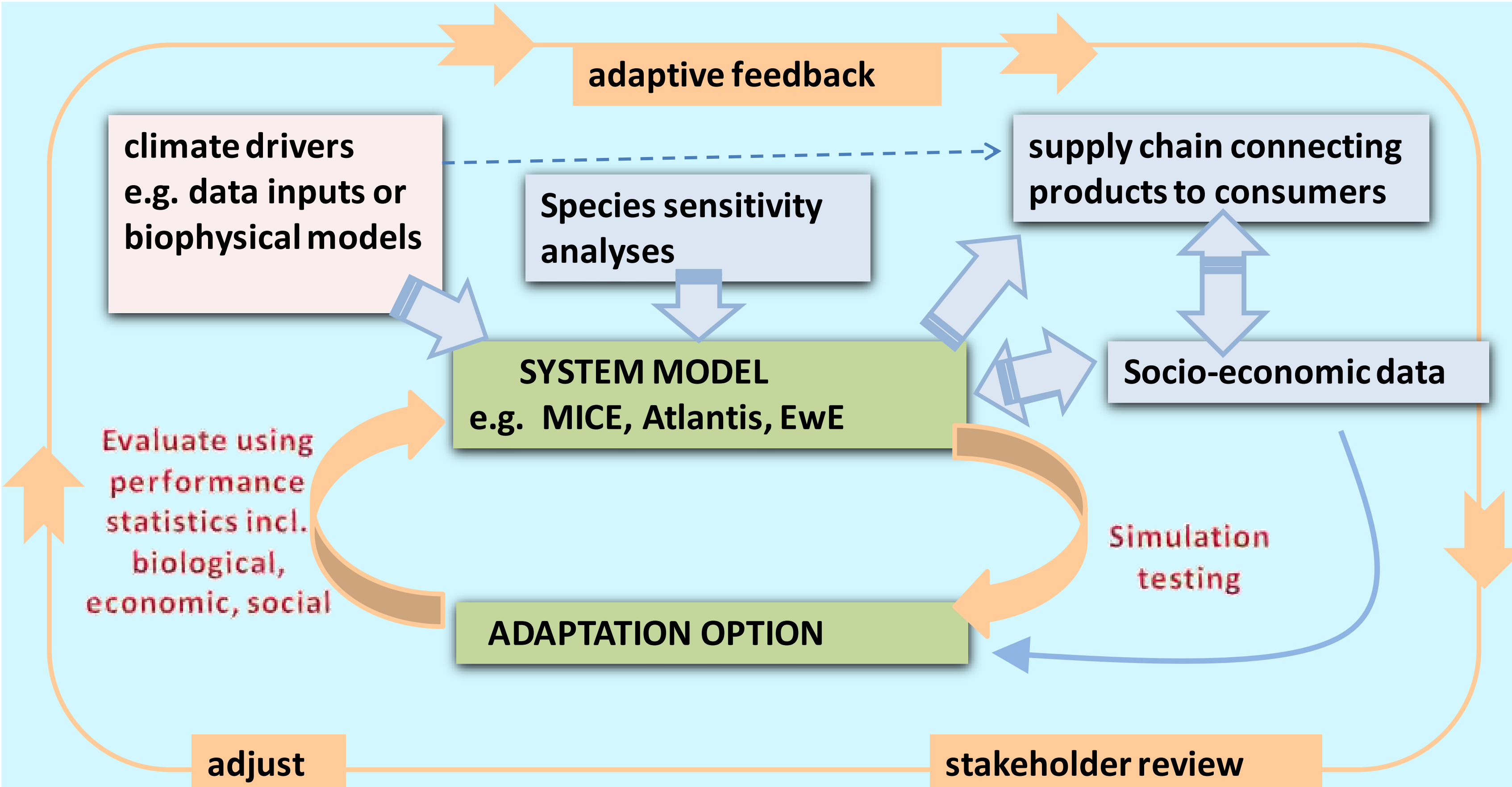
No.	Common name	Species name
1	Sandfish	*Holothuria scabra*
2	Black teatfish	*Holothuria whitmaei*
3	Surf redfish	*Actinopyga mauritiana*
4	White teatfish	*Holothuria fuscogilva*
5	Prickly redfish	*Thelenota ananus*
6	Deepwater redfish	*Actinopyga echinites*
7	Hairy blackfish	*Actinopyga miliaris*
8	Leopardfish	*Bohadschia argus*

MSE as a risk management tool

- Climate **risk assessment** used as an input to dynamic model
- **Reference Set** (rather than single model) used to capture key uncertainties = ENSEMBLE
- Demonstration of use of MSE to test the **performance** (and adaptability) (especially in the face of **uncertainty**) of alternative **harvest strategies** in meeting fishery objectives, such as ensuring:
  - low **risk** of depletion (overall and local)
  - **high probability** of good catch / average profits
  - low **risk** of changing the multi-species community composition
  - **high probability** of managing through climate variability and change
- **Climate-smart** data poor strategy example:
  - 3-yr spatial rotation strategy for sea cucumbers

MSE – Management Strategy Evaluation

NEXT STEPS – *test climate-smart adaptation options*



www.marinehotspots.org

A Belmont Coastal Vulnerability Theme Project

Global Understanding for local solutions: Reducing vulnerability of marine-dependent coastal communities (GULLS)

‘EXTREME EVENT’ RESILIENCE’:
If a system is perturbed, will it bounce back or fall over?

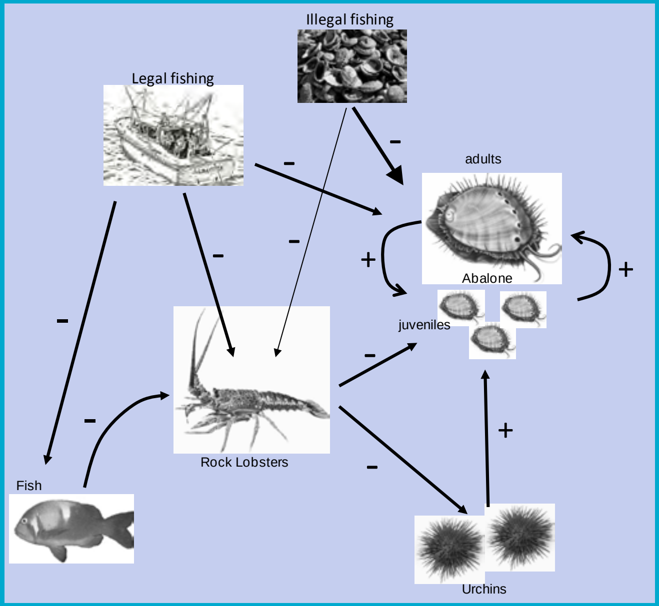
1. Multispecies & ecosystem models:

   a. Understand responses to perturbations, recovery times, resilience

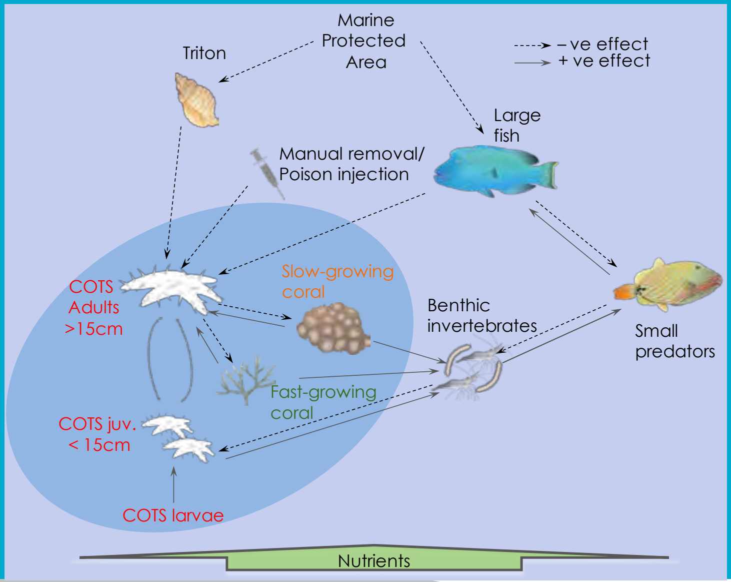
   b. Increasing variation in population numbers (marine species) may be a useful indicator that a system is approaching a tipping point

2. Application examples:
   a. Overfishing reduces resilience
   b. Thresholds for management

Model results can inform monitoring and management



Blamey et al. 2014



Morello et al. 2014

‘PERMANENT PRESS’ RESILIENCE’: *Climate-smart strategies to build resilience to multiple stresses*

1. MSE can support effective risk management
2. Uncertainty in biological understanding + risk of climate change effects and their impacts
3. Even when integrating across broad range of uncertainties, possible to distinguish between performance of alternative management strategies

Need to road-test climate-smartness of management strategies

Acknowledgements:

Plagányi, É., Ellis, N., Blamey, L.K., Morello, E., Norman-Lopez, A., Robinson, W., Sporcic, M., Sweatman, H. 2014. Ecosystem modelling provides clues to understanding ecological tipping points. *Mar Ecol Prog Ser* 512: 99–113

Photo: Rob Tarr

Blamey, L.K., Plagányi, É.E. and G.M. Branch. 2014. Was overfishing of predatory fish responsible for a lobster-induced regime shift in the Benguela? *Ecol. Modelling* 273: 140-150

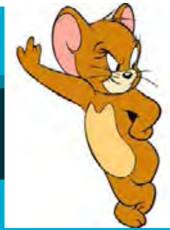
Plagányi, É.E., Skewes, T., Haddon, M. and N. Dowling. 2013. Risk management tools for sustainable fisheries management under changing climate: a sea cucumber example. *Climatic Change* 119:181–197

Plagányi, É., Punt, A., Hillary, R., Morello, E., Thebaud, O., Hutton, T., Pillans, R., Thorson, J., Fulton, E.A., Smith, A.D.T., Smith, F., Bayliss, P., Haywood, M., Lyne, V., Rothlisberg, P. 2014. Multi-species fisheries management and conservation: tactical applications using models of intermediate complexity. *Fish Fisheries* 15:1-22

Obrigado
Thank you

Oceans and Atmosphere Flagship
Dr Éva Pláganyi

t +61 7 3833 5955
e eva.plaganyi-lloyd@csiro.au
w www.csiro.au



Models of
Intermediate
Complexity for
Ecosystem
assessments

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