CSIRO acknowledges the Traditional Owners of the land, sea and waters, of the area that we live and work on across Australia. We acknowledge their continuing connection to their culture and we pay our respects to their Elders past and present.

Multiple interacting species and the management challenges they pose

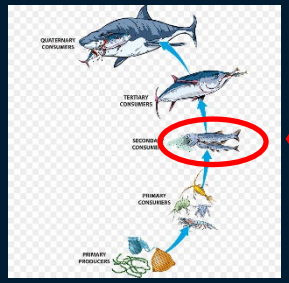
Australia

Éva Plagányi |16 August 2022

Seventh Meeting of the Scientific Coordination Committee (SCS7), Sitka

Harvest Strategies: from single-species to EBFM

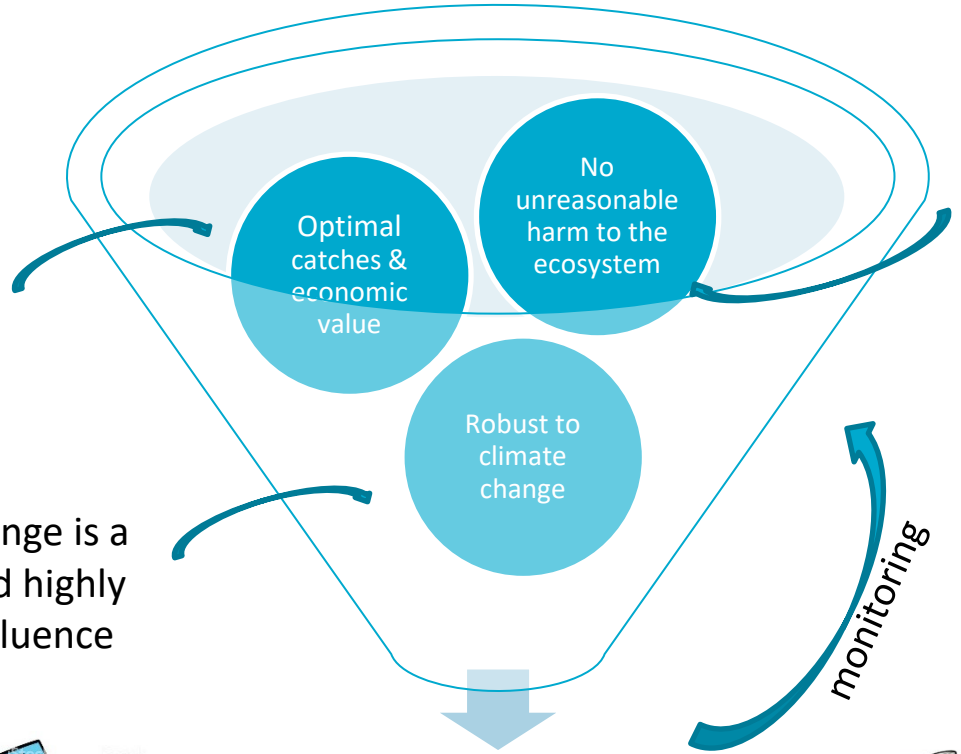
- Indicators (additional data or model outputs to inform on state of ecosystem)
- Reference Points (multispecies?)
- Monitoring (new challenges)
- Method of assessment (ecosystem models, MICE?)
- Decision rules / Harvest Control Rules (how to adjust to account for multispecies?)



Stock assessment
vs
EBFM = Ecosystem Based Fisheries Management

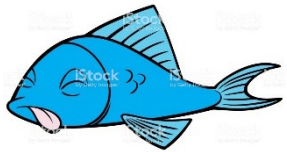
RIP Fisheries Management: Robust to Interacting Populations

Trade-offs in achieving multispecies MSY or MEY; targets need refining

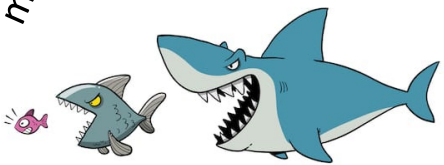


How to quantify? Declines in species, system resilience, tipping points

Climate change is a growing and highly dynamic influence



RIP fisheries management



Objectives when managing interacting species

1. Whole of Ecosystem

- Protect ecosystem integrity

2. Key species / influential trophic connections

- Focus on key species eg forage fish or project changes in interacting species

3. Conservation concern

- Focus may not primarily be due to trophic interactions but eg threatened status

4. Pest or immigrant/shifting species

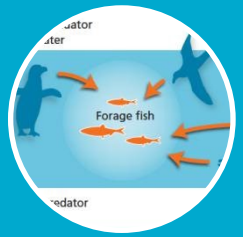
- Pest species or shifting distribution altering system dynamics: manage for desired outcome

Achieving Management: Robust to Interacting Populations

Whole Ecosystem

Structure & function; Resilience; Upper limits; MMSY, MMEY

Key (trophic) species



Optimal management; Acceptable impacts on non-target species; Improve predictive ability

Threatened species

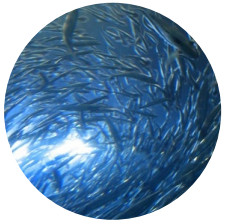
Limit mortality of threatened species;Bycatch mitigation; Recovery plans

Pest/Immigrant species

Pest: manage to protect rest of ecosystem; Climate immigrant: manage to impede or enhance immigration

Common models and methods: MICE, MSM, MSE, Risk assessments

Plaganyi et al. (in prep)



1. Whole of Ecosystem

- 1a) Protect overall ecosystem structure and function
  - Ecosystem indicators
  - Network approaches
  - Ecological Risk Assessments (ERAs)
  - Theoretical, empirical & model-based understanding tipping points
  - **Multispecies Models (MSMs) & strategic ecosystem models**
  - **Management Strategy Evaluation (MSE) testing**
  - **Risk assessment approaches**

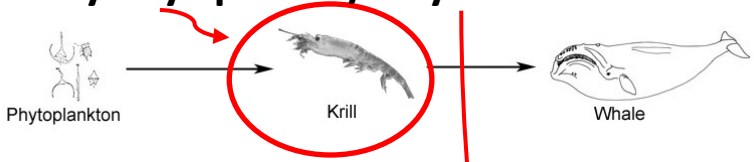
» Need rigorous science to meet biodiversity objectives but not overly penalise fishing industry given often pertains to major stocks

- 1b) Not exceeding the overall limits of system productivity

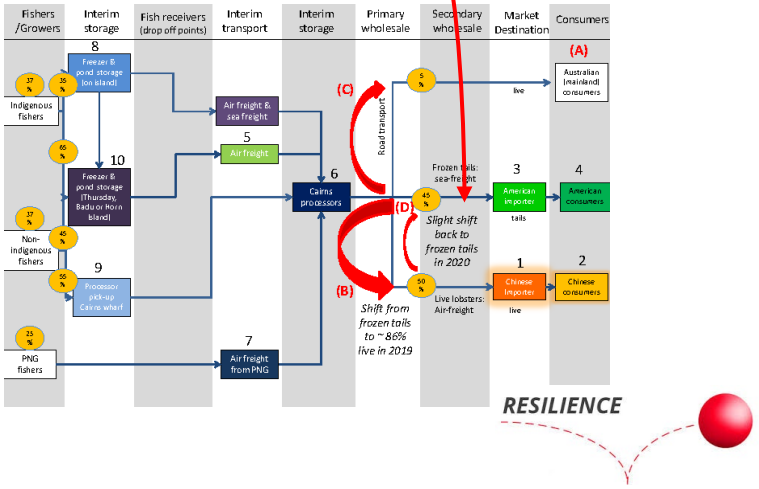
1a) Protect overall ecosystem structure and function

KEY NODES | TIPPING POINTS

1. Identify key species / key nodes in network



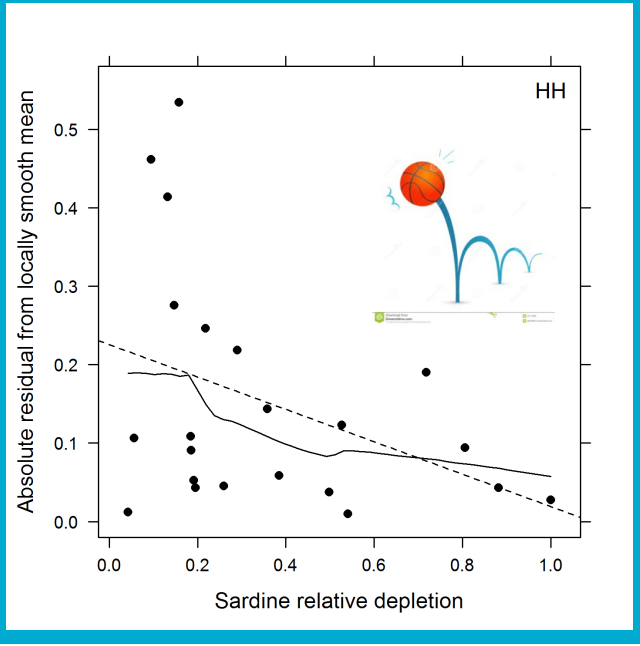
2. Quantify system resilience to perturbations



Plaganyi & Essington Fish Res 2014, Plaganyi et al. PLOS one 2014

Indicators: Increasing variation in population numbers

Multispecies indicators?



Plaganyi et al. MEPS 2014

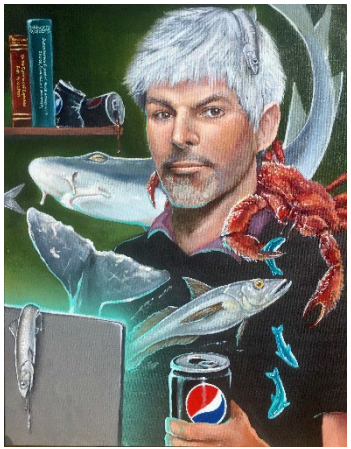
1b) Not exceeding the overall limits of system productivity

Target Reference Level	Limit Reference Level
• MMSY • Dynamic MMSY (e.g. Free et al 2019) • MMEY?	• Multispecies BLIM? • Conservative BLIM for some species • Ecosystem overfishing level (total catches ≤new production); NAFO roadmap (eg Koen-Alonso et al. 2013, 2019)

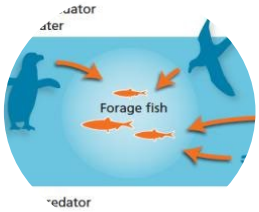
MMSY: Multispecies Max Sust Yield
MMEY: Multispecies Max Economic Yield
BLIM: limit reference point

2. Key species / influential trophic connection

- 2a) Identify and account for key species in an ecosystem
  - Indices or modelling approaches to identify key species



- 2b) Account for multispecies interactions
  - **MSMs & strategic ecosystem models**
  - **MSE testing**
  - **Risk assessment approaches**



Why MICE?

Models of
Intermediate
Complexity for
Ecosystem
assessments

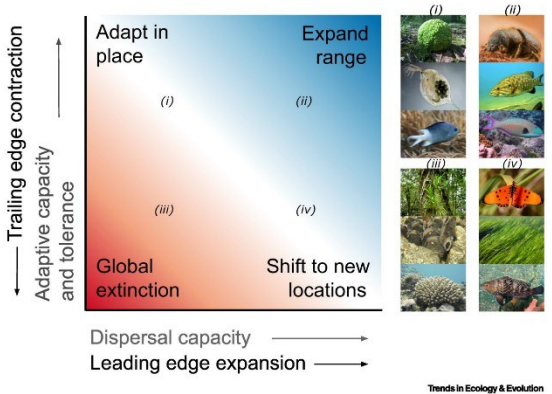
3. Interactions with species of conservation concern

- Meet conservation objectives
  - **MSMs & strategic ecosystem models**
  - **MSE testing**
  - **Risk assessment approaches**

4. Pest or climate immigrant species

- Manage pest species (or invading/shifting species)
  - Integrated Pest Management Framework
  - Climate-linked model with connectivity
  - **MSMs & strategic ecosystem models**
  - **MSE testing**
  - **Risk assessment approaches**

Pinsky et al. TREE 2022

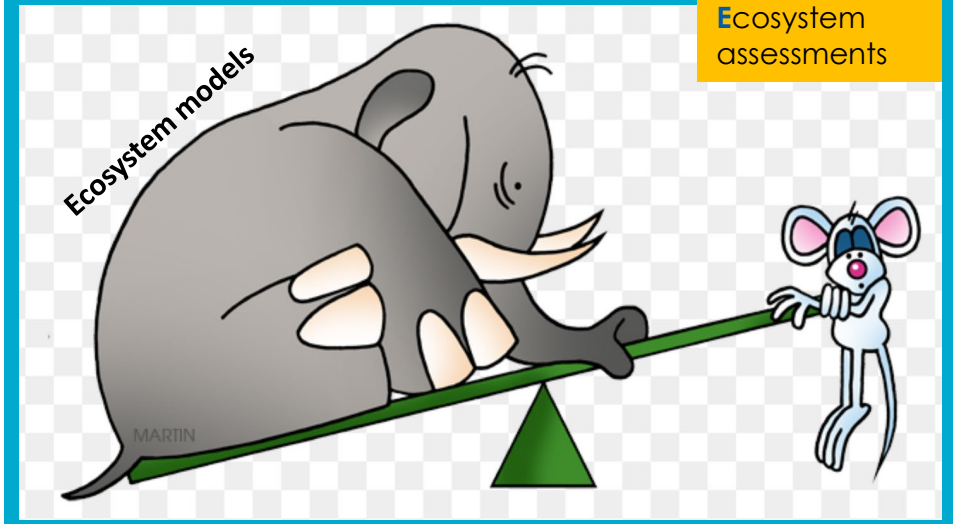


Where are the gaps in developing guidelines?

- We have many modelling tools – but not enough MICE!
- We sometimes have enough data?
- We need to define Operational Objectives (different for 4 suggested categories)
- We need Targets, Limits and/or Risk Thresholds to guide what's acceptable (regionally and nationally)
- Given above, we can use models to develop appropriate decision rules

Should MICE have more weight?

Models of
Intermediate
Complexity for
Ecosystem
assessments



Models of
Intermediate
Complexity for
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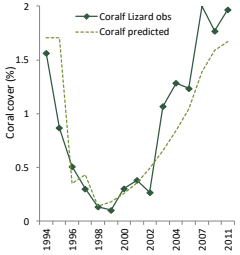
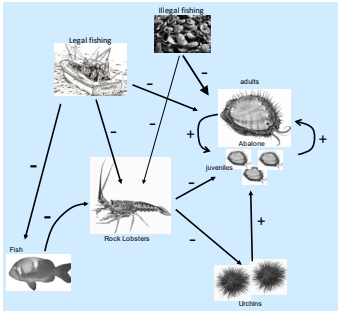
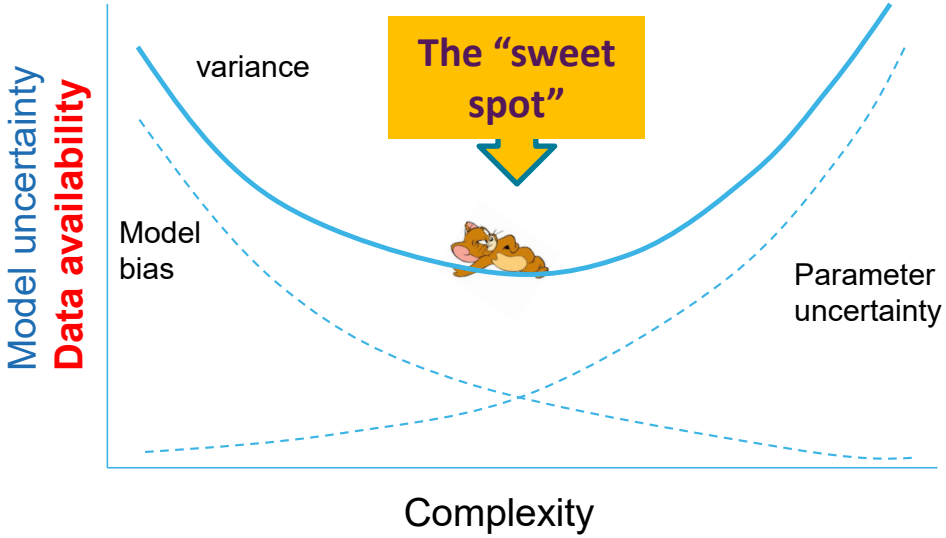
assessments



Morello et al (2014)



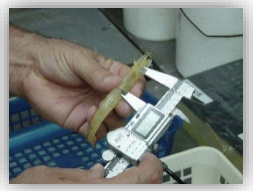
Blamey et al (2014)



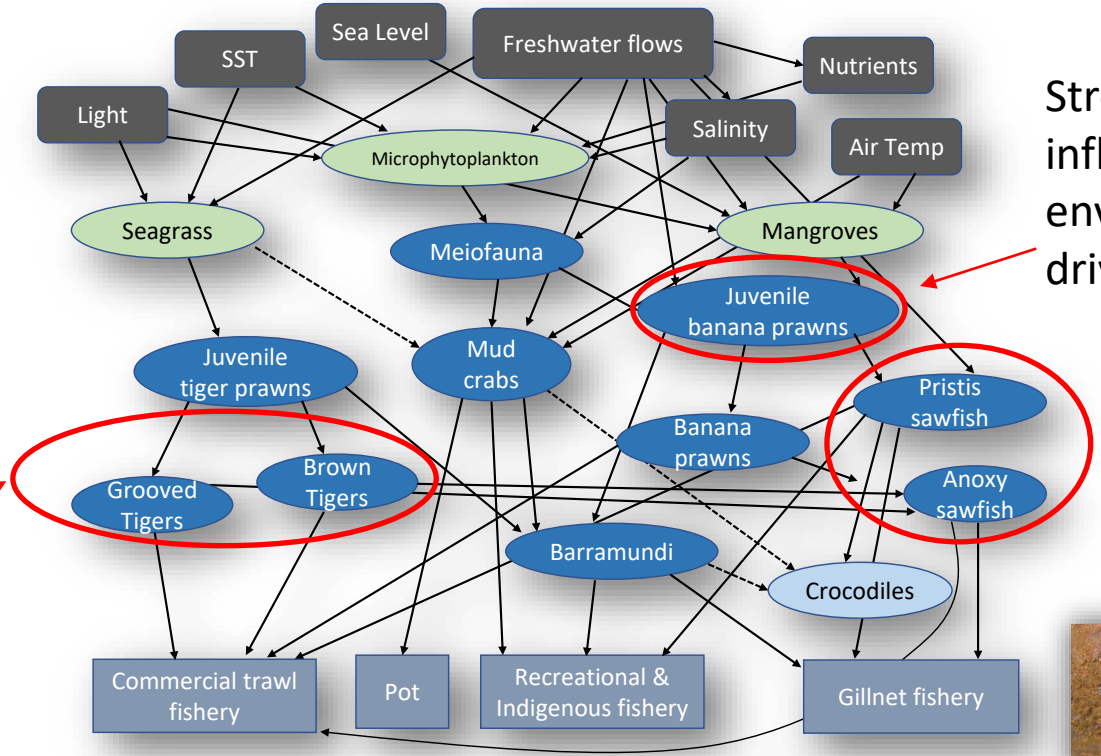
Plagányi et al. 2012; Collie et al. 2014 Fish Fisheries

- Ability to address tactical questions
- Intermediate complexity
- Focus on subset of ecosystem
- Tailor equations depending on data availability
- Address specific management question
- Fit to data
- Account for major uncertainties
- Linked physical and human dimensions
- Stakeholder consultation

An example: Australia's Northern Prawn Fishery broader ecosystem



Strongly influenced by environmental drivers

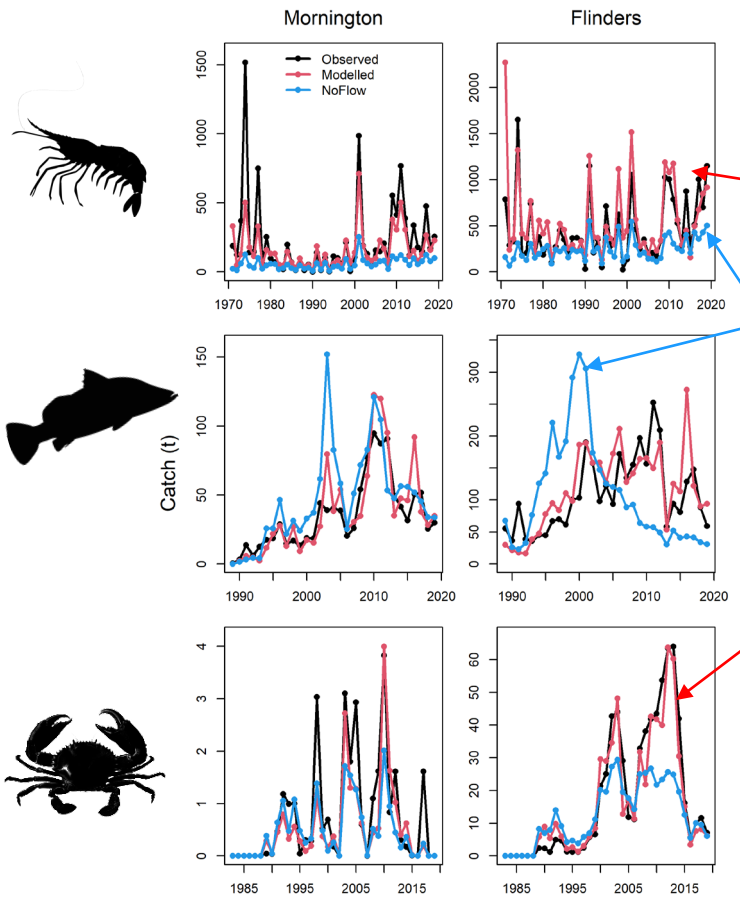


Managed using multispecies dynamic MEY

Globally-threatened sawfish: interactions

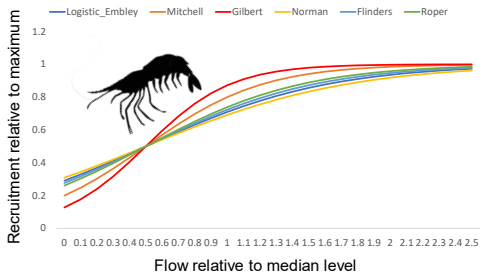
Plagányi et al. In Review

MICE: Spatial Multispecies linked with River Flow Model



No environmental driver

With environmental driver



- ✓ Fitted to 30-50yrs weekly or monthly **catch data**
- ✓ Ensemble to account for uncertainty

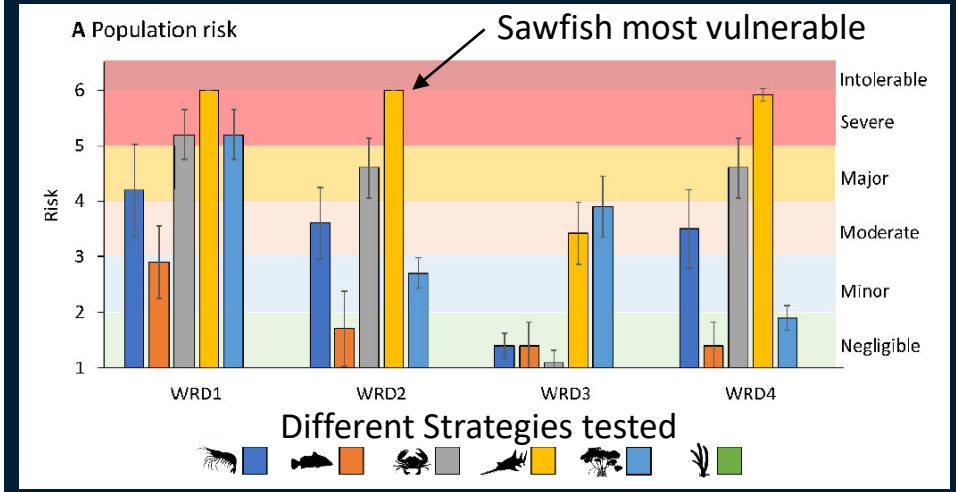
Plagányi et al. In Review

Example 1

MICE ensemble quantifies risk: Managers decide acceptable risk level

Risk Ratings	Scores	Criteria for local	Criteria for regional
Negligible	1	<5% locally	<5% locally
Minor	2	Minimal impact (<10%)	Minimal impact (<10%)
Moderate	3	At least 10% decrease in indicator (10-20%)	At least 10% decrease in indicat (10-15%)
Major	4	Wider and long-term impacts eg at least 20% decrease in indicator (20-30%)	Wider and long-term impacts eg least 15% decrease in indicator (15%-25%)
Severe	5	Very serious impacts - decline of at least 30% (30-50%)	Very serious impacts - decline of least 25% (25-33%)
Intolerable	6	Widespread and unacceptable loss - decline of at least 50%	Widespread and unacceptable - decline of at least 33% (i.e. one-third regionally)

Regional risks of alternative development scenarios

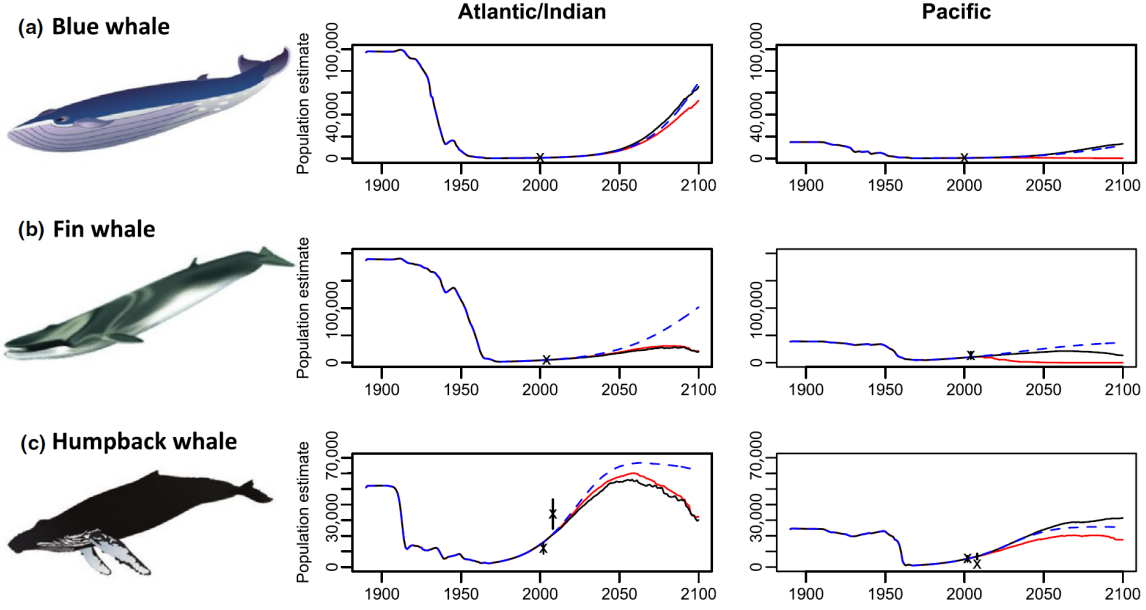


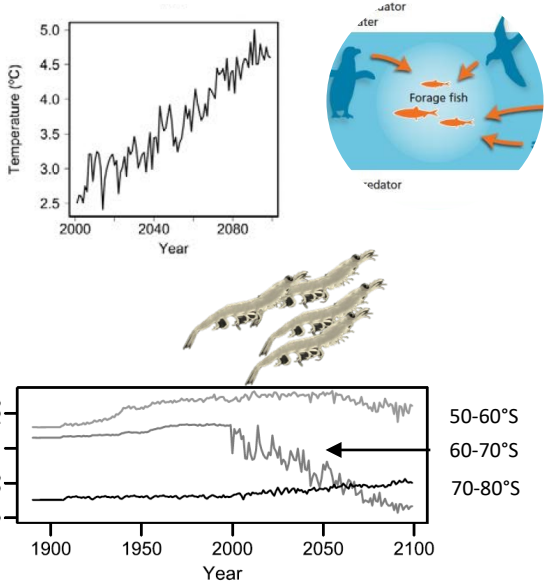
*MICE outputs – ensemble average (+STD) ; not Management Strategy Evaluation tested

Plagányi et al. In Review

Example 2: MICE Whale-Krill-Climate

----- no climate — climate drivers — climate incl sea-ice

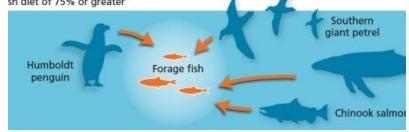




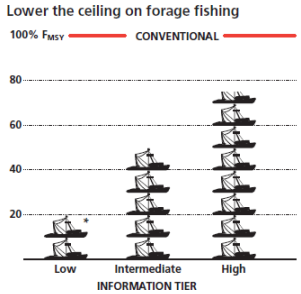
Historical trajectories driven by fishing; projections depend on prey (krill) & responses to increasing temperatures

Tulloch et al. 2017, 2019

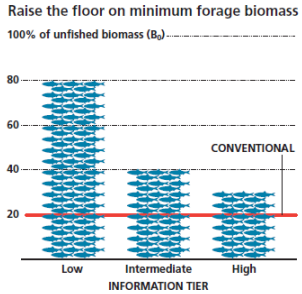
Figuring Forage Fish F's



Lower F_{targ}



Higher B_{lim}



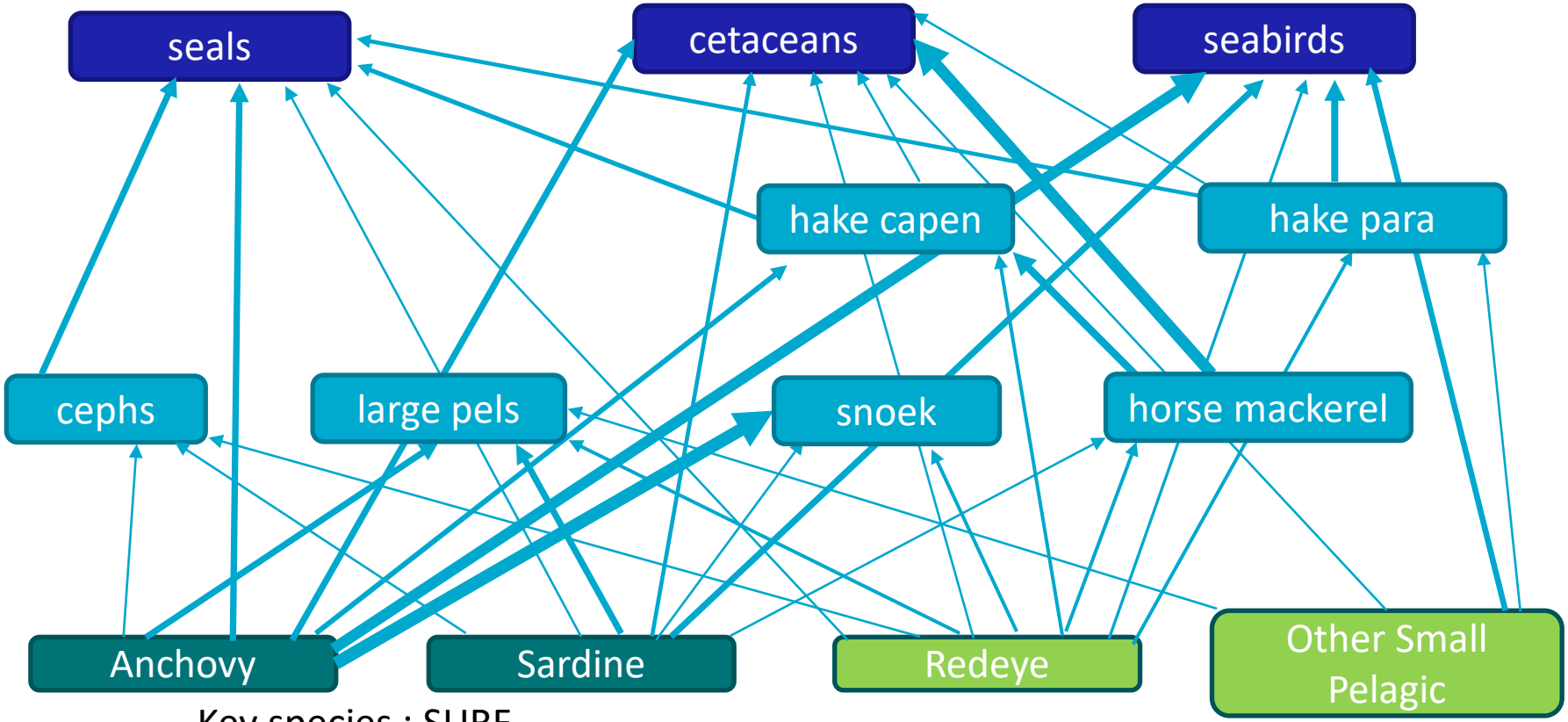
- Lenfest Pikitch et al. (2014) study: used EwE models and multiple independent lines of evidence
- Smith *et al*. (2011): similar conclusions using EwE and Atlantis

- CCAMLR Article II : acknowledging the importance of maintaining the ecological relationships between harvested, dependent and related populations of marine resources
- Spatial management approaches for central place foragers (Watters et al. 2013; Plaganyi et al. 2012; Free et al. 2021)
- Tailored approaches eg use MSE to test risk to penguins of alternative management strategies (Robinson et al. 2015)
- Risk-based management scheme given fishing amplifies forage fish population collapse (Essington et al. 2015)
- MSMs with portfolio effect

But see also Hilborn et al. 2017; Free et al. 2021 (less forage fishing ≠increase in predator); Hilborn et al. 2022 (weak relationship due to high natural variability & portfolio effect)

Southern Benguela Forage Fish portfolio

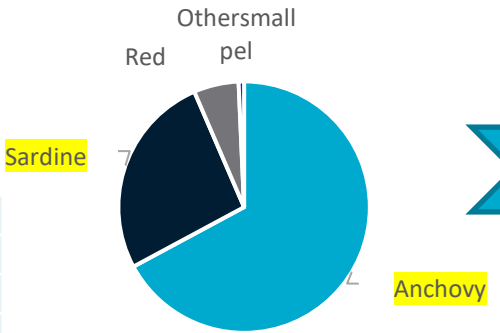
Simplified foodweb – based on Shannon et al 2008



Key species : SURF

Changing “keyness” of portfolio

Base



	SURF
Anchovy	**0.002**
Sardine	**0.001**
Redeye	<0.001
Other small pel	<0.001

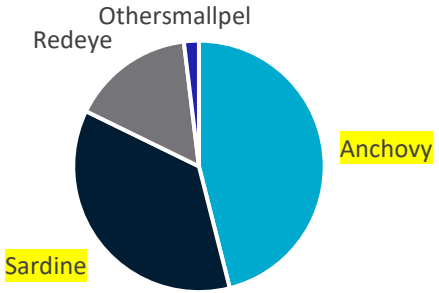
$$SURF_i = \frac{\sum_{j=1}^{S} p_{ij}^{\,2}}{L}$$

diet

links

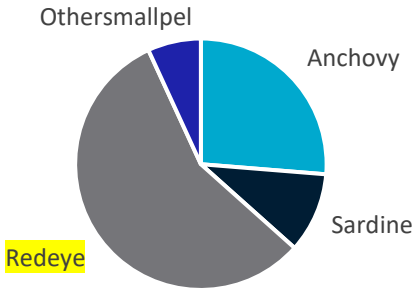
minor?
same key spp

Elastic - anchovy SURF halved; sardine same



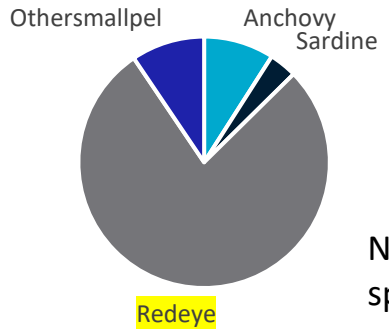
major?
lose key status

Stretched- anchovy&sardine 20% SURF



regime shift?

Tipping point? Anchovy & sardine 10% SURF



New key species

SURF (SUpportive Role to Fishery ecosystems) index (Plaganyi & Essington 2014)

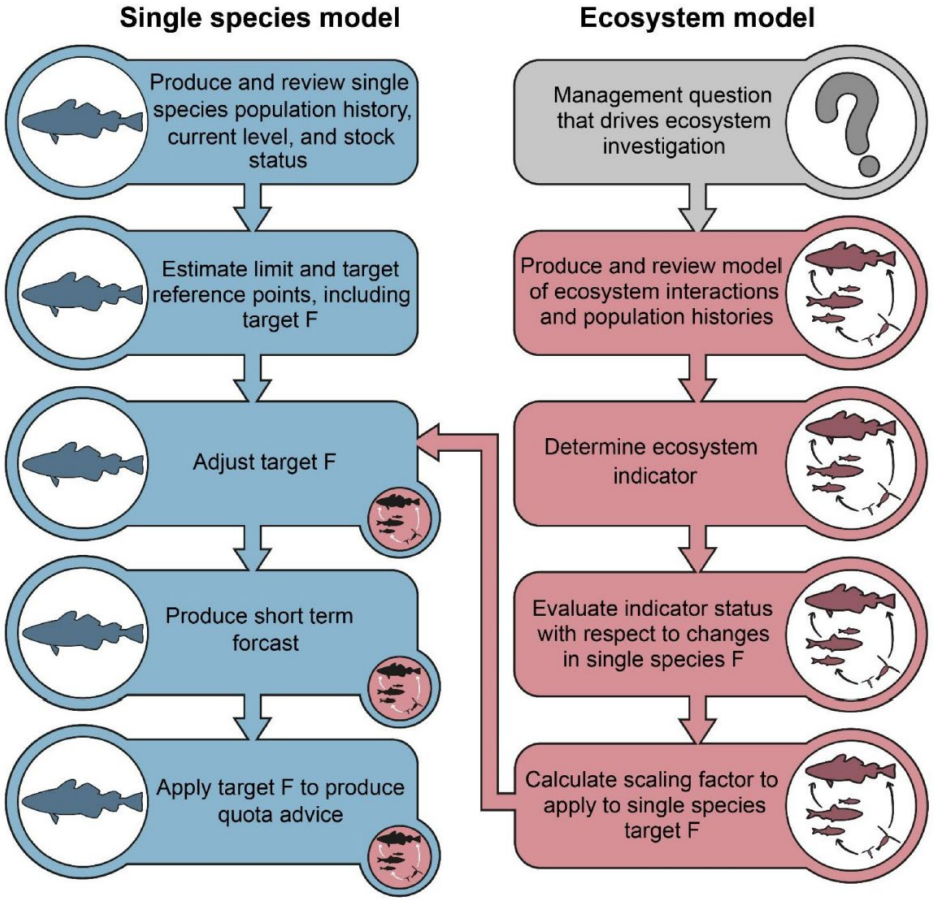
Some “key” thoughts re Ecosystem Resilience

- Changing ecosystem structure – especially key species – changes resilience of system
- Changes may be due to fishing or climate change
- Suggest simplify complexity using indices like SURF: define acceptable thresholds for change eg 50%* reduction in SURF as “lower limit ecosystem resilience threshold” – monitor with diet data so fishery catches don’t alter system beyond resilience threshold
- Use MSE to test appropriate choice of resilience threshold value

*SURF uses square of diet proportions so 50% decrease in SURF is 71% average decrease in all diet proportions (or variable proportions per species); in example this is biggest change before anchovy no longer function as a key species

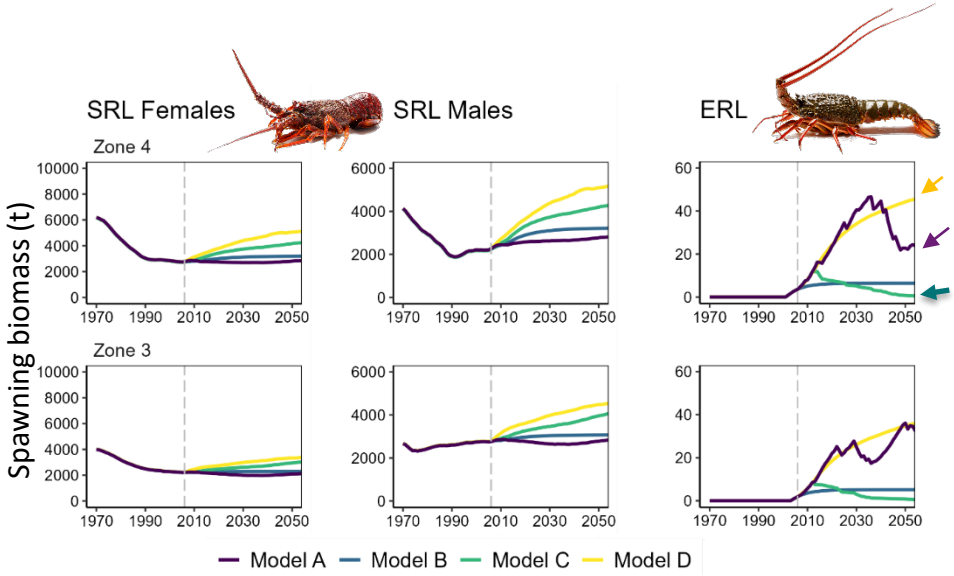
Adjusting Reference Levels: Howell et al. (2021); Bentley et al. (2020)

Howell et al. (2020) *".. In the Irish Sea, the focus was on identifying ecological drivers acting on the stocks, whereas in the US, the focus was on the menhaden stock as a driver in the ecosystem through trophic interactions. In both situations, a mechanism of adjusting the Ftarget to produce a revised Feco was identified as an efficient method for incorporating ecological information into the stock assessment process."*



Howell et al. (2020)

Example 3: Integrating physiological responses to Climate Change in MICE: complex climate and trophic drivers change predictions



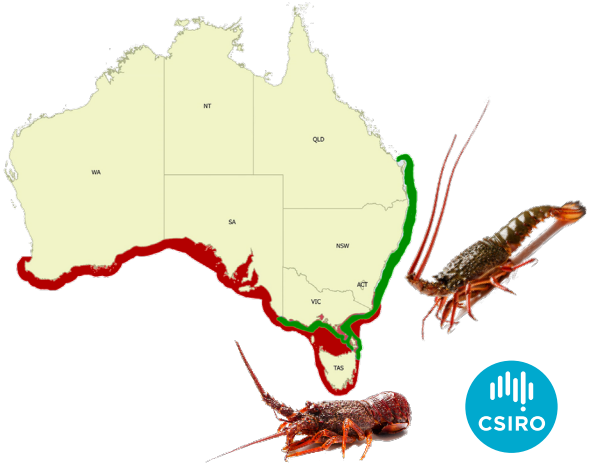
Heatwave effect

No physiological effects

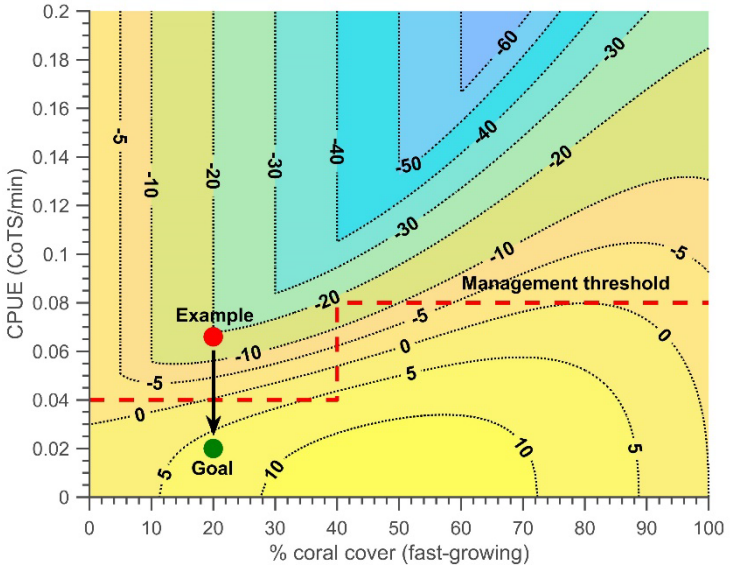
With physiological effects (aerobic scope and escape speeds)

Twiname et al. In Review GEB
See also Sunday et al. 2022 GCB

We need NEW models or our PREDICTIONS will increasingly FAIL

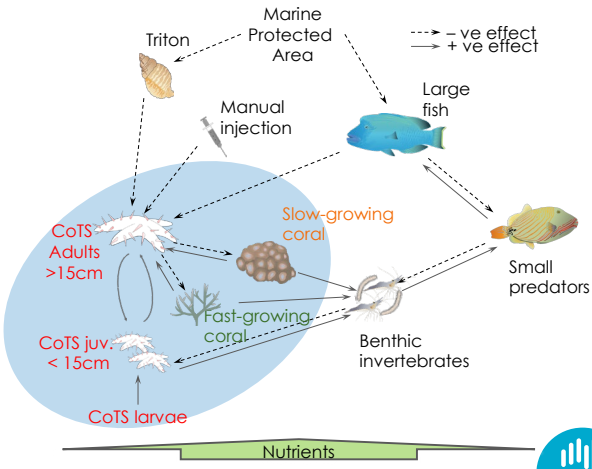


Example 4: MICE used to inform Ecological Threshold that pest species needs to be reduced down to meet conservation objectives for prey species



- **What mix of CoTS and coral achieves the objective of stemming declines in coral?**
- **Management program culls CoTS down to that level before moving to next reef**

PEST= Crown of Thorns Starfish (CoTS)

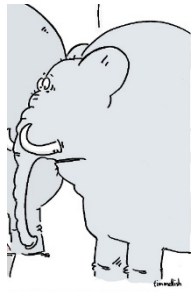


Targeted thresholds
- Ecological threshold
- An Allee-based threshold

COMBINED SPECIES MANAGEMENT TARGETS

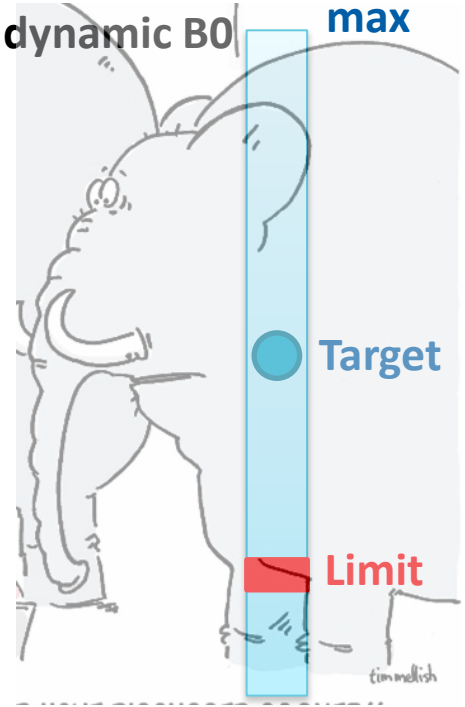
Morello et al. (2014); Plagányi et al. *Coral Reefs* (2020); Rogers & Plagányi *Nat Commn.* (2022); Rogers et al. In Review

How high to go revising reference levels?

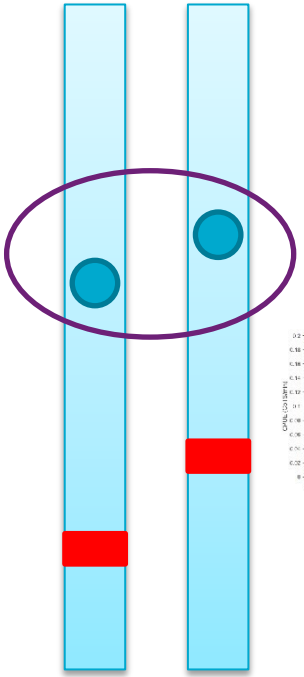


Single-species

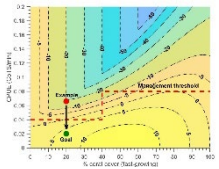
B0 or dynamic B0



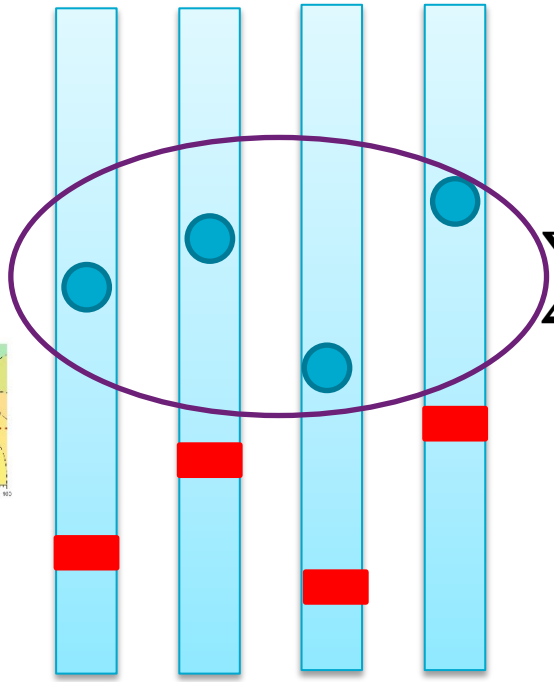
Predator-Prey or Threatened species



Joint solution



Multispecies



$$MMSY = \sum Joint\ feasible\ space$$

Or calibrate based on limit ref points

MSE (Management Strategy Evaluation): test risk of sub-optimal management/ lower limits breached

Of MICE and Methods

- MICE [or MSM (Multispecies Models)]:
  - ✓Quantify multispecies reference levels
  - ✓Use as Operating Model in MSE
  - ✓Couple with climate models
  - ✓Model range shifts
  - ✓Integrate mechanistic understanding
  - ✓Use ensemble outputs in Risk Assessment
- Bigger picture: Ecosystem models eg Atlantis, EwE
  - ✓But can use simpler network approaches to identify key species & test system resilience
  - ✓Or compute overall system limits (eg NAFO Total Catch Index TCI ecosystem reference point)
- Empirical-based eg Indicators
  - ✓Methods for detecting and predicting tipping points/regime shifts
  - ✓SURF (key species index) – monitor for change in system resilience

Lessons from MICE examples

MICE valuable for computing multispecies reference levels; rigorously quantifying impacts and uncertainties; focus on key species

Translate model outputs to risk metrics: pre-agreed acceptable risk levels or managers can decide acceptable risk per species/community

Climate change and trophic interactions are dynamically linked and ideally need climate-smart management strategies

Joint targets (eg phase plane approach) useful to identify optimal and acceptable regions management should aim to meet objectives of increasing/decreasing mortality on one species to conserve another (multidimensional is harder to visualise)

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Harvest Strategies for EBFM

- Indicators (additional data)
- Reference Points (multispecies)
- Monitoring (new challenges)
- Method of assessment (eg MICE work well)
- Decision rules (adjust to account for multispecies interactions – aim for targets & low risk of breaching limits; couple risk assessment)

Confronting the elephant in the room

How many can we fit? (system productivity)

How low can they go? (reference levels)

How not to drop the ball? (tipping points)

How to keep an eye on them: monitoring

How to stop them trampling other species?

And what will they do if the room starts to overheat? (climate change)

Thank you Sitka for the incredible nature on display!

Thank you

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