Approaches to Cumulative Impact Assessment

Skipton Woolley, Piers Dunstan, Scott Foster, Keith Hayes, Jeff Dambacher, Mike Fuller, Jason Hartog, Geoff Hosack, David Peel, Kate Thornborough, Nadine Marshall & Rick Stuart-Smith | 25/11/2019

Cumulative Impact Guidelines

KEY STEPS IN CUMULATIVE IMPACT ANALYSIS

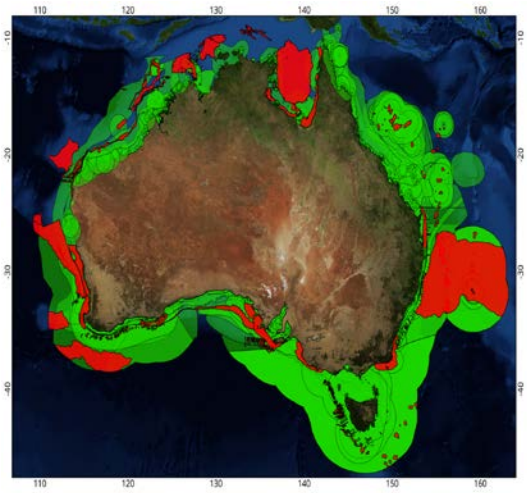
- **Step 1 Understanding Values**
  - Environmental, social, cultural and economic values can be identified within these habitats as being derived from components (i.e., species, habitats, processes) of GBR ecosystems, and should be identifiable with conceptual system models
- **Step 2 Understanding Pressures**
  - For the area under consideration , the intensity and distribution of pressures should be mapped. This should include consideration of both the spatial intensity and the temporal pattern.
- **Step 3: Conceptual Models of Key Habitats**
  - Conceptual models need to portray the ecological system at a level of resolution that is useful to the purposes of the risk assessment, striking a balance between simplicity and complexity.
- **Step 4: Zone of Influence**
  - The zones of influence that define the spatial extent over which a pressure influences a value need to be mapped spatially
- **Step 5: Risk Assessment and Uncertainty**
  - The existing impacts and potential risks of new activities or development projects that can potentially affect values need to be calculated. Cause-effect models can be used to identify measurement end-points for each of the assessment end-points associated with the values.

Building blocks of an integrated assessment

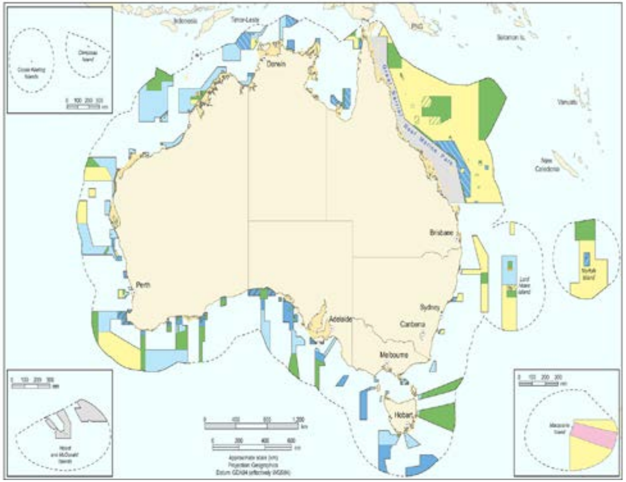
Cumulative Impact Guidelines

Values	Identify what and where they are
Pressures	Their distribution, intensity and interaction
Models	Describes system, identify indicators
Zones of Influence	Define dose-response across landscape
Risk & uncertainty	Predict outcomes (management success)

Spatial construct for describing, locating and managing values

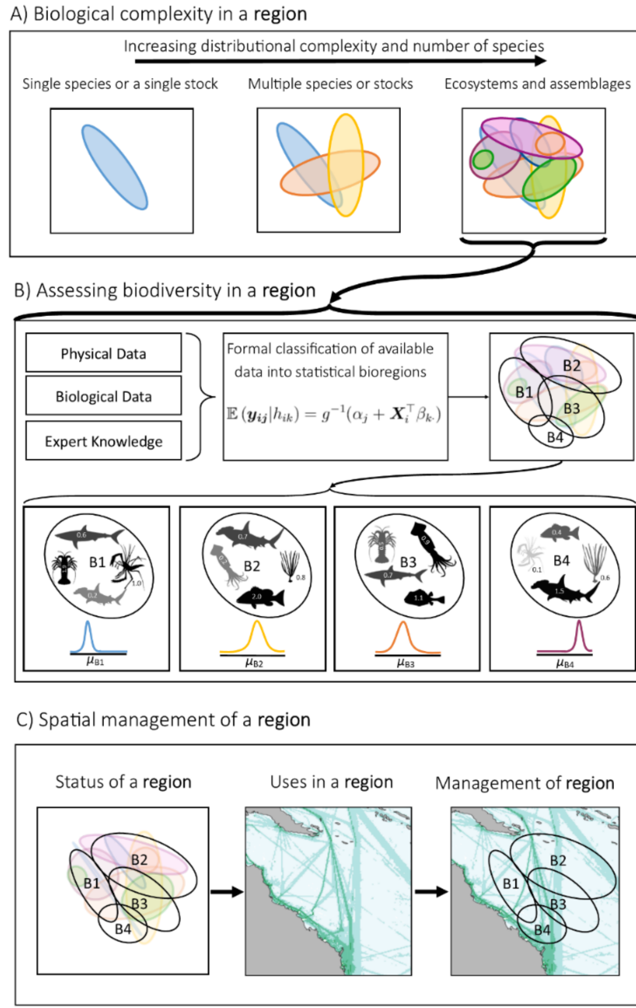


Key Ecological Features (red) and
Biologically Important Areas (green)



Australian Marine Park network

We usually do not have complete knowledge on the distribution of values.



Inhomogeneous Poisson Point Process Regions of Common Profile

- Indices:
  - $i = 1 : : : n$ (sites)
  - $j = 1 : : : S$ (species)
  - $k = 1 : : :K$ (assemblages /RCPs)
- Model conditional expectation (given site membership) for all species ($E(y_{ij}|z_{ik}) = 1)$)
- Adjust the profile as the species-wise expectation (offset and survey artefacts)

  - $h(\mathrm{E}(y_{ij}|z_{ik})) = \alpha_j + \boldsymbol{z}_i^\top \boldsymbol{\tau}_j$
  - $h(\mathrm{E}(y_{ij}|z_{ik})) = \alpha_j + \boldsymbol{z}_i^\top \boldsymbol{\tau}_j + \boldsymbol{w}_i^\top \gamma_j$

- Allow the probability of observing each RCP ($\boldsymbol{\pi}_i$) to vary with environment
- Multinomial regression model (but observations are latent)

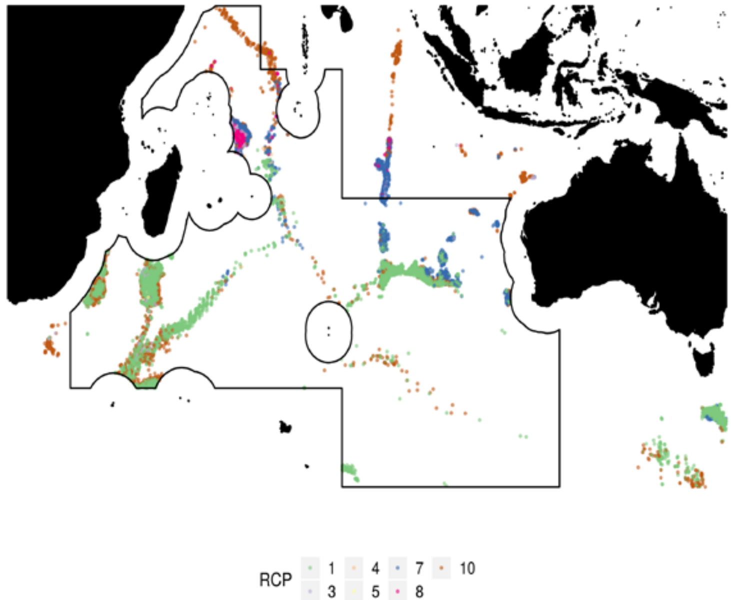
$$\pi_{ik} \triangleq \begin{cases} \frac{\exp(x_i^\top \beta_k)}{1+\sum_{k'=1}^{K-1} \exp(x_i^\top \beta_{k'})}, & \text{if} 1 \leq k \leq K-1 \\ 1 - \sum_{k'=1}^{K-1} \pi_{ik'}, & \text{if } k = K \end{cases}$$

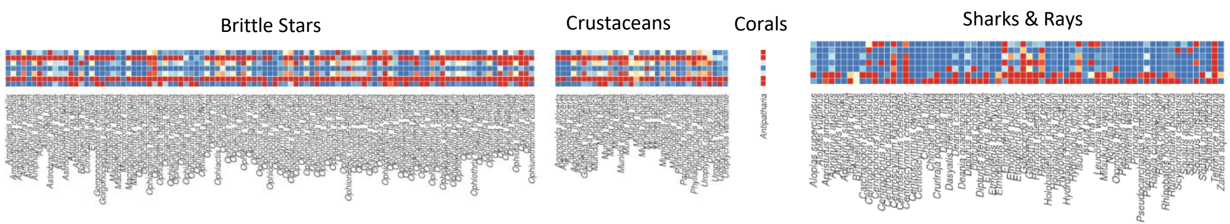
Provides information on:

- Number of assemblages
- Species present at location
- Estimate of uncertainty
- Improved estimation of rare species
- Environmental response
- Controls for unequal sampling effort

https://github.com/skiptoniam/ecomix

An example from Indian Ocean benthic deep-sea ecosystems



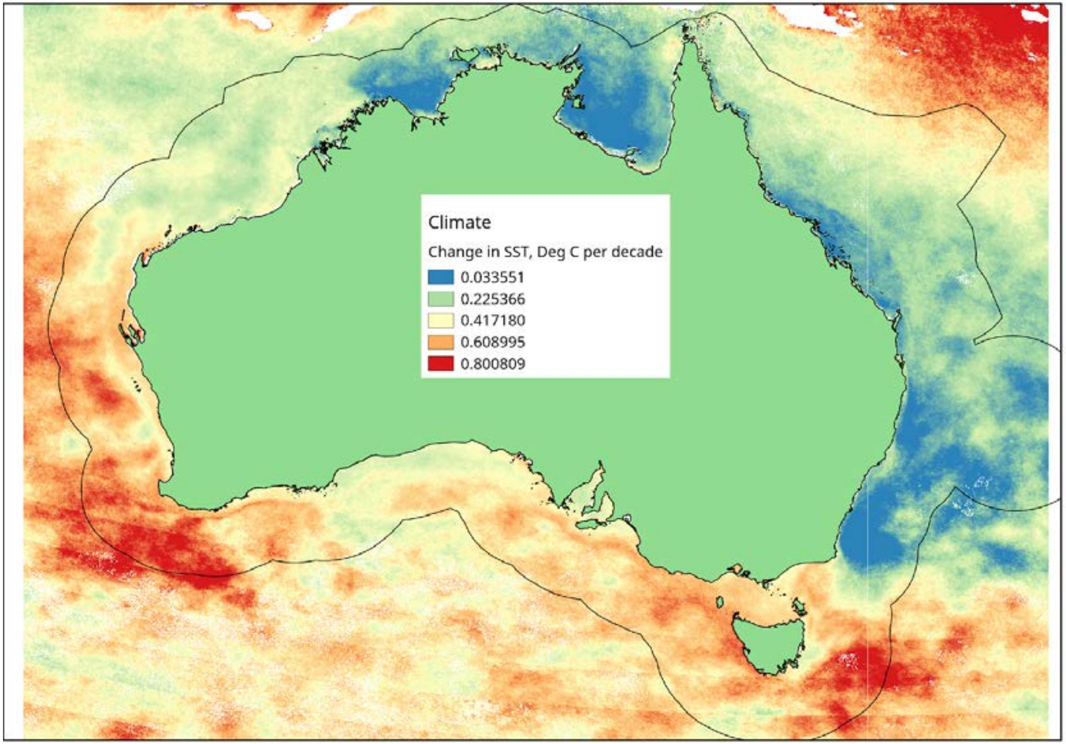


Building blocks of an integrated assessment

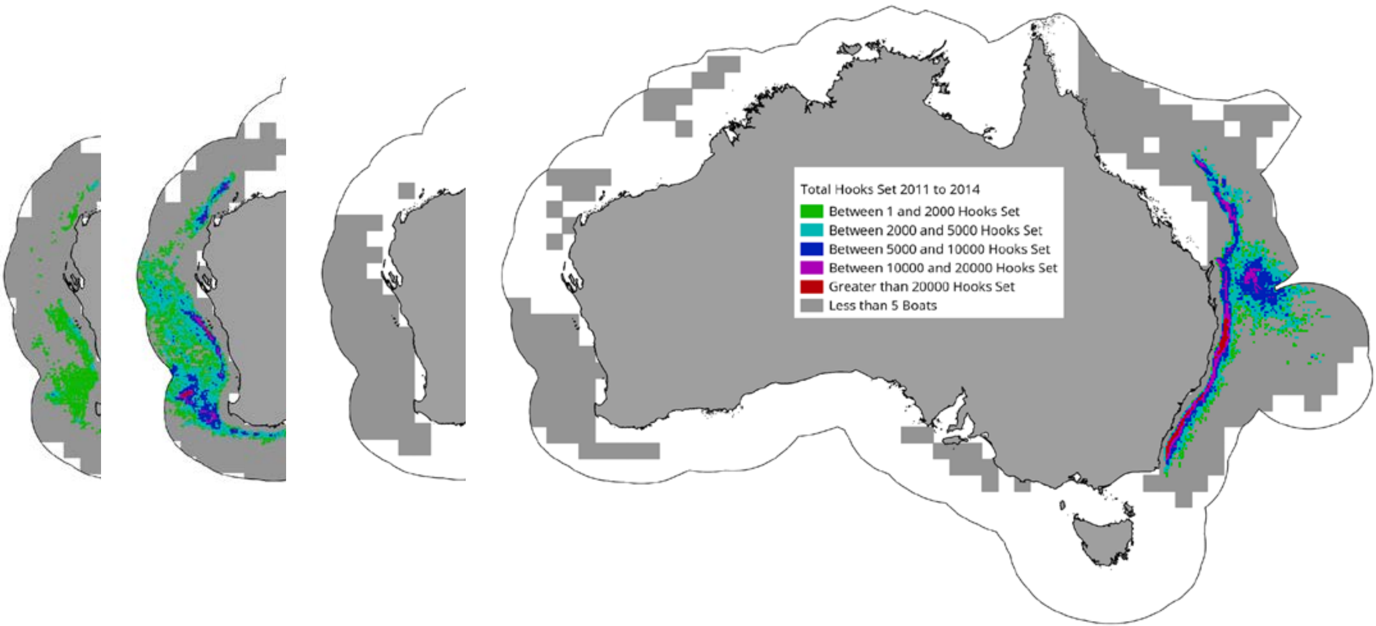
GBR Cumulative Impact Guidelines

Values	Identify what and where they are
Pressures	Their distribution, intensity and interaction
Models	Describes system, identify indicators
Zones of Influence	Define dose-response across landscape
Risk & uncertainty	Predict outcomes (management success)

Understanding pressures in changing world



Pressures are changing over time

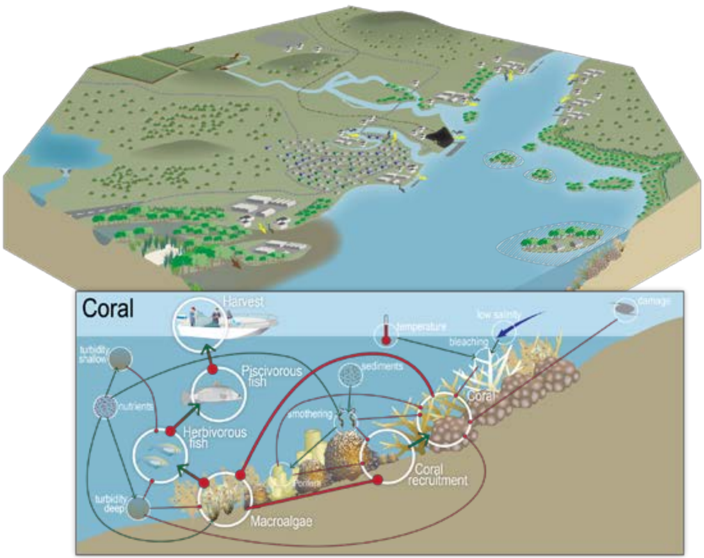


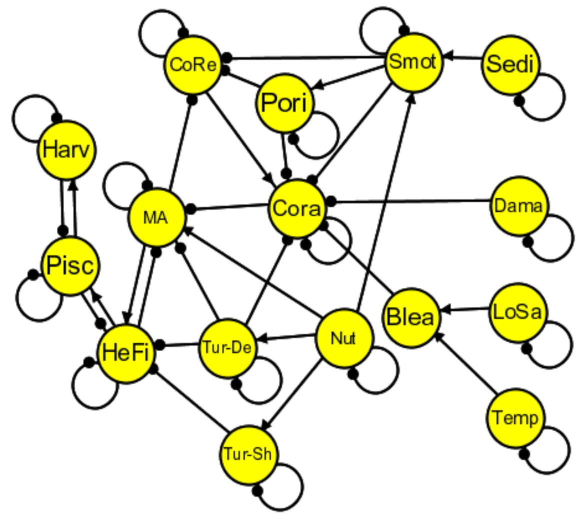
Building blocks of an integrated assessment

Cumulative Impact Guidelines

Values	Identify what and where they are
Pressures	Their distribution, intensity and interaction
Models	Describes system, identify indicators
Zones of Influence	Define dose-response across landscape
Risk & uncertainty	Predict outcomes (management success)

Conceptual model of coral reef ecosystem



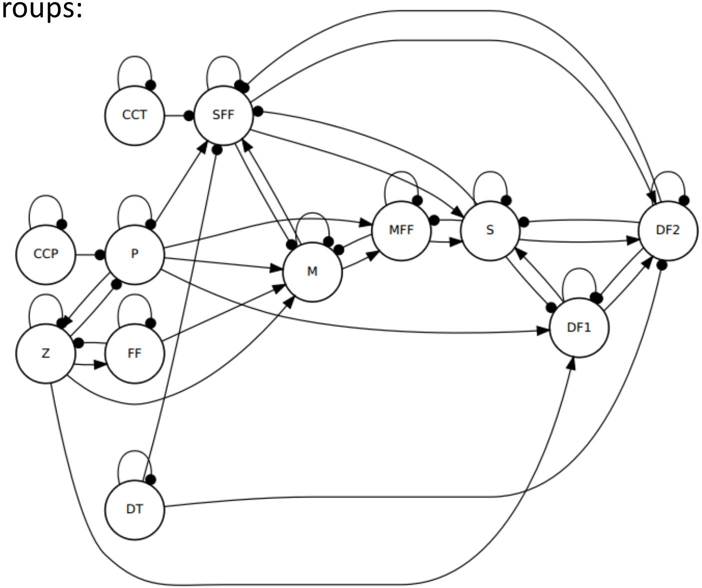


Assessing ecosystem risks due to changes in pressures

An example from Indian Ocean deep sea ecosystem.

A bathyal ecosystem with nine main functional groups:

- Phytoplankton (P)
- Zooplankton (Z)
- Food Falls (FF)
- Microbes (M)
- Sessile Filter Feeders (SFF)
- Mobile Filter Feeders (MFF)
- Detritus Feeders (DF1)
- Scavengers (S)
- Demersal Fish (DF2)



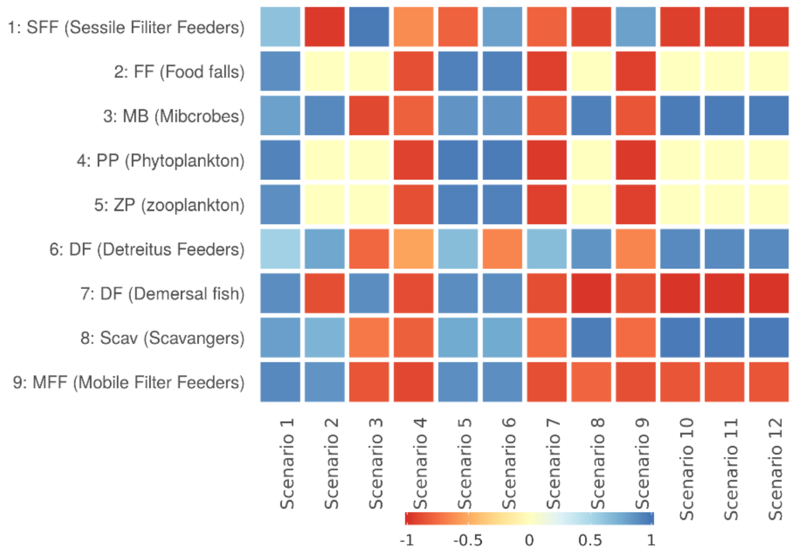
A bathyal ecosystem with three main pressures:

- Climate change temperature (CCT)
- Climate change productivity (CCP)
- Demersal Trawling (DT)

How are components of the ecosystem predicted to respond to cumulative pressures?

There are seven scenarios for the three pressures included in the qualitative model for RCP1

Scenario	Pressures
Scenario 1	+CCP
Scenario 2	-CCT
Scenario 3	+CCT
Scenario 4	-CCP
Scenario 5	+CCP & -CCT
Scenario 6	+CCP & +CCT
Scenario 7	-CCP & -CCT
Scenario 8	-CCP & -DT
Scenario 9	-CCP & +CCT
Scenario 10	+CCP, -CCT & -DT
Scenario 11	+CCP, +CCT & -DT
Scenario 12	-CCP, -CCT & -DT



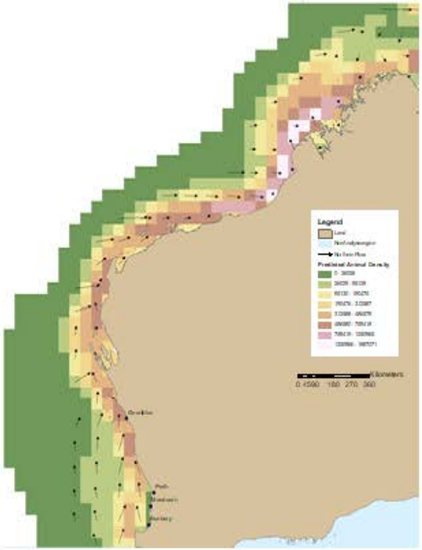
Building blocks of an integrated assessment

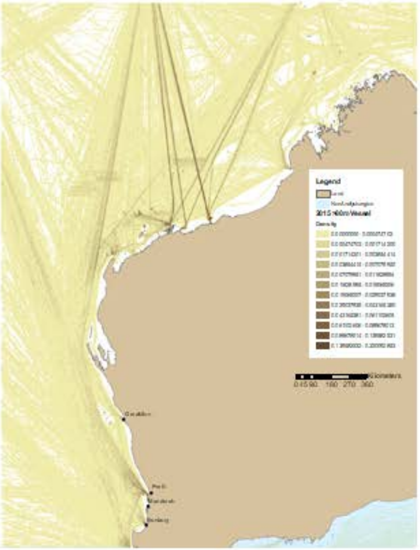
GBR Cumulative Impact Guidelines

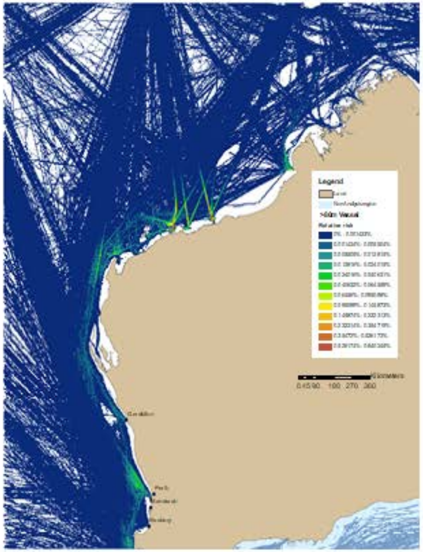
Values	Identify what and where they are
Pressures	Their distribution, intensity and interaction
Models	Describes system, identify indicators
Zones of Influence	Define dose-response across landscape
Risk & uncertainty	Predict outcomes (management success)

Pressure-value overlays (single)

Animal Distribution + Vessel Density → Strike Risk





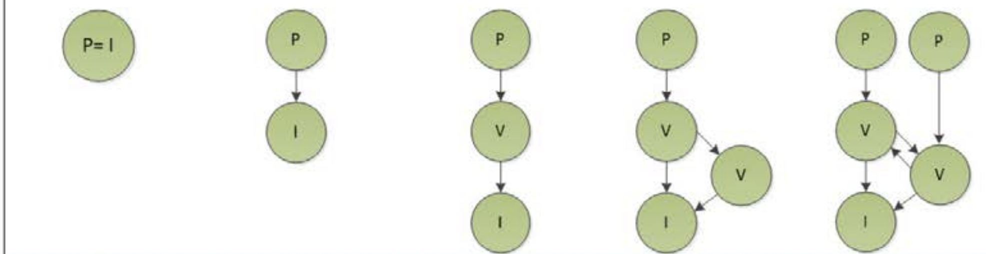


Building blocks of an integrated assessment

GBR Cumulative Impact Guidelines

Values	Identify what and where they are
Pressures	Their distribution, intensity and interaction
Models	Describes system, identify indicators
Zones of Influence	Define dose-response across landscape
Risk & uncertainty	Predict outcomes (management success)

Sufficiency of methods for predicting change



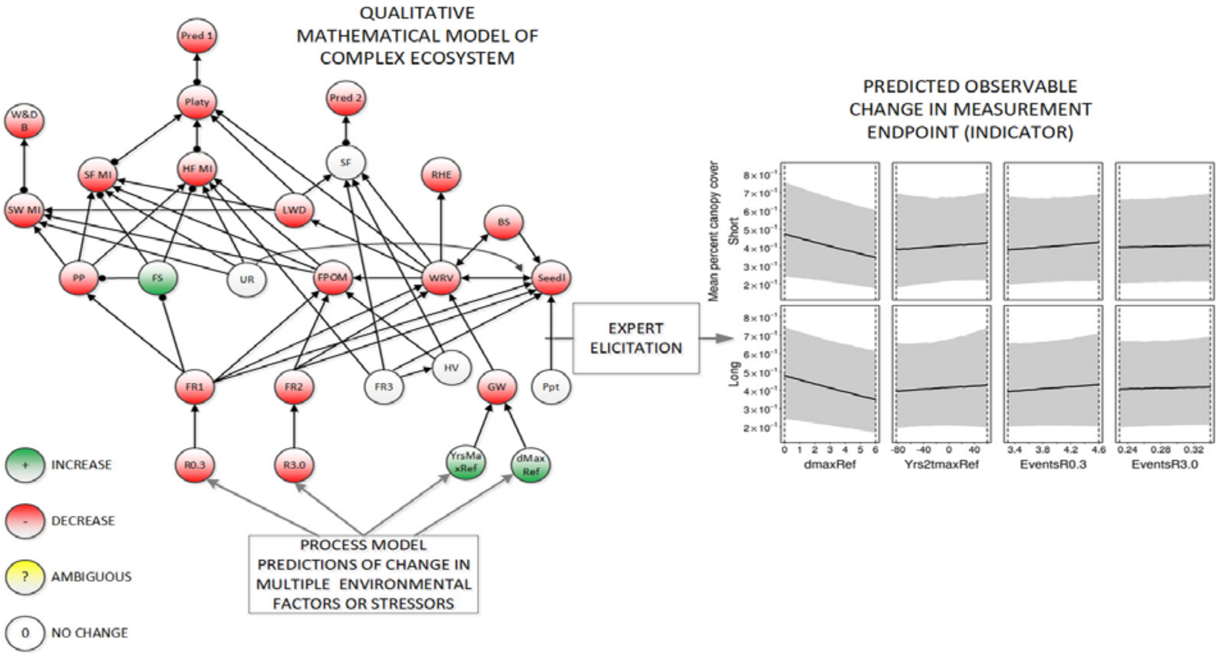
	COMPLEXITY OF CAUSE AND EFFECT RELATIONSHIP				
	NONE[1]	SIMPLE[2]	DIRECT[3]	DIFFUSE[4]	FEEDBACK[5]
Unstructured list	•	•			
Objective-indicator matrix	•	•			
Value-impact matrix		•	•		
Structured list		•	•		
Influence diagram or cartoon		•	•	•	
Fuzzy cognitive map		•	•	•	
Bayes Net		•	•	•	•[6]
Statistical model		•	•	•	•[7]
Qualitative process model		•	•	•	•
Quantitative process model		•	•	•	•

[1]No cause-effect relationship, the pressure is the indicator
[2]Pressure directly impacts indicator variable
[3]Pressure directly impacts a variable that has knock-on effects to indicator variable
[4]Pressure indirectly impacts an indicator variable via multiple interaction pathways.
[5]Multiple pressures simultaneously impact complex system with feedbacks between variables
[6]Standard Bayes nets constructed with expert opinion are typically limited to acyclic graph structures. Dynamic Bayes nets can account for feedbacks, but are difficult to parameterize
[7]Feedback not possible with classic statistical techniques (e.g., general and generalized linear models, multilevel models, structural equation models). Incorporation of process models within statistical analyses (e.g., state space modelling) can account for system feedbacks; such techniques, however, require extensive data, especially for large systems

Changes due to changes in pressures

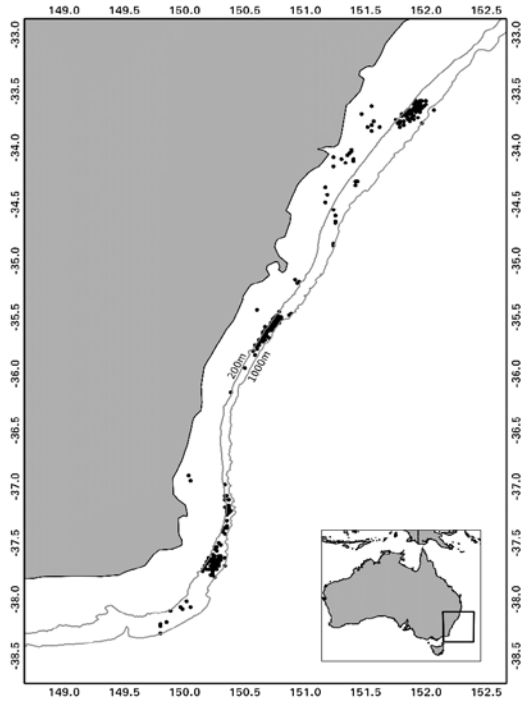
- Qualitative Ecosystem models are the basis for application of an ecosystem approach to cumulative impacts.
- Allow for the description of systems.
- Mathematical analysis of the dynamics of the system allows us to identify which ecosystem components are changed by which pressures.
- Can be used to identify components that are the best indicators of ecosystem state for any particular set of pressures.
- Application to deep sea systems in combination with IPPM Finite Mixture Models allows the identification species that will be impacted, ecosystem level impacts and identifies indicator species for further analysis.

Moving from qualitative to quantitative observable predictions of change

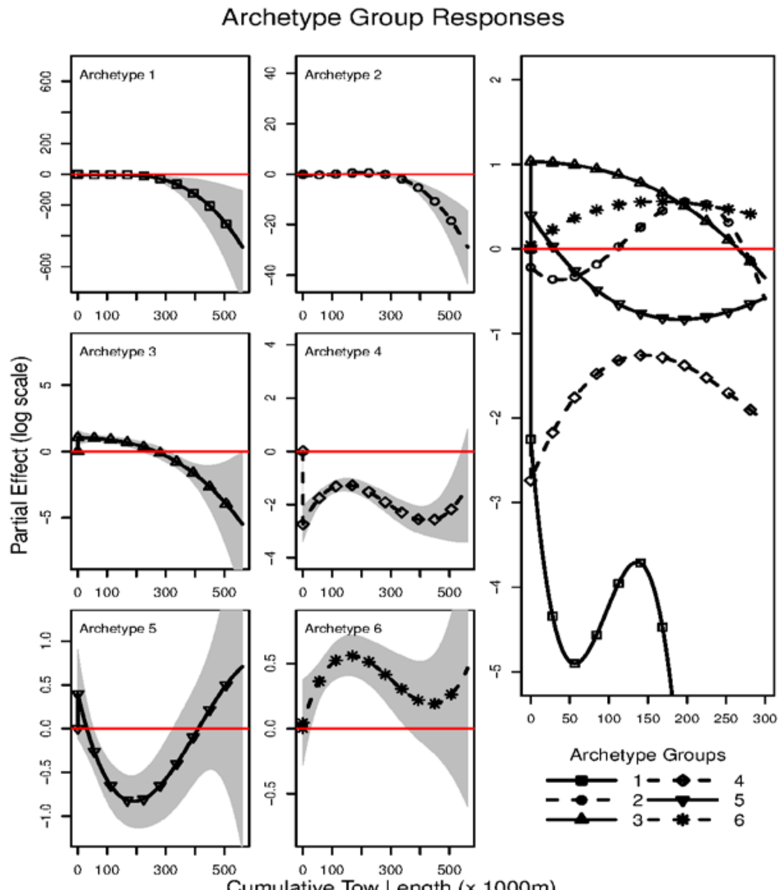


Quantitative Modelling and Monitoring - Cumulative Effects of Trawl fisheries

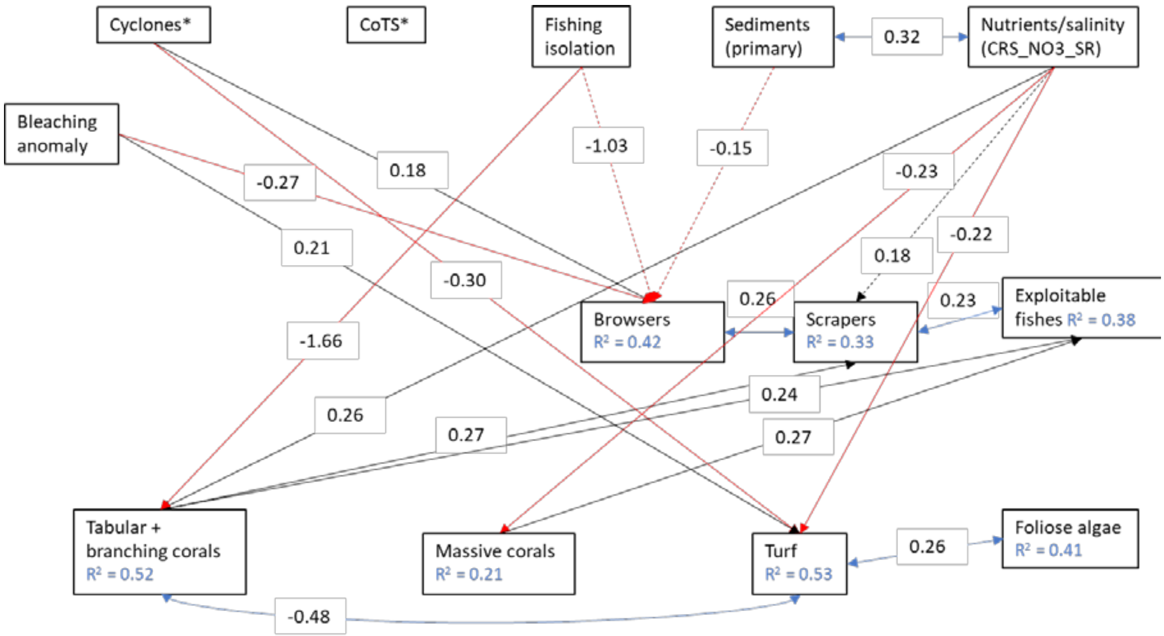
- A modification of multiple species approach
- Does trawl fisheries alter the abundance of commercial and non-commercial species?
- Are there any common patterns across species groups?
- Kapala data does (for SE Australian trawl fishery survey span 1979-1997, coinciding with the rapid growth period of the trawl fishery.
- Analyse counts of 100 species and ~ 180 sites
- In addition we have spatial covariates
  - Depth, distance-along-coast, day/night, and cumulative trawl history
  - Cumulative trawl history is the number of metres trawled in a bounding 0.01 ◦ grid cell containing the survey site



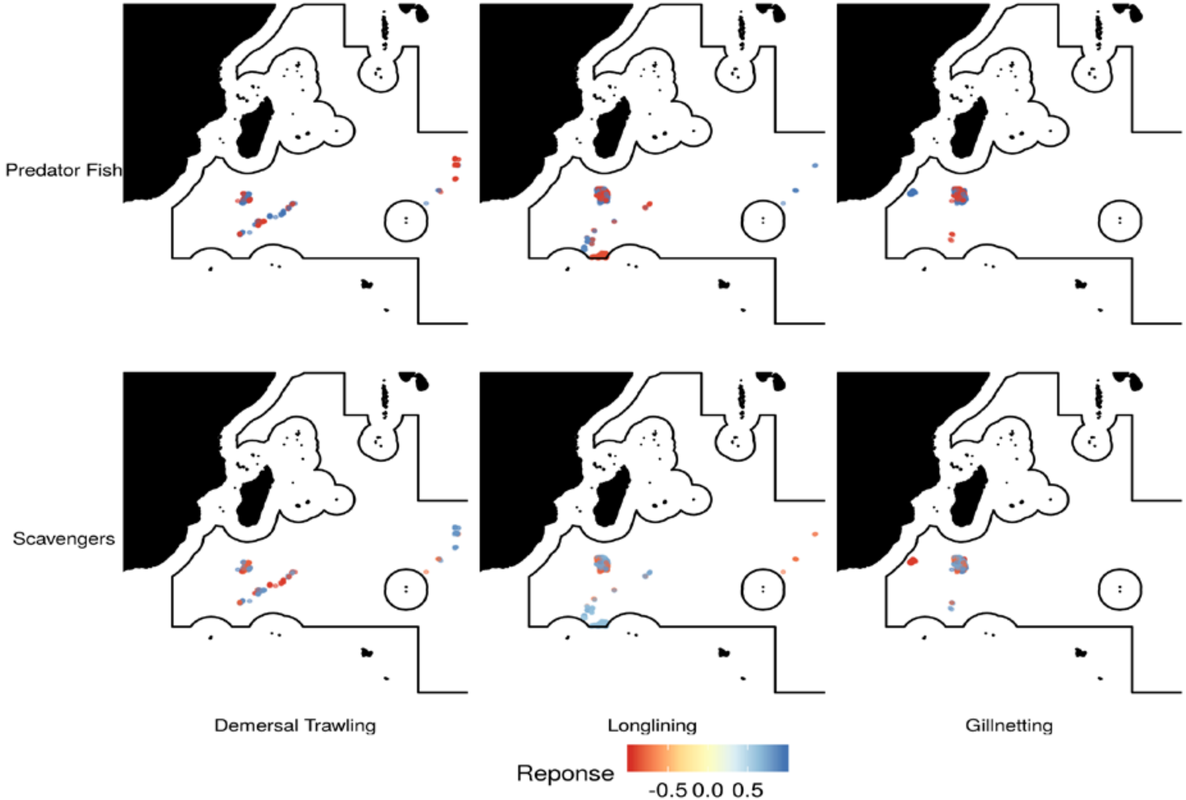
Groups of species respond to cumulative trawling pressure in different ways



Statistical model of GBR reefs post bleaching



Spatial prediction of model responses



Summary

- This is a systematic approach to cumulative impacts assessment
- Qualitative Ecosystem models are the basis for application of an ecosystem approach to cumulative impacts.
- They allow for the description of systems.
- Mathematical analysis of the dynamics of the system allows us to identify which ecosystem components are changed by which pressures.
- Can be used to identify components that are the best indicators of ecosystem state for any particular set of pressures.
- Application to deep sea systems in combination with IPPM Finite Mixture Models allows the identification species that will be impacted, ecosystem level impacts and identifies indicator species for further analysis.

Thank you

Marine Resources & Industry
Skipton Woolley
Research Scientist

skip.woolley@csiro.au