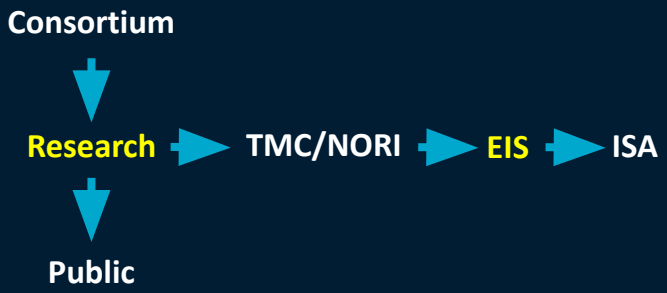
# Integrated Ecosystem Assessment and Ecosystem-Based Management Framework for Polymetallic Nodule Mining in the CCZ

CSIRO Consortium

Jeffrey Dambacher & Piers Dunstan|1 November 2022

# Consortium's role, rights & interests

- Provide independent research to TMC/NORI
- TMC/NORI will use research in development of environmental impact statement and monitoring and management of mining operations if approved by ISA
- Retain rights to freely publish, reproduce, disclose and communicate all research to public
- Increase scientific rigor of ecological risk assessments and management for data-poor systems



# Primary objective

Translate regulatory goal “not causing serious harm” into evidence-based scientific framework that is adaptive, transparent and verifiable

# Project methods

Literature review

Expert elicitation & workshops

Ecosystem models

Bayesian general linearized models

Monitoring data

- Nodule collector tests
- Management effectiveness

# Framework components

## Integrated ecosystem assessment

DPSIR framework

Ecosystem services & functions

## Identify indicators

Informative & causal

Measurability, interpretability, utility, efficiency

## Risk analysis

Ecosystem models

Pressure-state interactions

Spatial zones of influence

## Ecosystem-based management

Define goals, targets, operational objectives & decision rules

# Boolean search of deep-sea science authors 2002-2022

**Clarion**
Clarion Clipperton

**Deep**
deep sea
abys*

**Disturb**
assess*
disturbance
impact
mining
noise
plume
predict*
probabilit*
quanti*
recoloniz*
recovery
risk
sedimentation
vulnerab*

**Life**
bacteria*
benth*
*fauna*
fish
foram*
life
microb*
*nodule*
*pelagi*
*vertebrate*

**System**
biogeochem*
carbon
communit*
cycl*
*diversity
ecolog*
ecosystem
function*
habitat
model*
nutrient
sediment*
service

Deep
45,250 pub.

Clarion
350 pub. / 602 authors

DeepSystem
28,929 pub.

DeepLife
18,712 pub.

DeepDisturb
13,488 pub.

DeepClarion
267 pub.

DeepLifeSystem
14,842 pub. / 23,931 authors

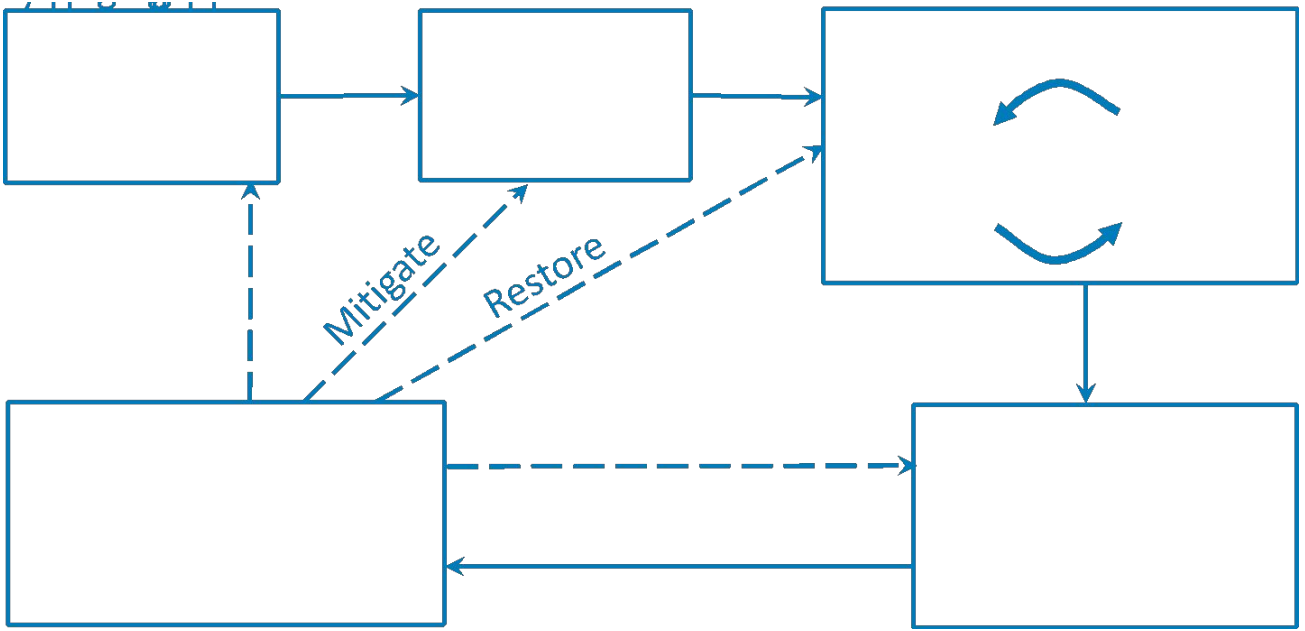
DeepLifeDisturb
6,403 pub. / 13,549 authors

DeepLifeSystemDisturb
6,117 pub. / 13,211 authors

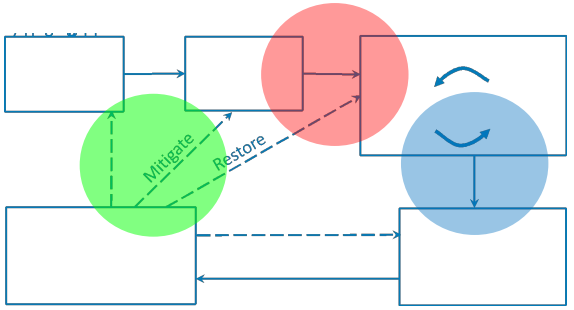
**DeepLifeSystem & DeepLifeDisturb (eq. wt.)**
**14,842 & 6,403 pub. / 12,671 authors**

- **Author's ranking based on number of publications and number of citations**
- **Top authors sent invitations to attend ecosystem modelling and risk assessment workshops (January 2023 Los Angeles & London)**

# DPSIR framework for integrated monitoring and management of ecological and human systems



# Key challenges
## *Problems of attribution*




### Pressure-State Interactions
- DPSIR implies ecosystems respond predictably to pressures but gives no further guidance of attributing cause-effect relationships.
- Requires causal understanding of ecosystem dynamics.

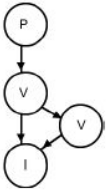
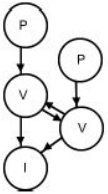
**Models**

### State-Impact Interactions
- DPSIR calls for detailed mapping of system state to human wellbeing.
- Requires linking human values to measurable system components.

**Values**

### Response Interactions
- DPSIR requires linking management responses to defined objectives.
- Requires complete set of indicators for full integration of monitoring and management programs.

**Objectives**

| Tools | Complexity of cause-effect relationship | | | | |
|---|---|---|---|---|---|
| | None[1] | Simple[2] | Directed[3] | Diffuse[4] | Feedback[5] |
| |  |  |  |  |  |
| **1.** Unstructured list | ● | ● | | | |
| **2.** Objective-indicator matrix | ● | ● | | | |
| **3.** Structured list | | ● | ● | | |
| **4.** Value-impact matrix | | ● | ● | | |
| **5.** Conceptual diagram or cartoon | | ● | ● | | |
| **6.** Influence diagram | | ● | ● | ● | |
| **7.** Fuzzy cognitive map | | ● | ● | ● | |
| **8.** Statistical model | | ● | ● | ● | ●[6] |
| **9.** Bayesian network | | | ● | ● | ●[7] |
| **10.** Qualitative process model | | | | ● | ● |
| **11.** Quantitative process model | | | | ● | ● |

[1] No cause-effect relationship.
[2] Pressure directly affects indicator variable.
[3] Pressure directly affects a variable that has knock-on effects to indicator variable.
[4] Pressure indirectly affects an indicator variable via multiple interaction pathways.
[5] Multiple pressures simultaneously affect complex system with feedbacks between variables.
[6] Explicit analysis of feedback not possible with classic statistical techniques. Incorporation of process models within statistical analyses of time series (e.g. state space modelling) can account for system feedbacks; such techniques, however, require extensive data, especially for large systems.
[7] With difficulty; standard Bayesian networks limited to acyclic graph structures. Dynamic Bayesian networks can account for feedbacks, but are difficult to parameterise and analyse, typically making them impractical for complex systems.

(P) pressure or impact

(V) system variable — an element of the ecological or human system or benefit derived from that system that forms part of the cause-and-effect relationship but is not measured

(I) indicator variable — a measurable indicator (it could be a specific ecosystem element (e.g. seagrass abundance) or benefit derived from the ecosystem (e.g. income) or a surrogate measure for the health of matters of national environmental significance)

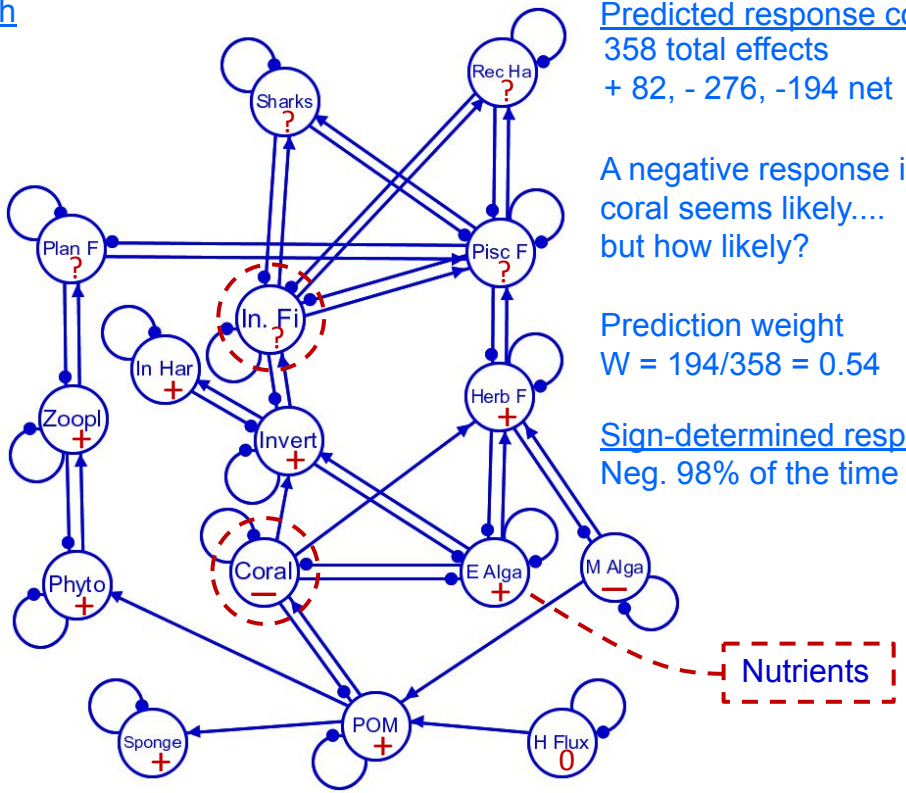
# Qualitative process models & predictions

## Pressure scenario: positive input to epiphytic algae

Response invertivore fish
177 total effects
+ 86, -91, -5 net

Prediction weight:
W = 0.028

Ambiguous response
Neg. 57% / Pos. 43%




Predicted response coral ?
358 total effects
+ 82, - 276, -194 net

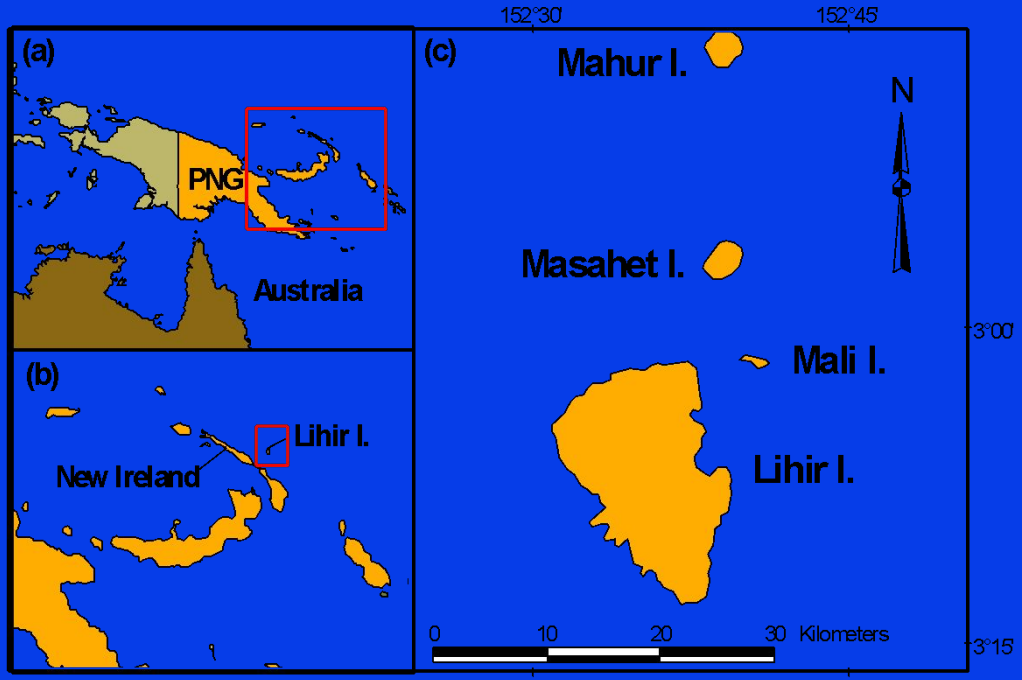
A negative response in coral seems likely....
but how likely?

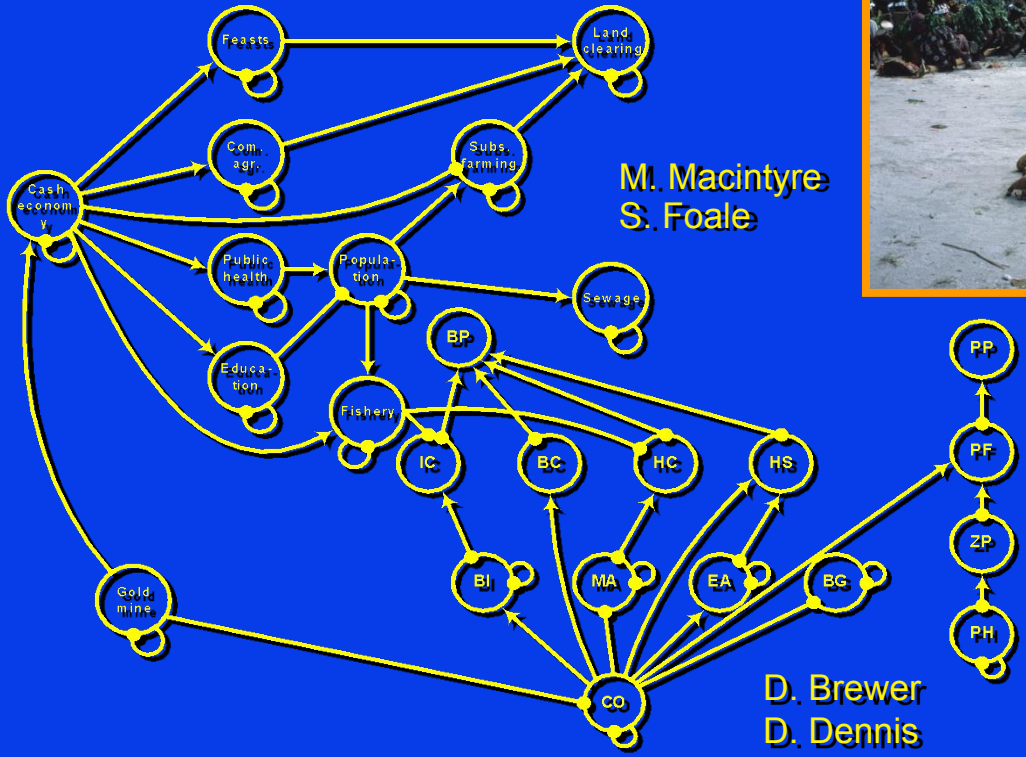
Prediction weight
W = 194/358 = 0.54

Sign-determined response
Neg. 98% of the time

Direct effects
Positive: →
Negative: —●

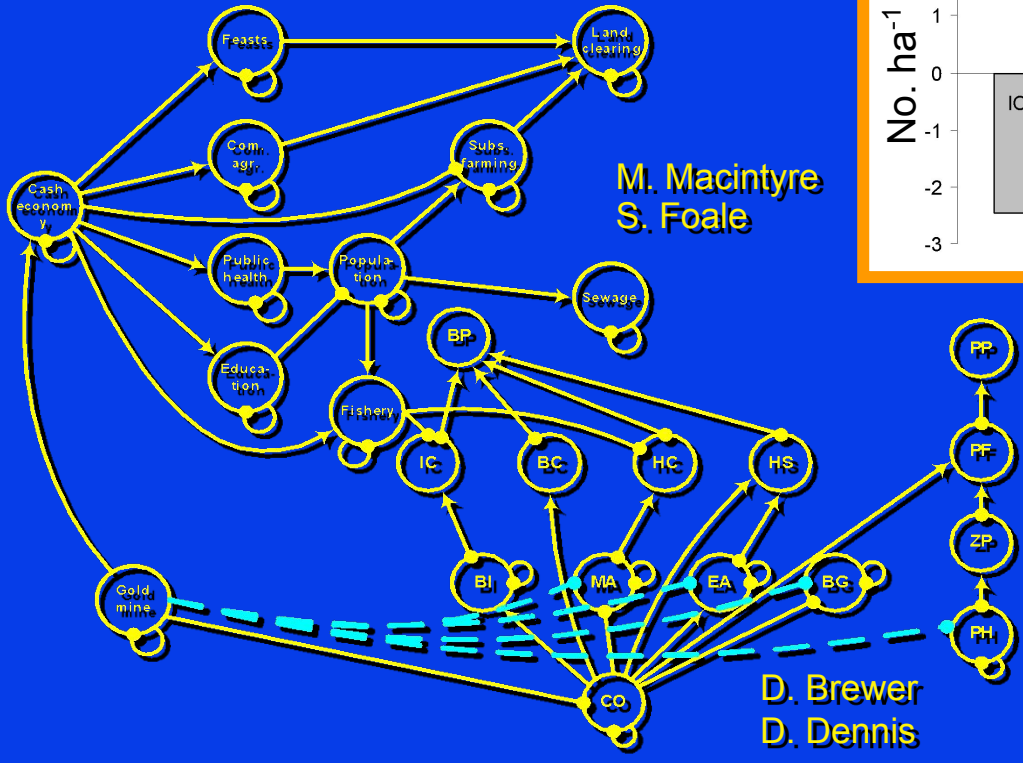
# Gold mine impacts on Lihir Island's socio-economic system and reef-edge fish community






M. Macintyre
S. Foale

D. Brewer
D. Dennis

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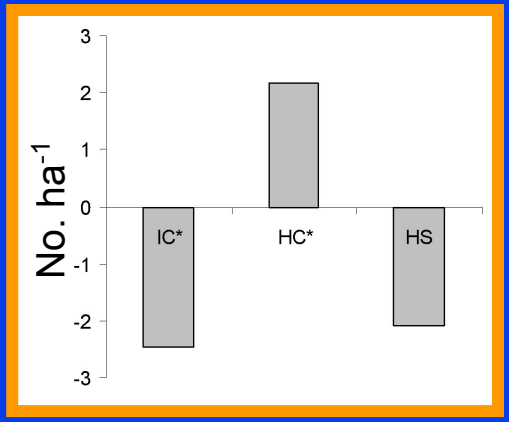
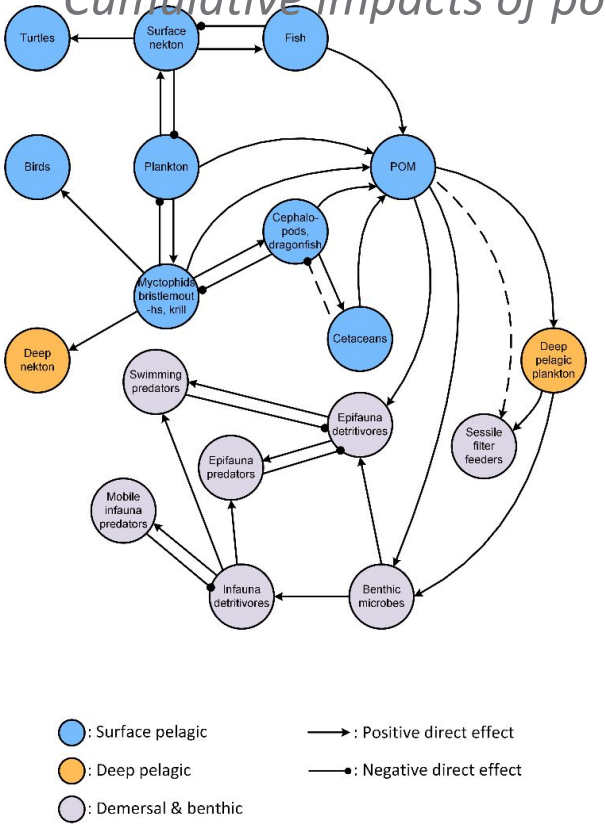
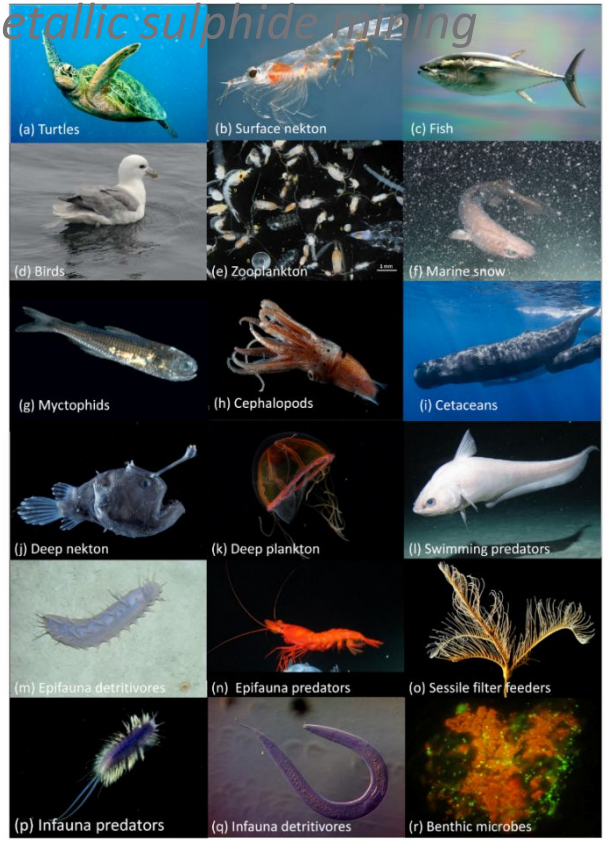



D. Brewer
D. Dennis

# Mid-Atlantic Ridge pelagic & benthic ecosystem

*Cumulative impacts of polymetallic sulphide mining*



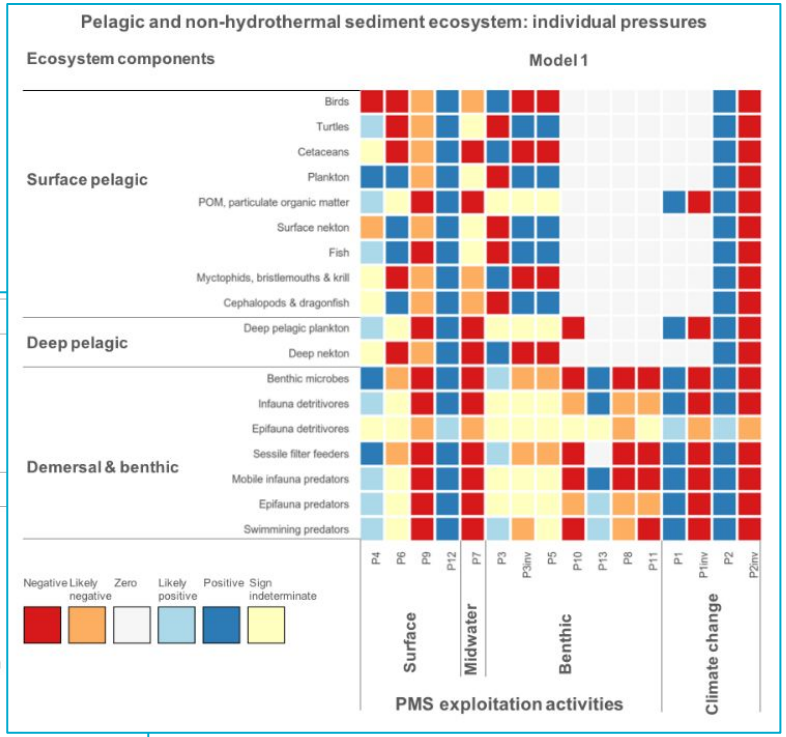
# Expert domain knowledge

Ecosystem interactions in signed digraph of pelagic and soft sediment habitats of the Mid-Atlantic Ridge; effects are positive (□) or negative (•—) in sign.

| Effect to | Effect sign | Effect from | Description | Reference |
|---|---|---|---|---|
| Turtles | □ | Surface nekton | Benefit of consumption | Bjorndal (1997), SeeTurtles.org (2020), Witherington (2002) |
| Surface nekton | •— | Fish | Predation mortality | Morato et al. (2016) |
| | □ | Plankton | Benefit of consumption | Morato et al. (2016) |
| Fish | □ | Surface nekton | Benefit of consumption | Morato et al. (2016) |
| Birds | □ | Myctophids bristlemouths & krill | Benefit of consumption | Conan et al. (2007), Danielsen et al. (2010), Edwards et al. (2013) |
| Plankton | •— | Surface nekton, myctophids bristlemouths & krill | Predation mortality | Morato et al. (2016) |
| POM | □ | Fish, plankton, Myctophids bristlemouths & krill cephalopods & dragonfish, cetaceans | Contribution to pool of particulate organic matter from carcasses or excretion of waste products | Anderson et al. (2019) |
| Cephalopods & dragonfish | □ | Myctophids bristlemouths & krill | Benefit of consumption | Drazen & Sutton (2016), Morato et al. (2016), Priede (2017), Sutton et al. (1996) |
| Myctophids bristlemouths & krill | •— | Cephalopods & dragonfish | Predation mortality | Drazen & Sutton (2016), Priede (2017), Sutton et al. (1996) |

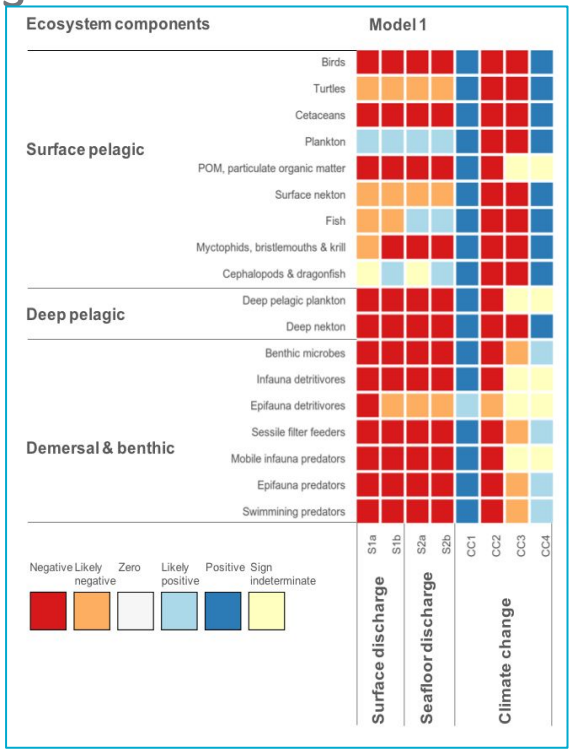
# Polymetallic sulphide exploitation pressures & cumulative impacts

| Pressure category | Abbreviation | Pressure description |
|---|---|---|
| Surface | P4 | Surface light |
| | P6 | Surface noise |
| | P9 | Turbid water, surface discharge |
| | P12 | Nutrients, surface discharge |
| Midwater | P7 | Water column noise |
| Benthic | P3 | Seafloor light, positive effect |
| | P3inv | Seafloor light, negative effect |
| | P5 | Seafloor noise |
| | P10 | Turbid water, seafloor discharge |
| | P13 | Nutrients, seafloor resuspension |
| | P8 | Seafloor sedimentation |
| | P11 | Seafloor toxicants |
| Climate change | P1 | Temperature increase, increased POM quality |
| | P1inv | Temperature increase, reduced POM quality |
| | P2 | Temperature increase, increased primary productior |
| | P2inv | Temperature increase, reduced primary production |

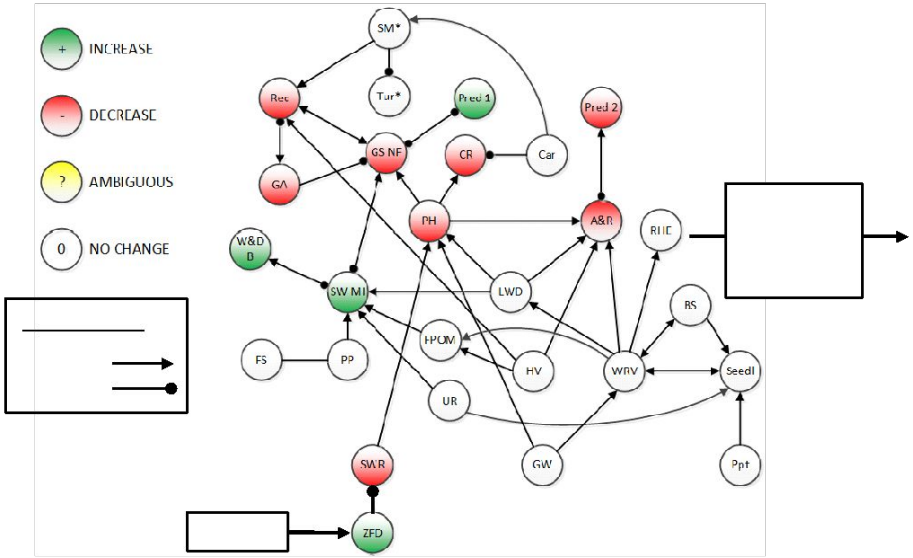


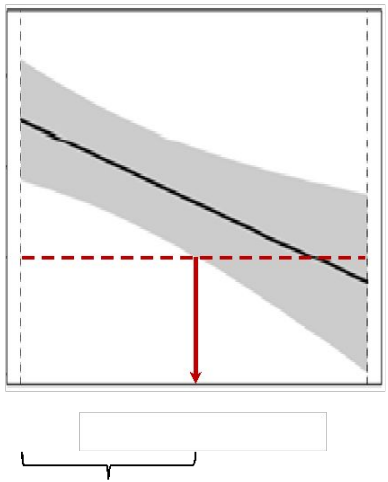
# Polymetallic sulphide exploitation multiple pressures & cumulative impacts

| Pressure category | Abbreviation | Perturbation scenario description | Pressure combinations |
|---|---|---|---|
| Surface discharge | S1a | Surface discharge, positive light effect | P3, P4 – P9, P11 – P13 |
| | S1b | Surface discharge, negative light effect | P3inv, P4 – P9, P11 – P13 |
| Seafloor discharge | S2a | Seafloor discharge, positive light effect | P3, P4 – P8, P10, P11, P13 |
| | S2b | Seafloor discharge, negative light effect | P3inv, P4 – P8, P10, P11, P13 |
| Climate change | CC1 | Positive effect POM quality and primary production | P1, P2 |
| | CC2 | Negative effect POM quality and primary production | P1inv, P2inv |
| | CC3 | Positive effect POM quality, negative effect primary production | P1, P2inv |
| | CC4 | Negative effect POM quality, positive effect primary production | P1inv, P2 |

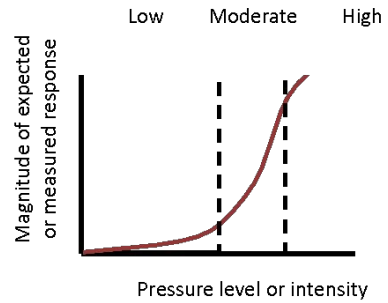


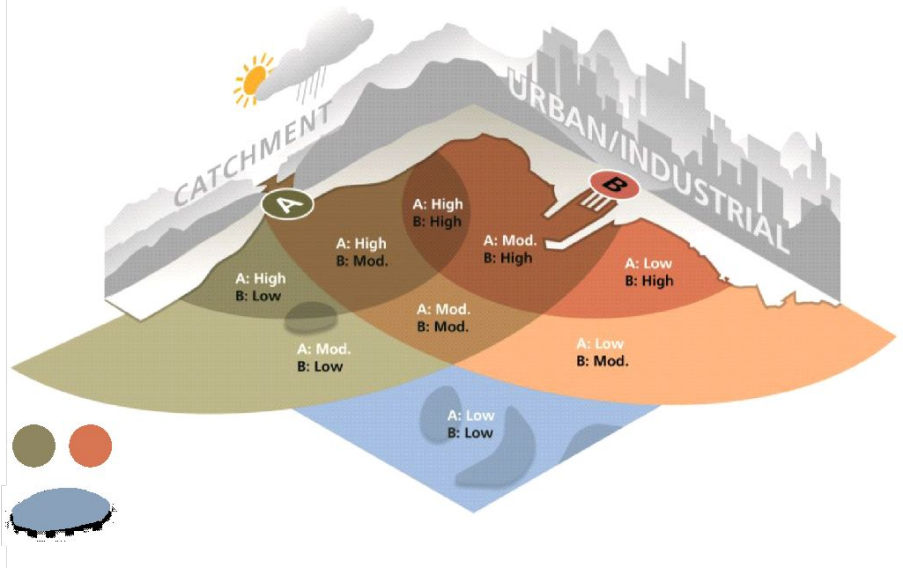
# Impact scenarios for Bayesian General Linearized Models



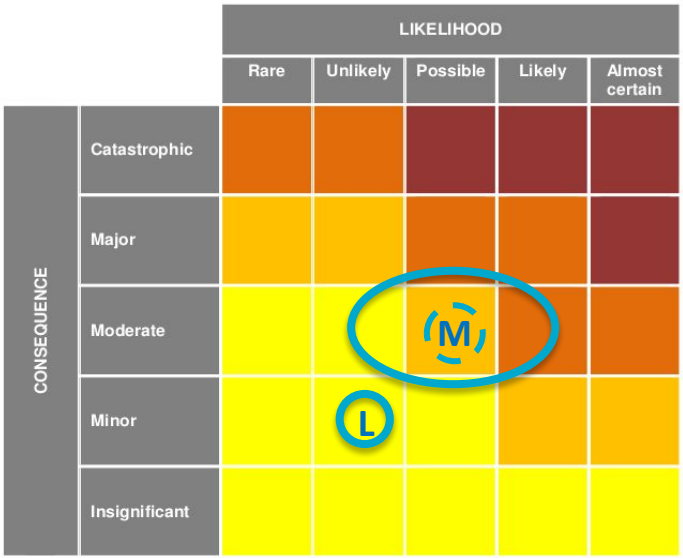



# Zones of influence

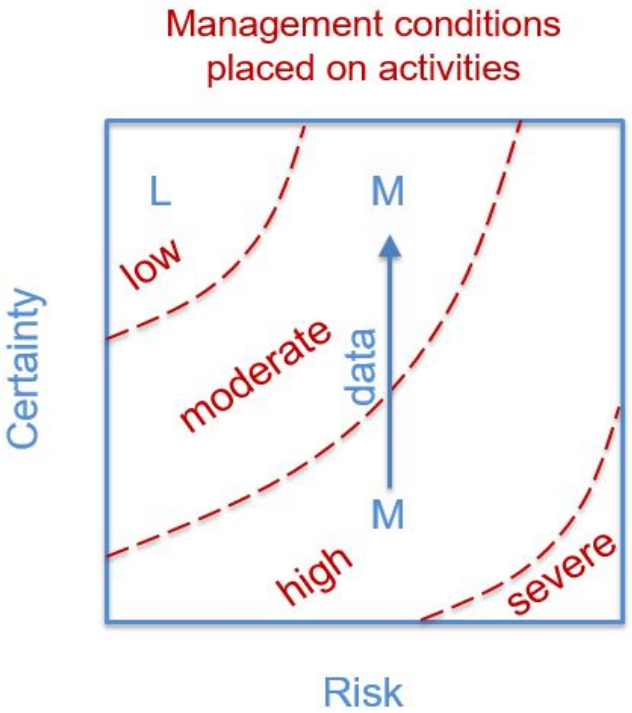


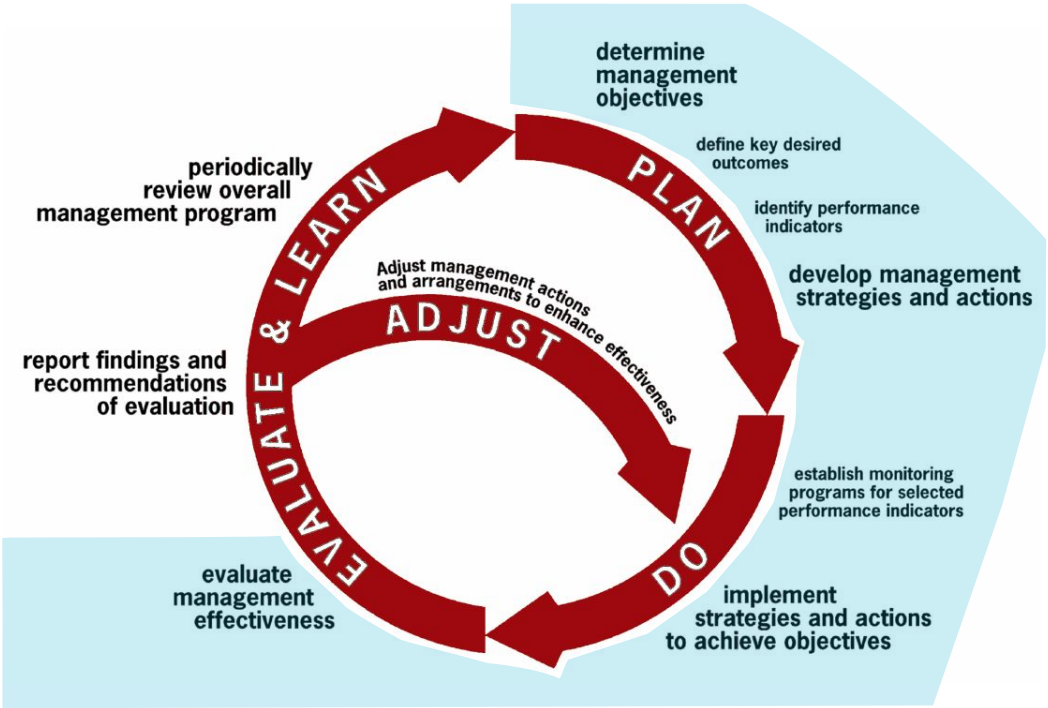
# Role of monitoring in risk assessments & adaptive management







# Ecosystem Based Management Cycle



# Key next steps

- Implementable and peer reviewed definition of serious harm meeting ISA's regulatory requirements
- Framework for ecosystem-based management
- Ecosystem qualitative modelling workshops
- Expert elicitations for assessment of risk


# Thank you

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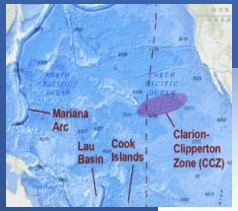
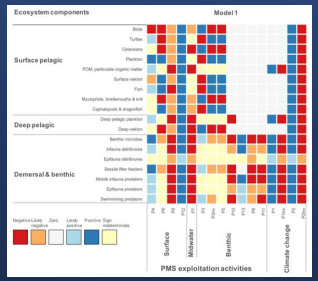
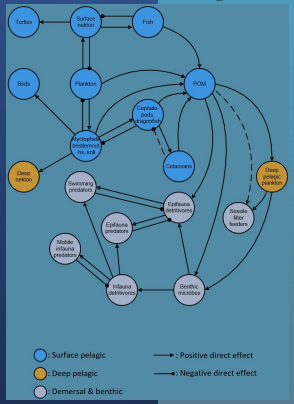
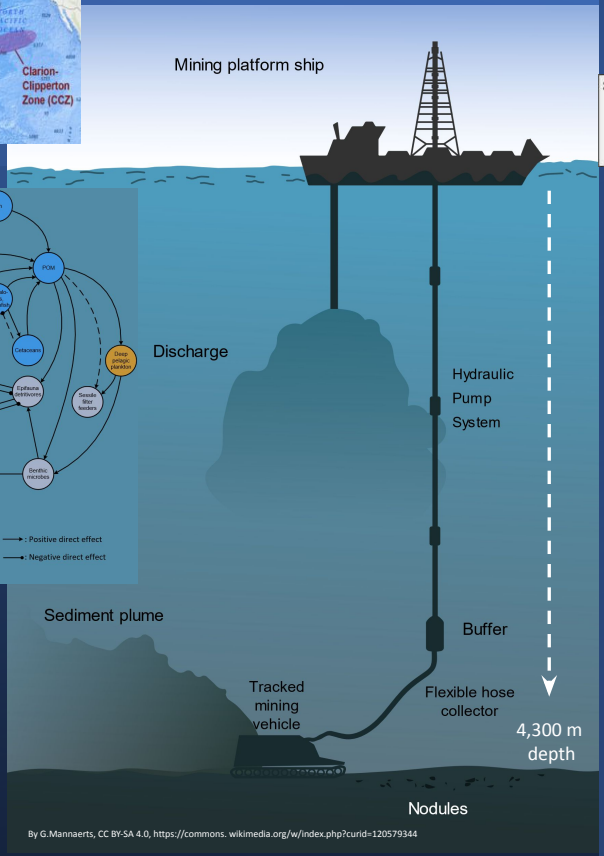
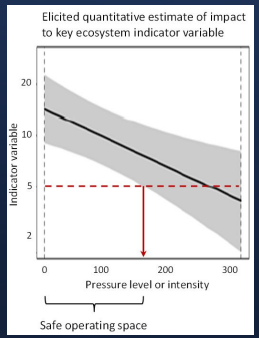
# DEEP SEA MINING OF POLYMETALLIC NODULES IN THE CLARION-CLIPPERTON ZONE


Methods
- Expert elicitation
- Qualitative mathematical modelling
- Bayesian general linearized models

Nodules valued for battery metals in transition to renewable energy

| 25 | 27 | 28 | 29 |
|---|---|---|---|
| Mn | Co | Ni | Cu |
| Manganese | Cobalt | Nickel | Copper |
| 54.938 | 58.933 | 58.693 | 63.546 |

CSIRO-led consortium
funded by The Metals Company, Canada
- CSIRO (Data61, O&A)
- Griffith University
- Museums Victoria
- NIWA
- University of the Sunshine Coast

Deliverables
- Integrated ecosystem assessment
- Ecosystem-based management framework
- Integrated monitoring program

Impact
- First integrated ecosystem assessment & ecosystem-based management framework implemented *prior* to industrial resource extraction
- Increase scientific rigor in assessments & management of complex data-poor ecosystems
- Publicly available results

Contested space
- Regulated by International Seabed Authority (167 member states & EU)
- Controversial issue dividing governments, NGOs and civil society

# Zone of Influence