



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

CSIRO Consortium

Jeffrey Dambacher & Piers Dunstan | 1 November 2022

Australia's National Science Agency





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

Consortium



Research



TMC/NORI



EIS



ISA



Public



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.)

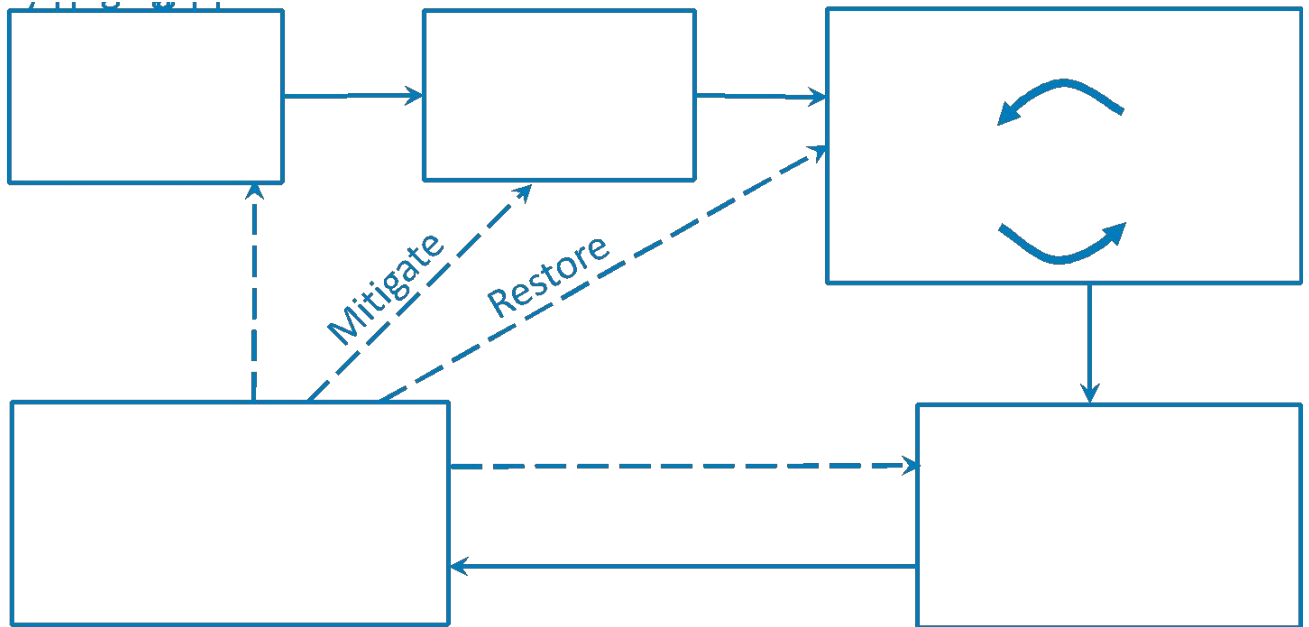
14,842 & 6,403 pub. / [12,671 authors](#)



- 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)



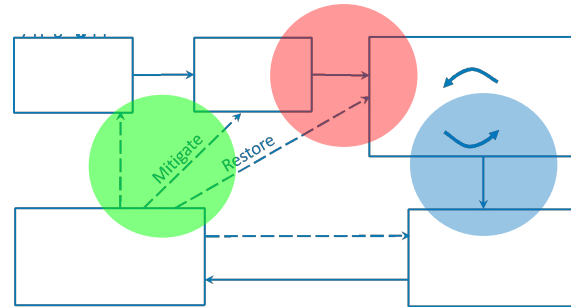
DPSIR framework for integrated monitoring and management of ecological and human systems





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

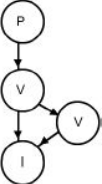
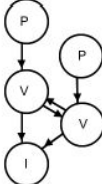
- DPSIR calls for detailed mapping of system state to human wellbeing.
- Requires linking human values to measurable system components.

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

	Complexity of cause-effect relationship				
	None ¹	Simple ²	Directed ³	Diffuse ⁴	Feedback ⁵
					
Tools					
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.

 pressure or impact

 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

 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%

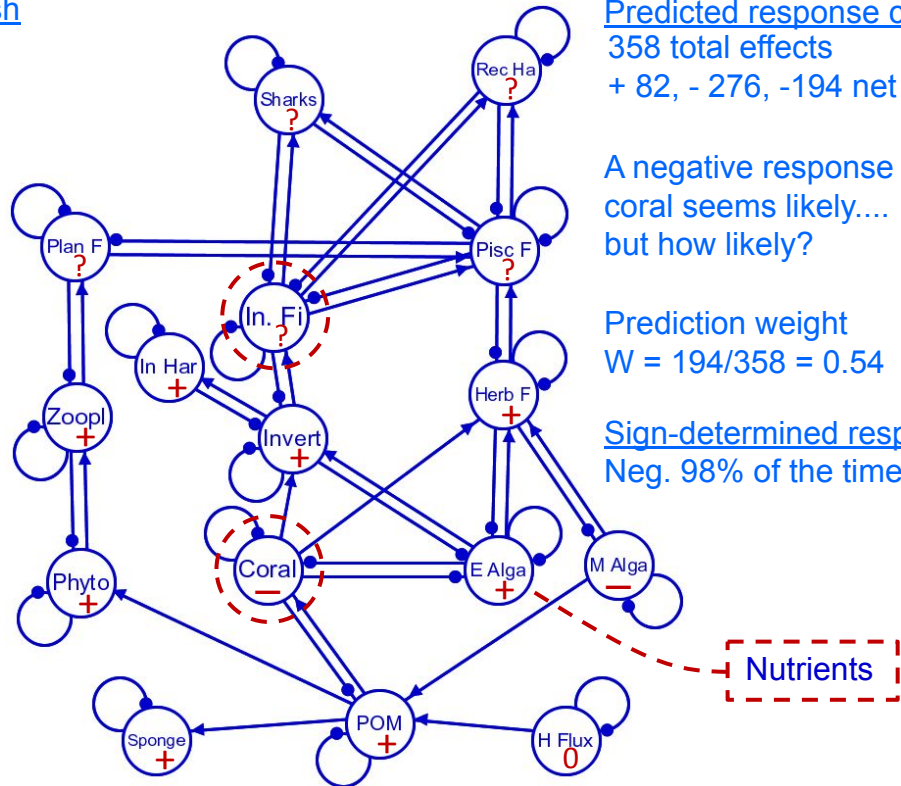
Predicted response coral ?

358 total effects
+ 82, - 276, -194 net

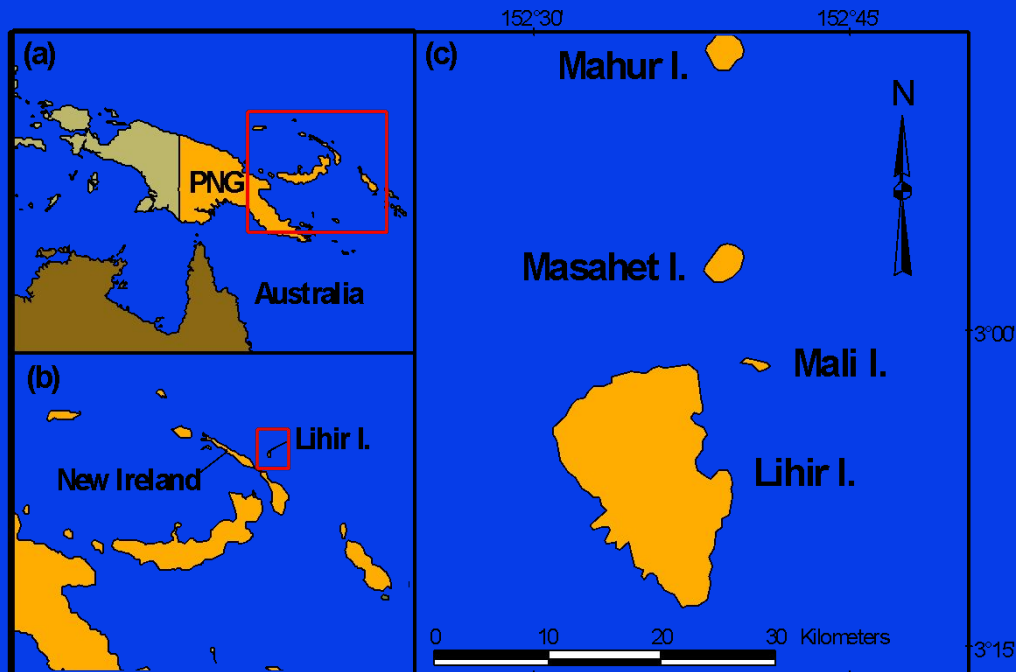
A negative response in coral seems likely....
but how likely?

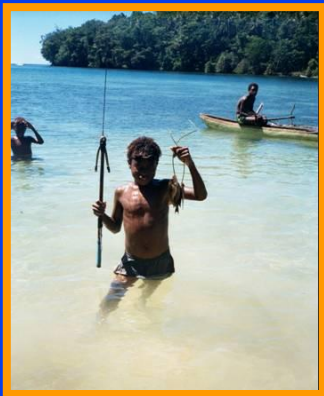
Prediction weight
 $W = 194/358 = 0.54$

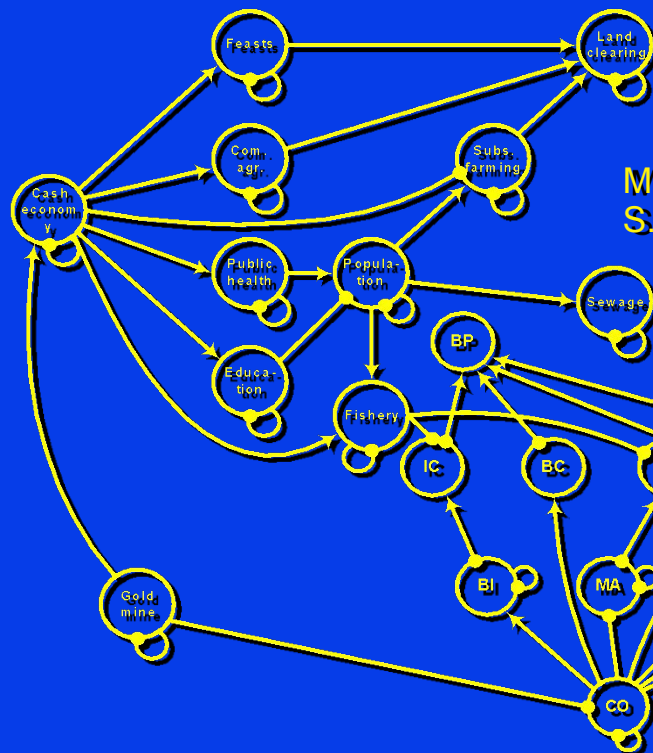
Sign-determined response
Neg. 98% of the time



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



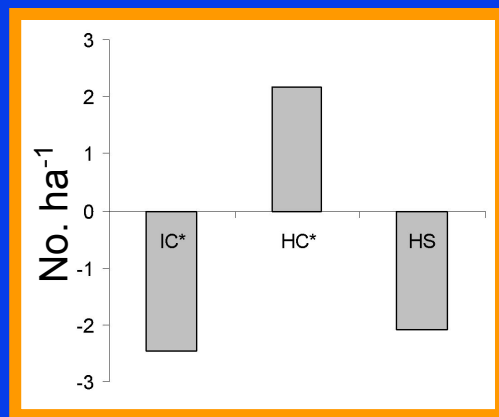
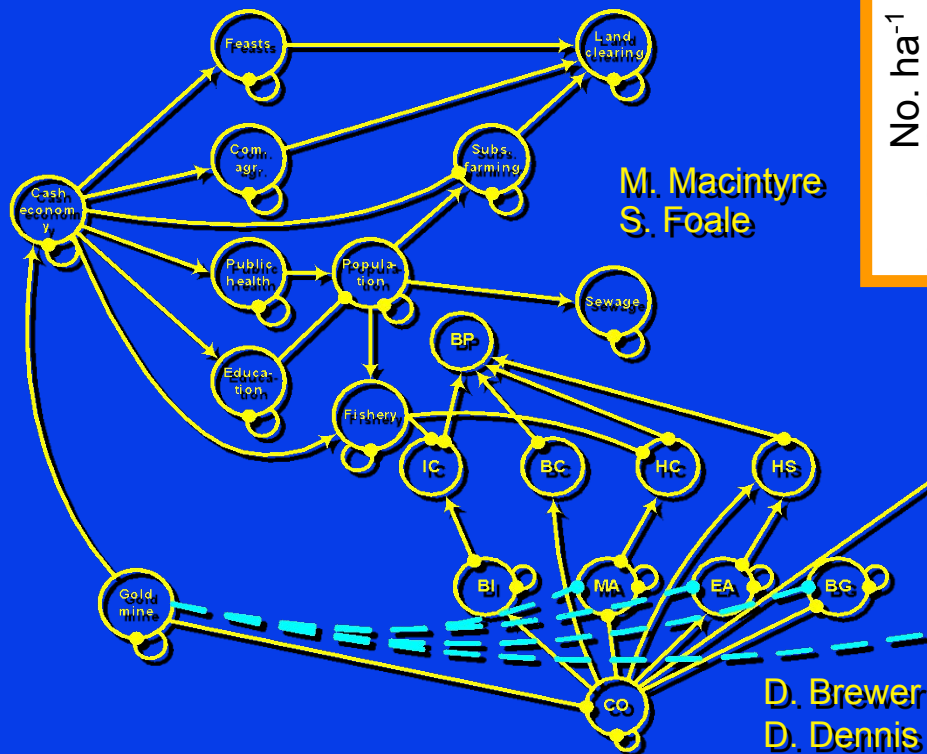




M. Macintyre
S. Foale

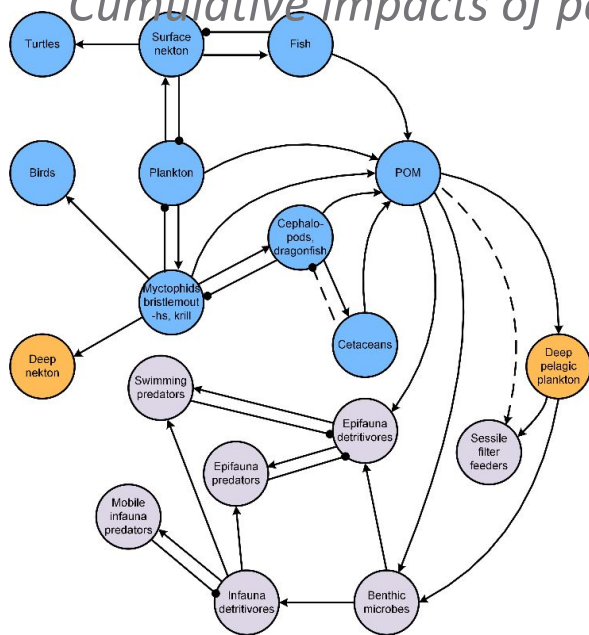


D. Brewer
D. Dennis



Mid-Atlantic Ridge pelagic & benthic ecosystem

Cumulative impacts of polymetallic sulphide mining



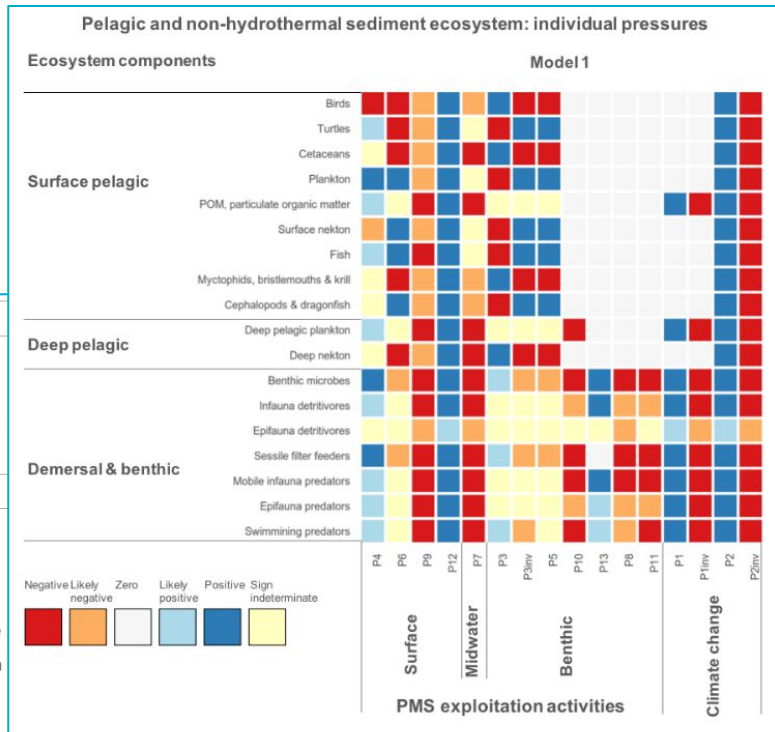
Expert domain knowledge

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)

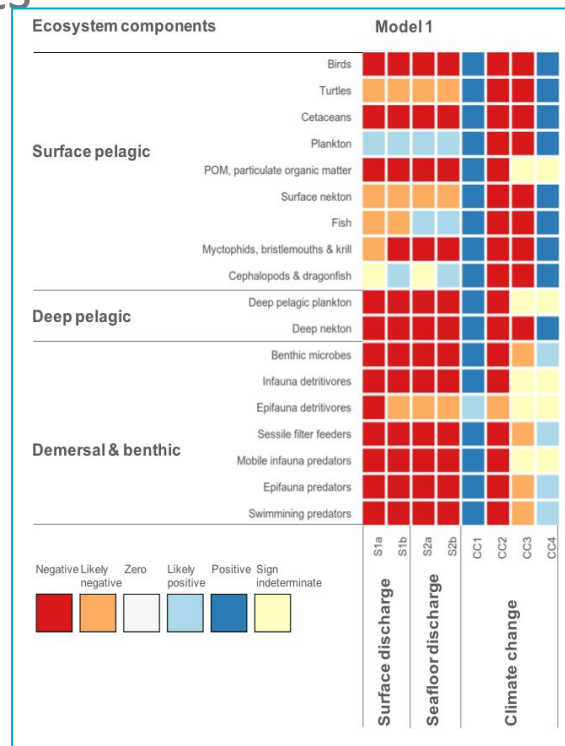
Polymetallic sulphide exploitation pressures & cumulative impacts

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 production
	P2inv	Temperature increase, reduced primary production

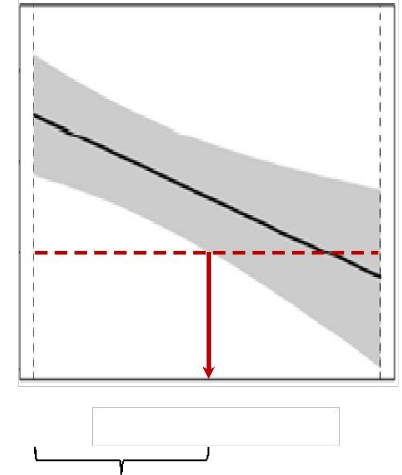


Polymetallic sulphide exploitation multiple pressures & cumulative impacts

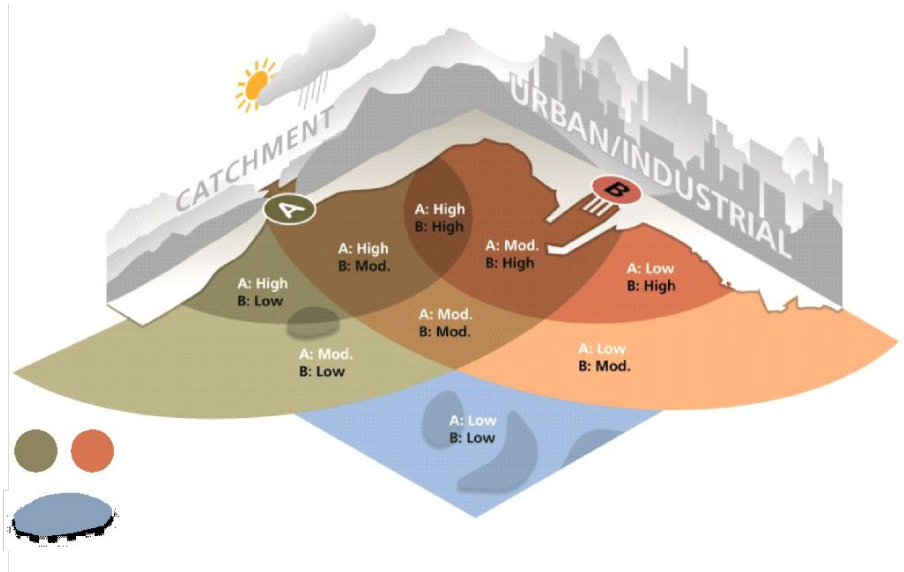
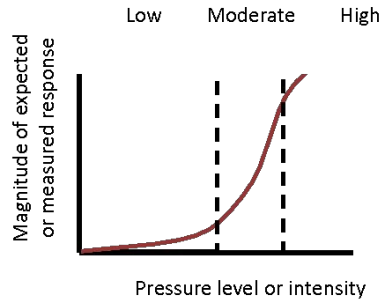
Pressure category	Abbreviation	Perturbation scenario description	Pressure combinations
Surface discharge	S1a	Surface discharge, positive light effect	P3, P4 – P9, P11 – P13
	S1b	Surface discharge, negative light effect	P3inv, P4 – P9, P11 – P13
Seafloor discharge	S2a	Seafloor discharge, positive light 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



— 2 —



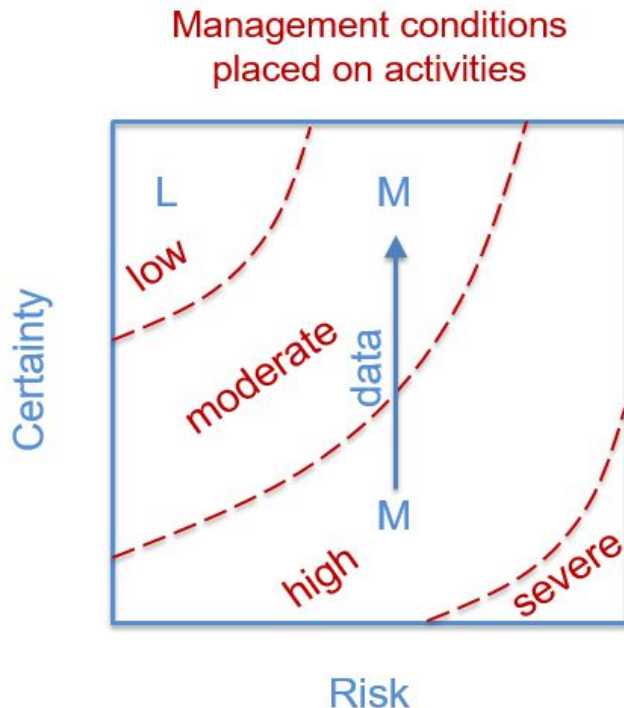
Zones of influence



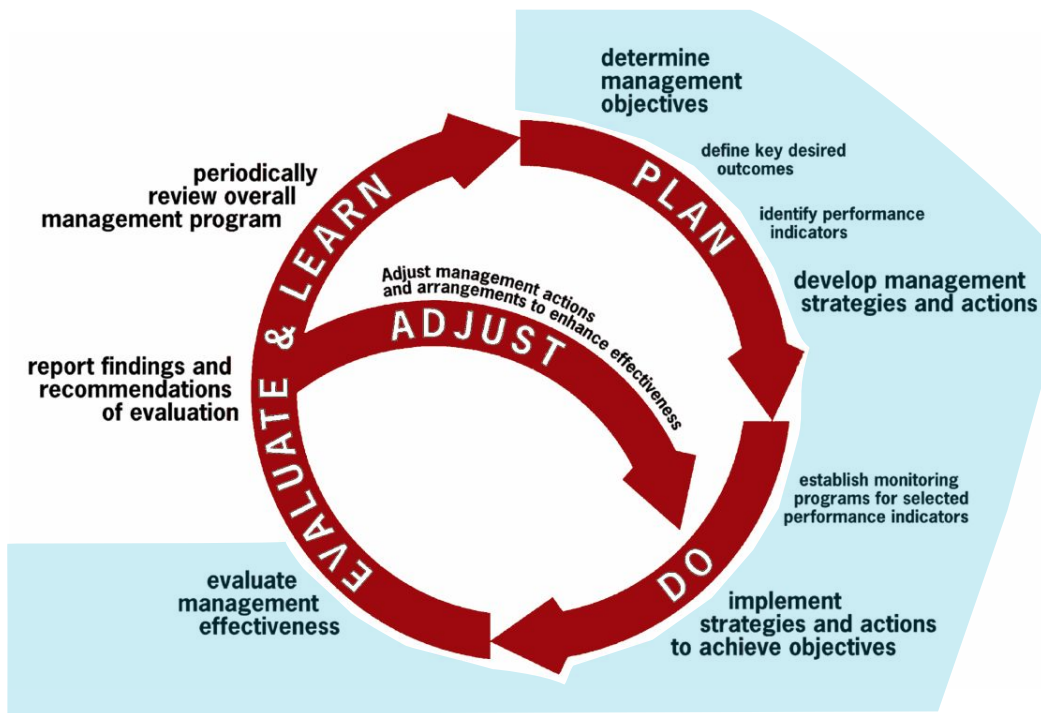
Role of monitoring in risk assessments & adaptive management

		LIKELIHOOD				
		Rare	Unlikely	Possible	Likely	Almost certain
CONSEQUENCE	Catastrophic					
	Major					
	Moderate			(M)		
	Minor		(L)			
	Insignificant					

Risk					
	Low	Medium	High	Very high	



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



Nodules valued for battery metals in transition to renewable energy

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

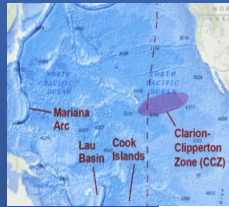
- Integrated ecosystem assessment
- Ecosystem-based management framework
- Integrated monitoring program

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



Mining platform ship

Discharge

Hydraulic Pump System

Buffer

Flexible hose collector

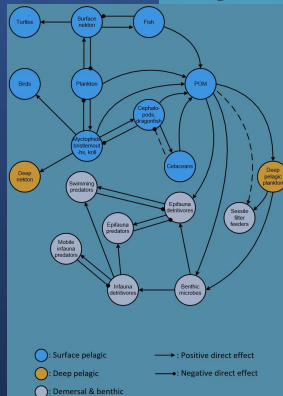
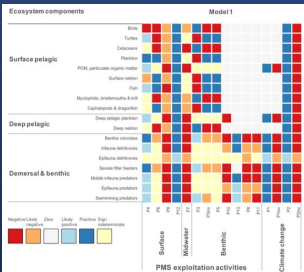
4,300 m depth

Nodules

Tracked mining vehicle

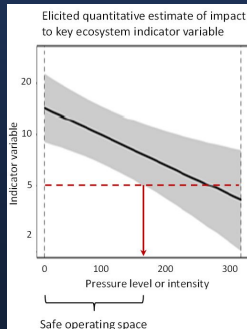
Sediment plume

By G. Mannaerts, CC BY-SA 4.0, <https://commons.wikimedia.org/w/index.php?curid=120579344>

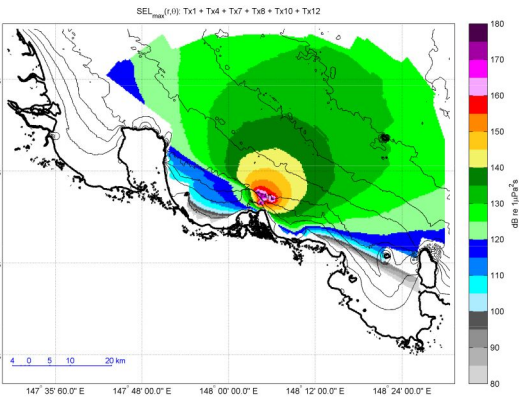


Methods

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



Zone of Influence



Noise – Cetaceans

