National SCIENCE Challenges

SUSTAINABLE SEAS

Ko ngā moana whakauka

Managing cumulative effects in the marine environment — research roundup

Rojas-Nazar U, Hewitt J, Pilditch C & Cornelisen C

May 2023

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About the Sustainable Seas National Science Challenge

Our vision is for Aotearoa New Zealand to have healthy marine ecosystems that provide value for all New Zealanders. We have 75 research projects that bring together around 250 scientists, social scientists, economists, and experts in mātauranga Māori and policy from across Aotearoa New Zealand. We are one of 11 National Science Challenges, funded by the Ministry of Business, Innovation & Employment.

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Managing cumulative effects in the marine environment

About this research round-up

The health of Aotearoa New Zealand's marine ecosystems continues to decline due to multiple stressors contributing to cumulative (and sometimes abrupt and non-linear) environmental change. Reversing this decline requires the ability to manage the cumulative effects (CE) of multiple stressors that impact on our marine waters and habitats. The challenge of managing CE is one of the most urgent and complex problems facing the world's coasts and oceans (Ministry for the Environment and Stats NZ 2019).

A growing body of research and reviews highlights that the cumulative effects of fishing, land-based activities, pollution, and climate change are key threats to ocean health (for example, Solutions 2009, Hodgson and Halpern 2019). To better understand CE to support decision-making and reverse current trends, the Sustainable Seas National Science Challenge/Ko ngā moana whakauka (Sustainable Seas) has made CE a core component of its research.

This research round-up is a synthesis of current Sustainable Seas knowledge geared toward improving how we manage for CE in the marine environment. This document:

- defines CE in the marine environment
- describes the challenges faced in managing CE
- summarises knowledge that can aid CE management
- highlights research aimed at further improving our ability to manage CE.

What are cumulative effects?

Several definitions of cumulative effects (CE) exist across science disciplines, legal mandates, and sector-based management policies. To reflect CE within an ecosystem-based management (EBM) context, Sustainable Seas has adopted the following definition for CE:

Cumulative effects arise from incremental, accumulating, and/or interacting stressors from human activities and natural events that overlap in space and/or time.

> Cumulative effects may:
> - be ecological/environmental only, but generally these lead to social, economic, and/or cultural effects
> - arise from single or multiple stressors
> - have direct and/or indirect effects
> - arise from past stressors
> - be made worse by climate change.

This definition aligns with the Aotearoa New Zealand Government's approach to decision-making for our marine environments (Ministry for the Environment and Stats NZ 2019). In particular, that stressors can come from human actions and natural processes, and the effects can be generated at any level or across them. Importantly, a single activity may create more than one stressor and affect the ecosystem in multiple ways (see Figure 1 for an example).

Management of CE within an EBM framework aligns with the concept of ki uta ki tai/from the mountains to the sea. Based on mātauranga Māori, ki uta ki tai offers a place-based understanding of environmental change derived from intergenerational observations and the transmission of that knowledge in Aotearoa New Zealand, crossing boundaries and showing the interconnectivity between land and sea. Ki uta ki tai also fully captures the interconnectedness of ecosystems inclusive of people (Tipa et al 2016, Kainamu-Murchie et al 2018), providing a unifying metaphor that aligns with healthy ecosystems.

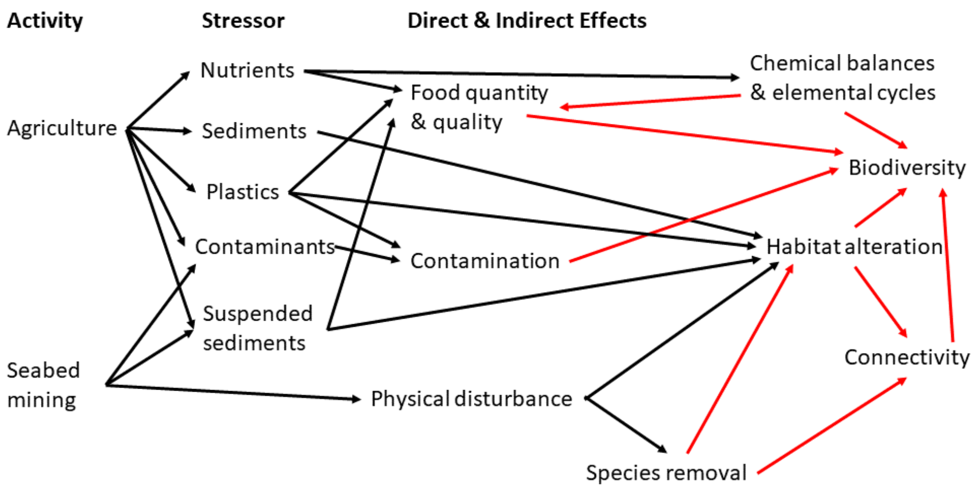

Figure 1: Example of the multiple stressors that can be generated from land-based agriculture and seabed mining, and some of the ecosystem components that can be affected by these stressors. Direct and indirect effects on ecosystem components are shown by black and red arrows respectively.

Estuaries, for example, are exposed to many stressors that may come from the land, within the estuary or the ocean (Figure 2), that cumulatively affect the ecological functioning, and in turn the social, economic, and cultural values they provide. While the deep ocean of the Exclusive Economic Zone (EEZ) does not presently have so many activities occurring within it, this may change in the near future with increased need for offshore power generation and development of offshore aquaculture. Furthermore, all marine environments face the impacts of global climate change, which include warming and more acidified waters, as well as disruptions to food webs caused by overharvesting of apex predators and other species that are important in human diets.

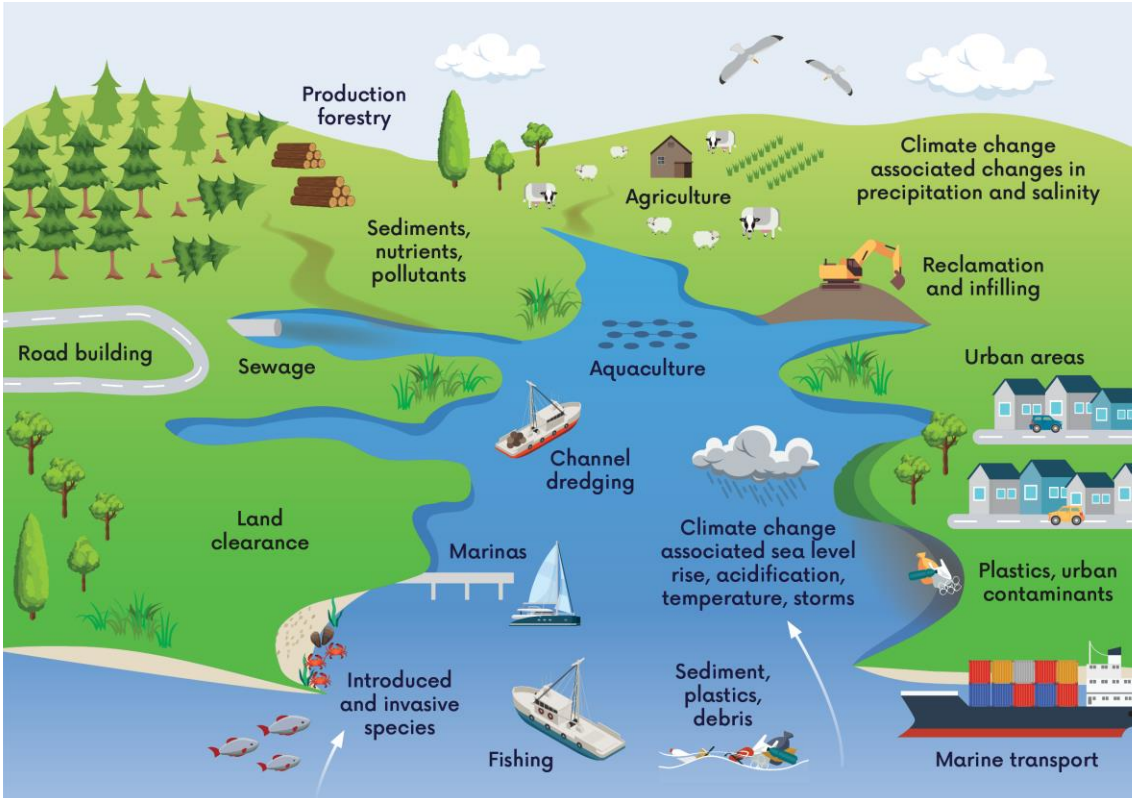

Figure 2: Stressors affecting estuaries (adapted from biome-estuaries.weebly.com/threats-to-estuaries)

Why do we worry about cumulative effects?

Multiple stressors generally interact synergistically in marine systems (for example, Crain et al 2008, Thrush et al 2008, Foley et al 2017). This means that the effects of stressor interactions are much greater than simply adding up the individual effects of stressors in isolation of each other. Understanding the interactive effects of multiple stressors that characterise coastal habitats is challenging because most research to date has focused on the effects of 2-3 simultaneous stressors on selected species or community assemblages, often under controlled laboratory conditions. Research internationally and within Aotearoa New Zealand has demonstrated that it is the slowly accumulating ecological responses to stressors that are often at the heart of ecosystem tipping points (ie a sudden loss of ecological health) and cause 'surprises' for environmental managers (Thrush et al 2016). Because the ecological responses to CE can lag behind the cause, they are often not visible until after crossing a threshold — or just before, when it is too late to act.

What are the challenges of managing cumulative effects?

Many social-ecological challenges to effective CE management exist in the marine environment, for example, the fragmented regulatory system and the difficulty in establishing cause and effect due to the complex nature of stressor interactions across space and time. Management is further complicated by lags in environmental response to single stressor management amidst the emergence of further issues and consequences of multiple stressors interacting over time.

Five key challenges exist to effective CE management.

1. Fragmented regulatory structure

The current regulatory system is fragmented, inconsistent, and dispersed, with 25 statutes governing 14 agencies across 7 spatial jurisdictions. The reforms of the current Resource Management Act (RMA) with three new acts provides an opportunity to improve the state of our environment by providing better regulatory frameworks for addressing CE. This includes considering the CE from climate change, other potential future activities or natural stressors and ensuring all activities within the Coastal Management Area (CMA) and wider EEZ are considered within environmental impact assessments, including fishing.

2. Lack of integration of social and cultural values

The current legal system in Aotearoa New Zealand has the provision to operationalise the integration of social and cultural values in holistic management, particularly under the RMA, but no such action has been applied yet.

3. Lack of consideration of scale dependencies.

Management of CE is often not aligned with the scale at which the effects occur, and CE are often comprised of stressors that are produced over different scales.

4. Lack of information on how the environment responds to, and recovers from, different stressors accumulating over time.

A major challenge for all those seeking to manage stressors on the marine environment is accurate knowledge. Worldwide, functional responses of coastal ecosystems to cumulative stressors is not well understood. Research related to the CE of multiple stressors acting simultaneously in the real world has proven challenging (Hodgson et al 2019) and consequently is considered the greatest source of uncertainty in CE management (Crease et al 2019).

5. Increased uncertainty over outcomes of decisions.

Uncertainty in CE management is problematic because CE can lead to abrupt changes in ecosystem function, which can occur unexpectedly when the interactions among different stressors are not fully understood.

Sustainable Seas research addresses key challenges of CE management

CE must be managed more effectively to improve marine ecosystem health, as well as the social, cultural, and economic values that the marine environment provides. As we move towards enabling EBM approaches for the marine environment, we can start overcoming challenges in CE management using the knowledge and tools generated in Sustainable Seas.

Sustainable Seas has been working with a range of researchers and co-development partners to increase our understanding and knowledge of CE in Aotearoa New Zealand. This work spans ecological, social, economic, and cultural dimensions. Our research provides empirical evidence that shows that CE in the marine and coastal environment cannot continue under the business-as-usual management approach.

The next sections present approaches and tools generated in Sustainable Seas that can aid CE management in Aotearoa New Zealand.

Developing a regulatory system that can effectively address CE

Two projects from Phase 1 of Sustainable Seas (2016–2021) explicitly recognised the problems with current isolated regulatory and management systems. A cross-challenge workshop with researchers from Sustainable Seas, Biological Heritage and Our Land and Water, as well as international researchers, explored the management and research conducted within and across ecosystem domains (land, freshwater and marine). They recognised that now most management of activities is caried out separately within each domain (see Figure 2 in Gladstone-Gallagher et al. 2022). Therefore, one of their recommendations was that to better recognize drivers of change earlier, collaboration needed to be fostered, at a management and governance level, between those who have priorities in different domains.

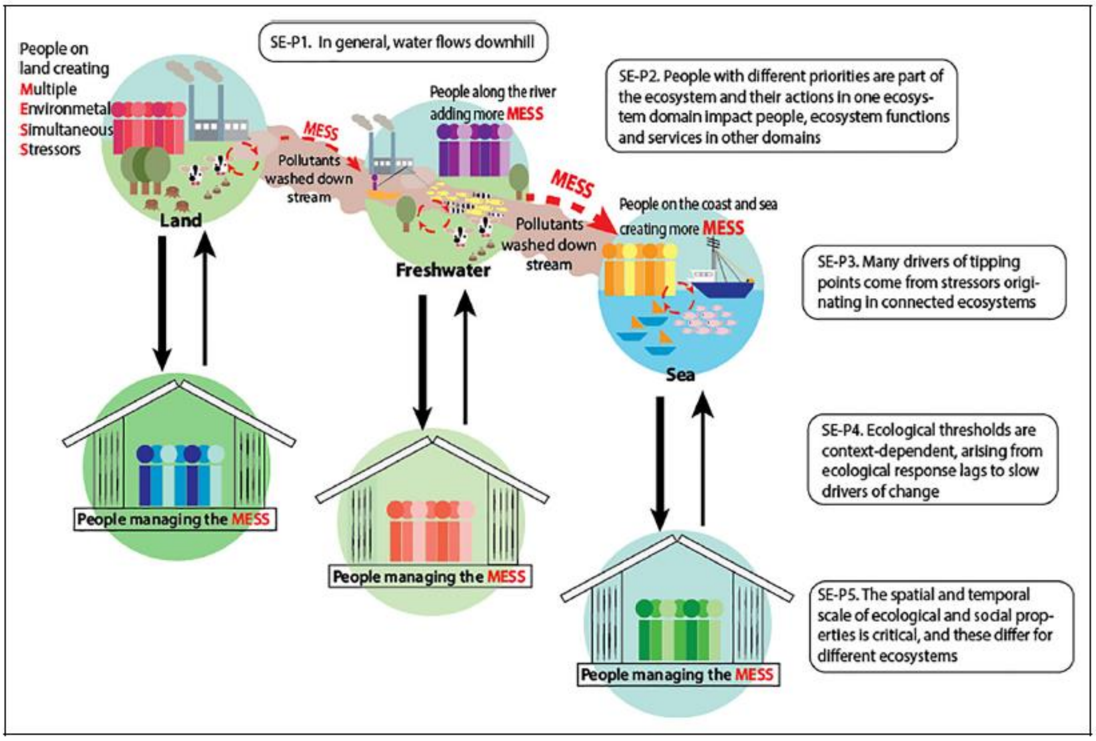

Figure 2. Diagrammatic representation of the fracturing of environmental management among ecosystem domains. The fracturing among ecosystem domains prevents social feedbacks to upstream management. The diagram lists the social–ecological properties (SE-P1–5) of cross-domain connections that demand a reprioritization of environmental management. The differential arrow thickness between people and the ecosystem domain indicates that the quantum of the "MESS" is greater than the ameliorating environmental management. DOI: https://doi.org/10.1525/elementa.2021.00075.f2

Another Phase 1 project brought together 24 different organisations and agencies in a series of workshops to develop an initial suite of principles for CE management in Aotearoa New Zealand (Davies et al 2019). These principles (see Figure 3), while largely like the principles for EBM, support the concept of ki uta ki tai and explicitly recommended treating the whole environment, without jurisdictional boundaries, as well as the use of both regulatory and non-regulatory approaches in dealing with CE. The principles for CE management are intended to address management challenges; for this reason, they are more focused on the social aspects of CE than ecological. They consider direct effects on the natural ecosystem and the flow-on from these to human systems (social, cultural, and economic), as well as the direct effects on those human systems.

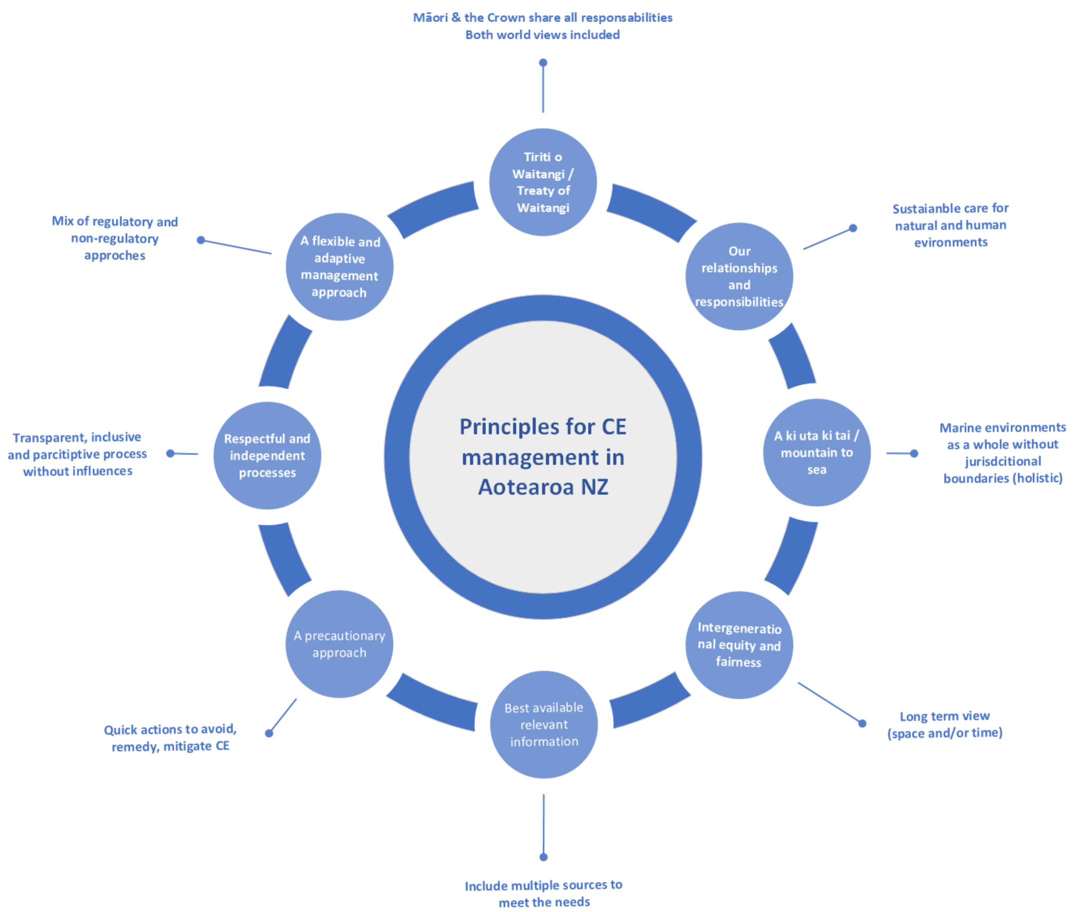

Figure 3**:** Aspirational principles to manage cumulative effects in Aotearoa New Zealand developed during Phase I of the Challenge by Davies and collaborators. Sourced from *Davies K, Fisher K, Couzens G, Faulkner L, & Hewitt J. (2019). Principles for cumulative effects management in Aotearoa New Zealand. Resource Management Journal, 11-15.*

Further work has continued into Phase 2 (2021–present) in one main project, *Policy and legislation for EBM*. The use of regulatory and non-regulatory governance structures are one of the four pou (enabling conditions) suggested as necessary conditions for EBM in this project (Fisher et al 2022). The project investigated recent initiatives to improve interactions between regulatory agencies (Urlich et al 2022[i]).

Comparing attempts to implement EBM (which explicitly demands CE management) in laws and policies of Chile, Australia and Aotearoa New Zealand, the project has suggested that policymakers focus on enabling the relational processes of EBM – through institutions and processes that subscribe to a common vision and allow for change over time[ii]. They suggest that a combination of detailed rule and institution-making (hooks) and high-level norm-setting (anchors) could enable a relational approach to EBM (Figure 4). Hooks are suggested to be combinations of new, amended, and (where appropriate) existing rules, tools, and processes that reinforce and enable a coordinated approach to EBM across sectoral frameworks, that are properly resourced and mandated by government and supported by effective institutions and community participation. Anchors are overarching or constitutional legal and policy objectives that set a shared vision and ecological 'bottom lines'.

[i] https://www.sustainableseaschallenge.co.nz/tools-and-resources/characterising-the-regulatory-seascape-in-aotearoa-new-zealand/
[ii] https://www.sustainableseaschallenge.co.nz/tools-and-resources/hooks-and-anchors-for-ebm/

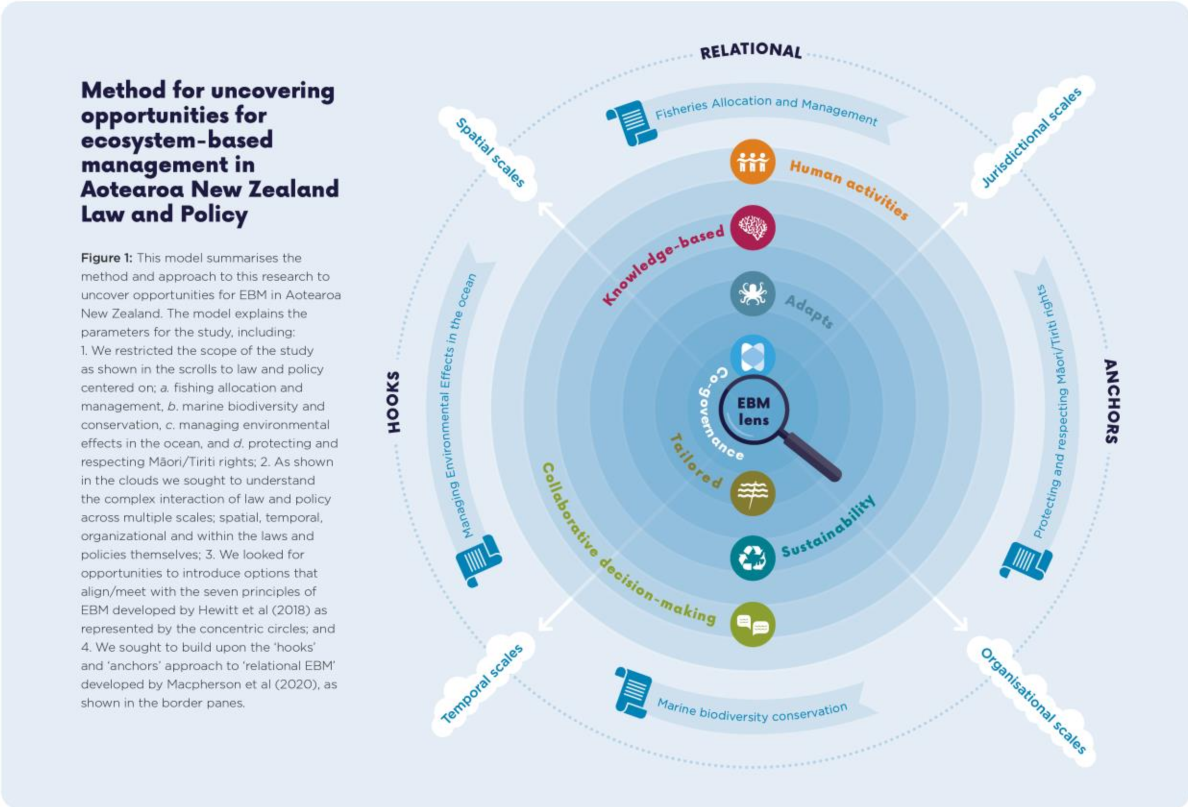

Figure 4: Methods for uncovering opportunities for ecosystem-based management in Aotearoa New Zealand law and policy sourced from Macpherson et al.

The project *Ecological responses to cumulative effects* has summarised problems and ways forward. A paper documenting the problems associated with uptake of research in Aotearoa New Zealand includes problems specific to legislation and management (Hewitt et al 2022a). Specifically, it highlights the differences in language used by law and regulations, management agencies, business, and researchers. For example, the terms "baselines", "business as usual", and "sustainability" all have different interpretations across industry, government, and environmental sectors. The project also highlights the constraints for decision-making that result from Aotearoa New Zealand's reliance on case law. Local decisions are frequently challenged in the Environment Court, where judges will often set future precedents.

A briefing[iii] was also created specifically for the treatment of CE in estuaries, highlighting:

- why CE are highly place-specific
- what we do and don't know
- how that would affect the application of national limits.

Place-based risk assessments that focus on moving towards targets set by locals are suggested as a less risky solution than setting national limits (see Figure 5).

[iii] https://www.sustainableseaschallenge.co.nz/tools-and-resources/reframing-environmental-limits-for-estuaries/

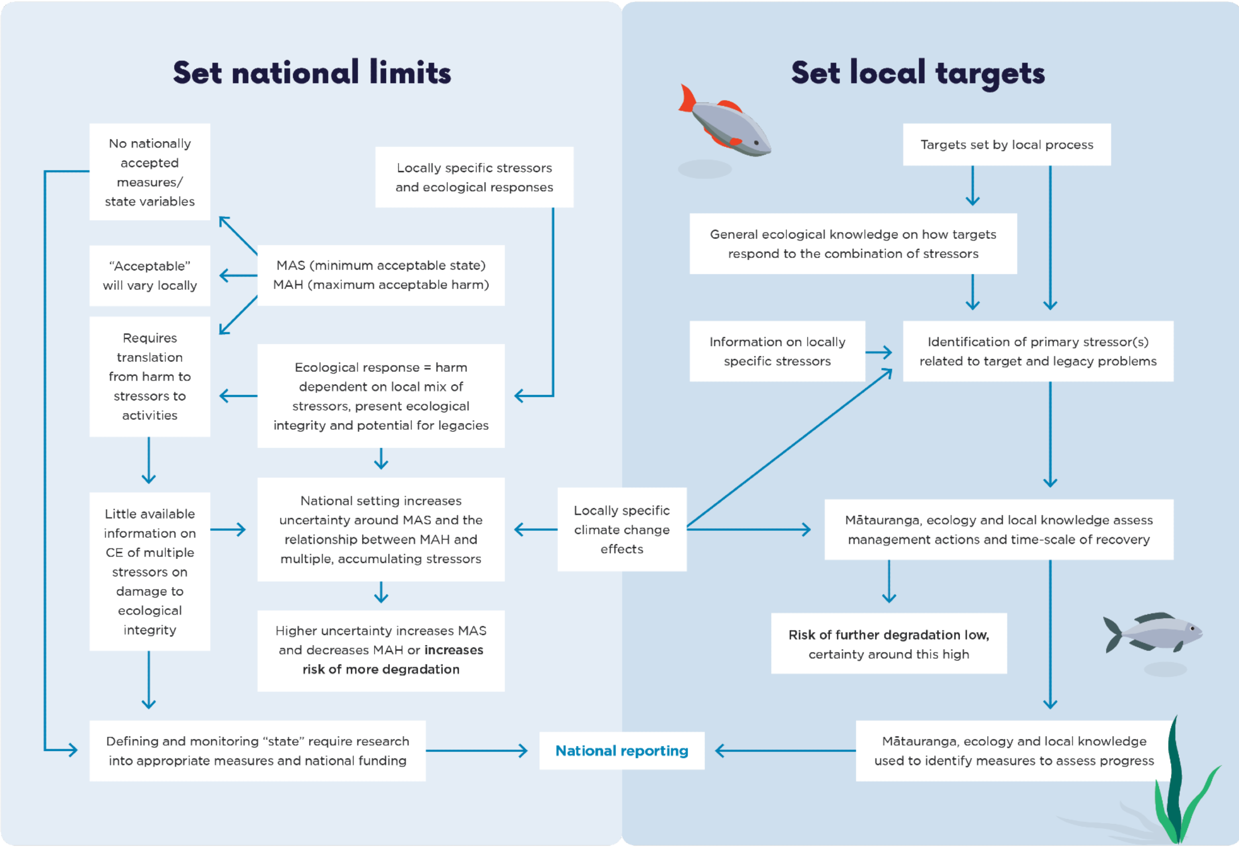

Figure 5: Knowledge requirements and advantages of setting local recovery targets in comparison with national limits for estuaries.

Future outputs on developing a regulatory system for CE

Future research within *Policy and legislation for EBM* is intended to create a framework that will enable CE management. The overall structure will be based on the "hooks" and "anchors" previously defined and will include a discussion as to how marine spatial planning practices can align with the objectives of EBM.

Three other projects are also working on aspects of regulation/governance that will support CE management. Two of these *Tangaroa Ararau* (Led by Beth Tupara-Katene) and *Enabling kaitiakitanga and EBM* (Led by Lara Taylor & Dan Hikuroa) will be finishing this year. The third project *Scale and EBM* (Led by Joanne Ellis) began in the last year. Included in this project is an analysis of legal approaches to managing issues of scale in marine contexts.

Improving integration of social and cultural values to move towards the holistic management of CE

In Phase 1, specific research was conducted into how to build participation (Le Heron et al 2019[iv]) and to elicit and deal with non-monetary values (Tadaki et al 2021). The latter research viewed valuations as the collection of information about people's values and relationships to the environment. A summary[v] suggested that any valuation process should:

- acknowledge that all valuation exercises are influenced by political and social context
- make deliberate and explicit choices about how the process will respond to this context
- explain choices and how they might affect social and environmental outcomes.

Building social and cultural values into decision making aligns with the principles for CE management (see Figure 3 above) and contributed to the Aotearoa Cumulative Effects Framework (ACE, Crease et al. 2019[vi]) produced in Phase 1 (Figure 6). ACE uses purpose-built scenarios based on realistic Aotearoa New Zealand situations to explain how to

[iv] https://www.sustainableseaschallenge.co.nz/tools-and-resources/ingredients-tool/
[v] https://www.sustainableseaschallenge.co.nz/tools-and-resources/addressing-politics-when-conducting-valuation/
[vi] https://www.sustainableseaschallenge.co.nz/tools-and-resources/ace-framework/

incorporate CE management into decision-making in the marine environment. The framework was created with a range of agency co-development partners to facilitate or guide collaboration and participation in CE management across a range of scales under existing legislation, institutions, and interests, such as future experts in CE governance, science, management, decision-makers, practitioners, iwi/Māori, and stakeholders. It poses a series of questions that can help a collaborative group to identify where uncertainty exists throughout the CE management process (Foley et al. 2019) and encourages participants to identify who should be involved in defining vision and goals.

ACE does not outline how to do CE assessments nor identify what management interventions may be successful in achieving goals and aspirations. Instead, it explains how to establish management goals and objectives, conditions, boundaries, and key players.

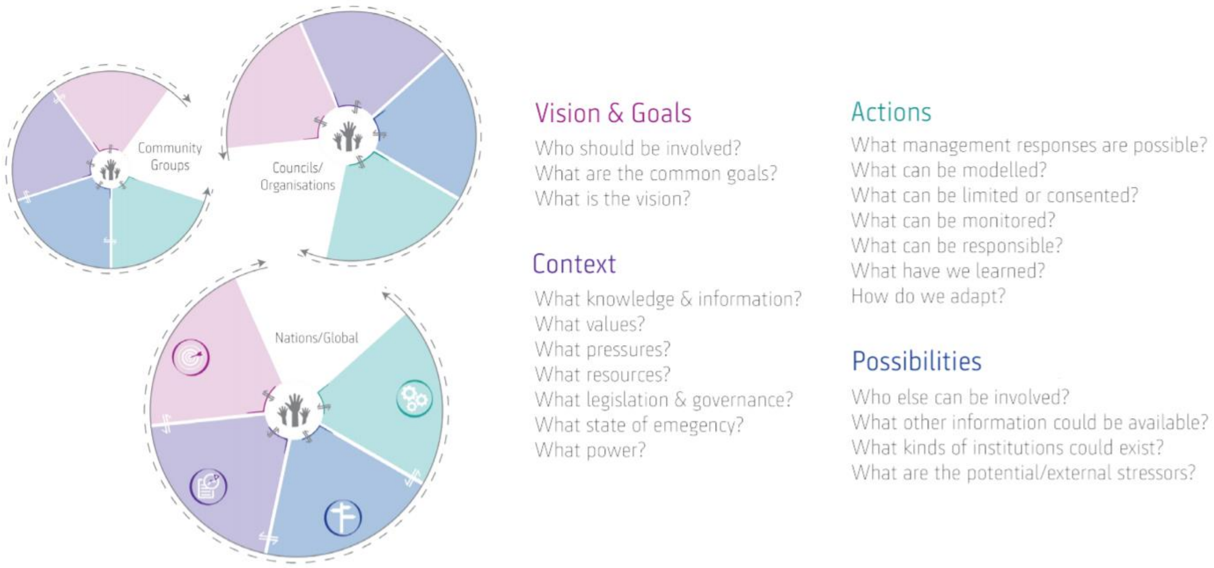

Figure 6: Aotearoa Cumulative Effects (ACE) Framework for facilitating collaboration and participation in CE management across a range of scales under existing legislation, institutions, and interests.

In the Phase 2 project *Policy and legislation for EBM,* the need to better integrate social and cultural values into management was reiterated by including values as three of the four pou (enabling conditions for EBM (Fisher et al 2022): diversifying knowledge production; prioritising equity, justice, and social difference; and recognising interconnections and interconnectedness).

Also in Phase 2, as part of *Communicating risk and uncertainty*, a multi-criteria decision-making framework was developed. This framework allowed exploration of three environmental drivers (habitat structure, benthic diversity and adult fish biomass); three social drivers (aesthetics, mega-faunal sightings and recreation fishing); and three economic drivers (commercial fishers, fishing industry and tourism).

Future research on improving integration of social and cultural values
Future research related to this is being conducted in Tangaroa projects and the Te Ao Māori synthesis strand.

When working across different scales, management of CE is often not aligned with the scale at which the effects occur, and many stressors change their relative importance with scale. CE are also not geographically restricted; a cross-scale, holistic EBM approach enables effective management of CE. Work has been done to directly investigate the effect of scale on governance arrangements and on illustrating some scale mismatches inside the project on *Policy and legislation for EBM.* A paper (Fisher et al. 2022) has investigated governance models that span local, regional and national arrangements, and outcomes. An agent-based model based on multi-species complex fisheries management was developed for Tasman/Golden Bay with workshops led by Fisheries New Zealand (Allison 2022). This model[vii] and the underlying data highlighted differences in scale both between the species comprising the complex and between species' habitat usages and the management area.

Future outputs on working across different scales

A project specifically looking at EBM and scale has recently been funded (*Understanding and communicating the various implications of scale for EBM*; Joanne Ellis). This work has three sections: S1) A review of existing knowledge of scale dependencies from other Sustainable Seas projects (just completed), S2) Analysis of scale-dependencies, specifically in the legal-policy, ecological, socio-psychological, mātauranga Māori and economic realms, and S3) Creating visual summaries to aid understanding of cross-scale implications and contribute to robust, transparent decision making.

Knowing how the environment responds to, and recovers from, different accumulating stressors

In Phase 1 numerous projects documented responses of a variety of ecosystem components to stressors, although these were generally not analysed or discussed in the context of CE. One project that did specifically set out to investigate CE was a national experiment conducted in 15 estuaries investigating the CE of two of NZ's most important stressors in estuaries (nutrients and suspended sediment). Due to the way the suspended sediment stressor was measured (as light available for photosynthesis at the seafloor), interactive effects with a third stressor (sea level rise) could also be predicted. Here are the key findings[viii].

- Ecosystems in turbid waters had no capacity to process increased nutrients, unlike those in clear waters (Thrush et al 2021).
- Ecosystem functioning in estuaries with high turbidity was impacted more by biodiversity loss than in clear water (Gammal et al 2022).
- In some turbid estuaries, primary production by microphytes (MPB) on intertidal flats (which are vulnerable to sea level rise) can only occur during low tide (Mangan et al 2020).
- While microphytobenthic biomass increased with nutrient addition, lipid reserves in an important shellfish were reduced, as was the nutritional quality of this shellfish to higher trophic levels (Hope et al 2020).
- National or regional standards for nitrogen loading will be a blunt management tool.

In Phase 2, some projects specifically set out to inform the management of CE. An initial review of available CE assessment tools (CEAs) revealed that these had lagged behind the complex systems literature and so were of limited use. CEAs have focused on the sequential progression of stressor cause and effects chains rather than recognising feedbacks, emergent properties, and the complexity of weak and strong interactions over different timescales. In particular, they focus on stressor footprints, despite ecosystem responses being able to be disconnected from the footprints. The review analysed the tools against three questions (Table 1 below), finding that no tools met all criteria (Figure 6).

[vii] https://www.sustainableseaschallenge.co.nz/tools-and-resources/co-developing-an-agent-based-model-to-support-ecosystem-based-management-decision-making/

[viii] https://www.sustainableseaschallenge.co.nz/tools-and-resources/managing-turbidity-nutrients-and-sea-level-rise-on-coasts/

Table 1: Criteria important for fit-for-purpose CE assessment tools

Criteria	Categories
C1 Are non-additive interactions among stressor responses considered?	a) No b) Yes - multiplicative categories (ie, synergistic, or antagonistic) c) Yes - quantitative relationships (often non-linear) of responses to stressors
C2 Are cumulative impact scores based on place-based responses?	a) Not place-based b) Place-based vulnerabilities incorporated for some ecosystem components c) Place-based responses consider interactions between ecosystem components including how past legacy effects in a place can influence how the ecosystem responds
C3 Are spatial and temporal dynamics of the ecological responses to stressor(s) considered?	a) No b) Yes - spatial extent of the response is considered in impact scores c) Yes - temporal elements of response are considered in impact scores d) Yes- full recognition of spatio-temporal elements such as disturbance regimes, connectivity and landscape heterogeneity

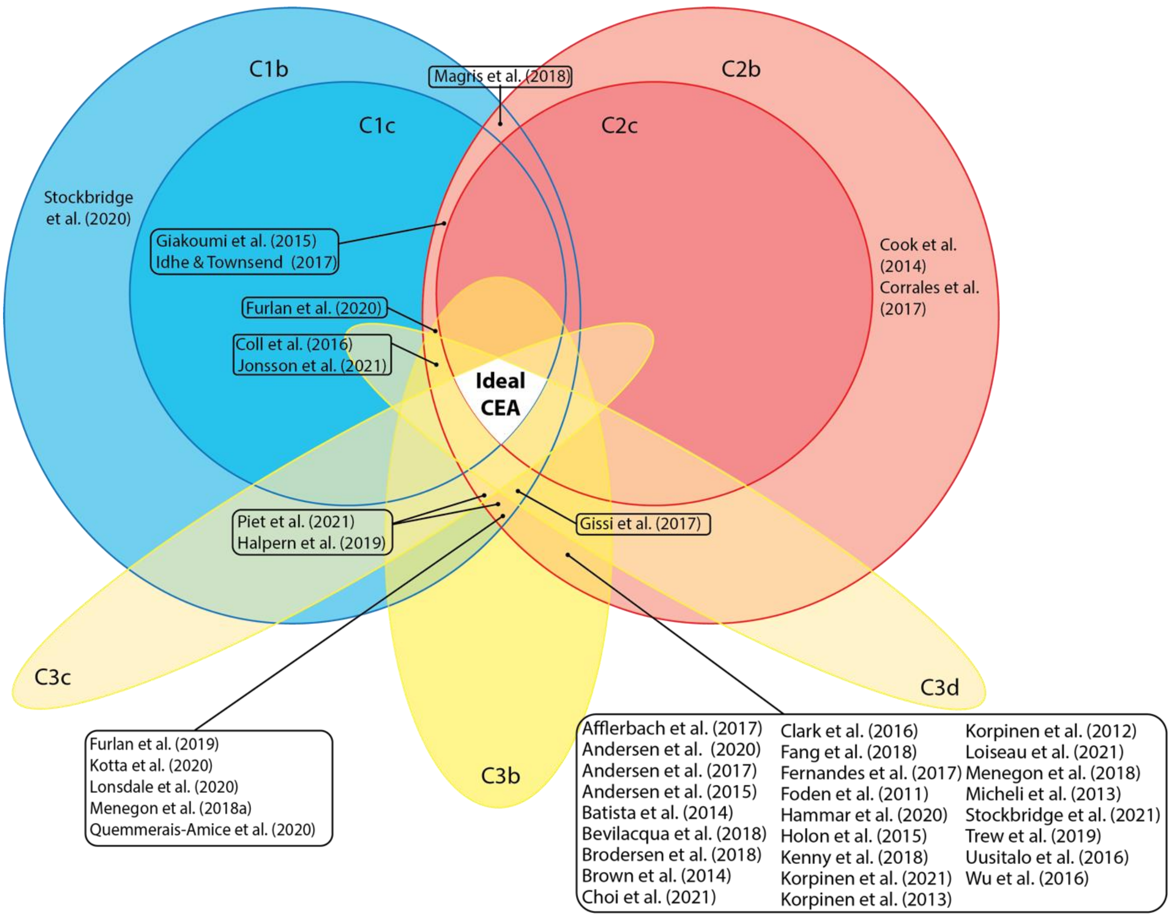

Figure 7: Summary of the assessment of CEAs against the ecological criteria in Table 1. The centre of all overlaps represents the ideal CEA which meets all the criteria.

A series of system mapping projects conducted in the Golden Bay[ix], [x] and Hawke's Bay[xi] areas highlighted the need to be able to deal with criteria C2b, C2c and C3d (Table 1). Systems mapping is powerful tool to visualise connections across social/ecological spaces. For example, Sustainable Seas worked with a non-statutory multi-stakeholder group (Hawke's Bay Marine and Coastal group (HBMaC)) and their sponsor, to develop a conceptual system map, demonstrating the interlinked influences of two main environmental stressors – land derived sediments and seafloor disturbance due to fishing (Figure 8 and Connolly et al. 2020[xii]). Following this, a model was developed to explore the outcomes on seafloor communities when combinations of reductions in sediment and fishing stressors were applied[xii]. These types of spatial models underpin CE assessments.

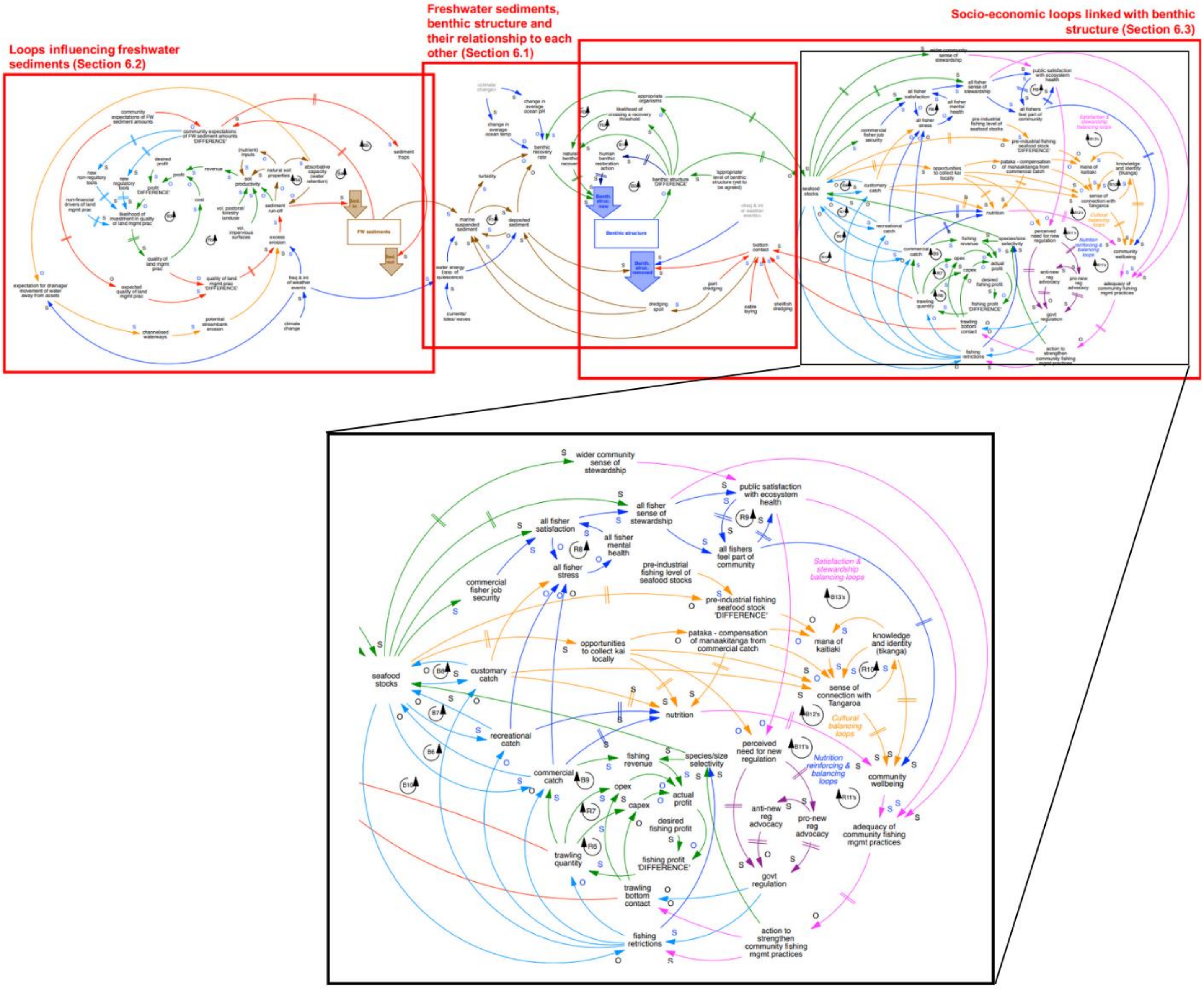

Figure 8: System map of the Hawke's Bay coastal region. [A higher resolution map is available (Connolly et al 2020[xii]).](#)

[ix] https://www.sustainableseaschallenge.co.nz/tools-and-resources/literature-review-risk-assessment-frameworks-ebm-aotearoa-new-zealand/

[x] https://www.sustainableseaschallenge.co.nz/tools-and-resources/system-dynamic-mapping-and-managing-multi-species-complexes/

[xi] https://www.sustainableseaschallenge.co.nz/tools-and-resources/final-report-systems-mapping-in-hawkes-bay-stage-1/

[xii] https://www.sustainableseaschallenge.co.nz/assets/dms/Reports/Hawkes-Bay-Seafloor-Model/HawkesBaySeafloorModelReport_22Aug2022.pdf

However, CE management also includes recovery from CE. A vital decision in actions to support recovery is when recovery will happen when stressors are removed or when active enhancement is required. A process to prioritise locations for recovery from CE has also been developed based on a series of decision trees that work with low information (an example from Hewitt et al. 2022b is given in Figure 9).

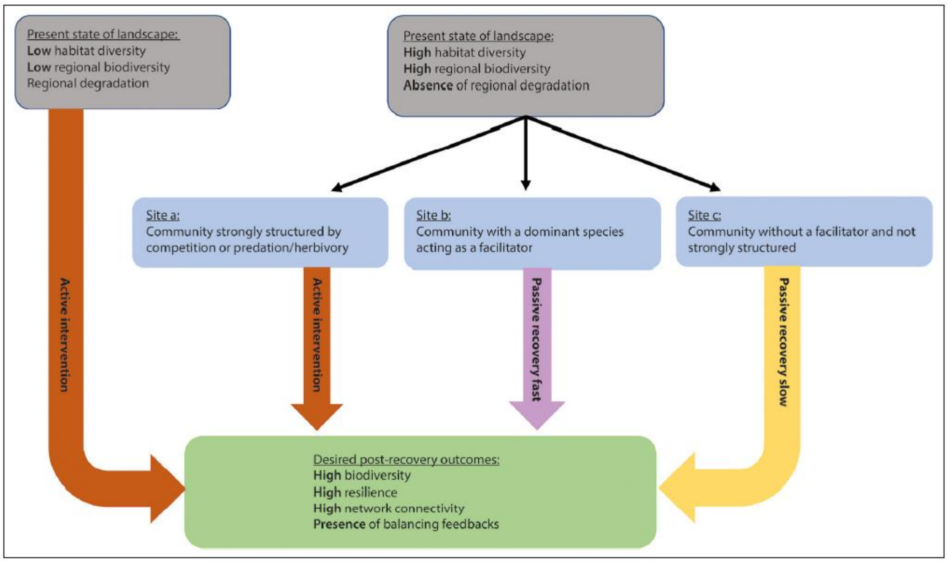

Figure 9: Management types (coloured arrows) to achieve recovery of seafloor communities or ecosystems (green rectangle) depend on the present condition of sites (blue rectangles) and the surrounding landscapes (grey rectangles). Sourced from Hewitt et al. 2022b.

Together, these pieces of work highlight the need to focus on the most relevant information. Redefining evidence to allow a full range of knowledge (such as ecological theory, mātauranga Māori, local or expert knowledge) to be used, rather than relying on highly numeric data, is probably the most important step forward we can take towards CE management.

Future outputs on knowledge of how the environment responds to CE:

Understanding ecological responses to CE (Simon Thrush and Kura Paul-Burke)

- An education tool that explains moving from stressor footprints to cumulative ecological response footprints and how response footprint assessments can be done
- Guidance and a decision tree framework that focusses on an ecological assessment of the risk of cumulative effects in place

Spatially explicit cumulative effects tools (Carolyn Lundquist)

- An approach for incorporating climate change into spatial protection from fishing impacts to identify areas which may provide climate refugia whilst still providing efficient protection for current distributions

Managing for CE within the context of risk and uncertainty

Risk assessments for CE within an EBM framework have specific requirements that may not be generally met by all presently available risk assessment tools. A first task for the project *Communicating risk and uncertainty* was to understand what a successful risk and uncertainty assessment needed to include (Clark et al 2022).

- Interactions, feedbacks, and indirect effects
- Threshold response and non-linear dynamics
- Risk to ecological, cultural, social, or economic values of interest and to multiple ecosystem components
- Changes in risk through time and across space
- The location context
- Explicit inclusion and communication of uncertainty

CE risk assessments must also accommodate different knowledge types and separately assess recovery.

The project also reviewed existing New Zealand risk assessment methods[xiii] and discovered that, except for Bayesian network models (BN), most risk assessment methods were not fit-for-purpose to address CE within EBM. This work demonstrates why BN was selected to create a model to explore outcomes of different management scenarios for fisheries, sediment and nutrient inputs, and restoring seabed habitat, seabed health, and scallop populations[xiv].

The link between environmental stressors and fisheries has also been explored for pāua. A report describing pāua biology and summarising the risks to pāua of the combination of climate change (predominantly as long-term temperature increases and short-term heat waves) and terrestrial-driven sedimentation is the initial output of a project developing methods to systematically assess environmentally driven risks and opportunities for pāua businesses, and potential response strategies that could underpin maintaining pāua quota values.

Another project (*Perceptions of risk and uncertainty*) has focussed on developing guidelines for how to start a risk assessment in the CE space where multiple activities, different world views and power structures are at play. This has been linked strongly with work that explores Māori perspectives of risk and uncertainty, identifying issues from the perspective of Māori experts in the natural resource management field (Hyslop et al. In press).

Given the uncertainty that CE creates for management, reports from the Parliamentary Commissioner for the Environment (Parliamentary Commissioner for the Environment 2020) and Ministry for the Environment (Ministry for the Environment and Stats NZ 2019) have highlighted monitoring as a critical part of CE management. Both reports emphasise establishing a robust monitoring system to help local government and communities make informed decisions. Ideally, this would be standardised, independently assessed, and include metrics based on mātauranga Māori. Unfortunately, in Aotearoa New Zealand, very few guidelines are available on ecological, environmental, or monitoring information.

To support the government's recommendations, Sustainable Seas has produced two main guidance documents relevant to coastal and marine monitoring.

- An assessment of NZ monitoring for its appropriateness for detecting tipping points (Hewitt and Thrush 2019)[xv]
- Seven key lessons for managers to consider when designing long-term monitoring programmes for change in ecosystems particularly apply to monitoring for CE, when the drivers of change are unknown[xvi] (lessons were derived from Auckland Council's extensive monitoring of estuaries)

[xiii] https://www.sustainableseaschallenge.co.nz/tools-and-resources/literature-review-risk-assessment-frameworks-ebm-aotearoa-new-zealand/
[xiv] https://www.sustainableseaschallenge.co.nz/tools-and-resources/bayesian-network-model-seabed-health-and-scallop-fisheries/
[xv] https://www.sustainableseaschallenge.co.nz/public/assets/dms/Guidance/Monitoring-for-tipping-points-in-the-marine-environment/Guidance-Monitoring-for-marine-tipping-points.pdf
[xvi] https://www.sustainableseaschallenge.co.nz/tools-and-resources/lessons-for-designing-long-term-monitoring-programmes/

Future outputs on managing for CE within the context of risk and uncertainty:

Upholding the value of pāua quota (Katherine Short and Tony Craig)

- A calculating model of risks to the commercial Wairarapa Coast pāua fishery (PAU2). This will be used to inform quota valuation as well as response strategies and co-investment requirements.

Perceptions of risk and uncertainty (Paula Blackett and Shaun Awatere)

- A framework and guidance document and series of fact sheets on dealing with risk and uncertainty in decision making

Communicating risk and uncertainty (Joanne Ellis and Fabrice Stephenson)

- An infographic detailing how to select methods for visualising risk and uncertainties, based on the amount and type of evidence available and types of outcomes of interest.
- Two examples of a risk assessment method for Moana and the Iwi Collective Partnership

Understanding ecological responses to CE (Simon Thrush and Kura Paul-Burke)

- A method for assessing the risk of three types of management action (adaptive, reduce and let recover, active recovery) for ecosystems conducted in conjunction with *Communicating risk and uncertainty*.

Awhi Mai, Awhi Atu (Kura Paul-Burke and Rich Bulmer)

- A method for assessing potential areas for restoration of mussels conducted in conjunction with Communicating risk and uncertainty.

Conclusion

To improve CE management, Sustainable Seas supports a transition of our current resource management system into EBM with a cross-scale, holistic approach. But this requires building the capacity of legislators and decision-makers (for example, planners, policy makers) to understand complexity. While there is undoubtedly a role for science-policy liaisons and co-developed programmes such as Sustainable Seas, the chances of good environmental outcomes for the next generation will increase with education to navigate different knowledge systems and undertake the joined-up thinking needed to transform relationships between people and nature. We need to foster development from school children through to universities, and on to whole-of-career learning. Building capacity across society is essential for solving issues related to using knowledge to support our environment, particularly in the context of CE.

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