National Science Challenges | SUSTAINABLE SEAS | Ko ngā moana whakauka

Addressing risk and uncertainty in decision-making

Most risk assessment methods and processes in use in Aotearoa New Zealand do not support cumulative effects assessments, the needs and aspirations of Māori, or ecosystem-based management (Clark et al 2021).

For example, current methods generally do not consider differing worldviews and desired outcomes, nor do most methods operate well in a world of cumulative effects from multiple activities and sparse numeric data. The choice of risk assessment methods matters as many methods can constrain an assessment and its outcomes.

Decision-making tools that can communicate risk (including indirect effects) and the degree of uncertainty associated with a particular decision are urgently required.

About this document

This guidance is for people and organisations involved in environmental risk assessments. It explains why better risk assessment methods are urgently needed and recommends a new process to better address risk and uncertainty in marine decision-making processes. It shows how this new process could be applied in different scenarios.

Recommendations

We recommend more standardised best practice risk assessment methods to account for broader values, multiple activities and stressors, and cumulative effects. Specifically, we recommend you follow four important steps.

- Identify perceptions of risk.
- Identify the best risk assessment method and tools to support your decision-making processes.
- Consider uncertainty.
- Link risk and uncertainty information with management decisions.

What is risk and uncertainty?

Risk can be defined in numerous ways but generally refers to the likelihood that some event with undesirable consequences will occur. Assessment of how likely the event occurring is, and the severity of the consequences, are usually accompanied by some uncertainty. Generally, the risk of an ecological shift increases under cumulative pressures and this risk should be coupled with management interventions (Gladstone-Gallagher et al 2024a).

A social definition of perceptions of risk is 'the way that individuals (institutions, communities, groups, iwi and hapū) understand and expect to experience the impact or implications of an event or change or action to something they value, for example a place, activity, or relationship or to a desired future outcome' (Le Heron et al 2024).

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Guidance is needed on risk assessment methods for multiple activities and cumulative effects

To date, no recommended best practice risk assessments for Aotearoa are in place, with a large variety of methods used and those methods usually assessing the risk associated with a single stressor (Clark et al 2021). Uncertainty has also been viewed as a major obstacle, along with lack of data. These are seen as obstacles to progressing cumulative effects management, despite relevant marine legislation and policy requiring the consideration of cumulative effects (Macpherson et al 2023).

Consequently, guidance on methods that could communicate risk of multiple activities and cumulative effects as well as the degree of uncertainty associated with particular management actions (whether they be inaction, allowing new activities or reducing stressors) is urgently required.

Current risk assessment methods can constrain information and outcomes

Risk assessments are made at various places and levels within our management agencies, government policy and planning, and businesses. Only rarely is the type and method of assessment considered and specified, despite some methods constraining the information that can be included and limiting the ability to consider a full range of actions and outcomes – as well as generating arguments about the risks of various actions.

A new process can lead to better decisions and outcomes

We've developed a process to help people setting up risk assessments to understand and record what constraints are being applied to the risk assessment; this process includes asking 'who is at the table' and 'what do they bring with them'. We've also created a decision-tree to select a risk assessment method that does not constrain the process further (Sustainable Seas 2023).

The risk assessment methods we recommend can be used at local to national scales and allow transparency in uncertainties attached to both the level of risk and whether the actions assessed will successfully support desired outcomes. These methods can be used:

- within statutory and non-statutory marine decision-making processes to ensure that decisions are based on all relevant information
- to formalise advice on risks given by government agencies
- by consultants and businesses generating social and environmental risk assessments.

Improved risk assessment methods can communicate risk and the degree of uncertainty

Central to marine management decision-making is the need for risk assessment methods and frameworks that can assess risks to a broad range of values (and their associated uncertainties), arising from multiple and cumulative pressures.

The uncertainty associated with complex ecosystem responses to pressures is often considered high, primarily due to:

- difficulties in collecting baseline knowledge
- a background of environmental variability
- climate change (Hewitt et al 2016)
- the need to consider effects from ecological and social systems that create indirect effects on ecological health, economic health, and social and cultural values (Holsman et al 2017).

Making decisions in the face of uncertainty is challenging because actual outcomes may differ from predicted outcomes. Uncertainty is viewed as one of the major obstacles to progressing cumulative effects management in Aotearoa, leading to decision paralysis (Foley et al 2019).

Consequently, decision-making tools that can communicate risk (including indirect effects) and the degree of uncertainty associated with a particular decision are urgently required.

Decision-making around management actions is often carried out via a risk assessment process. Perceptions of risk, including differences in worldviews, disciplinary training and positionality, can influence both the decision-making processes and the resultant decisions (Blackett et al 2023), as can inadequate communication and unclear management objectives or outcomes (Link et al 2012).

Addressing these factors should be the start of any risk assessment process. Analytical methods to support risk assessment range from simple, qualitative assessments in which risk is expressed as categories (for example, high and low), to quantitative assessments that use empirical data to model risk, and to approaches that explore a broad range of possible future scenarios (Inglis et al 2018, Clark et al 2021).

In presenting risk assessment estimates, underlying sources of variability, and therefore uncertainty, must be acknowledged. For ecosystem-based management, underlying ecological complexity, and feedback within ecosystems, should be recognised and communicated where possible.

We recommend a four-step process for environmental risk assessments

The following recommendations provide guidance on how risk and uncertainty can be better addressed in consenting practice, and for informing strategic planning, including developing targets and limits.

The key audience is regional and central government, as well as people and organisations involved in environmental risk assessments.

We recommend following a four-step process.

- Identify perceptions of risk.
- Identify the best risk assessment method to support decision-making processes.
- Consider uncertainty.
- Link risk and uncertainty information with management decisions.

Step 1: Identify perceptions of risk

Risk assessments should generally begin with an understanding of differences in people's desired outcomes and how they perceive risk, including the 'risk to what' and 'why'. Thinking about where the idea of risk comes from, and how it can be better understood in different contexts, leads to better outcomes and more robust decisions.

We've developed a process to unpack components of risk in terms of 'who is at the table' and 'what do they bring with them' (figure 1).

This process includes:

- establishing a reflective and participatory process to build shared understandings
- understanding the invisible shapers of risk perception to expose commonalities and differences in perceptions of risk and uncertainty, leading to productive conversations
- using our set of tools and guidance to help navigate the different perceptions of risk and uncertainty that are inherent in multi-use marine environments (Sustainable Seas 2023).

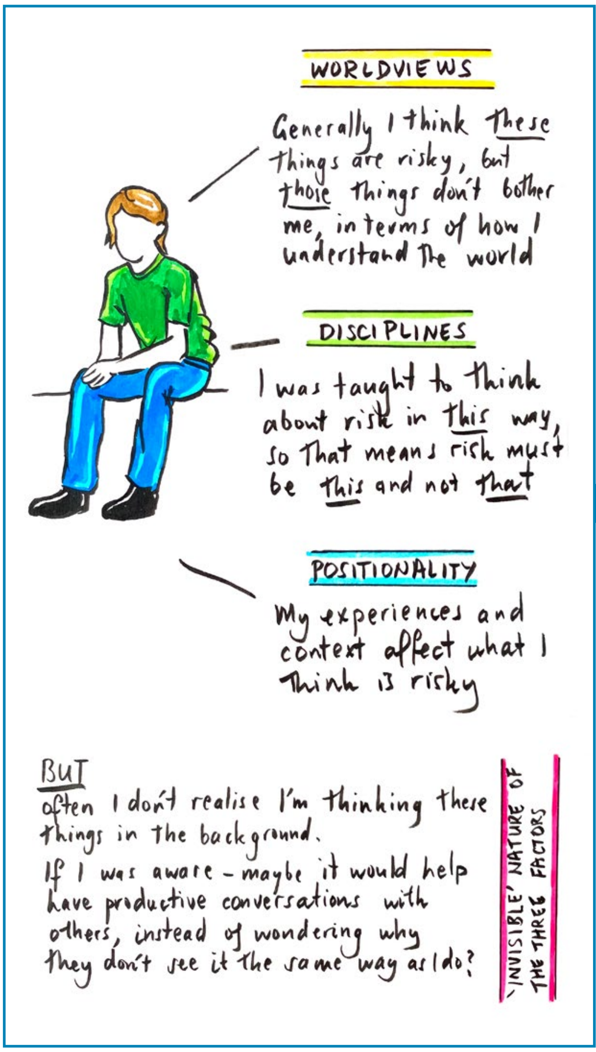
Identifying differences in risk perception addresses an important question in multi-use marine environments. How do we better navigate this fraught subject and progress towards policies and practices that consider cumulative effects and enable ecosystem-based management (EBM)?

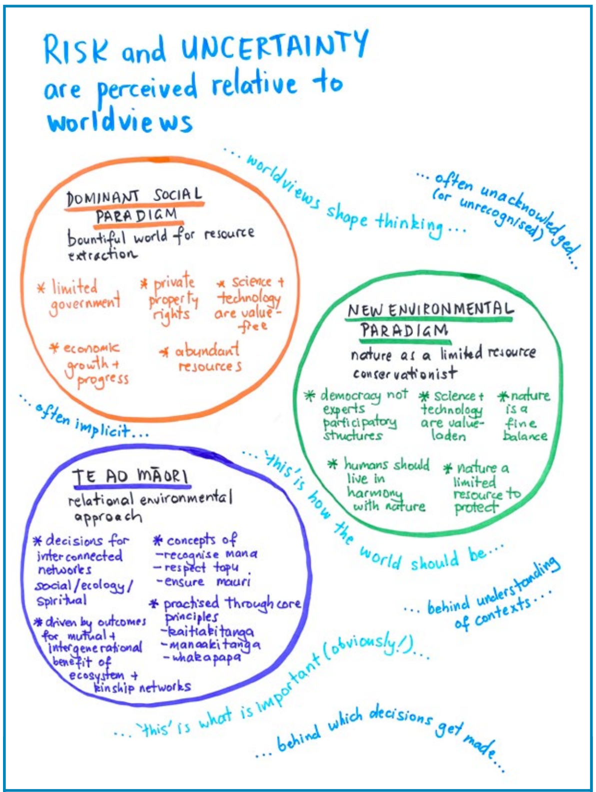
Choosing the right risk assessment tool/s to support decisions on consents or for strategic planning is critical. Different tools and practices can create different futures.

Step 2: Identify the best risk assessment method to support decision making processes

Risk assessments provide a practical method by which consent applicants, planners and decision-makers can better consider cumulative effects across time and space. The assessment methods we discuss here can be used within statutory and non-statutory marine decision-making processes to ensure that decisions are transparent and based on relevant best-available information.

- We recommend matching methods to requirements and have developed a decision tree to select fit-for-purpose tools (Figure 2). All the methods can incorporate a range of knowledge types (numeric, expert judgement, mātauranga and local knowledge).



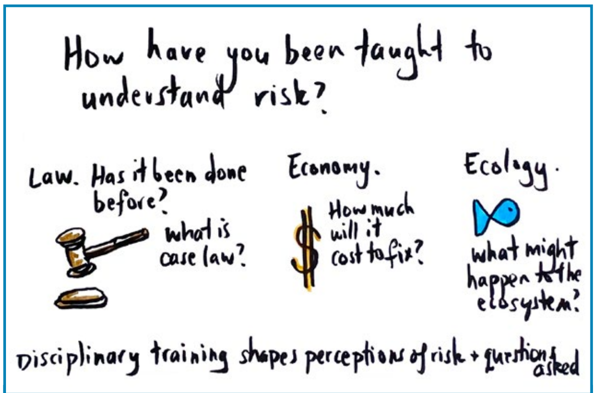


WORLDVIEWS

Ask: What worldviews do I identify with?

Then: What risks make sense in my worldview?

What risks make sense for other worldviews?



DISCIPLINES

Ask: How have I been taught to understand risk through my education and training?

Then: How does this affect the way I think about what is risky?

What might people who have been trained in different disciplines think is risky?

POSITIONALITY

Ask: What positionalities do I occupy now and at other times?

Then: How does where I stand affect my perception or risk?

What might other people think is risky because of their situation?

Figure 1 Individual reflection on worldviews, disciplines, and positionality to help identify perceptions of risk

- Adopting a hierarchical framework can match need to the complexity of the risk assessment. At the simplest level, likelihood consequence (LC) or Bayesian network (BN) methods can inform a risk assessment. At more complex levels, BN can provide assessments of risk to ecological, social, cultural and economic factors, and include associated uncertainties. In between, agent-based models (ABM) can also provide assessments of risk to ecological, social, cultural, and economic factors – however, uncertainties are not so well treated. BN and ABM can cover scenario modelling of actions intended to aid recovery.
- The ecological and stressors principles approach (Gladstone-Gallagher et al 2024b) only considers ecological outcomes, but is particularly useful with limited numeric data, location-specific ecological complexity, and for considering cumulative effects and recovery. This approach can also be used as a screening tool to determine how important it is to conduct a risk assessment that is fit for ecosystem-based management and holistic management (see example scenarios below).
- Only where there is good existing data that can deal with the relevant complexities would we recommend using biophysical models which should be coupled with social and cultural impact assessments.

Non-formal or scoping risk assessments can be applied initially to inform gaps analysis and to guide management advice. The benefits of doing this include that they are rapid screening methods and can support management decisions. However, they must be well documented because they can be hard to support if questioned. An added benefit is that the information elicited from the scoping can be used to populate formal risk assessments (including likelihood consequence and Bayesian network).

When a formal risk assessment is needed, the level of assessment required will be linked to the scale and complexity of the scenario. At the simplest level LC and BN methods can be used to inform risk assessments. At higher levels, BN and ABM can provide assessments of risk to ecological, social, cultural and economic factors. These methods allow iwi and stakeholder participation in building their structures. Participation in building structure (components, links, outcomes and actions) allow group discussions of commonality and differences in perceptions of risk.

While the ecological and stressors principles approach (Gladstone-Gallagher et al 2024b) only considers ecological outcomes, it's particularly useful with limited numeric data, location-specific ecological complexity, and for considering cumulative effects and recovery. These methods can all incorporate a range of knowledge types (numeric, expert judgement, mātauranga, and local knowledge).

Likelihood consequence methods can be difficult to navigate if many outcomes, actions and drivers require assessment. However, they can be easily translated into Bayesian networks (BN) if this occurs. BNs are the method that most clearly describes uncertainty related to risk. Both BN and ABM can cover scenario modelling of recovery as well as the degradation of desired outcomes.

We recommend matching tool selection to requirements using the decision tree (figure 2) to select fit-for-purpose tools.

Decision tree to help choose a risk assessment method

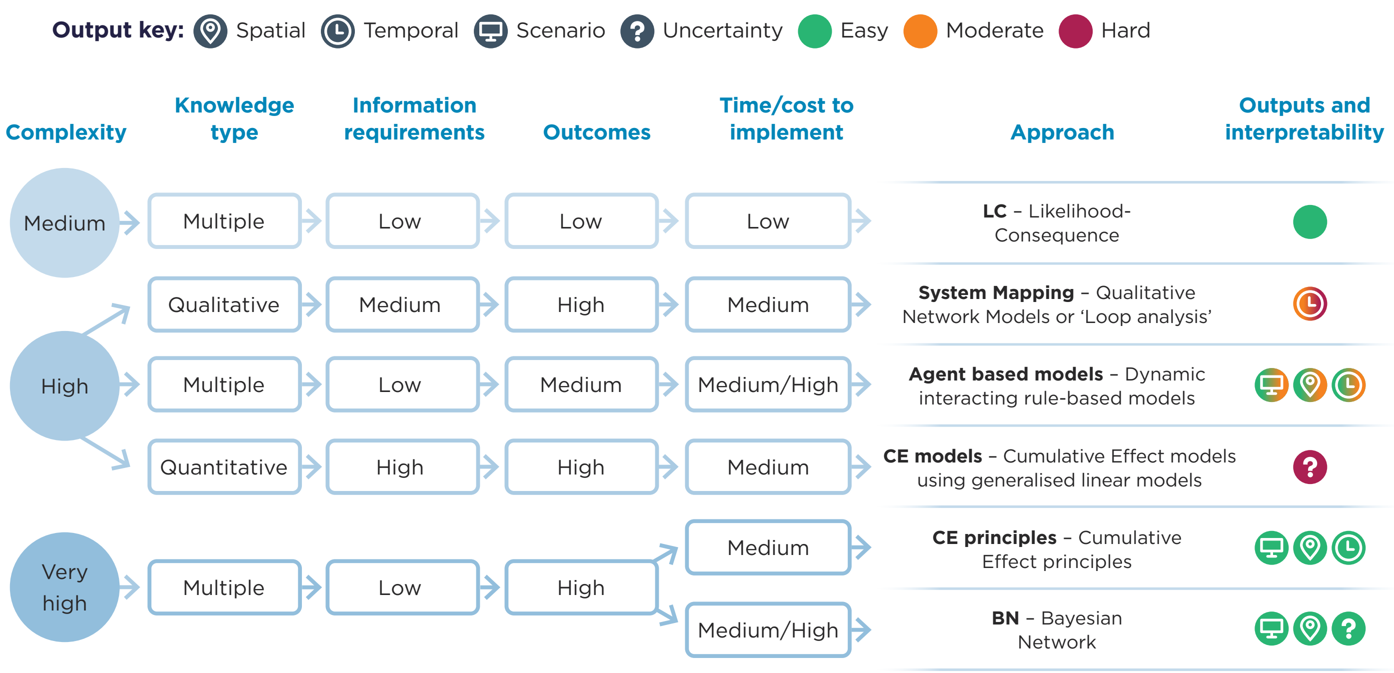


Figure 2 Decision tree to help choose a risk assessment method. *See Table 1 on the following page for definitions*

Table 1 Definitions of decision tree considerations

Considerations	Definitions
Complexity	**System complexity; number of stressors, response variables, etc.**
Low (‡)	Single stressor, single response
Medium	Multiple stressors or responses, no interactions or feedbacks
High	Multiple stressors or responses, interactions, indirect effects
Very high	Multiple stressors and components, feedbacks, interactions, indirect effects
Knowledge type	**Type of knowledge that can be used**
Quantitative	Numerical values
Qualitative	Descriptive data, eg expert opinion, principles, social surveys
Mātauranga Māori	Māori knowledge – the body of knowledge originating from Māori ancestors, including the Māori world view and perspectives, Māori creativity and cultural practices.
Multiple	A combination of knowledge types (mātauranga Māori and at least one of: quantitative and qualitative data; semi-quantitative)
Information requirements	**Amount of available information**
Low	Not much information exists or is available, limited knowledge of system or case-study area
Medium	Some information or knowledge of the system/study area exists, including eg local knowledge, (limited) monitoring data or data from experimental studies, not location specific/for all components
High	An abundance of information exists to work with, including extensive spatial or temporal survey/monitoring data, spatial data layers at high resolution, local knowledge and/or mātauranga.
Outcomes	**Number and types of components included (ecological, social, economic, cultural etc.)**
Low (‡)	Single component (1). One type of value
Medium	Multiple components (3–4). One type of value
High	Multiple components (3–4). Multiple types of values
Time/cost to implement	**Ease of implementation, cost or time, expertise required**
Low	Simple method, low cost and time (eg within a week), low expertise/skill required
Medium	Moderate time/effort to implement the method (eg weeks-months), some expertise/skill required
High	Expensive or time consuming, needing specialists
***Interpretability**	**Easy of interpretation of risk assessment outputs**
🟢 Easy	Understood by a lay person
🟠 Moderate	Understood by a lay person if the outputs are explained
🔴 Hard	Expert/technical knowledge required to understand the outputs

Step 3: Consider uncertainty

Fundamentally, risk occurs when the something of value is at stake and the outcome is uncertain (Ingles et al 2018).

Step 2 helps choose a method to assess how likely an event occurring is, and the severity of the consequences.

Step 3 is a reminder to explicitly consider uncertainty. This step matters because regional councils and central government must make decisions without perfect information, on behalf of stakeholders, who may challenge a decision in court.

While many people find it difficult to separate the effect of uncertainty on their perception of risk, and Māori do not separate the two, uncertainty is often viewed as a major obstacle to progressing cumulative effects management.

The level of uncertainty influences methods, participation, and interventions

The greater the level of uncertainty, the more important it is for stakeholders to participate in analysing risk (Ingles et al 2018, Table 1). The spectrum of uncertainty ranges from relatively well understood relationships (level 1) to some disagreement (level 2) and complex cause-effect relationships about cause-effect processes (level 3) to events that cannot be predicted based on present knowledge (level 4) (Ingles et al 2018).

The level of uncertainty will influence the type of assessment method needed, stakeholder participation, and the intervention required (figure 3).

When thinking about uncertainty, consider the following.

- Risk assessments and management decisions shouldn't be held up by a lack of 'perfect' data. The methods we recommend can use many different knowledge types and explicitly consider uncertainty when required.
- Uncertainty has two faces: it should not just be presented for the most likely outcome, but its opposite as well. How people respond to uncertainty depends on how it's presented. For example, medicine often presents '1 in 4 New Zealanders will have cancer', rather than '3 in 4 will not'. To avoid bias, present both sides. 'There is an 80% chance that this action will prevent any further degradation' should be balanced with 'There is a 20% chance that this action will result in further degradation'.
- As uncertainty about the nature of the risk increases, skilled facilitators and structured participatory processes in risk assessments are needed to enable open discussion of competing arguments, beliefs, and values about the risk problem and to evaluate management options amongst diverse stakeholders (Ingles et al 2018).

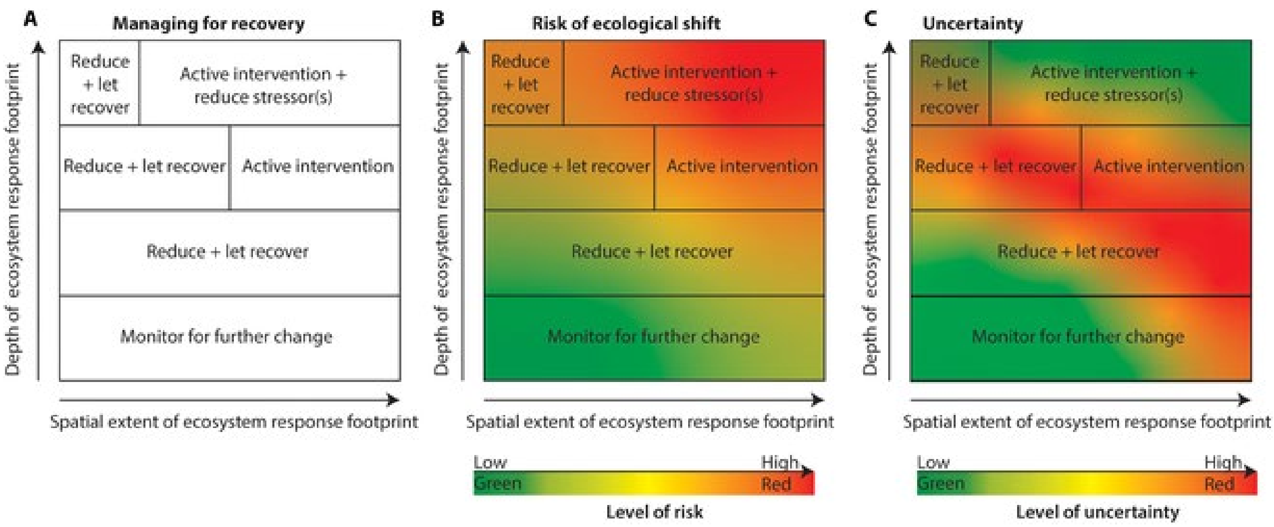


Figure 3 Summary of the type of management actions that are likely required to manage different types of response footprints, as well as (B) the level of risk of poor ecological outcomes and (C) the uncertainty surrounding this risk (from Low et al 2023)

Step 4: Link risk and uncertainty information with management decisions – ecological and stressor principles can help

New frameworks are needed to help link the risks associated with cumulative effects and appropriate management actions. Our research has developed two key interconnected concepts.

- 'Ecosystem response footprints' (Low et al 2023)
- 'Ecological and stressor principles' (Gladstone-Gallagher et al 2024b).

These concepts aim to improve assessments of cumulative effects and risk to support ecologically relevant management actions, for example:

- approve, modify, or decline consent
- monitor for further change, trigger interventions to limit stress
- identify requirement for assisted recovery etc (*Addressing cumulative effects in marine management decisions*).

The 'Ecosystem response footprints' concept (Low et al 2023) assesses the ability of an ecosystem to respond and adapt to change. These footprints are dynamic in space and time and relate to the physical and ecological components of the stressor regime and the receiving environment.

A new method developed by the Sustainable Seas National Science Challenge is focused specifically on assessing risks of management actions when data is limited, based on ecological principles, and links actions with management outcomes (Gladstone-Gallagher et al 2024b). This approach is useful for considering cumulative effects and actions aiding recovery. Ecological and stressor principles are used to provide an indication of the ecological and stressor state of a system (Gladstone-Gallagher et al 2024b, *Addressing cumulative effects in marine management decisions*). Principles can be used as a screening tool to determine how important it is to conduct a more comprehensive risk assessment. This framework can also indicate the likely response to protective and restorative interventions to maintain or improve ecosystem health.

- **Ecological principles** account for an ecosystem's ability to respond, resist, or adapt to change. These principles recognise the role of intrinsic ecological dynamics and particular types of species in generating responses.
- **Stressor principles** characterise the stressor regime, either past, present, or predicted future. These principles focus on the ecosystem elements they impact on and how stressor effects interact.

When combined, these principles can inform management strategies by indicating:

- the risk of an ecosystem undergoing a functional shift to a more degraded state
- the likelihood of an ecosystem naturally recovering
- the uncertainty associated with different management actions (Gladstone Gallagher et al 2024b and Low et al 2023).

These frameworks provide a useful approach to linking risk with appropriate management action. Our guidance document on *Addressing cumulative effects in marine management decisions* has more information on the ecological principles approach, including full definitions of the principles.

Example scenarios

Here are two hypothetical scenarios of how cumulative effects and risk assessments could be considered. These scenarios cover different scales of activities.

1. Consenting an aquaculture development in an open coastal bay

Proposal to develop a finfish aquaculture operation in an open coastal bay (figure 4).

What is the cumulative impact of the activity?

Step 1. What are your aims or objectives? Where do you want to be?

- Determine if an aquaculture development could be accommodated within a coastal bay by assessing its cumulative impact.
- Consider what the short- and longer-term goal is for the area. For example, look for outcome statements about the bay and surrounding area and its existing values or restoration goals, either already written or being consulted on.

Step 2. What's affecting the location?

- Consider present stressors: sedimentation, nutrients, low nutrient processing capacity, moving water lowering hypoxia, fishery impacts – moderate to high stressor status as assessed using stressor state principles.
- Consider new or proposed activity stressors: food, carbon footprint, organic matter to seafloor, microplastics, barriers to migratory species, genetic changes to wild species, pesticides/drugs, excretion, noise, structures, shading, biosecurity – high stressor status as assessed using stressor state principles.

Step 3. What is the state of the current ecosystem and how is it responding to the stressors?

- What is the status of the ecological communities within the activity footprint?
  - Consider species and communities present, resilience and vulnerability to additional stress. For example, moderate biodiversity with few slow-growing species and historic evidence of shellfish beds but no longer present – moderate ecological status as assessed using ecosystem state principles.
- What is the status of the ecological communities within the ecological response footprint?
  - Consider species and communities present, resilience or vulnerability to additional stress, connectivity with species within activity footprint for example, *Atrina* (horse mussel) beds, scallop beds, subtidal seagrass adjacent to proposed development – high ecological status as assessed using ecosystem state principles.
- What is the direct effect of the activity?
  - For example, the load of organic matter to the seafloor is small but deep causing loss of habitat diversity within the – moderate ecological status, high stressor status.

What are the cumulative effects of the activity?

  - Impacts on ecological connectivity within or outside of footprint, resilience/vulnerability of ecological communities, historic shellfish presence and associated recovery potential, spatiotemporal variability in ecological connectivity/biodiversity/stressor footprints – moderate to high ecological status, high stressor status.

- What are the risks and uncertainties?
  - Impact of the proposed activity on ecological connectivity within the ecosystem response footprint. Uncertainty about larval connectivity between the proposed activity footprint and ecosystem response footprint. Uncertainty about the future ecosystem response footprint in response to chronic stressor impacts such as sedimentation and how this will impact ecological resilience to proposed activity. Risk of generating greater ecological declines than expected outside of the direct activity footprint.
  - For large scale projects a formal risk assessment should be considered such as Bayesian networks, which allow iwi and stakeholder participation in the building of the model, a range of ecological, cultural, social and economic outcomes and drivers, location-specific ecological complexity, cumulative stressors and a range of knowledge types to be used for example, numeric, expert judgement, mātauranga, and local knowledge. Where there are high levels of data, mechanistic biophysical models with separate social models can be used, although care should be taken to ensure that critical connections and components are encompassed by the models. These methods can produce risk measures and their associated uncertainties central to management decision.

Step 4. What's our management approach for this location?

- Possible approaches based on result of assessment are:
  - As the cumulative effects of the proposed development assesses the area to have high ecological status and high stressor status, the risks of the development justify further in-depth assessment of cumulative effects from the activity before decision to proceed with the application.

Conclusion

The risks of the development justify further in-depth assessment. This conclusion is because the cumulative effects assessment of the proposed development assesses the area to have high ecological status and high stressor status, and many of the identified risks lie outside the activity area and have uncertainty attached to them.

The in-depth assessment could initially focus on generating a likelihood-consequences matrix for the components identified through the cumulative effects assessment. However, the number of components identified suggests that a method able to cope with more complexity would be useful.

Given the number of associated uncertainties, a Bayesian network model will be more useful than an agent-based model.

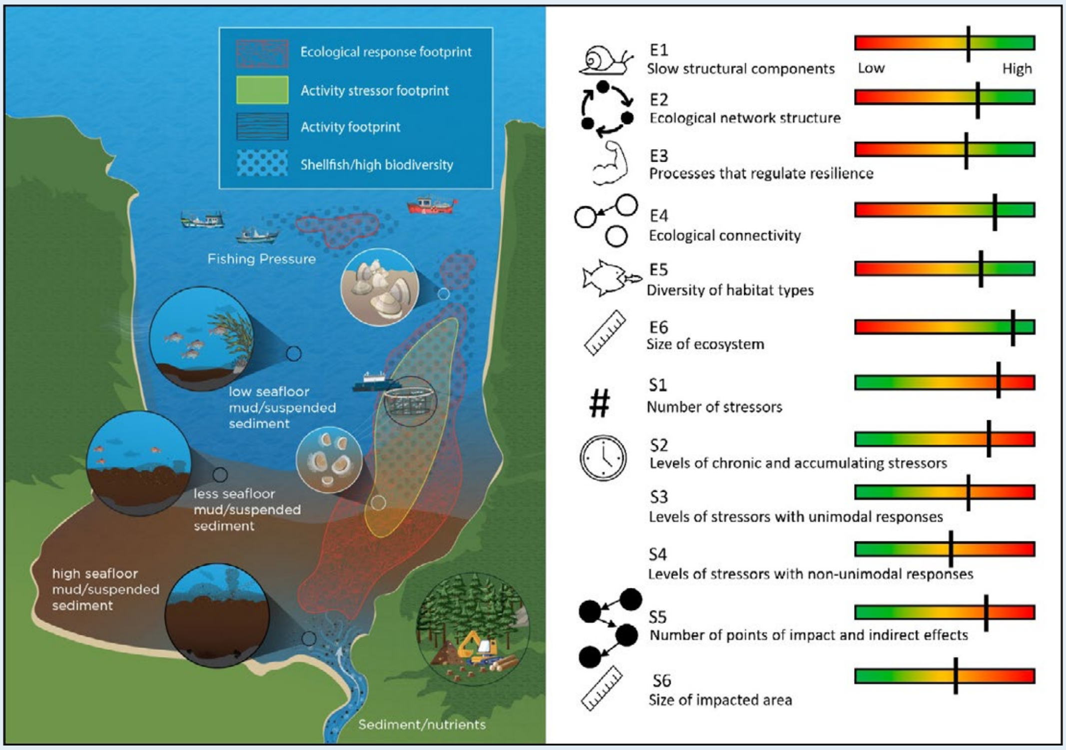


Figure 4
Large scale finfish aquaculture scenario showing the status of associated ecological and stressor principles (based off Gladstone-Gallagher et al 2024b). Green = low risk and red = high risk

2. Consenting a seawall within a harbour

Steps 1 to 2 are covered in detail in our *Addressing cumulative effects in marine management decisions* guidance document. In summary, these steps are:

» **Step 1. Identifying the aims or objectives. Where do you want to be? Consider short- and longer-term goals for the area.**

» **Step 2: What's affecting the location? Identify present stressors and new or proposed activities (especially those related to the seawall development).**

- Potential stressors related to proposed development: intertidal and subtidal reclamation and loss of organisms within the immediate area, prevention of inland migration of marine environments or coastal squeeze, modification of hydrodynamics – moderate stressor status
- Potential stressors within the wider ecosystem response footprint: sedimentation, nutrient loading, heavy metal contamination, fishing, sea level rise – moderate stressor status

» **Step 3. What is the state of the current ecosystem and how is it responding to the stressors? This question depends on location. Here are two examples.**

Seawall 1. Example of when a consenting officer may request a more in-depth ecological cumulative effects risk assessment. The cumulative effects screening reveals (figure 5):

- High-density large-size cockle bed immediately down shore of the proposed development (last remaining within the harbour), where seawall prevents future migration. Pipi populations present on either side of proposed seawall (whose larval connectivity may be impacted) and mangroves/saltmarsh located in the upper elevations – high ecological status.
- What are the risks and uncertainties?
  - » Impact of the proposed activity on ecological connectivity within the wider ecological response footprint
  - » Uncertainty over how the proposed seawall may impact pipi larval and juvenile connectivity between the proposed activity footprint and wider ERF
  - » Potential for upside surprises generating greater ecological declines than expected outside of the direct activity footprint

Likelihood consequence should be employed to produce more formal estimates of risk and uncertainty associated with the seawall. Elicited information from scoping exercises can be used to populate the LC assessments aiding in the cost and speed of producing more formal assessments.

Seawall 2. Example of when further ecological risk assessment may not be required. The cumulative effects screening reveals (figure 5):

- Proposed seawall is in muddy arm of an estuary, with very low benthic biodiversity. No evidence of slower growing structural species, low ecological network structure, low ecological service provision, low ecological connectivity from current location to elsewhere, low diversity of habitats, large amount of other representative area surrounding the proposed seawall location – low ecological status and low stressor status.
- What are the risks and uncertainties?
  - » Relatively minor ecological risks identified.

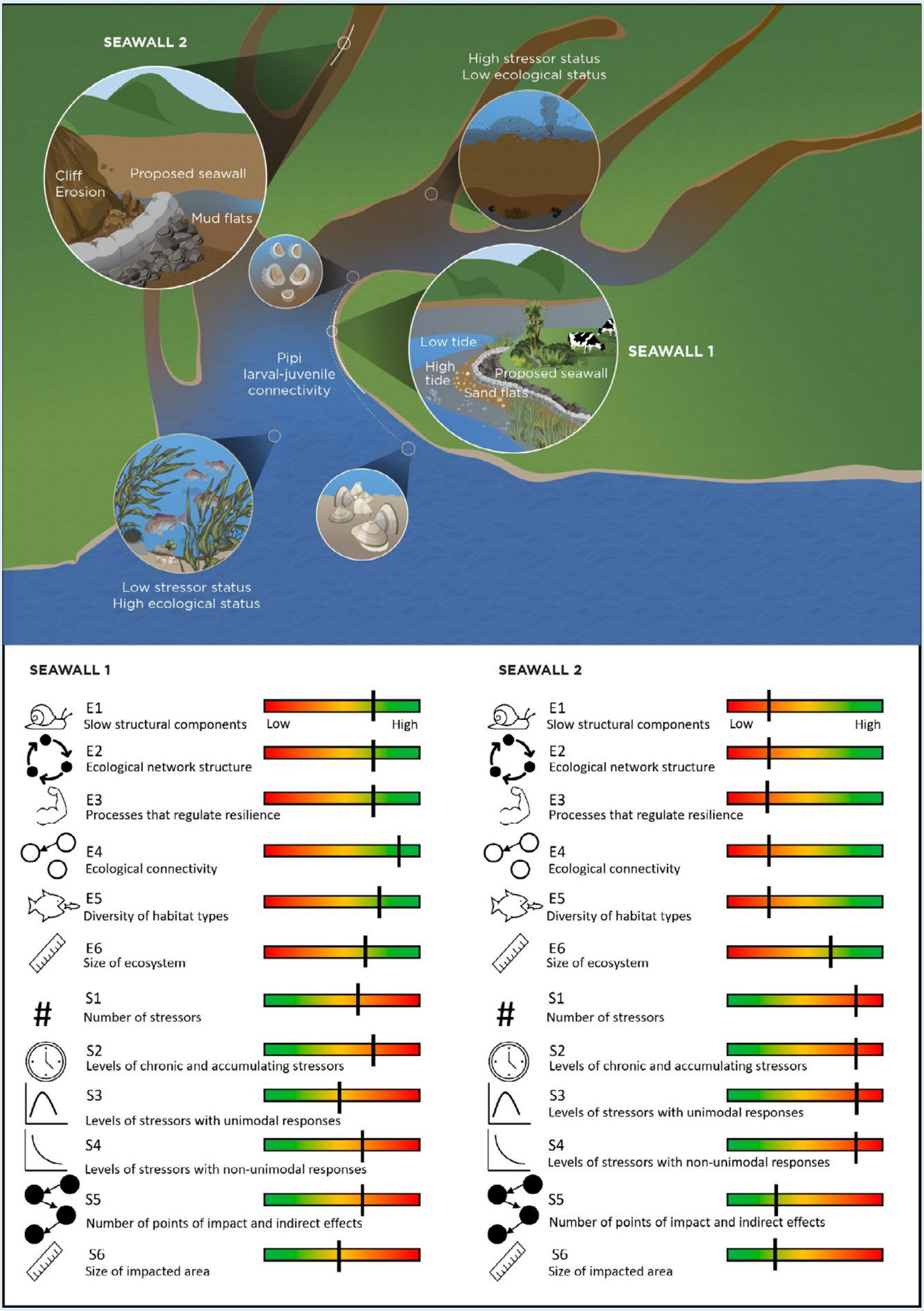


Figure 5 Small scale seawall scenario showing the status of associated ecological and stressor principles and how this varies based on location within a harbour (based off Gladstone-Gallagher et al 2024b)

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For more information and support with marine management decisions, please see our other synthesis project summaries and guidance documents in this series.

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