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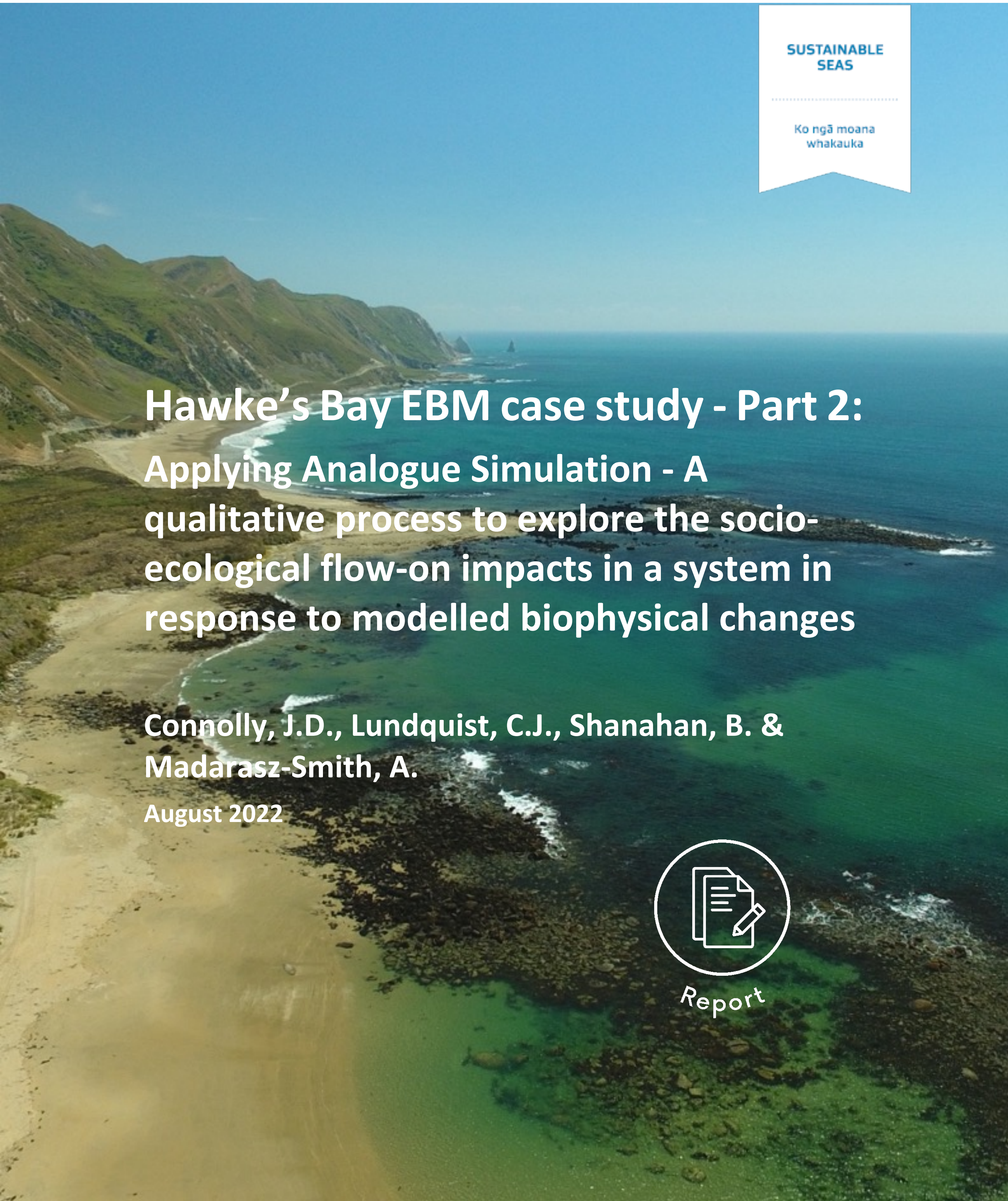

Hawke’s Bay EBM case study - Part 2:

Applying Analogue Simulation - A qualitative process to explore the socio-ecological flow-on impacts in a system in response to modelled biophysical changes

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August 2022

Report

Report for Sustainable Seas National Science Challenge project Enhancing implementation of EBM in the Hawke's Bay (Project code S1)

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For more information on this project, visit:

https://www.sustainableseaschallenge.co.nz/our-research/hawkes-bay-regional-study/

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 60+ 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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Cover image: Rangaiika Beach and Cape Kidnappers. Credit: Oliver Wade.

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Glossary of terms

Term	Description
CRI	Crown Research Institute
FINZ	Fisheries Inshore New Zealand
Fisheries NZ	Fisheries New Zealand. Previously part of the Ministry of Fisheries, now part of the Ministry for Primary Industries. (See also MPI)
Hapū	Divisions of Māori iwi (tribes), determined by genealogical descent, usually consisting of a number of extended family groups.
HBRC	Hawke's Bay Regional Council
Hui	A formal or informal gathering or workshop, typically used in New Zealand to refer to Māori gatherings.
Iwi	Extended kinship group, tribe, nation, people, nationality, race - often refers to a large group of people descended from a common ancestor and associated with a distinct territory.
Km	Kilometre
Manāki/ Manākitanga	Manāki: to show respect, generosity and care for others by supporting, take care of, or give hospitality to. Manākitanga : The process of the above.
Mātauranga/ Mātauranga Māori	Complex and dynamic knowledge system originating from Māori ancestors, informed by intergenerational cues, practices and understandings of the natural world.
NIWA	National Institute for Water and Atmospheric Research
NM	Nautical Mile
NSC	National Science Challenge
Tangaroa	Atua (god) of the sea and fish. He was one of the offspring of Rangi-nui and Papa-tū-ā-nuku and fled to the sea when his parents were separated. Sometimes known as Tangaroa-whaiariki.
Whānau	Family, immediate or wider.
Whanaungatanga/ Whakawhanaungatanga	Process of establishing relationships, relating well to others.

Executive Summary

The Sustainable Seas National Science Challenge (the Challenge) has sought to apply tools developed in Phase 1 of the Challenge to local case studies. This report describes the application of a qualitative and discussion-based process of using the system map developed by the Hawke's Bay Marine and Coastal group (HBMaC) for the Hawke's Bay, to infer potential changes over time across a range of biophysical and socio-ecological factors in that system map, based on outputs from the seafloor model developed as part of the same case study. This process has been referred to as Analogue Simulation.

This report is one of three issued concurrently. Lundquist et al. (2022a) describes the detail of the seafloor model; while Lundquist et al. (2022b) provides an overview of the entire case study process, including the development of the system map (described in Connolly et al. (2020).

The methodology for applying analogue simulation is a simple process whose main inputs are the graphs produced by the seafloor model, and whose main outputs are conceptual graphs of change over time that are developed by HBMaC. These are shown in figure ES1.

Of critical importance to this analogue simulation process is that participants must not see the results of the seafloor modelling (or whatever input information is used) before the analogue simulation process is run. This is so that their reactions and discussions are not biased by prior knowledge of the results.

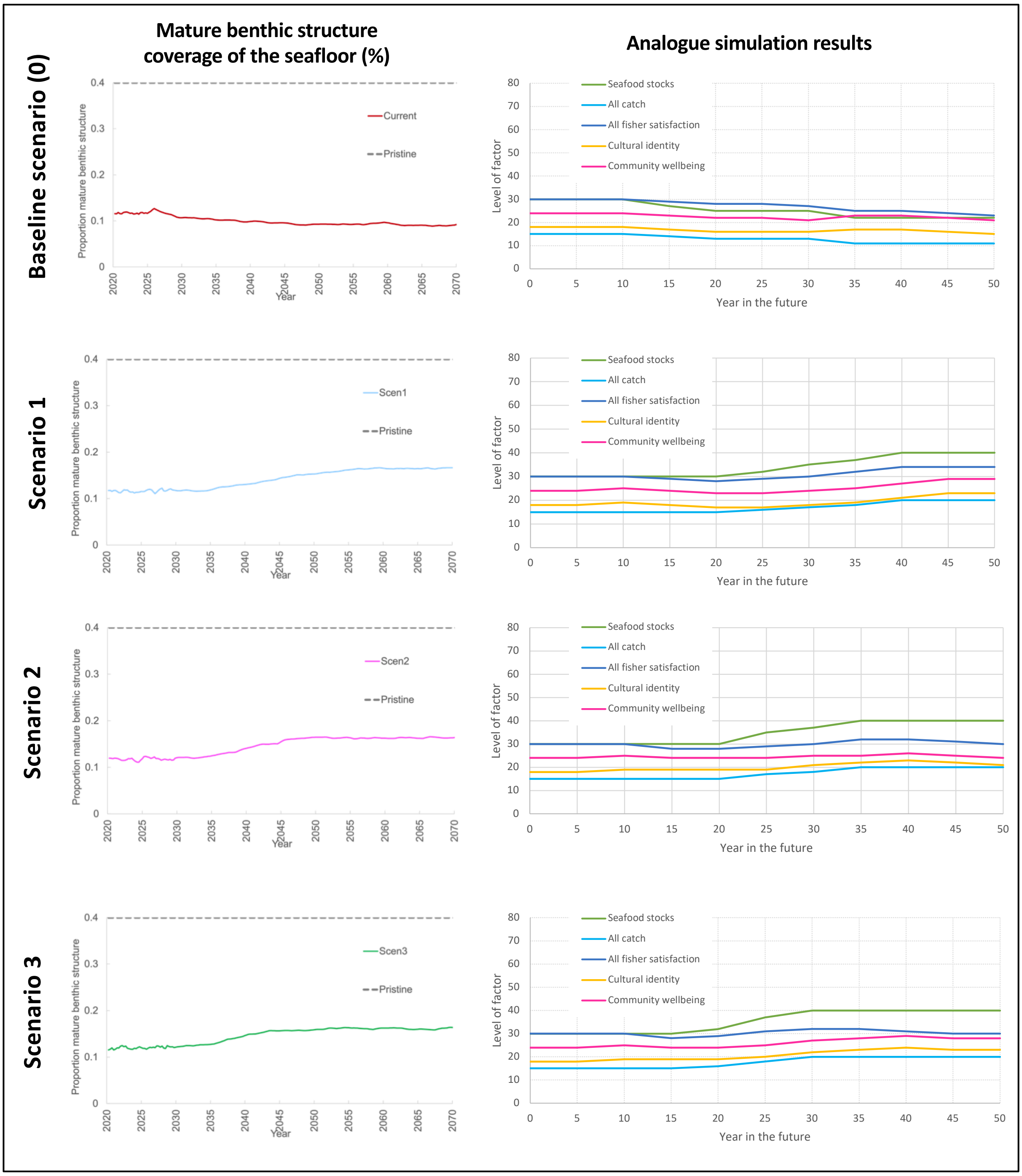
The results highlighted useful observations about how the group responded to the outputs of the modelling and how they anticipated these outputs to 'flow through' to the other biophysical and socio-ecological variables. These were:

- Declines in benthic structure and any associated declines in seafood stocks were assumed to occur at the same time, as any removal of benthic structure was deemed to remove habitat and limit the amount of seafood stocks that could be supported. Increases in benthic structure and any associated increase in seafood stocks were realised after a delay, reflecting the time lags in recovery following reduction of stressors.
- Where intervention has occurred, social indicators all follow a similar broad pattern:
    - Satisfaction, cultural identity and wellbeing tend to increase after action has been taken but before recovery was observed, reflecting the impact that achieving such a positive outcome has on these factors;
    - Social indicators tend to decline after a while before recovery is observed, due to the delays involved in the regeneration of firstly benthic structure then seafood stocks. This is likely to be a non-linear relationship – i.e. there may be more pronounced dissatisfaction the longer it takes for recovery to present;
    - Social indicators all increase as seafood stocks increase;
    - Social indicators all then tend to decline again slightly after the maximum recovery has been achieved, indicating likely dissatisfaction with the overall level of recovery, in relation to the level of action taken.

Other useful insights and observations from the analogue simulation participants were:

- HBMaC participants observed that it was likely that ongoing action would be necessary, rather than a one-off intervention. This was due to the time delays involved before any action has an effect, and the lesser than anticipated impact that action seemed to have;
- The different scenarios all tended to end in the same result of around 16-17% coverage of mature benthic structure on the seafloor, although some scenarios reached this point faster. It would have been useful to have more iterations of the modelling process to better understand which factors were more powerful to change. Only one modelling iteration was possible within the resource constraints of this project.

Figure ES1. Results of the Analogue simulation exercise



1 Introduction

This report describes a qualitative process for exploring the impacts of change over time across multiple factors. This was undertaken as part of Stage 2 of the Hawke's Bay case study on Enabling Ecosystem-based Management, funded by the Sustainable Seas National Science Challenge (the Challenge) .

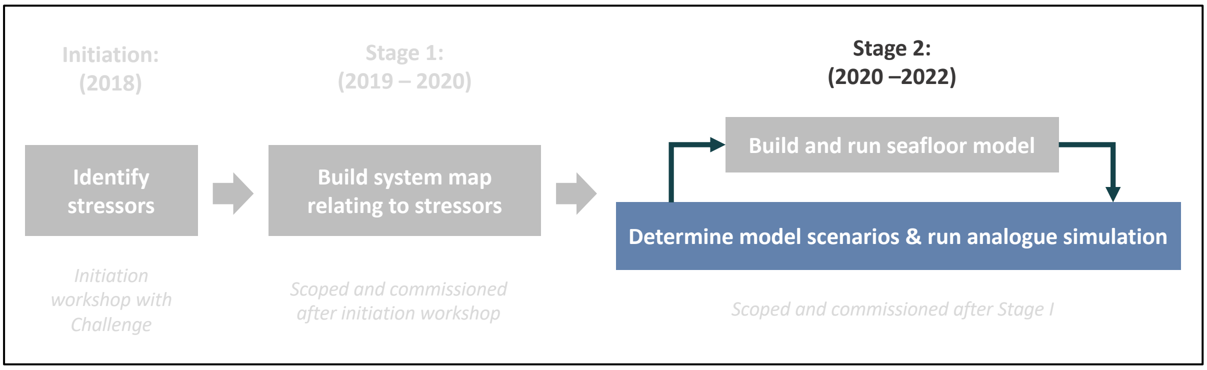
The process was the application of a qualitative and discussion-based process of using the system map developed in an earlier stage of the case study. Changes over time across a range of biophysical and socio-ecological factors were explored in that system map, based on outputs from the seafloor model developed as part of the second part of this case study. This process is known as Analogue Simulation.

The next section (Section 2) provides some background to the Challenge and the case study. Section 3 outlines the methodology – how it is based on systems thinking from System Dynamics, and how it is performed in detail. Section 4 describes the results of the process and Section 5 provides a summary.

This report is one of three completed concurrently after the completion of the second part of the case study. This report summarises the analogue simulation process; Lundquist et al. (2022a) describes the seafloor model used in the case study in detail; and Lundquist (2022b) summarises the overall process of the entire case study – from inception to completion.

A diagram showing how these different parts of the case study fit together, and the part that is described in this report, is shown in Figure 1.

Figure 1. The section of Project II of the case study that is described in detail in this report



2 Background

This report summarises some of Stage 2 of this case study. This section outlines some background to the Challenge, the Hawke's Bay case study, and the HBMaC group. It also outlines how this report fits with several other concurrent reports that were issued as a result of Stage 2 of this case study, and outlines what each covers.

2.1 The Sustainable Seas National Science Challenge

The Sustainable Seas National Science Challenge (initiated in 2014) is one of 11 Ministry of Business, Innovation and Employment-funded Challenges aimed at taking a more strategic approach to science investment. The Challenge Objective is: "*To enhance utilisation of our marine resources within environmental and biological constraints*" and its Mission is: "*To transform Aotearoa New Zealand's ability to enhance our marine economy, and to improve decision-making and the health of our seas through ecosystem-based management* (EBM)".

Phase 2 (2019-2024) of the Challenge supports research within multiple case studies to inform and enable EBM approaches to decision-making through partnerships with interested regional or central government agencies. These case studies hope to establish proof of concept of EBM approaches, and provide key lessons about putting theory into practice to further enable EBM in Aotearoa NZ.

2.2 Hawke's Bay case study

Hawke's Bay was selected as one of the Challenge's Phase 2 case study areas for research on implementing ecosystem-based management in a real-world context using tools, processes and analyses developed within Phase 1 of the Challenge research. The case study was initiated following discussions with the Hawke's Bay Regional Council, and with the Hawke's Bay Marine and Coastal Group (a non-statutory multi-stakeholder group, see section 2.3 for more details).

Sediment deposition from land and disturbance to the seafloor from fishing activities were identified as key stressors to the Hawke's Bay marine ecosystem and how these are inter-connected was explored in Stage 1 of this case study, where a system map outlining how these stressors are interconnected was developed (see Connolly et al., 2020).

This second stage of the case study explores how the system map may be used in conjunction with seafloor modelling to explore how the flow on impacts of biophysical change may present in other parts of the socio-ecological system, and what implications that may have for research and, eventually, decision-makers.

2.3 The Hawke's Bay Marine and Coastal Group (HBMaC)

The Hawke's Bay Marine and Coastal Group (HBMaC) is a multi-stakeholder group with representation from government agencies, mana whenua, recreational and commercial fishing interests. It was established in 2016 (independently of the Challenge) due to concerns over the perceived localised depletion of inshore finfish stocks and environmental degradation in the Hawke's Bay marine area. HBMaC have highlighted that there is general consensus that there has been a degradation of the marine environment of Hawke's Bay, however the scale, direction and underlying causes of this change are unclear.

Members of HBMaC are supported by their parent organisations to be part of this process. At the same time, thoughts and opinions contributed as part of this group, in no way undermine the decision-making mandate and processes that need to occur at each of the organisations represented.

2.4 How this report fits with other concurrent and related reports from the case study

After the project initiation workshop in 2018, the Hawke's Bay case study was developed around two consecutive stages.

Stage 1 was the development of a qualitative system map based around two main stressors of the marine environment – increasing sedimentation and the loss of benthic structure. This was completed in early 2020. That project is described in **one report**:

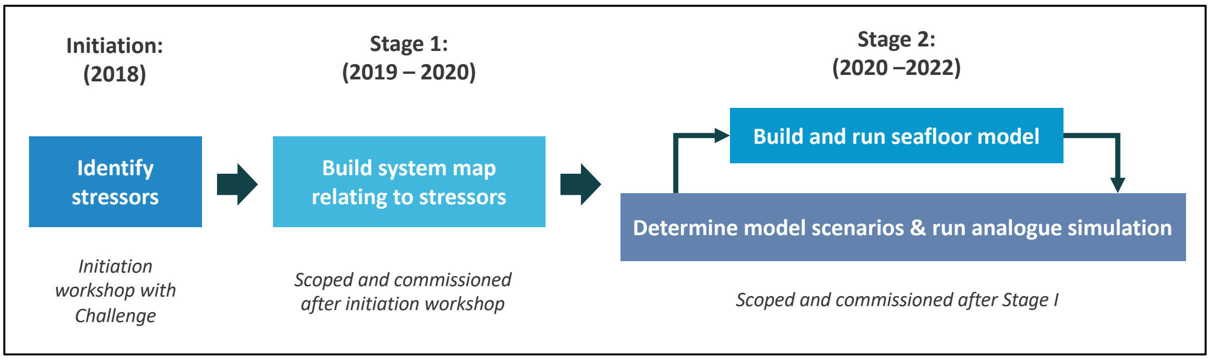
- Connolly, J.D., Lundquist, C.J., Madarasz-Smith, A. & Shanahan, R. (2020). *Hawke's Bay EBM case study - Part 1: System mapping to understand increased sedimentation and loss of benthic structure in the Hawke's Bay.* (A report for the Sustainable Seas National Science Challenge). Hamilton, New Zealand: Deliberate.

Stage 2 was scoped after the completion of Project I. This stage coupled two tools developed earlier in the Challenge – the System map and the Seafloor model – to explore how these tools might work together, still with a focus on the two stressors of increased sedimentation and loss of benthic structure. This was run from late 2020 – mid 2022. This project is described in **three separate yet related reports**, outlined below:

- An overview of the process for the entire case study is provided in: Lundquist, C.J., Connolly, J.D., Shanahan, R, & Madarasz-Smith, A. (2022b). Enabling Ecosystem-Based Management in the Hawke's Bay: Overview of Stages 1 and 2 of the case study process. Summary report prepared for the Sustainable Seas National Science Challenge. Hamilton, New Zealand: NIWA.
- A detailed description of the Analogue Simulation is provided in **this** report: Connolly, J.D., Lundquist, C.J., Shanahan, R. & Madarasz-Smith, A. (2022b). Hawke's Bay EBM case study - Part 2: Applying Analogue Simulation - A qualitative process to explore the socio-ecological flow-on impacts in a system in response to modelled biophysical changes. Report prepared for the Sustainable Seas National Science Challenge. Hamilton, New Zealand: Deliberate.
- A detailed description of the Seafloor model is provided in **a companion report**: Lundquist, C.J., Bulmer, R.H., Yogesh, N., Allison, A., Leunissen, E., Brough, T. (2022a). Development of a seafloor model of disturbance impacts on benthic structure in the Hawke's Bay. Report prepared for the Sustainable Seas National Science Challenge. Hamilton, New Zealand: NIWA.

The two projects within the case study and how they fit together sequentially are conceptualised in Figure 2.

Figure 2. Conceptual map of Projects I & II in this case study



3 Methodology

The analogue simulation process described in this report is an attempt to extend the insights gained from the development of a system map (or system diagram). It does this by qualitatively exploring anticipated changes over time in flow-on impacts between factors connected in a diagram of cause and effect (the system map). Based on discussions as a group, and in response to other modelled biophysical changes, amounts or numbers of tokens allocated to factors of interest in that map were adjusted. A token was simply a representation of some form of conceptual quantity – for example a counter, marble or token. The process is an *Analogue simulation*: *Analogue* refers to humans as the tool by which changes are calculated; *Simulation* refers to the process of capturing anticipated changes numerically with tokens, the changes in which are then graphed afterwards.

Analogue simulation is one way in which the qualitative product of a system map can be used. Other ways are described in Connolly et al. (2020); an extract from that report is provided in Appendix 1.

This Analogue Simulation process couples the System map to the outputs of the Seafloor model. Scenario outputs from the Seafloor model include modelled changes in biogenic structure on the seafloor in response to biophysical changes, namely changing the sediment load from land and/or changing the amount of bottom contact in the ocean through fishing activity. The Seafloor model produced output graphs (among other useful visual outputs) of anticipated changes in biogenic benthic structure over time. These graphs were the key input for the Analogue Simulation exercise.

The Seafloor model is described separately in Lundquist et al. (2022a).

3.1 Analogue simulation based on systems thinking

The systems thinking[1] approach used in this report is based on the discipline of System Dynamics, the fundamentals of which are described more fully in Connolly et al. (2020)[2]. For a detailed understanding of systems thinking concepts, the reader is encouraged to read that report. To aid an understanding of the analogue simulation process, a recap of the important systems thinking concepts of exploring behaviour over time, accumulation, and feedback are provided below.

3.1.1 Understanding trends (behaviour of time graphs)

Understanding the behaviour (or trends) over time of a particular factor(s) of interest is central to systems thinking. Different 'systems' of interconnected causal factors produce different behaviours over time in different factors of interest (there is not 'one' system). Therefore, focussing on one or several behaviours over time helps you to understand the 'system' of inter-connected causes that is creating that behaviour over time.

The behaviours over time that the system map was built around were:

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[1] For a detailed introduction to the concepts of Systems Thinking, the reader is referred to *The Fifth Discipline – the art and practice of the learning organisation* (2nd ed.) by Peter Senge (2006) as an accessible introduction.

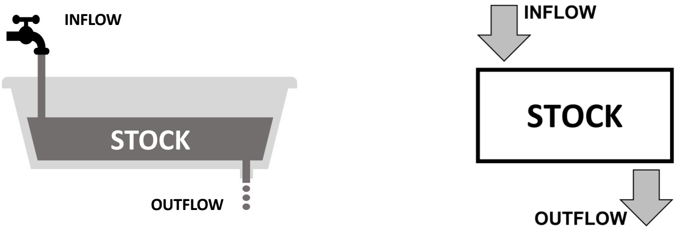
[2] System maps have also been used in several other pieces of research within the Challenge. It should be noted that while the methodology has been the same in all cases, in some instances a different name may have been used. For example, the term *'System mapping'* has been used in this report, and in two further projects: the initial pilot in Tasman Bay and Golden Bay (Connolly, J. (2019). *Piloting the use of System mapping in the Sustainable Seas National Science Challenge*. (A report for the Sustainable Seas National Science Challenge). Hamilton, New Zealand: Deliberate); and a report on the Blue Economy (Connolly, J.D. & Lewis, N.I. (2019). *Sustainable Seas National Science Challenge: Conceptual systems maps of 'Blue economy' activities*. (A report for the University of Auckland). Hamilton, New Zealand: Deliberate). In a report on the application of system mapping to Te Ao Māori perspectives (in print), the term *'Causal mapping'* has been used.

- An *increasing* level of sediment on the seafloor; and
- A *decreasing* level of benthic structure on the seafloor.

3.1.2 Accumulation

A factor of interest's behaviour over time, presented graphically, is a temporal visualisation of accumulation, decumulation, or no change in that factor. Systems thinking uses the analogy of a *bathtub* to conceptualise how such 'stocks' of things build up, decline, or remain the same. An example is shown Figure 3.

Figure 3. Using the bathtub analogy (stocks and flows) to conceptualise accumulation and decumulation

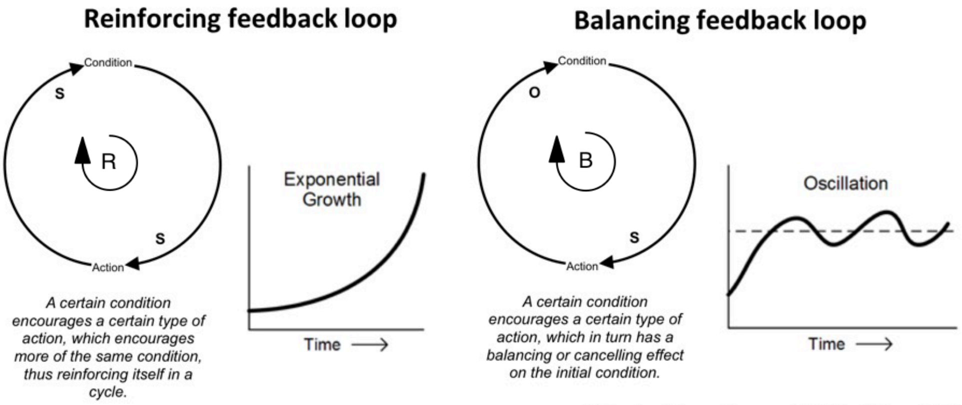


Importantly, s**tocks can ONLY increase through more inflow** (the tap over the metaphorical bathtub), **and ONLY decrease through more outflow** (the drain in the metaphorical bathtub), for whatever you are interested in – just like the level of water in a bathtub.

3.1.3 Feedback loops

Systems thinking is based on expanding from seeing causality as linear (which it is between two factors), to seeing causality as circular (which it often is between two or many more factors). Articulations of such circular causality are called *feedback loops*. There are two types of feedback loops, *reinforcing* and *balancing* (Senge, 1990). See Figure 4 for the two types of feedback loops.

Figure 4. The two types of feedback loops



A certain condition encourages a certain type of action, which encourages more of the same condition, thus reinforcing itself in a cycle.

A certain condition encourages a certain type of action, which in turn has a balancing or cancelling effect on the initial condition.

Adapted from Senge (1990) & Ford (2010)

In a *reinforcing feedback loop*, the direction of influence provided by one factor to another will transfer around the loop and influence back on the originating factor in the *same* direction, *reinforcing* and amplifying the original influence. ***Reinforcing loops are what drive growth or decline within a system.***

In a *balancing feedback loop*, the direction of influence provided by one factor to another will transfer around the loop and influence back on the originating factor in the *opposite* direction, *balancing out* the original influence. **Balancing loops create *control, restraint or resistance* within a system**.

Feedback loops can be made up of more than two factors and can be mapped together to form a system map). How these interact provide insight into how a wider system operates.

3.2 Overview of process used

An overview of the analogue simulation process is described below. It is composed of two main steps, between which the seafloor model is developed:

- **Develop scenarios to model with group:** Setting scenarios to be modelled, this informs the seafloor model. Scenarios also need to be compatible with how the analogue simulation process will be run *using the seafloor model's output graphs as an input to that process*. See section 3.2.1.

-- Seafloor model built by modellers and scenarios run.

- **Running the analogue simulation exercise:** Using the outputs from the seafloor model, run an analogue simulation process to explore the flow on impacts of change (or not). See section 3.2.2

3.2.1 Develop scenarios to model with group

As noted in section 3.1, understanding trends over time and how these are influenced by accumulation or decumulation in key factors, is central to the systems thinking and analogue simulation approach. As such, it is necessary for the scenarios being modelled to be able to be expressed in terms of changes (or not) in behaviour over time.

A 'scenario' as described here is a change in one or multiple factors that are key inputs to the seafloor model. Three factors were available for adjustment. These factors and the options for changing them are outlined in Table 1 below.

Table 1. Options for factors in scenarios

Factor	Description	Changes to be agreed by group
Areas and intensity and fishing effort	Determine one or multiple geographic areas (i.e. shapes drawn on a map) that will experience a one-off change in intensity of fishing effort. As fishing effort is not consistent across the sea floor, any changes in intensity will be relative. This will result in similar variability of intensity but all changed by a similar relative amount, i.e. more and less intensely fished areas will still vary, relatively.	• Discrete geographic area(s) where fishing will continue, yet changes in intensity will occur; • The intensity change to fishing (e.g. -10%). • What year this change is to occur (one off step change).
Areas of fishing closures (therefore areas of 0% fishing effort)	Determine one or multiple geographic areas that will experience a one-off change to no fishing occurring, i.e. fishing intensity will now be 0%.	• Discrete geographic area(s) where fishing closures will reduce fishing effort to zero; • What year this change is to occur (one off step change).
Change in sedimentation load to ocean from rivers	Determine a linear rate of absolute change in sediment load that will begin in an agreed year. This will reduce until either the estimated pre-European contact volume, or the end of the simulation period, is reached. All main river inputs in the model reduce at the same absolute rate. Changes in sedimentation are averaged across the entire sea floor of the Hawke's Bay, i.e. there is no spatial resolution of sedimentation by river in this version of the seafloor model.	• What percentage change reduction will occur over what time period (e.g. 10% over 20 years). • What year this change begins. The reduction is linear from there and then returns to flat lining at a new level once the reduction is completed. For example, a sediment reduction of '10% over 20 years' equals 0.5% reduction per year for 20 years from the current (100%) level, after which it continues as a flat line at an amount that is 80% of current sedimentation.

3.2.2 Running the analogue simulation exercise

After the scenarios are determined, the model is updated and run. The main factor being modelled in the seafloor model, is the level of biogenic benthic structure on the seafloor. The key output from the model that is necessary for the Analogue Simulation exercise is a graph over time (present time to 50 years in the future) of the expected change in this benthic structure.

This graph is them used as a key input to a qualitative discussion of how changes in this graph will, over time, likely cause or result in changes in other factors in the system map. This reflects the causal nature of the relationships that are at the core of the systems map. An example of this was undertaken at the end of the system mapping project and is described in Connolly et al. (2020).

The Analogue Simulation process is essentially a qualitative and participatory way of 'calculating' flow on change over a series of time steps. The 'calculating' is undertaken by the participants through discussion and dialogue ('Analogue'), which results in a set of behaviour over time graphs showing the flow on impacts of changes for each scenario ('Simulation').

3.2.2.1 Determine starting conditions

The key questions that need to be answered before running the analogue simulation exercise are:

- What is the overall timeframe of the simulation?
- What will the timesteps be within that timeframe?
- What part (all or some) of the system map will be used to guide the analogue simulation?
- What are the key factors in which changes will be estimated and tracked?
- What are the key delays between these factors?
- What are the 'starting condition' levels for each of those factors (in tokens)?
- Determine a relative scale of change for factors for each timestep (consistent across all).

Of the above, the starting conditions are abstract and relative and intended to reflect an approximation of reality. Therefore, they should be informed by data and knowledge where available/possible; or estimated by the group as best as possible otherwise. But they will all need to be represented with the same tokens (i.e. consistent units) being used across the simulation exercise.

The answers for these key questions in this case study are shown in Table 2.

Table 2. Key questions and answers for the analogue simulation exercise in Hawke's Bay

Factor	Description
What is the overall timeframe of the simulation?	50 years. Consistent with the seafloor model.
What will the timesteps be within that timeframe?	5 years per timestep. This applies to the analogue simulation process only (the seafloor model has a much finer timestep). This results in 10 timesteps or decision steps for the group per scenario.
What part (all or some) of the system map will be used to guide the analogue simulation?	Most of the right hand side of the system map will be used to guide this analogue simulation. From the level of benthic structure the influences flow to the right. For a copy of this part of the system map, see Appendix 2. The influences also eventually flow *back* again thus changing the factors set in the scenarios, as is the nature of circular causality. This, however, was *not* done in this analogue simulation exercise, because the factors in the seafloor model were set and not able to be adjusted. This simulation exercise was, therefore, an exploration of 'flow-on influences' from changes in benthic structure only. For more detail of this, see section 3.2.3, *Limitations of methodology*.
What are the key factors in which changes will be estimated and tracked?	Five factors were tracked through this analogue simulation process. These are listed below. Some are factors from the original system map, others are combinations of several factors in the system map. These are noted where this is the case. • **Seafood stocks** (original factor) • **All catch** (a combination of factors capturing customary, recreational and commercial catch). • **All fisher satisfaction** (a combination of factors capturing fisher satisfaction, stress, mental health, sense of stewardship and extent that they feel part of the community). • **Strength of cultural identity** (a combination of factors capturing the quality of fish stocks in relation to pre-industrial fishing levels, the mana of kaitiaki, the strength of knowledge and identity and the strength of connection with Tangaroa). • **Community wellbeing** (original factor)
What are the key delays between these factors?	Delays were identified *before* the following factors, i.e. any changes that occur in these variables are deemed to occur
What are the 'starting condition' levels for each of those factors (in tokens)?	For ease of set up, starting conditions informed by those used in the example run in 2020 were used. Two exceptions were that the factor 'Seafood stocks' was determined by the look-up table used to determine the relationship between benthic structure and Seafood stocks (see Appendix 3), and 'All catch' was determined as half the level of the Seafood stocks. During the exercise it was decided that all fisher satisfaction was considered too low, so it was adjusted and retrospectively adjusted to the simulations already run (in this project). The starting conditions below reflect that adjustment. • **Seafood stocks**: 30 tokens • **All catch**: 15 tokens • **All fisher satisfaction**: 30 tokens • **Strength of cultural identity**: 18 tokens • **Community wellbeing**: 24 tokens The scales for all factors went up to 80 tokens. A 'full container' of 'Seafood stocks' (80 tokens) is considered to be reflective of the pre-European level of Seafood stocks. The relative levels of all other factors were estimate off this relative amount from this factor .
Determine a relative scale of change for factors for each timestep (consistent across all)	The relative scale of change used in this simulation was: • **No change:** 0 tokens • **A little change:** 1 token • **Medium change:** 2 tokens • **A lot of change:** 3 tokens

3.2.2.2 Set up analogue simulation space

The analogue simulation space is usually physical and the system map should be set as the main visual prompt to guide discussions. Due to COVID restrictions, in this project the analogue simulation space was virtual, representing how the table *would* have been laid out in person.

The main components that need to be set up in the physical space are:

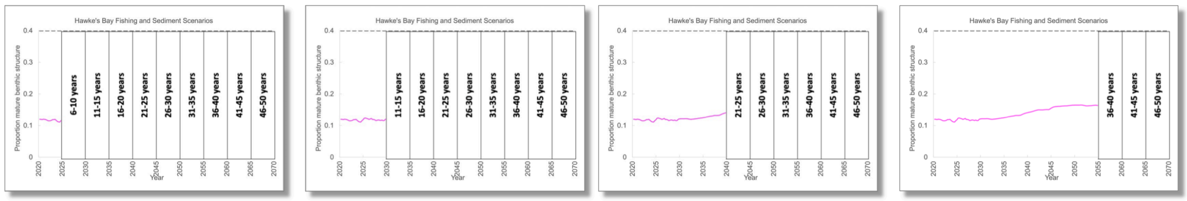
- The system map as a prompt to guide discussion. In this instance, to make the discussion prompts clearer, an amended version of the system map that included the amalgamated factors as listed in 0 was used.
- Containers for the tokens used to represent the factors being tracked. These are filled with the number of tokens that reflect the 'starting conditions' for each factor (the level each factor is currently at). In this instance these containers and tokens were also virtual. However, in physical situations these may be counters, marbles, beans, or whatever tokens may be appropriate to use.
- Delays into these containers are represented as additional small containers before the main containers where factors are tracked. Changes in factors with delays will be placed in these delay boxes first, then moved to the main container in the following timestep. Tokens in the delay boxes are not tracked in the table or graph. This means that any change in a variable with a delay will take two time steps to present as a change, this will result in a delayed change in the output graph.
- The scenario factors and the input graph from the seafloor model (see ***Important note*** below). These provide the stimulus for the conversation.
- A table to track any changes in the variables is prepared. See Figure 6.

Important note:

It is critically important to the analogue simulation exercise that the input graph from the seafloor model is only revealed timestep by timestep – therefore the input graph should be hidden at the start of the exercise. This helps prevent bias in the discussion of the group, as if they know in advance *how* the graph changes over the 50-year timeframe and *where* (what level) it ends up, this is *highly likely to bias or prejudice their discussions*. Therefore, detailed discussions of the model results should be planned for *after* the analogue simulation process.

An example of how an input graph is gradually revealed, timestep by timestep, is shown in Figure 5.

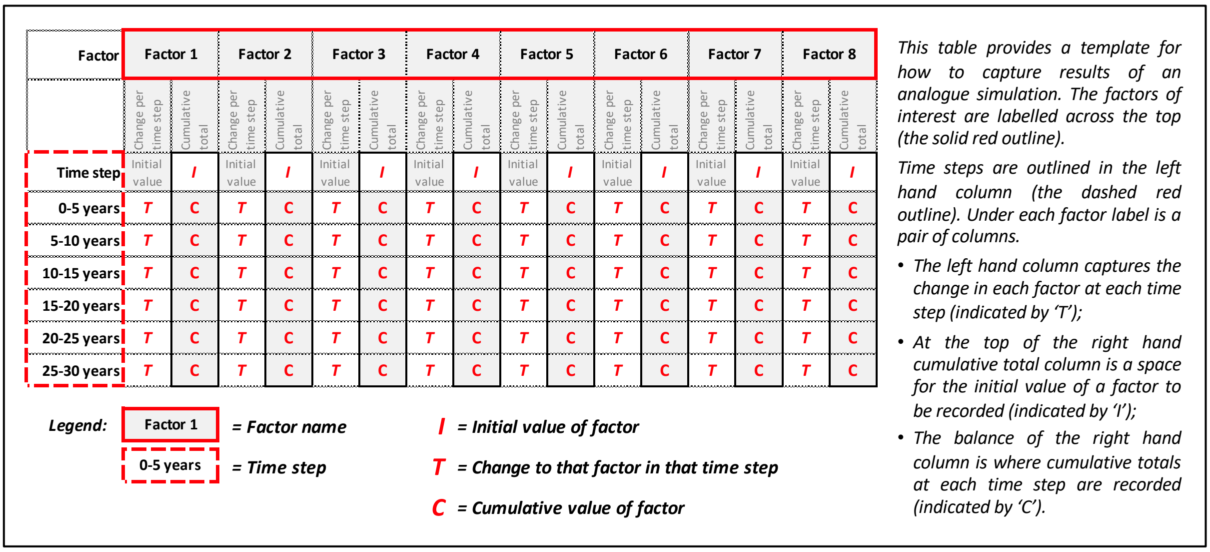
Figure 5. Example of gradually revealing the input graph information



after 1 timestep **after 2 timesteps** **after 4 timesteps** **after 7 timesteps**

An example of a prepared analogue simulation space is shown in Figure 7.

Figure 6. Table to track changes to factors during analogue simulation process



Factor	Factor 1		Factor 2		Factor 3		Factor 4		Factor 5		Factor 6		Factor 7		Factor 8	
	Change per time step	Cumulative total	Change per time step	Cumulative total	Change per time step	Cumulative total	Change per time step	Cumulative total	Change per time step	Cumulative total	Change per time step	Cumulative total	Change per time step	Cumulative total	Change per time step	Cumulative total
Time step	Initial value	*I*	Initial value	*I*	Initial value	*I*	Initial value	*I*	Initial value	*I*	Initial value	*I*	Initial value	*I*	Initial value	*I*
0-5 years	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C
5-10 years	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C
10-15 years	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C
15-20 years	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C
20-25 years	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C
25-30 years	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C	*T*	C

Legend:

Factor 1 ***= Factor name***

0-5 years ***= Time step***

I = Initial value of factor

T = Change to that factor in that time step

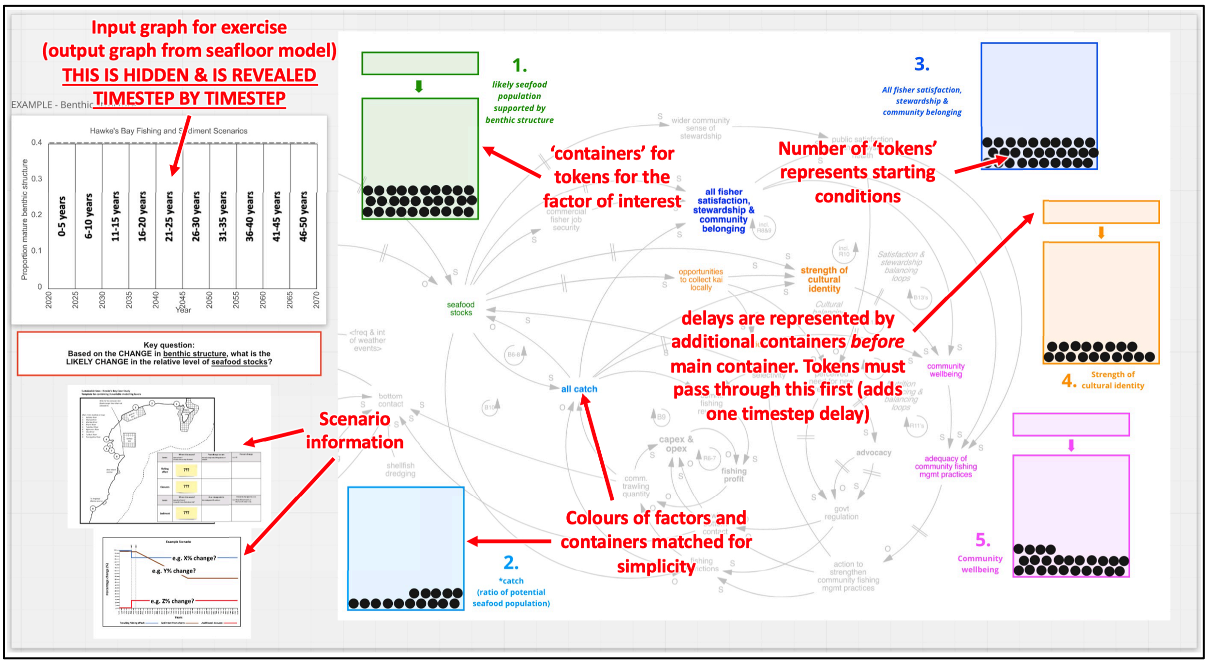
C = Cumulative value of factor

This table provides a template for how to capture results of an analogue simulation. The factors of interest are labelled across the top (the solid red outline).

Time steps are outlined in the left hand column (the dashed red outline). Under each factor label is a pair of columns.

- *The left hand column captures the change in each factor at each time step (indicated by 'T');*
- *At the top of the right hand cumulative total column is a space for the initial value of a factor to be recorded (indicated by 'I');*
- *The balance of the right hand column is where cumulative totals at each time step are recorded (indicated by 'C').*

Figure 7. Example of a prepared analogue simulation space



Input graph for exercise (output graph from seafloor model) THIS IS HIDDEN & IS REVEALED TIMESTEP BY TIMESTEP

'containers' for tokens for the factor of interest

Number of 'tokens' represents starting conditions

delays are represented by additional containers *before* main container. Tokens must pass through this first (adds one timestep delay)

Scenario information

Colours of factors and containers matched for simplicity

3.2.2.3 Run the analogue simulation

Once the starting conditions have been determined and the analogue simulation space has been set up, it is now possible to run the analogue simulation process.

Each scenario is introduced and discussed. The participants are reminded what the scenario is and what factors have changed. The output graph from the seafloor model is not yet revealed. Then, for each of the 10 timesteps of the scenario, the process set out in Table 3 is followed.

Table 3. Process for each timestep in each scenario

<table>
<tr><th>Step</th><th colspan="2">Step description</th></tr>
<tr><td>1. **Reveal the change in the current timestep on the input graph***
*** (one timestep at a time only)***</td><td colspan="2">The change in the current timestep on the input graph is revealed. As noted earlier, in this case study the benthic structure graph that is the output of the seafloor model is the input graph for this exercise.</td></tr>
<tr><td rowspan="7">2. **Discuss and update the flow on impacts from that factor to and through the other factors in the system diagram.**</td><td colspan="2">One at a time, discuss how each factor may change in response to changes in those factors that influence it – directly or indirectly. This is informed by knowledge if available, otherwise discussion within the group.
This was done in the following order with the following supporting knowledge.</td></tr>
<tr><th>Factor (in order):</th><th>Change in factor informed by:</th></tr>
<tr><td>**Seafood stocks**</td><td>Look-up table estimating benthic structure impact on fish stocks. Refer to Appendix 3 for details.</td></tr>
<tr><td>**All catch**</td><td>Assumed as half of seafood stocks. This does **NOT** infer the catch is half of the stock. It simply allows enough tokens to represent changes in the catch.</td></tr>
<tr><td>**All fisher satisfaction**</td><td>Change determined by the group in discussion.</td></tr>
<tr><td>**Strength of cultural identity**</td><td>Change determined by the group in discussion.</td></tr>
<tr><td>**Community wellbeing**</td><td>Change determined by the group in discussion.</td></tr>
<tr><td colspan="3">***-- Repeat steps 1 and 2 for all 10 timesteps of each scenario, then the scenario is completed --***</td></tr>
</table>

3.2.3 Limitations of methodology

A summary of some identified limitations of the methodology are described below:

- This process is a qualitative process designed to *synthesise* a wide variety of information together for high level insights. It necessarily simplifies a wide range of detail in subject areas, which are not able to be represented in the results. However, insights are intended to be complementary to the detail of these subject areas, not in competition with them.
- From the benthic structure factor in the middle of the System map, circular causality is described through different socio-ecological components on the righthand side of the system map, back to the benthic structure in the middle of the System map. This analogue simulation process *only tracks the flow-on impacts from changes in the benthic structure to the socio-ecological factors on the righthand side of the map*. This is because changes in the scenario factors modelled in the Seafloor model are set across the entire 50-year period. Therefore, in this instance there is no feedback to these factors in the analogue simulation exercise.
- The Seafloor model is a comprehensive computational model. It also only represents *part* of the system map. Therefore, it should be remembered that the system map covers a far wider range of variables and factors than are captured in the Seafloor model. To model all these would take a significant amount of effort and may not even be possible at all. Participants (and the reader) are encouraged to remember this and recognise that the insights associated with the analogue simulation exercise likely come with a higher level of assumption, and a greater number of caveats, than those from the Seafloor model.
- The analogue simulation process is not intended as a process to help refine factors or assumptions *within the Seafloor model* (or any model that it may be coupled with). The level of uncertainty associated with discussion is considered too high. Yet this does not mean that details of the Seafloor model (or any other model) may not be crowdsourced in a participatory way (for example, river plumes in the ocean may be estimated by a group as this is not dependent on, or a result of, the analogue simulation process).

4 Results

This section outlines the results of the analogue simulation process. It is divided into two sections: scenarios modelled and results of analogue simulation exercise.

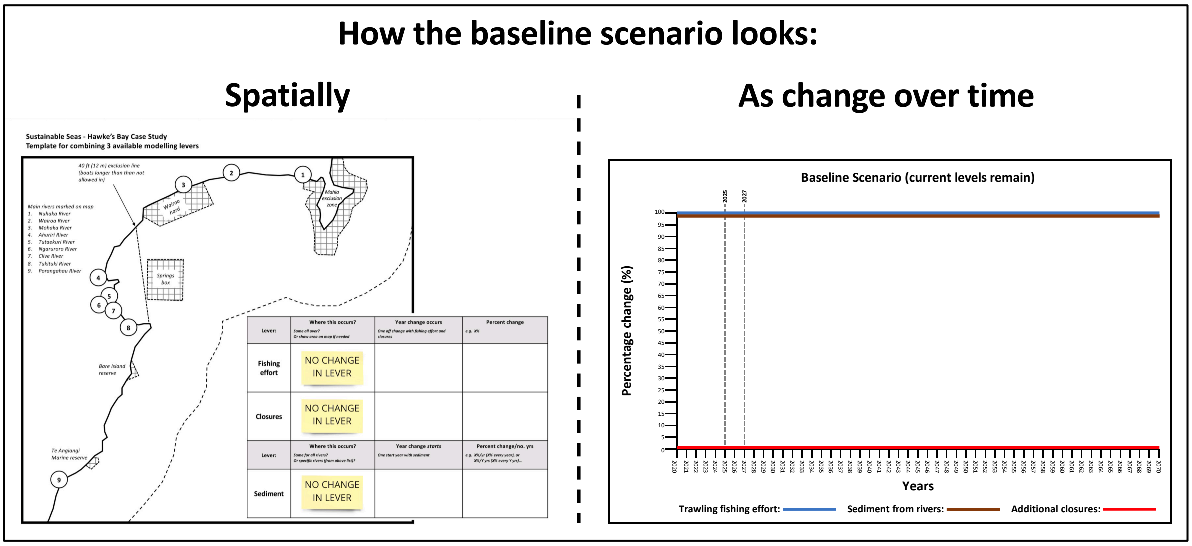
4.1 Scenarios modelled

Four scenarios were modelled – One *baseline scenario* where the levels of the three factors available in the model remained at current levels; and *three scenarios* where one or multiple of these factors were adjusted.

For a detailed description of how these were modelled mathematically, see Lundquist et al. (2022a). For a lay-person description of how these were described by the participants and in discussions see: Figures 8-11 for a spatial and temporal visualisation; and Table 4 for a numerical description of scenario results.

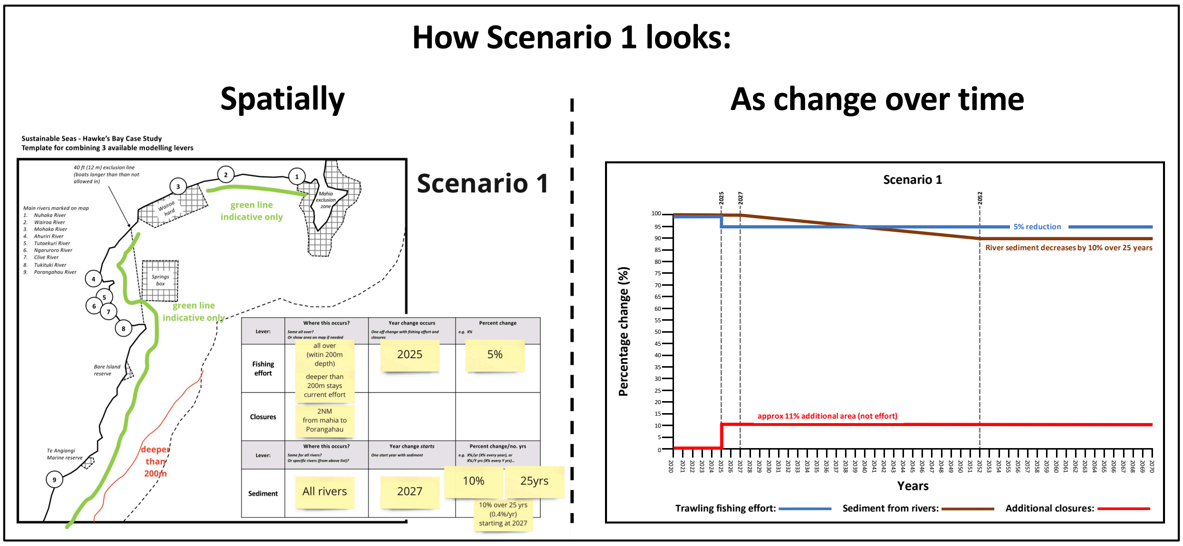
Given the inshore fisheries focus of the groups discussions to date and to reflect the lack of representation of deepwater fisheries in the group, all fishing effort deeper than 200 m was deemed to remain at current levels under all scenarios.

Figure 8. Baseline scenario – spatially and over time



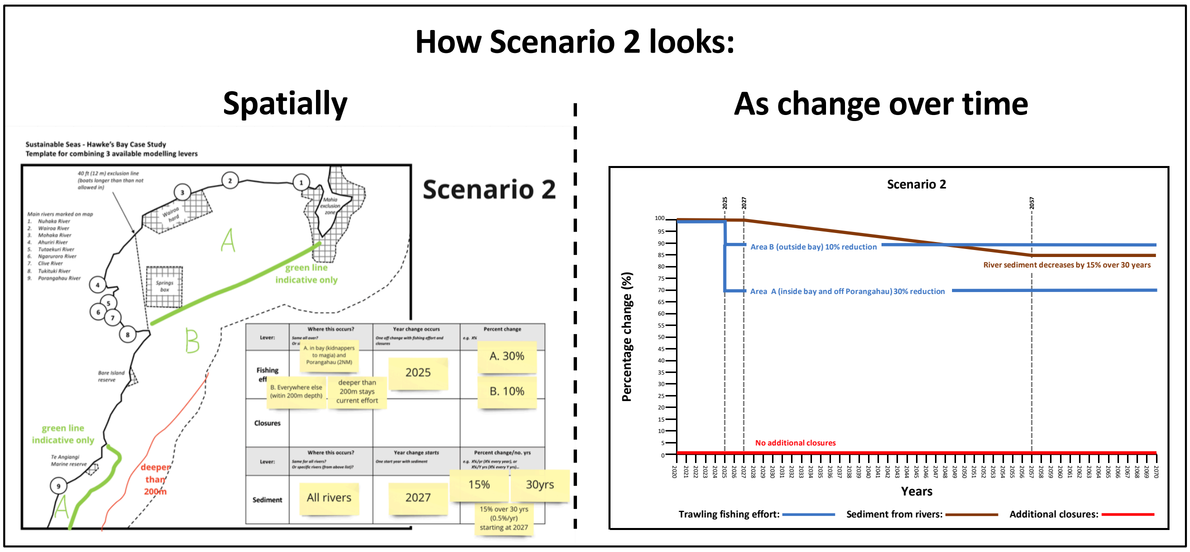
Lever:	Where this occurs? *Same all over?* *Or show area on map if needed*	Year change occurs *One off change with fishing effort and closures*	Percent change *e.g. X%*
Fishing effort	NO CHANGE IN LEVER		
Closures	NO CHANGE IN LEVER		
Lever:	Where this occurs? *Same for all rivers?* *Or specific rivers (from above list)?*	Year change *starts* *One start year with sediment*	Percent change/no. yrs *e.g. X%/yr (X% every year), or X%/Y yrs (X% every Y yrs)...*
Sediment	NO CHANGE IN LEVER		

Figure 9.Scenario 1 – spatially and over time



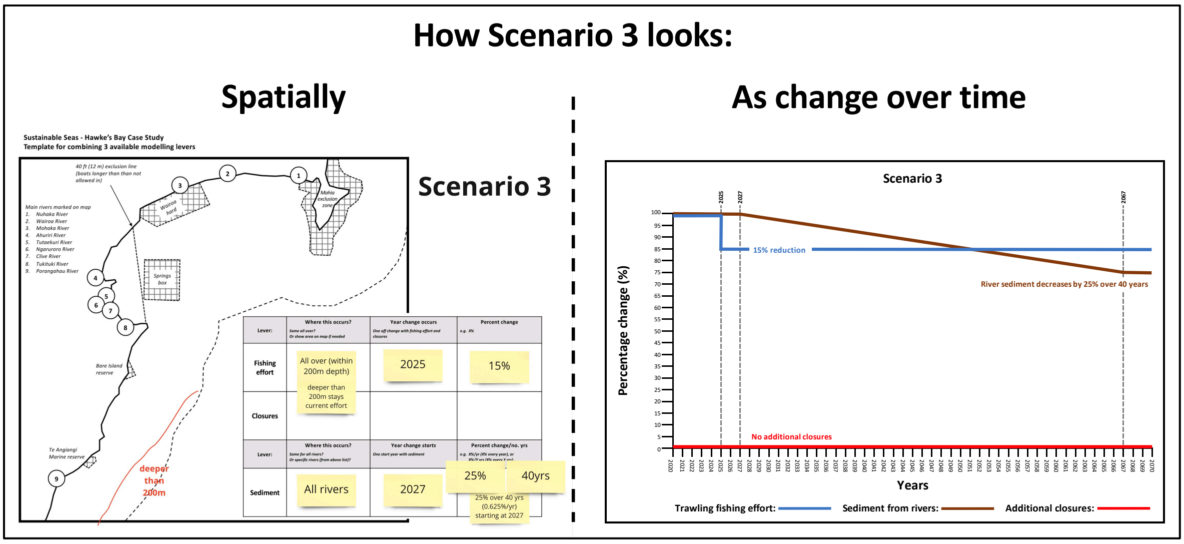
Lever:	Where this occurs? *Same all over? Or show area on map if needed*	Year change occurs *One off change with fishing effort and closures*	Percent change *e.g. X%*
Fishing effort	all over (witin 200m depth) deeper than 200m stays current effort	2025	5%
Closures	2NM from mahia to Porangahau		
Lever:	**Where this occurs?** *Same for all rivers? Or specific rivers (from above list)?*	**Year change *starts*** *One start year with sediment*	**Percent change/no. yrs** *e.g. X%/yr (X% every year), or X%/Y yrs (X% every Y yrs)...*
Sediment	All rivers	2027	10% 25yrs 10% over 25 yrs (0.4%/yr) starting at 2027

Figure 10. *Scenario 2 – spatially and over time*



Lever:	Where this occurs? *Same all over? Or si*	Year change occurs *One off change with fishing effort and closures*	Percent change *e.g. X%*
Fishing eff	A. in bay (kidnappers to magia) and Porangahau (2NM) B. Everywhere else (witin 200m depth) deeper than 200m stays current effort	2025	A. 30% B. 10%
Closures			
Lever:	**Where this occurs?** *Same for all rivers? Or specific rivers (from above list)?*	**Year change *starts*** *One start year with sediment*	**Percent change/no. yrs** *e.g. X%/yr (X% every year), or X%/Y yrs (X% every Y yrs)...*
Sediment	All rivers	2027	15% 30yrs 15% over 30 yrs (0.5%/yr) starting at 2027

Figure 11. *Scenario 3 – spatially and over time*



Lever:	Where this occurs? *Same all over? Or show area on map if needed*	Year change occurs *One off change with fishing effort and closures*	Percent change *e.g. X%*
Fishing effort	All over (within 200m depth) deeper than 200m stays current effort	2025	15%
Closures			
Lever:	**Where this occurs?** *Same for all rivers? Or specific rivers (from above list)?*	**Year change *starts*** *One start year with sediment*	**Percent change/no. yrs** *e.g. X%/yr (X% every year), or X%/Y yrs (X% every Y yrs)...*
Sediment	All rivers	2027	25% 40yrs 25% over 40 yrs (0.625%/yr) starting at 2027

Table 4. Description of scenarios modelled

Scenario	Brief description	Changes in model variables		
		Sedimentation[3]	Fishing effort	Additional fishing closures
Baseline scenario (Scenario 0)	**No change.** The model variables remain at current levels. For the entire 50-year period of the simulation.	No change. Current sedimentation levels remain.	No change. Current levels of fishing effort and spatial variability remains.	No change. Current closures remain.
Scenario 1	**Nearshore closure focus with some reduced fishing and sedimentation.** A fishing closure similar to that around Mahia Peninsula is extended to Porongahau. The closure width is approximately 2 NM (~3 km), in addition to existing closures. In addition there is **some** reduction in fishing effort (5%) and **some** sedimentation reduction of 10% over 25 years.	Sedimentation from all major rivers reduces by 10% over 25 years, i.e. 0.4% per year until reaching a level of 90% of current. Reduction start year: 2027 Reduction stop year: 2052	Fishing effort across all remaining areas outside of closures, within 200 m deep, reduced by 5%. Spatial variability within fishing effort remains.	Additional fishing closure within 2 NM (~3 km) of shore, n addition to existing fishing closures.
Scenario 2	**Major inshore fishing reduction and moderate sedimentation reduction.** No additional fishing closures. Existing closures remain. There is a **major** reduction in fishing effort of 30% within the Bay (inshore of a line between Mahia and Cape Kidnappers and a section off the mouth of the Porangahau River), and a 10% reduction in fishing effort everywhere else, up to 200 m deep. **Moderate** Sedimentation reduction of 15% over 30 years.	Sedimentation from all major rivers reduces by 15% over 30 years, i.e. 0.5% per year until reaching a level of 85% of current. Reduction start year: 2027 Reduction stop year: 2057	Fishing effort changed in two spatial areas. Area A: Inshore of a line between Mahia and Cape Kidnappers and a section off the mouth of the Porangahau River, reduced by 30%. Area B: Everywhere else within 200 m depth contour, reduced by 10%. Spatial variability within fishing effort remains.	No change. Current closures remain.
Scenario 3	**Moderate inshore fishing reduction and major sedimentation reduction.** No additional fishing closures. Existing closures remain. There is a **moderate** reduction in fishing effort of 15 % across the entire area, up to 200m deep. **Major** sedimentation reduction of 25% over 40 years.	Sedimentation from all major rivers reduces by 25% over 40 years, i.e. 0.625% per year until reaching a level of 75% of current. Reduction start year: 2027 Reduction stop year: 2067	Fishing effort across all areas outside of closures, within 200 m depth contour, reduced by 15%. Spatial variability within fishing effort remains.	No change. Current closures remain.

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[3] Reduction in sediment is delayed by a few years to allow time for current land use change practices and regulations to be adopted.

4.2 Results of analogue simulation exercise

The results of the analogue simulation exercise are presented in the figures below. These are presented in graphical form and indicate the level of tokens in the 'container' for each factor of interest. The container scale goes up to 80 (see 'Starting conditions' in Table 2 for maximum values).

Two graphs are presented in the results for each scenario.

- The output graph from the seafloor model, which was used as the input information for analogue simulation exercise; and
- The resulting graph of the factors discussed and changed in the Seafloor model.

For all scenarios it is estimated that prior to-European contact, the percentage coverage of mature benthic structure on the seafloor was around 40%. Hence this is shown as the upper 'pristine' level on the Seafloor model output graph. The current levels are assumed to be around 12%. See Lundquist et al. 2022a for more details.

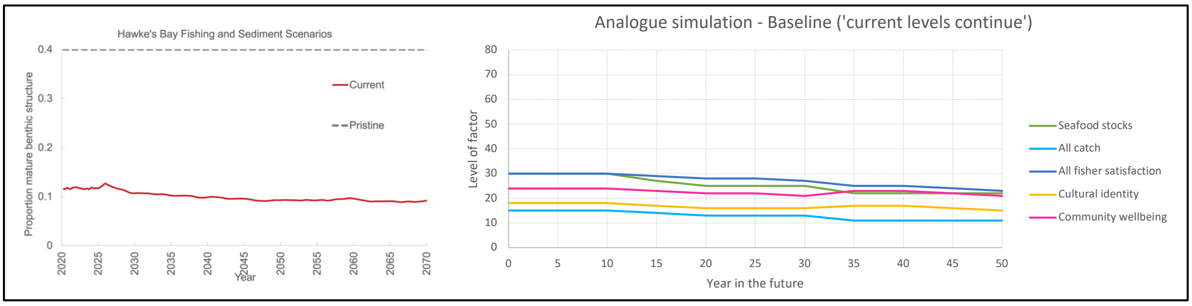
4.2.1 Baseline scenario results

The **baseline scenario** assumed that the scenario factors remained at their current levels for the next 50 years. The Seafloor model indicated that the mature benthic structure coverage of the seafloor would continue to gradually decline from around 12% currently, to around 9% in 50 years' time.

The analogue simulation results reflect a similar trend. Decreases in benthic structure meant that Seafood stocks were also assumed to decline (in line with the look up table described earlier (see Appendix 3). These then flowed on to decreases in the other social factors of interest. All fisher satisfaction trended down over the entire timeframe. The strength of Cultural identity, as well as Community wellbeing from the flow on impact, experienced a slight upturn around year 30-35. This was because some members of the group highlighted that continued inaction (i.e. no change in the factors) would actually galvanise local hapū (and perhaps other parts of the community) to become more organised and cohesive and demand action on the state of the scenario factors.

While this is likely true, it is noted that because the modelling was not dynamic in real time (i.e. the scenario factors in the seafloor model could not be adjusted in response to this demand for action). Thus, this upturn in cohesion is not reflected in the seafloor modelling results, whereas in reality this may result in action.

Figure 12. Analogue simulation results – Baseline scenario (Scenario 0)



4.2.2 Scenario 1 results

Scenario 1 assumes the exclusion of fishing from within ~3 km (2 NM) of the coast from the Mahia Peninsula through to Porangahau (from 2025). It also assumes minor decreases (5%) in fishing effort everywhere else (from 2025) and minor decreases in sedimentation from all rivers (from 2027).

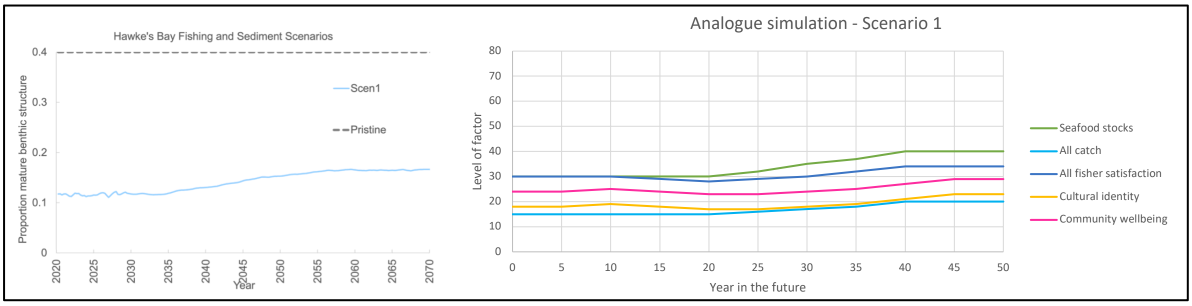
This results in similar levels of benthic structure (~12%) until around 2035 when a slight increase begins to occur. This continues until around 2055 after which it remains fairly constant at around 17% coverage.

Seafood stocks and All catch remain constant until around 20 years into the future (~2042), after which they begin to increase slightly. This reflects the delay in the regeneration of the seafloor where fishing activity has been excluded and the flow on delay associated with the regeneration of the seafood stocks.

The social factors trended differently. Firstly, the strength of Cultural identity and Community wellbeing turned up slightly after 5 years (~2027). This reflected the positive impact that taking action will have on some elements of various communities' wellbeing. That is, there would be a sense of pride, ownership and satisfaction that action had been taken to improve the health of the ocean.

However All fisher satisfaction, the strength of Cultural identity and Community wellbeing all then trended *down* slightly after 10 years (~2032) before flatlining and/or beginning to trend upwards around 20 years later when the seafood stocks begin to recover. This was because when the group was discussing the impact of their changes in increments of 5 years, they did not see the impact of benthic structure recovery then the recovery of seafood stocks flow through as quickly as they would have expected. This was because of the delay associated with both. They discussed the fact that this would likely then erode some of the satisfaction and wellbeing built up in the communities. These only recovered after actual seafood stocks began to recover.

Figure 13. Analogue simulation results –Scenario 1



4.2.3 Scenario 2 results

Scenario 2 assumes a major reduction in inshore fishing within the bay and around Porangahau, and mild reduction everywhere else (both from 2025) and a moderate reduction in sedimentation (from 2027).

This results in similar levels of benthic structure (~12%) until around 2030-35 when a slight to moderate increase begins to occur. This continues until around 2055 after which it remains moderately constant at around 16% coverage

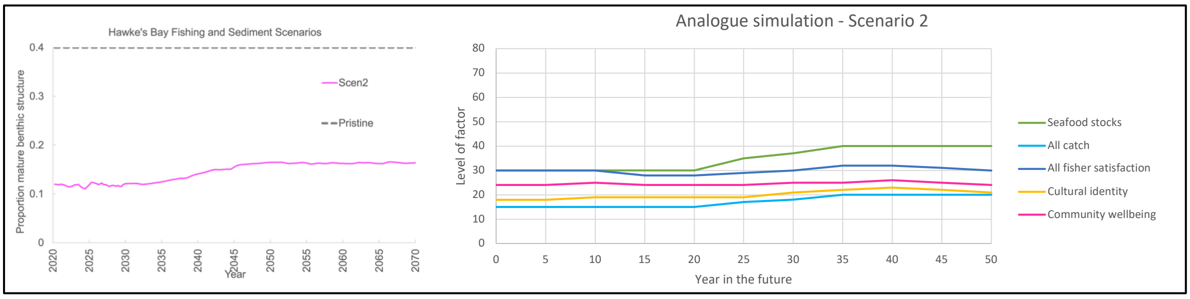
As in Scenario 1, seafood stocks and catch remain constant until around 20 years into the future (~2042), after which they increase more rapidly than Scenario 1. This again reflects the delay in the regeneration of the seafloor where fishing activity has been reduced and the flow on delay associated with the regeneration of the seafood stocks.

The only social factor to noticeably decrease before increasing again was All fisher satisfaction. The discussion in part reflected that this was because the commercial fishers (who make up some of the 'All fisher satisfaction' factor) had made a significant reduction in fishing effort. This factor begins to recover slowly after seafood stocks recover and plateaus when seafood stocks do, after 35 years (~2057).

The strength of Cultural identify increased slightly after 5 years (~2027) indicating the social and personal capital generated by being assumed to be involved in helping decide and implement the changes in the factors. This further increases after 25 years (~2047), when seafood stocks are visibly recovering.

Noticeably, all three social factors declined after 40 years (~2062), even though Seafood stocks and All catch remained constant at an increased rate. The discussion with the group highlighted that this reduction was because the group had expected higher impacts from the reasonable changes they had made. It was therefore likely that there would be some delayed disappointment in the impact of their interventions after this period of time.

Figure 14. Analogue simulation results –Scenario 2



4.2.4 Scenario 3 results

Scenario 3 assumes a major reduction in sedimentation from rivers (from 2027) and a moderate reduction in fishing effort across the bay (from 2025).

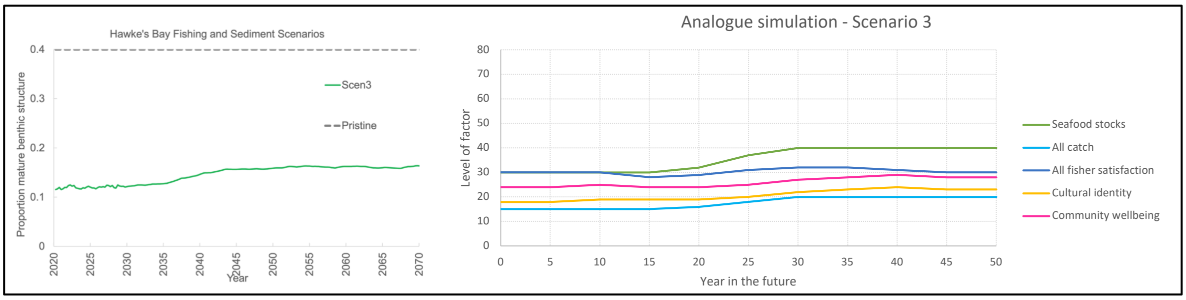
This results in similar levels of benthic structure (~12%) until around 2030 when a slight increase is experienced, then a fairly moderate increase between 2035 and 2045, after which benthic structure remains fairly constant at around 16% coverage. This is a faster recovery than the other scenarios yet to a level that is reasonably consistent with the other scenarios.

Seafood stocks and All catch experience a slight increase after 15 years (~2037) and a more dramatic increase between 20-30 years (~2042-52) after which time they remain constant, in line with the benthic structure.

As per Scenarios 2 and 3, the strength of Cultural identity and Community wellbeing experience an increase after the implementation of reduced fishing and the impacts of reduced sedimentation begin to take effect. Similarly, All fisher satisfaction experiences a decline after moderate reductions in fishing effort but then recovers more quickly in line with the more rapidly recovering seafood stocks.

All fisher satisfaction plateaus when the recovered seafood stocks plateau, yet the strength of Cultural identity and Community wellbeing continue to increase slightly afterwards. All social factors decline after the seafood stocks have plateaued for a while, suggesting dissatisfaction with the overall level of recovery in benthic structure and seafood stocks, in relation to the relative size of the interventions taken.

Figure 15. Analogue simulation results –Scenario 3



4.2.5 Generalisable insights

The scenario results described above highlighted useful observations about how the group responded to the results of the modelling and how they anticipated those to 'flow through' to the other biophysical and socio-ecological variables. These were:

- Declines in benthic structure and any associated declines in seafood stocks were assumed to occur at the same time step, as any removal of benthic structure was deemed to remove habitat and limit the amount of seafood stocks that could be supported. Increases in benthic structure and any associated increase in seafood stocks were realised after a delay, reflecting the time any recovery would take to present.
- Where intervention has occurred, social indicators all follow a similar broad pattern:
  - Satisfaction, cultural identity and wellbeing tend to increase after action has been taken but before recovery was observed, reflecting the impact that contributing to achieving a [potential] positive outcome has on these factors;
  - They then tend to decline after a while before recovery is observed, due to the delays involved in the regeneration of firstly benthic structure then seafood stocks. This is likely to be a non-linear relationship – i.e. there may be more pronounced dissatisfaction the longer it takes for recovery to present;
  - They then all increase as seafood stocks increase;
  - They all then tend to decline again slightly after the maximum recovery has been achieved, indicating likely dissatisfaction with the overall level of recovery, in relation to the level of action taken.

Other useful insights and observations from the analogue simulation participants were:

- The group observed that it was likely that ongoing action would be necessary, rather than one-off change. This was due to the time delays involved before any action has an effect, and the lesser than anticipated impact that action seemed to have;
- The different scenarios all tended to end in the same result of around 16-17% coverage of mature benthic structure on the seafloor, although some scenarios reached this point faster. It would have been useful to have more iterations of the modelling process to better understand which factors were more powerful to change. Only one modelling iteration was possible within the resource constraints of this project.

5 Summary

This report has outlined the application of a qualitative and discussion-based process of using the System map developed in the Hawke's Bay case study, to infer potential changes over time across a range of biophysical and socio-ecological factors in that system map, based on outputs from the Seafloor model developed as part of the same case study. This process has been referred to as Analogue Simulation.

This report is one of three issued concurrently. Lundquist et al. (2022a) describes the detail of the seafloor model, while Lundquist et al. (2022b) provides an overview of the entire case study process, including the development of the System map (described in Connolly et al. (2020).

The methodology for applying analogue simulation has been described, as have the results from the exercise.

Critically, it has been noted that the participants in the analogue simulation process must not see the results of the seafloor modelling (or whatever input information is used) before the analogue simulation process is run. This is so that their reactions and discussions are not biased by prior knowledge of the results.

The results highlighted useful observations about how the group responded to the results of the modelling and how they anticipated those to 'flow through' to the other biophysical and socio-ecological variables. These were:

- Declines in benthic structure and any associated declines in seafood stocks were assumed to occur in the same time, as any removal of benthic structure was deemed to remove habitat and limit the amount of seafood stocks that could be supported. Increases in benthic structure and any associated increase in seafood stocks were realised after a delay, reflecting the time any recovery would take to present.
- Where intervention has occurred, social indicators all follow a similar broad pattern:
    - Satisfaction, cultural identity and wellbeing tend to increase after action has been taken but before recovery was observed, reflecting the impact that achieving such a positive outcome has on these factors;
    - They then tend to decline after a while before recovery is observed, due to the delays involved in the regeneration of firstly benthic structure then seafood stocks. This is likely to be a non-linear relationship – i.e. there may be more pronounced dissatisfaction the longer it takes for recovery to present;
    - They then all increase as seafood stocks increase;
    - They all then tend to decline again slightly after the maximum recovery has been achieved, indicating likely dissatisfaction with the overall level of recovery, in relation to the level of action taken.

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- The group observed that it was likely that ongoing action would be necessary, rather than once-off change. This was due to the time delays involved before any action has an effect, and the lesser than anticipated impact that action seemed to have;
- The different scenarios all tended to end in the same result of around 16-17% coverage of mature benthic structure on the seafloor, although some scenarios reached this point faster. It would have been useful to have more iterations of the modelling process to better understand which factors were more powerful to change. Only one modelling iteration was possible within the resource constraints of this project.

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Appendix 1

Different ways of gaining insight from a system map

This appendix provides a copy of section *7.1 Different ways of gaining insight from a system map*, from Connolly et al. (2020). This outlines four possible ways that insight can be gained from a system map only, without it being developed into a computational system dynamics (or other method) model. The process described in this report is an application of point 4, below.

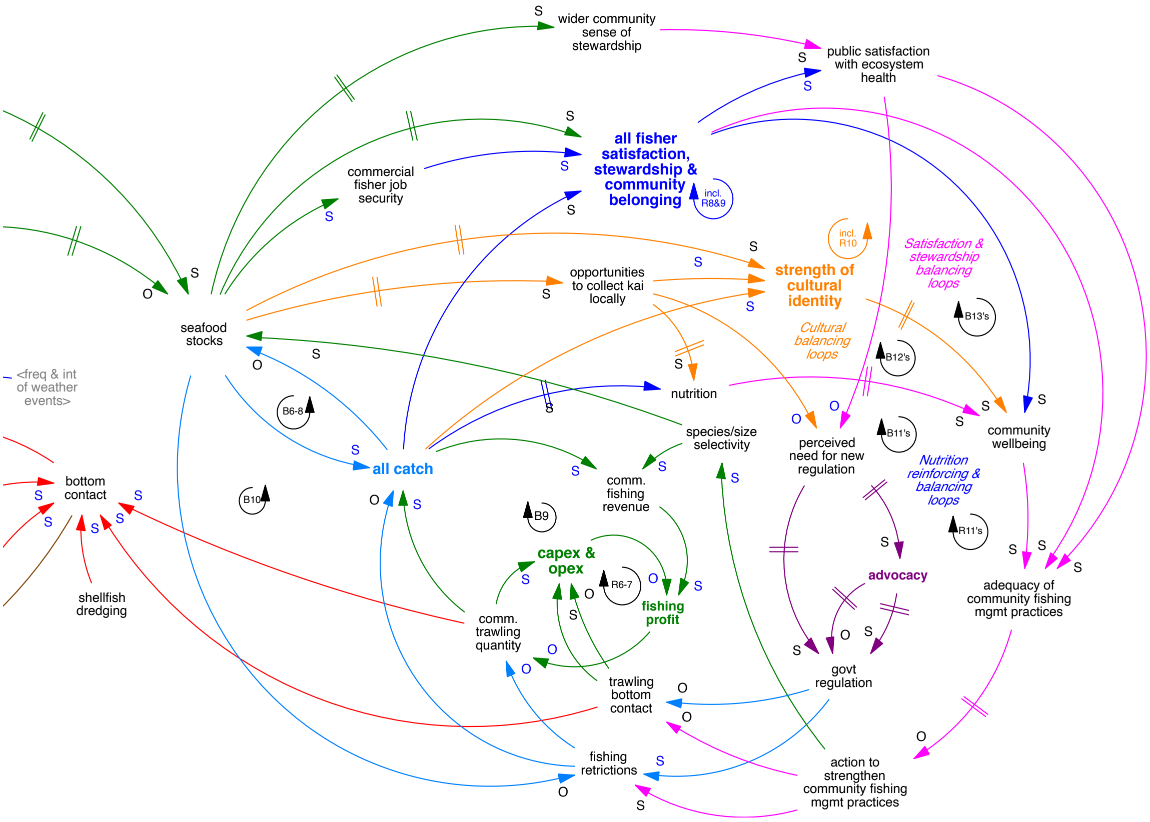
Note that references to other sections are from the previous report cited above, not this report.

> "[A previous section] described how system maps, like that described in this report, sit at the lower end of the spectrum of complexity for the use of System Dynamics tools. As you move up the spectrum of complexity small-scale simulation models can be developed, and eventually large-scale and complex simulation models.
>
> Yet low complexity does not mean that only low levels of insight or stakeholder alignment are achieved. Often the opposite is true – significant insight and stakeholder alignment can be gained from participatory processes that developed system maps.
>
> Insight can be achieved in a variety of ways, each building upon the other. All of these are subjective and are listed below:
>
> 1. At the very least, the system map helps visually demonstrate the interconnected nature of the system that is being mapped.
> 2. System maps also highlight the circular nature of causality, where it has been identified. This allows insight into how much of a system's behaviour comes from endogenous versus exogenous influence. This can help reframe participants perceptions of how much influence is from 'external' sources and how much is from 'within'.
> 3. Using the system map as a tool to guide discussion, the anticipated dynamic behaviour of some elements in the system can be discussed and explored as a group. Earlier, the development of the system map was anchored in discussing the trends of behaviour in the system up until this point in time (see section 5). At this point, the discussion is anchored around how the system may behave *from this point onwards*, effectively bringing the discussion back full circle to talking about trends over time.
> 4. This discussion of trends over time can be aided by the use of a technique referred to here as *analogue simulation*. This is effectively the same subjective discussion about what the dynamics of the system will do in the future, yet it is aided by the use of tangible counters for change (up or down) in specific factors of interest, within set time steps over a period of time. As this is a manual process of determining the changes in each factor, it obviously excludes the rigour of mathematic calculations so it is not intended as a substitute for mathematical modelling. However, it is intended as a an additional 'hands on' aid to increase insight and learning."

Appendix 2

Simplified version of system map

The below is a simplified version of the 'right hand side' of the system map described in Connolly et al. 2020. This covers most of the socio-cultural elements of the system map used in the Analogue Simulation exercise.



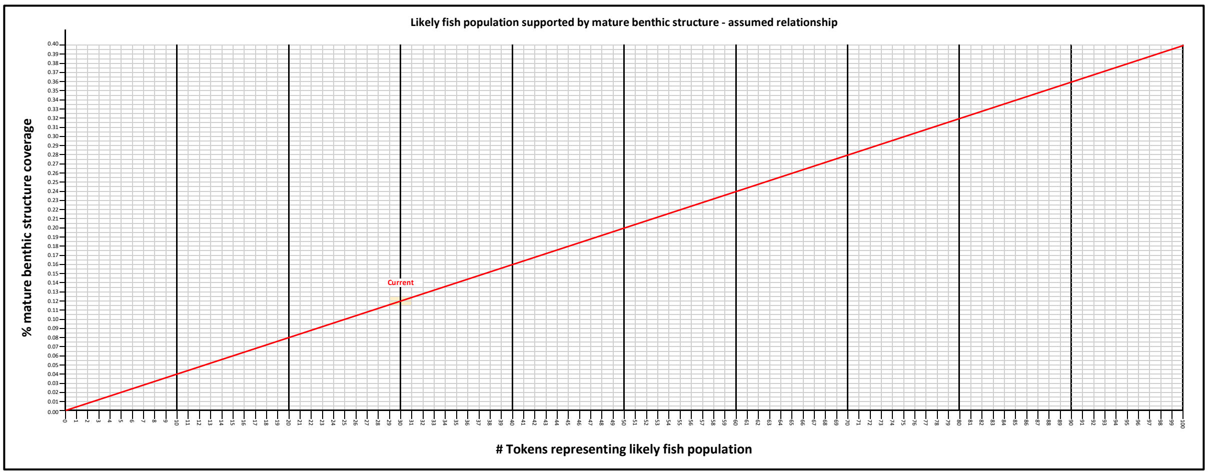
Appendix 3
Seafood stocks look up table

During the analogue simulation process, the following look up table was used to determine the relative change in seafood stocks based on the change in benthic structure, as estimated by the seafloor model. This was developed by the marine scientists in the project team.

It is intended as an informal heuristic to inform relative changes in seafood stocks and should be viewed as such. It is not intended as an accurate representation of how stocks of all seafood species would respond to changes in biogenic benthic habitat/structure.

The look up table for relationship between percentage of mature benthic structure coverage (of the Bay area), compared to the number of tokens representing the likely fish population, is shown below.

The starting condition for the seafood stocks was determined by the starting condition of the benthic structure in the model. This was 0.12 (or 12% coverage of the Bay area). The pre-European coverage of the benthic structure in the Bay is estimated to be 0.4 (or 40%). Therefore, at that level of 0.4, the seafood stocks are informally considered to be 100% of what they used to be.



Appendix 4

Complete graphical results for all scenarios

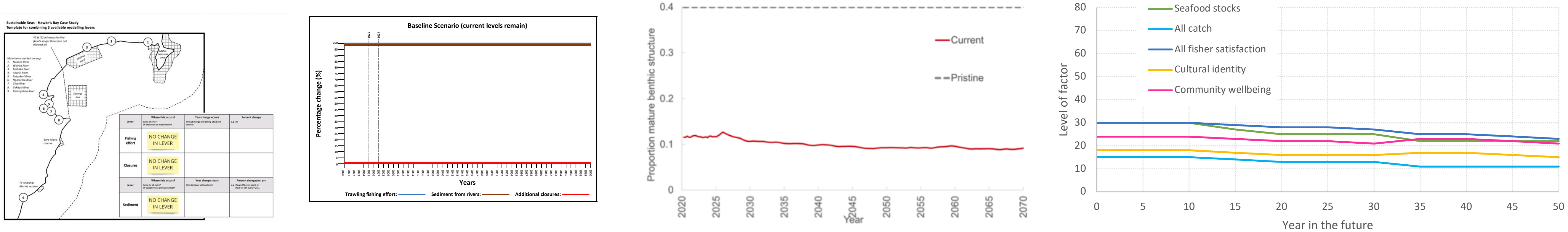
The following graphic collates all of the results from the scenario setting, modelling of the seafloor, and results of the analogue simulation together.

There are four columns:

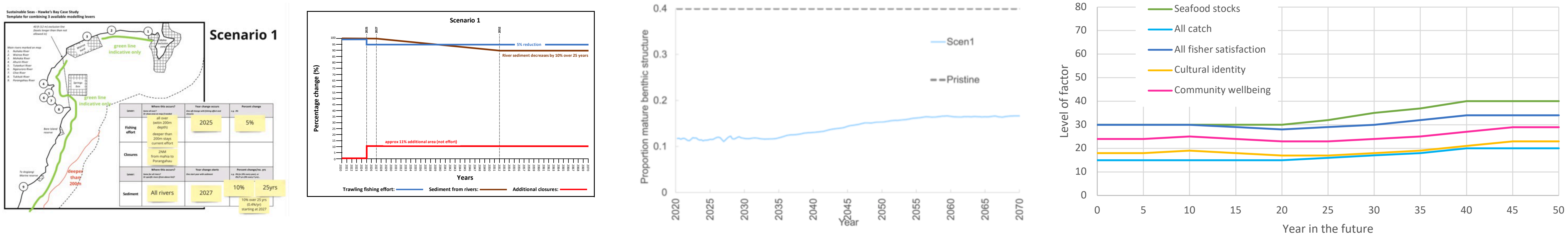
- The first column is a spatial articulation of the scenarios;
- The second column is a visual articulation of how the factors in the scenarios change over time;
- The third column is the output graph from the seafloor model, show how benthic structure changes in response to changes in the factors in the scenarios; and
- The fourth column is the results of the analogue simulation process, where the flow on impacts of the changes in benthic structure were discussed and estimated for key factors.

Input: Scenario map | **Input: Scenario factors change over time** | **Mature benthic structure coverage of the seafloor (%)** | **Analogue simulation results**

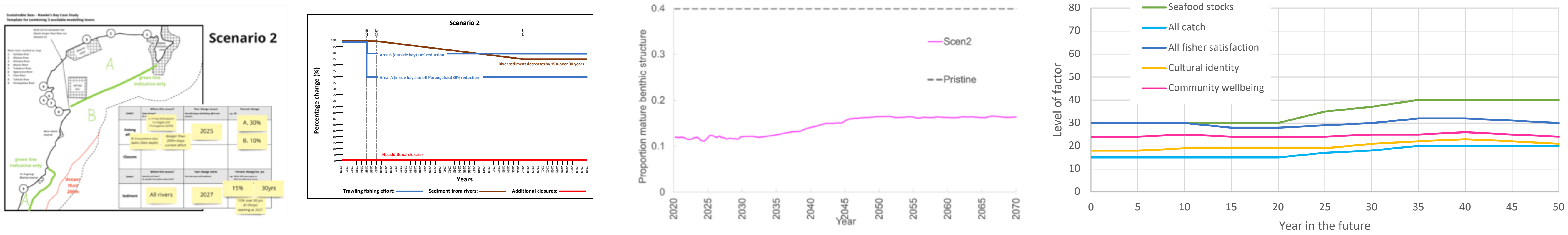
Baseline scenario (0)



Scenario 1



Scenario 2



Scenario 3