National SCIENCE Challenges

SUSTAINABLE SEAS

Ko ngā moana whakauka

USER GUIDE:

Tools for ecosystem-based management

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October 2023

Guidance

About Sustainable Seas Challenge

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

sustainableseaschallenge.co.nz

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Cover image: Putaki Bay, Hauraki Gulf © iStock

Kyakers in estuary, Abel Tasman National Park © iStock

Contents

Eddy swirl, Hapuku River, Wairarapa © Ryan Evison, NIWA

Introduction

The purpose of this guide is to help resource managers, kaitiaki and others to identify appropriate tools, developed and/or used by the Sustainable Seas Challenge, for ecosystem-based management (EBM) in Aotearoa. EBM is a holistic approach to managing human activities that ensures ecosystem health. Informed decision-making using an EBM approach draws on extensive scientific and cultural knowledge, which in turn is facilitated using a range of tools from simple decision frameworks to complex numerical models.

In this guide, the word 'tool' refers to resources that support the implementation of EBM, including guidelines, frameworks, and numerical and conceptual models. Examples range from the Aotearoa Cumulative Effects (ACE) framework for collaborative management of cumulative effects to Atlantis, a whole of ecosystem model capable of simulating ecological responses to different stressors and management actions. To help navigate these tools, we have compiled basic descriptor information that explains where and how they can be applied within the context of EBM, practical requirements around their use and application, expert contacts, and links to further information.

A total of 17 tools developed and/or used by Sustainable Seas are categorised based on their main feature or use type:

1. Numerical models
2. Monitoring tools
3. Decision-making tools
4. Participatory process tools.

The *Summary purpose matrix* (Table 1, p5) provides a glimpse of each tool's purpose.

In some cases, the tools are in a prototype stage, but can be taken up and further refined and used in real-world applications. For example, our *Hawke's Bay regional study* has used systems mapping and zonation models to inform management of cumulative effects and seabed health in Hawke's Bay.

Table 1: Summary matrix of tool applications

This provides an overview of applications for each tool described in this document. Additional tables providing further detail around tool features and comparison among them are provided in the appendix.

	Applications							
	Decision-making	Scenario exploration	Cumulative effects	Marine biosecurity	Ocean connectivity	Risk and uncertainty	Participatory process	Others[†]
Tasman/Golden Bay Atlantis Ecosystem model (p8)	✓	✓	✓				✓	✓
Tasman/Golden Bay Ecopath with Ecosim (EwE) model (p10)	✓	✓	✓				✓	✓
Tasman/Golden Bay MSSM (p12)	✓	✓	✓					✓
Ocean Tracker (p15)					✓		✓	✓
BactiMap – Real-time forecasting tool (p18)	✓			✓		✓		✓
Seabed health and scallop fisheries (p20)	✓	✓	✓			✓	✓	✓
Filling gaps in marine data (p22)	✓	✓						
Managing the impact of turbidity, nutrients and sea level rise on coasts and estuaries (p30)	✓		✓			✓	✓	✓
Using ecosystem service bundles to improve marine management (p31)	✓		✓					✓
Monitoring for tipping points in the marine environment (p32)	✓		✓	✓		✓	✓	✓
Lessons for designing long-term monitoring programmes (p34)	✓		✓			✓	✓	
EEZ biodiversity and Hawke's Bay zonation (p37)	✓	✓	✓			✓	✓	
Aotearoa Cumulative Effects (ACE) framework (p40)	✓	✓	✓			✓	✓	
Pātaka Korero to empower kaitiaki (p42)	✓	✓	✓	✓	✓	✓	✓	✓
Tasman/Golden Bay, Hawke's Bay and Blue Economy systems mapping for ecosystem-based management (p44)	✓	✓	✓				✓	
The Ingredients Tool (p47)	✓	✓					✓	

[†]Others include: Mātauranga Māori, knowledge content repository, and education and awareness

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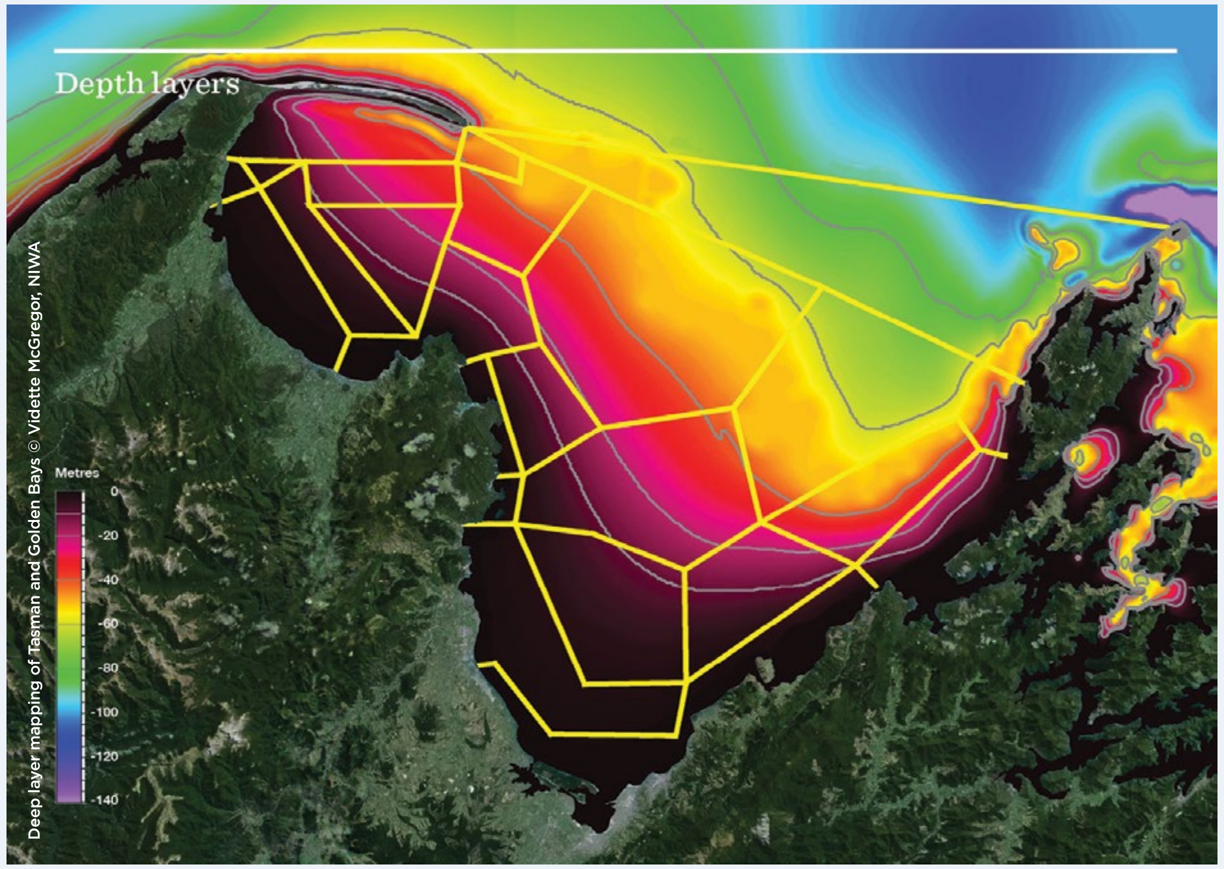
Numerical models

Marine ecosystems represent highly complex interactions among organisms and the surrounding environment and demonstrate strong connectivity among their habitats, surrounding coastal catchments, and offshore waters. The enormous size and dynamic nature of marine ecosystems makes it difficult to understand and capture all their complexity through scientific observations alone. One way to enable holistic management of these systems through EBM is the use of numerical models. Such models provide a virtual means of creating ecosystem components or even entire marine ecosystems to explore how they respond to different stressors, activities and management scenarios.

This section describes seven numerical models developed and/or applied within Sustainable Seas. These include three **ecosystem models** (Atlantis, Ecopath with Ecosim, and the multi-species size spectrum), two **oceanographic models** (BactiMap and Ocean tracker), one **cause/causality model** (Bayesian network), and one **statistical model** (Gradient Forest model). A comparison matrix of the three ecosystem models (Table 2, p14) delineates how each model can help in different scenarios.

Some numerical models are more complex than others, and therefore require a different level of expertise to run them and/or to interpret their outputs. Detailed information on their requirements can be found in each model description. More technical information about numerical models (e.g. software, model type, model code access, etc) can be found in the numerical model feature matrix (Table 3, p25). More detailed information on objectives and features is provided in Table 4 (p50) and Table 5 (p54).



Deep layer mapping of Tasman and Golden Bays © Vidette McGregor, NIWA

Tasman/Golden Bay Atlantis Ecosystem model

TYPE Ecosystem model	**SCENARIOS EXPLORATION** Yes
DISCIPLINE Widely ranging	**COMPLEXITY** Very difficult
END-USERS Widely ranging	**DATA FLEXIBILITY** High
DIMENSIONS 4D	**SKILL NEEDED** Numerical modelling and coding
SPATIAL SCALE Regional to local	**COST TO BUILD** $$$[1]
TEMPORAL SCALE Days to decades	**COST TO RUN** $[1]
ABILITY TO INTERPRET AND COMMUNICATE OUTPUTS Easy and able to be presented in accessible ways	

What is it?

The underlying Atlantis is a fully integrated ecosystem model. Its outputs can help in understanding what happens to an entire ecosystem when multiple impacts and activities occur simultaneously. The underlying code and framework were originally developed by CSIRO (Australia) and it is considered one of the best ecosystem modelling platforms in the world. It can incorporate a wide range of data spanning multiple disciplines and can be used to predict how ecosystems will look in the future under different management scenarios. Atlantis can therefore be used as a strategic planning tool, with outputs useful to a wide range of users, from central to local government, industry, researchers, iwi/hapū, as well as NGOs and community groups.

Atlantis is a versatile tool with applications relevant to fishing, ecological changes, policy decisions, aquaculture, climate change, and others, including public engagement and education. It is also a useful 'learning tool' as it allows exploration of how components of ecosystems are connected and identification of potential vulnerabilities. Atlantis is a very flexible interdisciplinary and transdisciplinary tool; it can span biophysical, socio-economic, and ecological disciplines and even incorporate mātauranga Māori into the model.

Applications in Sustainable Seas

An Atlantis model has been developed for the Tasman and Golden Bays (TBGB) region and one has also been built for the Chatham Rise. The model has been used to explore the implications of a range of management scenarios around fisheries and the resultant biomass of various fish species and underlying components.

How it works

The Atlantis model can be built for any spatial scale (regional to global) and set for time periods spanning decades. Atlantis is a three-dimensional model that integrates different components. The first two components refer to the spatial definition, which is horizontal (represented by polygons), and vertical (depth). The third component is time. The spatially-explicit nature of Atlantis allows it to perform different complex scenario representations for later use in spatial planning and decision-making.

The model uses a C++ code base (language)[2] that solves mathematical equations across a three-dimensional domain. The code can be downloaded from the CSIRO website. Atlantis model development can be split into two parts: data collection and model construction. This tool can use pre-existing data and/or new data.

Building an Atlantis model takes significant investment in time and resources. The first phase of the TBGB Atlantis involved 6 months of data collection, which included an extensive literature review (including grey literature), data gap filling through expert panels, and inputs from other previously run models. The second phase involved approximately 18 months of model development and included data treatment to generate inputs, testing for uncertainty and sensitivity, as well as expert panel testing.

Data inputs in the TBGB included physical (e.g. salinity, temperature), biological, and ecological data, and data related to fishing, including 51 species groups to model the biological processes. The TBGB Atlantis model did not include any socio-economic data or mātauranga Māori, nor did it include stressors other than fishing. However, these types of information and others can be added to the model in future (with added costs).

Atlantis produces direct outputs that are not easy to interpret or communicate, and extra processing is necessary. R software package can be used to produce user-friendly outputs such as tables, figures and visualisations using Shiny apps[3].

Like all models, Atlantis needs to be validated to understand levels of uncertainty around its outputs. The TBGB model was validated through three mechanisms (McGregor et al 2021):

1. Compared with two alternative models of TBGB (Ecopath with Ecosim (EwE), and multi-species size spectrum model)
2. Responses to including uncertainty through varying the oceanographic variables
3. Response to historical fishing (individual and system levels), and a biological parameter check (including mortality for productivity versus age, size and age, and also diet).

It is important to understand limitations of the model created by data gaps and high uncertainty. For example, the TBGB Atlantis model has not yet incorporated environmental hazards (e.g. floods and sediment), seabirds or migratory mammals.

What it takes to use it

To develop and use Atlantis requires a high level of modelling and coding skills, IT familiarity, a good level of mathematical knowledge to understand the underlying equations, and some understanding of the ecological and biophysical system to make sure that the model is running correctly. Creating inputs and outputs for the model benefits from the use of R software or similar. Atlantis code base and R are both free and publicly available, however it is beneficial to have a powerful computer or an iCloud to run this model. For example, to simulate 100 years requires approximately 48 hrs of computer running time. The TBGB model used a high-performance computing service called New Zealand eScience Infrastructure (NESI), which had an approximate cost of $3k per year.

Although the initial investment is high, Atlantis is more flexible than other models; once built it is easy to run multiple scenarios or adjust the model for different scenario situations, including those related to spatial decision-making, reducing the time invested for future uses.

For more information contact Dr Vidette McGregor: **vidette.mcgregor@niwa.co.nz**

Further information

Presentation

McGregor V, Datta S & Dutilloy A (2020). Webinar: Which ecosystem model works best for what you need? **sustainableseaschallenge.co.nz/ecosystem-models-webinar**

Model

Atlantis model: Tasman and Golden Bays **sustainableseaschallenge.co.nz/atlantis-tbgb**

Completed project

Ecosystems models project webpage **sustainableseaschallenge.co.nz/ecosystem-models**

Academic Publications

McGregor VL, Horn P, Dutilloy A et al (2021). From data compilation to model validation: comparing three ecosystem models of the Tasman and Golden Bays, New Zealand. PeerJ 9:e11712

McGregor VL, Fulton EA and Dunn MR (2020). Addressing initialisation uncertainty for end-to-end ecosystem models: application to the Chatham rise Atlantis model. PeerJ 8, e9254

McGregor VL, Horn PL, Fulton EA et al (2019). From data compilation to model validation: a comprehensive analysis of a full deep-sea ecosystem model of the Chatham Rise. PeerJ 7, e6517

External sources

McGregor VL (2019). TBGB data and code for exploration and validation of historic ecosystem models of the Tasman and Golden Bays **github.com/mcgregorv/TBGB**

Audzijonyte A et al (2017). Atlantis users guide part i: General overview, physics & ecology. CSIRO living document

1. Cost may vary depending on the scenario complexity, knowledge, and/or data needed. For example, simple scenarios (e.g. edit some parameters or force some values, then analyse the flow-on effects) cost will be low ($=<$50k). If more complicated scenarios require bringing in more knowledge and/or data and potentially re-developing some of the model, then it's more likely to be high ($$$ = >$200k).

2. C++ is a powerful and flexible general-purpose programming language. It can be used to develop operating systems, browsers, games, and so on.

3. Shiny is an R package that makes it easy to build interactive web apps straight from R. You can host standalone apps on a webpage or embed them in R Markdown documents or build dashboards. You can also extend your Shiny apps with CSS themes, html widgets, and JavaScript actions. r-project.org shiny.rstudio.com

See page 9 for footnotes

Tasman/Golden Bay Ecopath with Ecosim (EwE) model

TYPE Ecosystem model	**SCENARIOS EXPLORATION** Yes
DISCIPLINE Biological, ecology and fisheries	**COMPLEXITY** Medium
END-USERS Widely ranging	**DATA FLEXIBILITY** Medium
DIMENSIONS 2D	**COST TO BUILD** $$[1]
SPATIAL SCALE Local to global	**COST TO RUN** $[1]
TEMPORAL SCALE Daily timesteps. Models run over decades to century	
SKILL NEEDED Numerical modelling, and Excel or R coding	
ABILITY TO INTERPRET AND COMMUNICATE OUTPUTS Easy and able to be presented in accessible ways	

What is it?

The underlying Ecopath with Ecosim (EwE) is an ecological model that enables exploration of different resource management scenarios. The tool has been used since the 1980s, and has become popular among scientists and managers because it is easy and fast to build and run compared with other ecosystem modelling tools such as Atlantis. EwE models can be used for exploring impacts of fishing in conjunction with environmental shifts, trends, and fishing policies, and more recently for producing time-series predation mortality for use in single-species stock assessment. EwE models are limited to biological, ecological, and fisheries data, and although their outputs can contribute to spatial modelling tools, they are not directly useful for spatial planning.

Applications in Sustainable Seas

An EwE model has been developed for the Tasman and Golden Bays (TBGB) region. It was used as part of the process of validating Atlantis. It has also been assessed as a viable alternative model to the more complex Atlantis model for exploring fishery and ecological responses to anthropogenic and natural pressures.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See page 11 for footnotes

How it works

EwE is not spatial and can only work with species interactions over time. The model uses proxies rather than explicit dynamics. For example, in the TBGB EwE model, diet was one of the proxies used for spatial dynamics in terms of migration, and it was assumed the consumption for one group is mortality for another.

The model code is free; however, it requires Excel or the R software package to interact with inputs and outputs from the model beyond the default views provided within the EwE software. Because it requires less data than Atlantis, it runs simpler scenarios. The TBGB EwE model included 51 functional species groups (the same used in the TBGB Atlantis) and were modelled as pools of biomass (in t/km2). Because of the simple 1D structure of EwE, it was assumed that all 51 groups inhabit the entire study area. Other information needed was related to diet and prey preferences, fishing mortality, and initial conditions. These were the same as those used in the TBGB Atlantis.

Because this model does not have any spatial structure, it requires less data, time, effort, and cost to build than Atlantis. The average time for data collection is about 5 months, followed by approximately 3 months for model construction (including testing). Outputs from the EwE model come on excel spreadsheets, but further processing in R is needed to create end-user friendly outputs such as tables, figures and visualisations using the Shiny app.

The TBGB model was validated through the comparison with the Atlantis model (McGregor et al 2021).

What it takes to use it

Building EwE models requires moderate modelling skills and code writing, with a high knowledge level of R or Excel being beneficial. It is also an advantage if the modeller has a biophysical and ecological background so they are not solely reliant on experts within these fields.

EwE can be run directly from a medium performance computer (including laptops). Running this model is much faster than other ecosystem models like Atlantis.

» For more information contact Dr Vidette McGregor: **vidette.mcgregor@niwa.co.nz**

Further information

Presentation

McGregor V, Datta S and Dutilloy A (2020). Webinar: Which ecosystem model works best for what you need? **sustainableseaschallenge.co.nz/ecosystem-models-webinar**

Completed project

Ecosystems models project webpage **sustainableseaschallenge.co.nz/ecosystem-models**

Academic Publications

McGregor VL, Horn P, Dutilloy A et al (2021). From data compilation to model validation: comparing three ecosystem models of the Tasman and Golden Bays, New Zealand. PeerJ 9:e11712

McGregor VL, Fulton, EA and Dunn, MR (2020). Addressing initialisation uncertainty for end-to-end ecosystem models: application to the Chatham rise Atlantis model. PeerJ 8: e9254

McGregor VL, Horn PL and Fulton EA et al (2019). From data compilation to model validation: a comprehensive analysis of a full deep-sea ecosystem model of the Chatham Rise. PeerJ 7: e6517

External source

McGregor VL (2019). TBGB data and code for exploration and validation of historic ecosystem models of the Tasman and Golden Bays **github.com/mcgregorv/TBGB**

1. Cost may vary depending on the scenario complexity, knowledge, and/or data needed. For example, simple scenarios (e.g. edit some parameters or force some values, then analyse the flow-on effects) cost will be low ($=<$50k). If more complicated scenarios require bringing in more knowledge and/or data and potentially re-developing some of the model, then it's more likely to be high ($$$ = >$200k).

Tasman/Golden Bay multi-species size spectrum model (MSSM)

TYPE Numerical model	**SCENARIOS EXPLORATION** Yes
DISCIPLINE Biology, ecology and fisheries	**COMPLEXITY** Medium
END-USERS Widely ranging	**DATA FLEXIBILITY** Medium
DIMENSIONS 2D	**SKILL NEEDED** Numerical modelling and R coding
SPATIAL SCALE Local to global	**COST TO BUILD** $$[1]
TEMPORAL SCALE Days to decades	**COST TO RUN** $[1]
ABILITY TO INTERPRET AND COMMUNICATE OUTPUTS Moderate and able to be presented in accessible ways	

What is it?

The underlying multi-species size spectrum model (MSSM) provides a practical solution to simulate ecosystems in data-limited situations[2] and better understand how the whole ecosystem is behaving. The model uses biological, ecological, and fisheries information and can be applied to a wide range of questions relating to EBM and issues such as cumulative effects, tipping points, and ecosystem health. It is important to highlight that the model is an emerging tool, with active development ongoing with the potential to increase the number of current uses and purposes.

Outputs from the tool are suitable for use by government (central to local) and industry (e.g. fishing) sectors. However, its outputs may also be useful to other stakeholders such as NGOs and for education purposes.

Applications in Sustainable Seas

An MSSM has been developed for the Tasman and Golden Bays region as well as the Chatham Rise. The model was used as a simpler alternative model to the more complex Atlantis ecosystem model and was also built as part of the process to validate Atlantis.

How it works

Building an MSSM focused on fisheries required numerical data from fish species physiology (e.g. growth), length structure, and fishing data (e.g. CPUE – industrial and/or recreational fishing). The model assumes a homogenous system (it does not include spatial information). It also uses parameters related to primary production and fishing effort (mortality). To build the TBGB MSSM, data from 22 functional groups plus primary producers were needed. However, it did not include several species as they were not suitable[3]. Additionally, the model needed several species-specific parameters as data inputs.

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See page 13 for footnotes

The MSSM can be constructed and used from a desktop computer. For Sustainable Seas, it was constructed using the software R. The foundation for the work is the modelling framework *mizer* version 2.0.3. It is a package specific to marine ecosystem modelling. Both R and *mizer* are publicly available at zero cost but require familiarity and expertise for their use.

The time to collect data and construct and test the model is approximately 3 months, which is considerably shorter than ecosystem models such as Atlantis. The model can be applied at different geographical scales without major adjustments. It is easy to add or remove data for species, however other types of data input or adjustment are very difficult and, in many cases, not possible because the model is built for species data only. The time to run this model varies depending on the number of species analysed but generally ranges from seconds to minutes.

Direct outputs from the model require further processing to create functional outputs such as summary tables, figures, and visualisations using the Shiny apps. There are many such functions and plotting tools available in mizer, with additional ones being developed and tested at present. The software is hosted on Github[4], making it easy to report issues and suggest new features.

The Tasman and Golden Bay MSSM model has been validated through a three-way comparison (McGregor et al 2021) with the Atlantis model and an Ecopath with Ecosim model. Another way to validate this tool is by comparing the scenario results with historical fishing data.

What it takes to use it

Model development requires a high level of expertise working with R and a strong understanding of ecological systems. Mathematical and statistics knowledge is also beneficial.

Output users (such as decision-makers) need a general understanding of concepts related to multispecies interactions, food web, and ecosystems.

There is an international community that provides support for people working with MSSMs[5].

For more information contact Dr Alice Rogers: alice.rogers@vuw.ac.nz or Dr Samik Datta: samik.datta@niwa.co.nz

Further information

Presentation

McGregor V, Datta S and Dutilloy A (2020). Webinar: Which ecosystem model works best for what you need? **sustainableseaschallenge.co.nz/ecosystem-models-webinar**

Completed project

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Academic Publications

McGregor VL, Horn P, Dutilloy A et al (2021). From data compilation to model validation: comparing three ecosystem models of the Tasman and Golden Bays, New Zealand. PeerJ 9:e11712

McGregor VL, Fulton EA and Dunn MR (2020). Addressing initialisation uncertainty for end-to-end ecosystem models: application to the Chatham rise Atlantis model. PeerJ 8: e9254

McGregor VL, Horn PL and Fulton EA et al (2019). From data compilation to model validation: a comprehensive analysis of a full deep-sea ecosystem model of the Chatham Rise. PeerJ 7: e6517

Scott F, Blanchard JL and Andersen KH (2014). Mizer: an R package for multispecies, trait-based and community size spectrum ecological modelling. Methods in Ecology and Evolution 5(10) 1121-1125 **sizespectrum.org/mizer/**

External sources

McGregor VL (2019). TBGB data and code for exploration and validation of historic ecosystem models of the Tasman and Golden Bays **github.com/mcgregorv/TBGB**

R Project for Statistical Computing **r-project.org**

Mizer: Multi-Species Size Spectrum Modelling in R **cran.r-project.org/web/packages/mizer/index.html**

Multi-Species Size Spectrum Modelling in R **sizespectrum.org/mizer**

1. Cost may vary depending on the scenario complexity, knowledge, and/or data needed. For example, simple scenarios (e.g. edit some parameters or force some values, then analyse the flow-on effects) cost will be low ($=<$50k). If more complicated scenarios require bringing in more knowledge and/or data and potentially re-developing some of the model, then it's more likely to be high ($$$ = >$200k).

2. doi.org/10.1111/1365-2664.12238

3. The model did not include: fur seals, seabirds, benthic carnivores, benthic grazers, carnivorous zooplankton, detritivores, dredge oysters, benthic filter feeders, paua, rock lobster, benthic organisms, planktonic animals, heterotrophic plankton, green lip mussels, scallops and cockles.

4. GitHub, Inc. is a provider of Internet hosting for software development and version control using Git. It offers the distributed version control and source code management functionality of Git, plus its own features. github.com

5. app.slack.com/client/T01NM1E2KB6/C01P4M8QMU0

Table 2: Ecosystem models comparison

This matrix explains which of the three ecosystem models can be used in different scenarios: fishing, climate, or land effects. For example, for fishing removal scenarios, the three models can be used to explore it. However, if the scenario exploration is about area closure, only Atlantis can help to explore that. Brackets indicate that the Tasman/Golden Bay tools are not set up for these scenarios.

Which to use when:	Atlantis Ecosystem model	Ecopath with Ecosim (EwE) model	The multi-species size spectrum model (MSSM)
Fishing scenarios			
Effort (e.g. increase/decrease catches on particular groups, alternating different fishing times, trying different management target levels)	✓	✓	✓
Area closures (e.g. marine protected areas, close specific bay, protect a nursery ground for a species)	✓		
Managing by-catch (e.g. different types of fishing gear, or fishing practices, reducing by-catch mortality)	✓	✓	
Climate scenarios			
Changing levels of primary production	✓	✓	✓
Changing sea temperatures	✓	✓	
Alternative oceanographic conditions (e.g. physical, chemicals, etc)	(✓)		
Land effects			
Coastal erosion	(✓)		
River run-off/storm events	(✓)		
Changes in sedimentation	(✓)		

Ocean Tracker

TYPE Ocean modelling tool	**SCENARIOS EXPLORATION** Yes
DISCIPLINE Oceanographic	**COMPLEXITY** Difficult
END-USERS Widely ranging	**DATA FLEXIBILITY** High
DIMENSIONS 3D	**COST TO BUILD** $$[1]
SPATIAL SCALE Local to national	**COST TO RUN** $[1]
TEMPORAL SCALE 1-day to 10 years	
SKILL NEEDED Physical oceanography, high numerical modelling and Phyton computer coding	
ABILITY TO INTERPRET AND COMMUNICATE OUTPUTS Easy	

What is it?

The Ocean Tracker (OT), the modelling tool underlying the ocean plastic simulator developed for Sustainable Seas, is based on a Lagrangian particle tracking model (LPTM). The LPTM is used to create new insights from hydrodynamic models. The OT enables visualisations of complex data in an accessible form, thereby enabling the user to explore where 'virtual' particles can be transported in the ocean, which in turn provides information about ocean connectivity.

The tool is the outcome of two novel features: (1) the speed of calculating particle trajectories is far greater than any similar model: and (2) the ability to incorporate millions of particles using a desktop computer. These features make the model more powerful and efficient, enabling more robust estimation of dispersion and biophysical ocean connectivity by simulating a wider range of particle parameters and behaviours, while also making it possible to use the tool online.

Because OT is able to produce fast simulations, it opens up many potential uses in relation to particle tracking at different scales. For example, tracking the movement of larvae, the spread of pollution, the spread of disease or pest species, and identifying source-sink areas for different species of relevance in designating marine protected areas.

The current model has been built to be used at local to regional scale, however larger scales are being explored and the OT now encompasses Aotearoa New Zealand's Exclusive Economic Zone.

Applications in Sustainable Seas and beyond

Since the OT was developed, it has been applied by Sustainable Seas for a public engagement digital tool, and by end-users for commercial and biosecurity applications (see Figure 1 on page 16).

How it works

The OT takes the data from three-dimensional (3D) hydrodynamic models and calculates the tracks particles' released within that model. Most of the hydrodynamic information needed is oceanographic (e.g. currents, tides). The techniques have been optimised for unstructured grid particle tracking. They allow the simulation of millions of particles and more robust estimates of dispersion and bio-physical ocean connectivity for a wider range of particle parameters and behaviours. The techniques enable particle tracks to be calculated 100s of times faster than existing tools. For example, 2–3 million trajectories can be calculated overnight on a single computer core. Using multiple computer cores it can run 5–8 times faster.

The OT code represents a new code written in Python's NumPy[2] module to do basic arithmetic operations using arrays. The code is flexible and allows many changes and adaptations, but it requires high knowledge of Python.

The main output is a record of where particles have been over time, including some basic and raw oceanographic information such as water temperature, depth, salinity, etc. This information must be analysed with statistics to create visual outputs such as heat maps. Therefore, considerable post-analysis is needed to create the final output.

See page 17 for footnotes

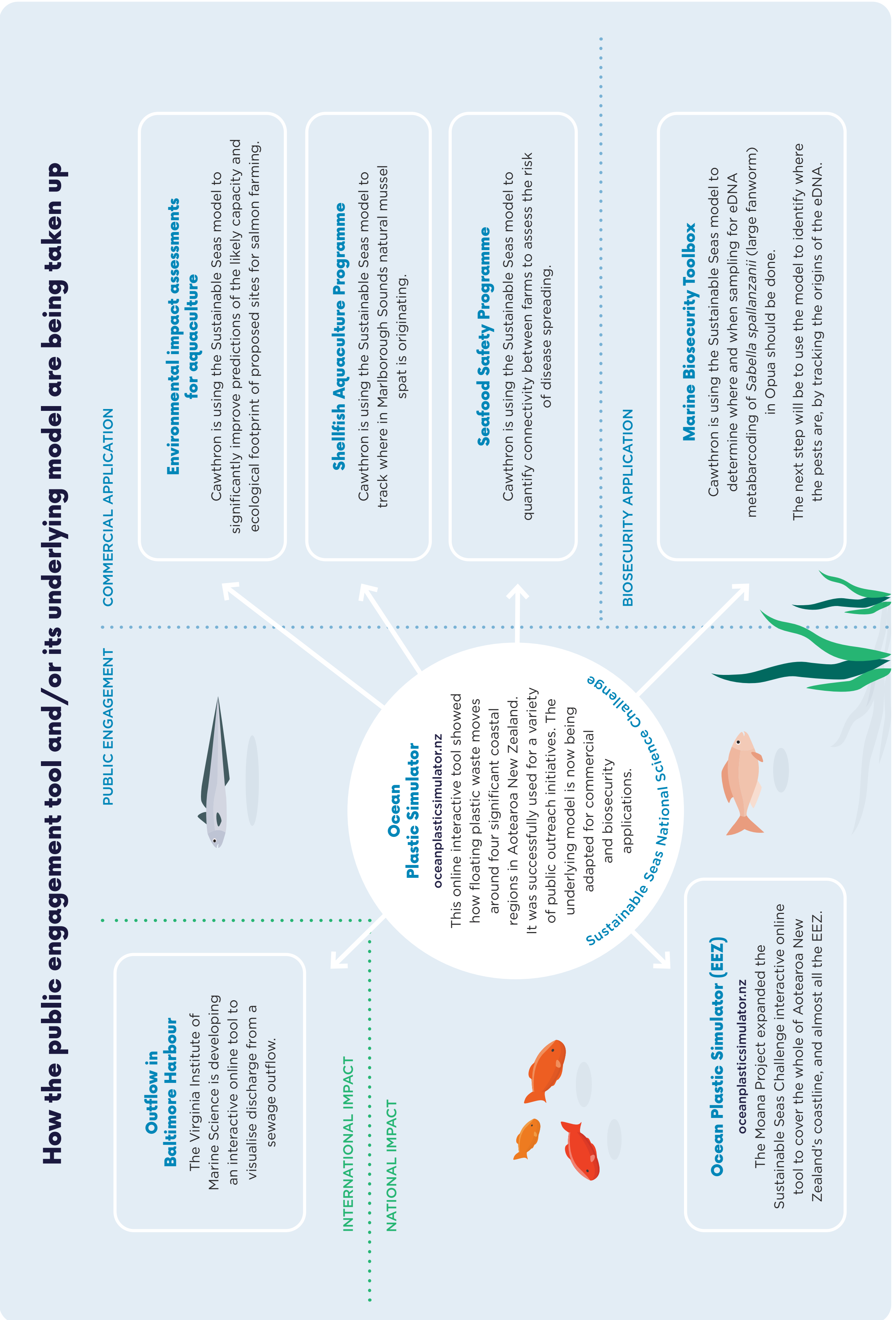


Figure 1

In some cases, the final output can be published on a website, which also requires extra work and the cost of website maintenance. The website needs minimum requirements to provide enough speed to let the model run.

What it takes to use it

The developer needs a strong background in modelling, code writing, and analysis using Python. Also, mathematics and statistics are important, plus a high level of oceanographic understanding.

Outputs from OT are user-friendly and do not require previous knowledge or expertise.

» For more information contact Dr Ross Vennell: **ross.vennell@cawthron.org.nz**

1. Cost may vary depending on the scenario complexity, knowledge, and/or data needed. For example, simple scenarios (e.g. edit some parameters or force some values, then analyse the flow-on effects) cost will be low ($=<$50k). If more complicated scenarios require bringing in more knowledge and/or data and potentially re-developing some of the model, then it's more likely to be high ($$$ = >$200k).

2. NumPy (Numerical Python) is an open source Python library that's used in almost every field of science and engineering (for more information visit: numpy.org/doc/stable/user/absolute_beginners.html)

Further information

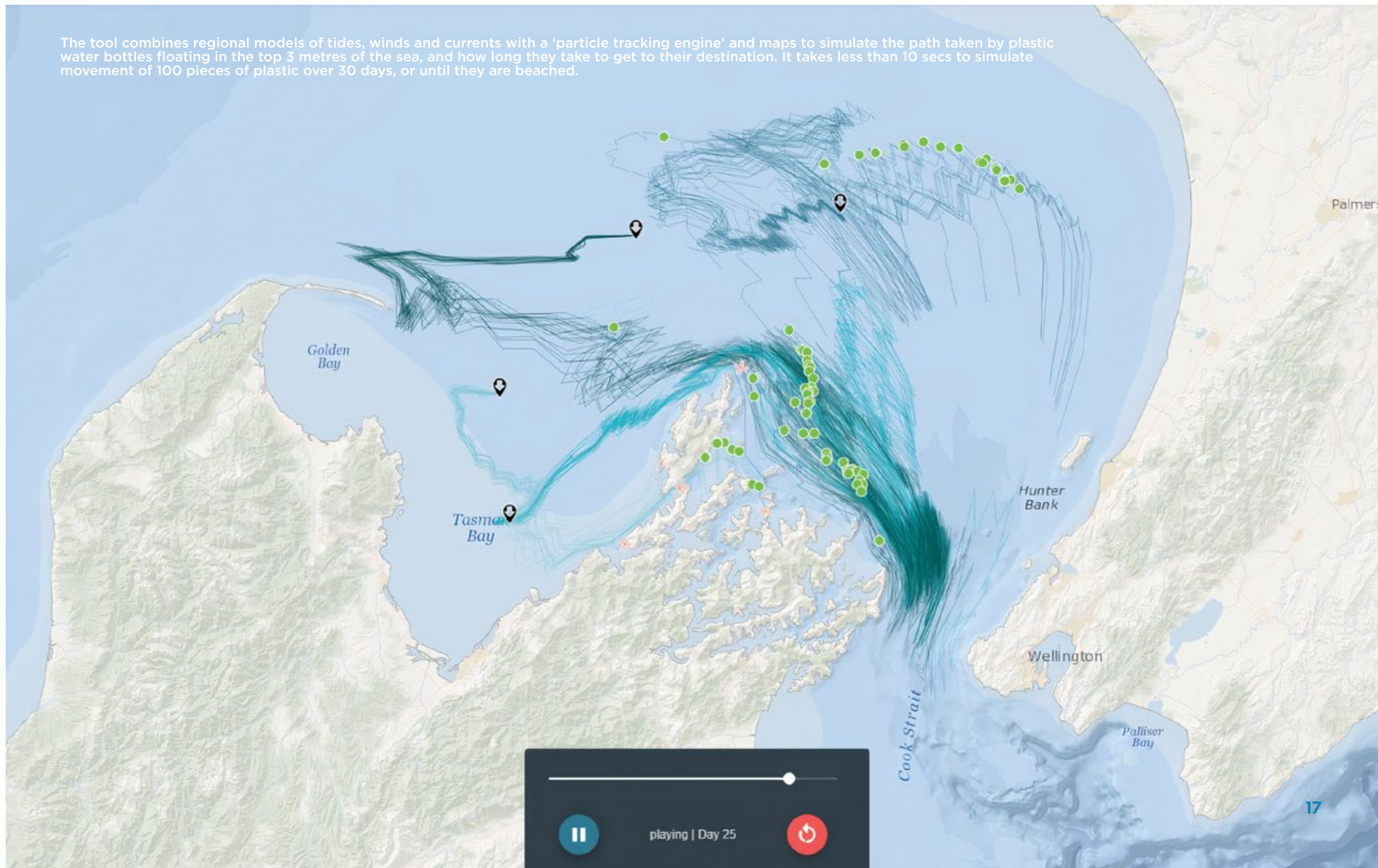
Presentation: Vennell R and Unwin H (2019). Webinar: Tracking ocean plastic **sustainableseaschallenge.co.nz/tracking-ocean-plastic**

Digital tool: Ocean Plastic Simulator **sustainableseaschallenge.co.nz/ocean-plastic-simulator**

Summary: Plastic, pests and industry – how a public engagement tool led to biosecurity and commercial applications **sustainableseaschallenge.co.nz/plastic-pests-and-industry**

Completed project: *Participatory tools* project webpage **sustainableseaschallenge.co.nz/participatory-tools**

Academic publication: Vennell R, Scheel M, Weppe S et al (2021). Fast Lagrangian particle tracking in unstructured ocean model grids. Ocean Dynamics 71(4), 423–437



BactiMap – Real-time forecasting tool

TYPE Numerical operational model	**SCENARIOS EXPLORATION** No
DISCIPLINE Widely ranging	**COMPLEXITY** Difficult
END-USERS Aquaculture farming and others	**DATA FLEXIBILITY** Medium
DIMENSIONS 4D	**COST TO BUILD** $$[1]
SPATIAL SCALE Local	**COST TO RUN** $[1]
TEMPORAL SCALE Hourly (24 hrs) – Weeks	
SKILL NEEDED High numerical modelling and multiple languages coding	
ABILITY TO INTERPRET AND COMMUNICATE OUTPUTS Online tool – Easy	

What is it?

BactiMap is a multidisciplinary catchment-to-sea model used to identify and forecast faecal bacteria (*Escherichia coli*) contamination risk to cultured mussels at aquaculture sites in Tasman and Golden Bays (TBGB). This is a versatile real-time forecasting tool, that can be used for multiple purposes beyond aquaculture. The tool combines a wide range of biophysical disciplines, including catchment hydrology, oceanography, water quality science, data science and statistics, and front-end web technologies. BactiMap was constructed by MetOcean Solutions, NIWA, and Cawthron.

BactiMap is used to predict when the bacteria of *E. coli* populations start to increase and decrease in the water around aquaculture sites at very fine scales (metres), and also shows the movement of low salinity water from river plumes. This bacterial information allows mussel farmers to plan for the safe harvesting of their product at finer spatial and temporal scales than is currently possible, which ultimately reduces the closure times for harvest. The current forecasting period is for 24 hrs into the future; however, it is possible that this model will be able to forecast for up to 10 days in advance if combined with longer-term[2] weather forecasts. Therefore, this tool should reduce some of the ongoing and expensive costs of mussel farming related to data collection (e.g. cleaning, calibration, loss of equipment) and spawning losses associated with reductions in access restrictions. This tool was developed for the TBGB aquaculture region, but it would be possible to scale up for other regions and potentially a national level.

While the focus of BactiMap is for commercial aquaculture, the information can be of interest to recreational users, researchers, and regional and central government (e.g. public health). This is because the secondary aim was to estimate potential risks to beach goers using *enterococci* bacteria[3] (a marine swimming indicator) and notify swimmers when it is safe to swim. The tool has potentially wider applications for managing contamination and access to recreational and customary harvest areas. Because this tool is based on operational models (run every day in real time), the underlying hydrodynamic data can be also used for other applications, such as oil spill response and maritime safety.

Applications in Sustainable Seas

BactiMap is being applied and further validated for the TBGB region to help predict when aquaculture sites and beaches are safe to access.

How it works

There are five models[4] underlying BactiMap: a weather model, river model, river flow-bacterial model, a marine hydrodynamic model, and a statistical 'management' model. These models run separately and are accessed by the website to produce the information displayed online. Each model in BactiMap was developed separately. They communicate through a series of application programming interfaces (APIs) that pass the relevant information between each model. All these models have been fed with quantitative data, where it exists, or modelled data in the absence of appropriate data. The main sources of data were aquaculture farmers and regional councils; additional targeted fieldwork was needed to produce data[5] for comparison and validation.

This tool was built in approximately 18 months; the first 12 months was model construction, and the rest was calibration and validation, including several hindcast simulations to check how well the model performed (compared with historic data).

See page 19 for footnotes

The five models built for TBGB could be adapted for other regions, reducing development to around 6–12 months, depending on the complexity of the area (e.g. number of rivers) and the availability of data (e.g. river data during floods and marine bacterial data). The current tool automatically updates twice daily (night and day).

The accuracy of this model has been validated with historical data and shown to be accurate for a year-long period. However, ongoing validation has been recommended for 3 years to enable a robust transition for regulatory sanitary management applications. After that, it is highly recommended to check it every 2–3 years (rivers re-sampling) to make sure that the model is performing well.

There are ongoing costs for this model, related to computation, staff and network costs. The current cost to maintain running of the TGBG model is approximately $60k year, which could be paid (at least in part) by users of the system[6].

What it takes to use it

BactiMap website is user friendly and does not require any special skills to use. For those looking to use the underlying models, it will require high-level numerical skills and understanding of maths, statistics, several code languages, modelling, and programming.

For more information contact Dr Ben Knight: ben.knight@cawthron.org.nz

Further information

Model — BactiMap: forecasting contamination risk to shellfish **sustainableseaschallenge.co.nz/bactimap**

Presentation — Mackenzie L & Knight B (2019). Webinar: Detecting and forecasting coastal contamination **sustainableseaschallenge.co.nz/detecting-and-forecasting-coastal-contamination**

Completed project — Forecasting contamination risk for shellfish harvest and beach use project webpage **sustainableseaschallenge.co.nz/real-time-forecasting-tool**

Dataset — Metadata catalogue: Forecasting contamination risk project **sustainableseaschallenge.co.nz/metadata-forecasting-contamination-risk**

1. Cost may vary depending on the scenario complexity, knowledge, and/or data needed. For example, simple scenarios (e.g. edit some parameters or force some values, then analyse the flow-on effects) cost will be low ($=<$50k). If more complicated scenarios require bringing in more knowledge and/or data and potentially re-developing some of the model, then it's more likely to be high ($$$ = >$200k).

2. Presently this tool has only been assessed for a recent 10-month period. Will require additional time and data to fully validate.

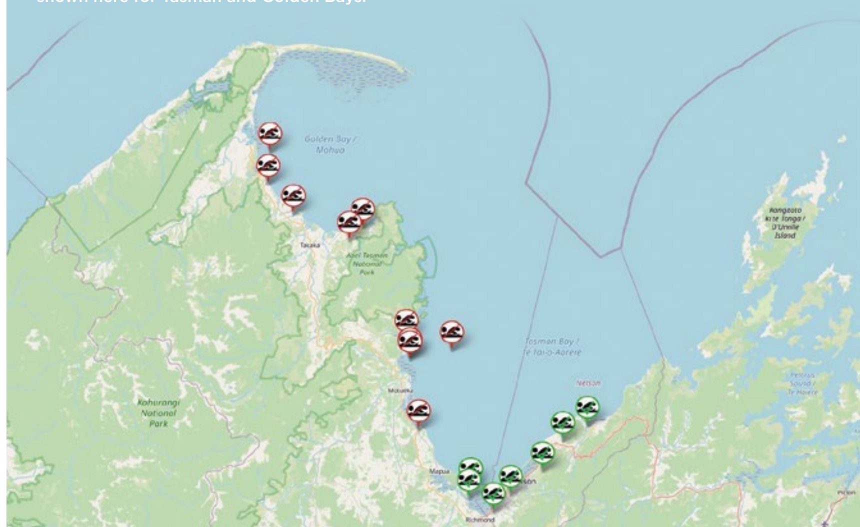
3. Comparisons between measured and modelled enterococci have been poor and additional efforts would be required to improve the model for this purpose.

4. Software Type: (1) Proprietary: NIWA – TOPNet, MetOcean – MOV portal; (2) Open-source: SCHISM Model.

5. Typical council data from rivers may not be suitable for characterising bacterial concentrations for this model, as it is a single sample, and characterisation of the relationship between river flows and bacterial concentrations requires high frequency sampling around flood events.

6. Currently, this tool is free to access. In the future, access to this tool will be provided through a subscription.

The tool provides a daily forecast of river plumes entering the sea and contaminant measurements that accurately estimate *E. coli* bacterial contamination risk, shown here for Tasman and Golden Bays.



Seabed health and scallop fisheries tool

TYPE Bayesian network model	**SCENARIOS EXPLORATION** Yes
DISCIPLINE Widely ranging	**COMPLEXITY** Medium
END-USERS Widely ranging	**DATA FLEXIBILITY** High
DIMENSIONS 4D	**SKILL NEEDED** Bayesian network and social science
SPATIAL SCALE Local to national	**COST TO BUILD** $$[1]
TEMPORAL SCALE Daily to years	**COST TO RUN** $[1]
ABILITY TO INTERPRET AND COMMUNICATE OUTPUTS Easy – Online	

What is it?

Bayes Net (or Bayesian network (decision) modelling) is a method that can be used to create transdisciplinary and participatory synthesis tools for management decision-making. The method is effective at allowing stakeholders and managers to interact, engage, and explore the effectiveness of alternative marine environmental management strategies. The management utility of the method is highest when a variety of people such as stakeholders, experts (e.g. ecology, biology, policy, etc), managers, and decision-makers are involved in its development[2]. The method can represent how a marine ecosystem is likely to respond to various management interventions. Its specific use is in management strategy evaluation against a given (stakeholder agreed) set of marine ecosystem goals.

This method does not have any scale limitation on its uses, however, because it is designed to be co-developed with stakeholders and managers at a practical decision-making level, it is more beneficial to use it at local or regional scales.

Applications in Sustainable Seas

A prototype BN (Bayes Network) has been developed for Tasman and Golden Bays (TBGB) to explore outcomes of different management scenarios aimed at restoring seabed health and scallop populations. This prototype was developed and configured by a small group of marine ecosystem scientists largely using expert elicitation. The use of the tool to assist in actual TBGB ecosystem-based management decision-making would require further development with involvement of stakeholders, managers, and iwi.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See page 21 for footnotes

How it works

The BN generates state probabilities for each component node in the BN network. The sum of these outcome probabilities can be expressed as a total score representing, in the case of the TBGB network, overall ecosystem health.

The tool can be used to investigate the utility of a wide range of management scenarios; however, it is important to decide which ones are the most realistic, practical, and useful in the process, because this will determine the management actions to take forward. For this reason, it is recommended to investigate no more than seven or eight management scenario options. The tool is preferentially used in facilitated meetings or workshops, although it can also be used in online meetings. In-person use of the tool as a group makes the process more powerful in terms of increasing trust and engagement among participants.

Building a BN can be relatively quick once the information for it has been collected. It can be constructed using a variety of commercially available Bayesian Network tools or using R software. For a case similar to our TBGB example, the whole process can take up to 2 months, but it may vary depending on the skills of the person developing and running the model, and on each participant (e.g. right expert panel selected, relationship between participants, etc.). Once built, there are software packages that can be used as a 'front-end' to the BNT to visualise outputs, and these can be web-based providing wide accessibility. This process will add cost associated with the ongoing use of software and the hosting and maintenance of the website.

It is important to highlight that the tool is not expected to provide a precise answer around the outcomes from management actions, but rather provide an agreed understanding of cause and effects in the marine environment, and what sort of management actions can be carried out for better environmental outcomes.

The same methodologies and approach used in TBGB can be applied in other locations.

What it takes to use it

The tool developer needs a strong background and working knowledge of Bayesian networks. Social science and facilitation skills are also needed. Running the tool however can be done by anyone who was involved in workshops (ie understands why certain components and management scenarios are included).

» For more information contact Jeremy McKenzie: **jeremy.mckenzie@niwa.co.nz**

Further information

Presentation — Webinar: Describing a Bayesian network tool for Tasman and Golden Bays scallop management **sustainableseaschallenge.co.nz/bdn-tool-tbgb-scallops**

Digital tool — Bayesian network tool: seabed health and scallop fisheries **sustainableseaschallenge.co.nz/BDN-seabed-health-and-scallops**

Guidance — Using Bayesian network models to bridge the gap between ecology and management **sustainableseaschallenge.co.nz/using-bayesian-network-models**

1. Cost may vary depending on the scenario complexity, knowledge, and/or data needed. For example, simple scenarios (e.g. edit some parameters or force some values, then analyse the flow-on effects) cost will be low ($=<$50k). If more complicated scenarios require bringing in more knowledge and/or data and potentially re-developing some of the model, then it's more likely to be high ($$$ = >$200k).

2. Please note that this tool requires a high degree of interactive involvement of stakeholders, managers, and science facilitators to develop the tool, although once developed it is simple to use.

Filling gaps in marine data

TYPE Statistical model	**SCENARIOS EXPLORATION** Yes
END-USERS Widely ranging	**COMPLEXITY** Difficult
DIMENSIONS 2D	**DATA FLEXIBILITY** Medium
SPATIAL SCALE Local to global	**COST TO BUILD** $$[1]
TEMPORAL SCALE No	**COST TO RUN** $[1]
DISCIPLINE Biological, ecology, fisheries and oceanographic	
SKILL NEEDED High numerical modelling and R coding	
ABILITY TO INTERPRET AND COMMUNICATE OUTPUTS Difficult, but able to be presented in accessible ways	

What is it?

Gradient Forest (GF) models are a mathematical modelling method that use multiple biophysical datasets (biological and environmental data) to predict composition turnover (how species change/differ geographically). Predicted compositional turnover can then be grouped to estimate spatial distributions of species found in the same geographical area (referred to as community assemblages). These assemblages can be used to identify 'biodiversity hotspots' where large numbers of endemic species are found and are threatened by habitat loss and other activities. This information enables trade-offs resulting from management decisions to be explored. The GF model developed in Sustainable Seas does not include any social or economic data inputs (e.g. distribution of fishing effort), however, these could potentially be included with further research[2].

GF models can be applied in ecosystem-based management (EBM) to inform decision-making in relation to marine resource use and spatial planning. GF modelling is particularly useful for describing spatial patterns when available data may be limited or sparse; for example, describing broad-scale patterns in marine biodiversity over large areas. GF modelling can be used at local to large scales (national or global). It is often easier and faster to build the model for a larger scale first, then process and adjust the number of clusters into a finer-scale model. For greater impact, GF models can be used with Zonation models to highlight priority areas for conservation.

Applications in Sustainable Seas

Using extensive datasets from 1000s of research trawls and high-resolution environmental data layers (in this case water chemistry variables and seafloor characteristics), GF modelling was used as a tool to accurately predict spatial groupings of more than 250 bottom-feeding (demersal) fish species across New Zealand's Continental Shelf Zone to depths of 2,000 m.

The model outputs are intended to be used by a wide range of decision-makers for EBM and spatial planning for marine protected areas in Aotearoa New Zealand.

Following on from this work, the Marine Protected Area Strategic Advisory Group (which includes staff from the Department of Conversation, Fisheries New Zealand and Ministry for the Environment) commissioned an extension of the model by including a greater number of biotic groups, i.e., including macroalgae, reef fish, benthic invertebrates and demersal fish (funded by the Department of Conversation). Results of this additional work are available in a report accessible from DOC's website.

See page 24 for footnotes

Figure 1. Each number represents a community assemblage of demersal fish that thrive in similar oceanographic and environmental conditions

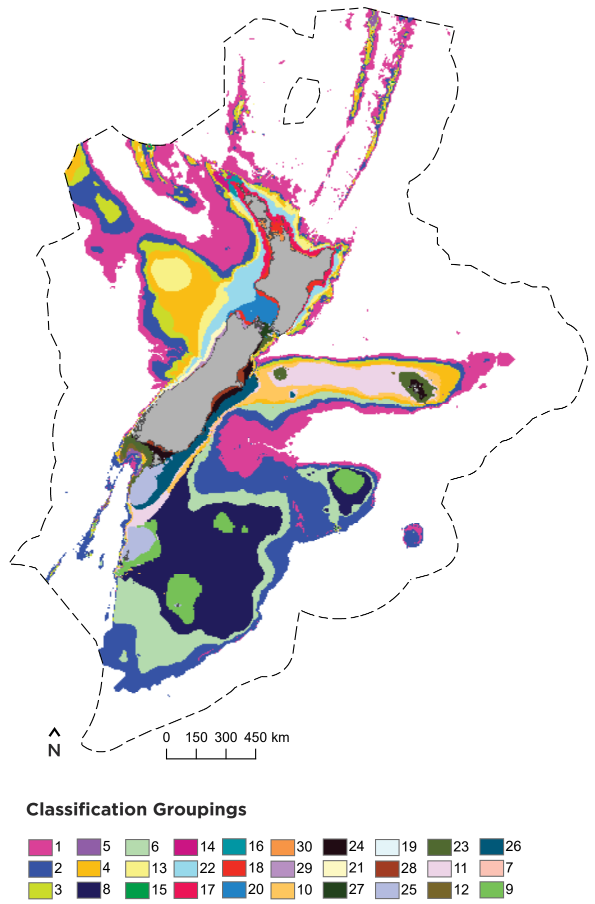
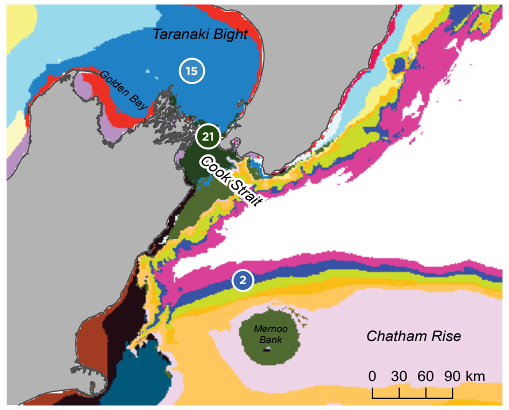


Figure 2. Cook Strait close up



Group 15

Environment: intermediate-to-shallow depths, high salinity and tidal currents, found north of the subtropical front

Key species: ling, javelinfish, lookdown dory, gemfish, silver roughy, deepsea flathead, leatherjacket

Group 2

Environment: very deep cold waters, low oxygen, species are widespread

Key species: orange roughy, Johnson's cod, Baxter's dogfish, four-rayed rattail, basketwork eel, smooth oreo

Group 21

Environment: intermediate-to-shallow depths, moderate oxygen, moderate-to-high currents, mostly found north of subtropical fronts

Key species: John Dory, barracouta, spiny dogfish, school shark, yellowtail jack mackerel

How it works

The process includes two analysis steps: the GF modelling and a classification analysis. For the first analysis, the R package 'Gradient Forest[3]' and the base package in the statistical computing software R are used to estimate species composition and turnover (see above for the input data). The second analysis classifies the information produced from the GF model (species composition and turnover) into groups that represent multiple assemblage's species groups. The analysis uses the location of species or taxonomic records (e.g. fish) in relation to environmental predictors (e.g. bathymetry, near-bottom temperatures, seafloor characteristics). Each species can be part of more than one group; however, groups are exclusive. It is possible to classify groups at different levels of resolution (scale) with a different number of species or groups.

This characteristic allows broad patterns in biodiversity to be explored while investigating the effects of sample size and scale on model performance. The model created for demersal fish is 2-dimensional and does not explicitly account for any vertical migration or any interaction with pelagic systems.

Building a GF model does not necessarily require a large biological dataset. For example, predicting assemblages from a GF-based classification would require fewer biological samples than predicting individual species distributions. The data for the demersal fish GF model was obtained from Fisheries New Zealand, and then uploaded into the international Ocean Biodiversity Information System (OBIS), which is an open data source. Data acquisition took approximately one week, including downloading the data and making sure that the data was in the right format for processing on the model.

See page 24 for footnotes

Building GF models from scratch, as in the case of the demersal fish model, took approximately six months for the first application. Subsequent GF models may take less time depending on the complexity of the data and the expertise of the analyst. The model code is openly accessible as it has been created in R software and published in a scientific publication facilitating its use.

The model produces several types of output files, including raster files (pixel based such as GIF) that require basic skills in geographical information systems (mapping software) to manipulate and visualise. Species allocation to groups by the model needs to be reviewed by an expert to gain ecological insight into individual species distribution patterns. The time that this process takes will depend on the environmental complexity, spatial scale (size), and the number of groups and species in the model. After a review is completed, all the group results need to be described by the modeller. Final outputs can be produced as technical reports for use for decision-making, or layperson summaries of the results for communication purposes.

The model developed for Sustainable Seas was validated with independent data, which showed it was very robust at predicting patterns of community assemblages and turnover (the change in species composition over space). The current model runs on species presence/absence, however, it would benefit from estimates of abundance, which would improve identification of biogenic habitats of importance to maintaining biodiversity.

What it takes to use it

The modellers must be competent users of R, with a high level of knowledge and understanding of coding, as well as data analysis. A moderate level of statistics is beneficial. In addition, ecological knowledge is needed to ensure the model is applied properly; for example, it is important to find the right experts on the species used in the model to make sure that the model is accurate and for further examination of ecological patterns.

A small or medium-scale dataset can be easily processed on a normal computer, however, for a large-scale dataset (e.g. large national datasets) a powerful computer is needed with large memory to store species and spatial information.

» For more information contact Dr Fabrice Stephenson: **fabrice.stephenson@waikato.ac.nz**

Further information

Guidance

Filling gaps in marine data using Gradient Forest models guidance document: **sustainableseaschallenge.co.nz/filling-data-gaps**

Academic Publications

Stephenson F, Leathwick J, Malcolm F et al (2020). A New Zealand demersal fish classification using Gradient Forest models. New Zealand Journal of Marine and Freshwater Research 54(1): 60–85

Stephenson F, Leathwick JR, Geange SW et al (2018). Using Gradient Forests to summarize patterns in species turnover across large spatial scales and inform conservation planning. Diversity and Distributions 24:1641–1656

External source

Stephenson F, Rowden A, Brough T et al (2021). Development of a New Zealand Seafloor Community Classification (SCC). Prepared for the Department of Conservation

1. Cost may vary depending on the scenario complexity, knowledge, and/or data needed. For example, simple scenarios (e.g. edit some parameters or force some values, then analyse the flow-on effects) cost will be low ($=<$50k). If more complicated scenarios require bringing in more knowledge and/or data and potentially re-developing some of the model, then it's more likely to be high ($$$ = >$200k).

2. Although GF models have not been used for forecasting; they could be.

3. Ellis N, Smith SJ, Pitcher CR. 2012. Gradient forests: calculating importance gradients on physical predictors. Ecology 93:156-168

Table 3: Numerical model features

The following matrix highlights specific features of numerical models (e.g. model type, software, spatial scale, etc). The Zonation tools, although categorised in this document as decision-making tools, are included here as it is driven by an underlying numerical model. Note that brackets mean that the tool created does not display the characteristic although the underlying method does.

	Tasman/ Golden Bay (TBGB) Atlantis (p8)	TBGB EwE (p10)	TBGB MSSM (p12)	Ocean Tracker (p15)	BactiMap (p18)	Seabed health and scallop fisheries (p20)	Filling gaps in marine data (p22)	EEZ Biodiversity and Hawke's Bay Zonation (p37)
Software								
Proprietary				✓	✓			
Open-source	✓	✓	✓		✓	✓	✓	✓
Model type								
Probabilistic				✓	✓	✓		
Deterministic	✓	✓	✓	✓	✓		✓	✓
Dynamic	✓	✓	✓	✓	✓	✓		
Model code access								
Open access	✓	✓	✓				✓	✓
Controlled access				✓	✓	✓		
Data flexibility								
Medium		✓			✓		✓	
High	✓		✓	✓		✓		✓

Table 3: Numerical model features (continued)

	Tasman/ Golden Bay (TBGB) Atlantis (p8)	TBGB EwE (p10)	TBGB MSSM (p12)	Ocean Tracker (p15)	BactiMap (p18)	Seabed health and scallop fisheries (p20)	Filling gaps in marine data (p22)	EEZ Biodiversity and Hawke's Bay Zonation (p37)
Data demands and needs								
Specific data types needed to use the tool	✓	✓	✓				✓	
Incorporates multiple types of data	(✓)	(✓)	(✓)	✓	✓	✓	✓	✓
Resolution of required data is flexible	✓	✓	✓			✓	✓	✓
Does not require high amounts of data			✓			✓	✓	
Transparency								
Working assumptions are stated clearly upfront							✓	
Working assumptions are expressed in modelling equations or software code	✓	✓	✓	✓	✓			✓
Working assumptions are understandable by all users						✓		
Spatial scale								
Regional	✓	✓	✓	✓		✓	✓	✓
National		(✓)	(✓)	✓		(✓)	✓	✓
Global		(✓)	(✓)				✓	(✓)
Temporal scale								
N/A							✓	✓
Daily	✓	✓	✓	✓	✓	(✓)		
Weekly	✓	✓	✓	✓	✓	(✓)		
Annual	✓	✓	✓	✓		(✓)		
Years	✓	✓	✓	✓		✓		

Table 3: Numerical model features (continued)

	Tasman/ Golden Bay (TBGB) Atlantis (p8)	TBGB EwE (p10)	TBGB MSSM (p12)	Ocean Tracker (p15)	BactiMap (p18)	Seabed health and scallop fisheries (p20)	Filling gaps in marine data (p22)	EEZ Biodiversity and Hawke's Bay Zonation (p37)
Dimensions (inc. time)								
2D		✓	✓	✓		(✓)	✓	✓
3D	✓			✓		(✓)		
Scenario exploration								
Yes	✓	✓	✓	✓		✓		✓
No					✓		✓	
Forecasting								
Yes	✓	✓	✓	✓	✓	✓	✓	✓
No								
Run-time/performance								
Real-time			✓	✓	✓	✓		
Delay	✓	✓					✓	✓
Output type								
Maps	✓			✓		(✓)	✓	✓
Models	✓	✓	✓			✓	✓	
Reports	✓					✓	✓	✓
Interactive web apps			✓	✓	✓	✓		
Validation of tool done								
Yes	✓	✓	✓				✓	✓
No						✓		
In progress				✓	✓			

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Guidance

This section includes four sets of guidance (Managing the impact of turbidity, Nutrients and sea level rise on coasts and estuaries, Using ecosystem service bundles to improve marine management, Monitoring for tipping points in the marine environment, and Monitoring estuaries in a changing world: Lessons for designing long-term monitoring programmes).

All of these have been developed by Sustainable Seas researchers. More detailed information on objectives and features of these tools is provided in Table 4 (p50) and Table 5 (p54). A summary around latest molecular techniques can be found in ***Conservation Genetics and Genomics***.

Manukau Harbour © Simon Thrush, University of Auckland

Managing the impact of turbidity, nutrients and sea level rise on coasts and estuaries

TYPE Guidance document	**DISCIPLINE** Widely ranging
SPATIAL SCALE Local to national	**END-USERS** Widely ranging

Overview

Scientists, stakeholders, and iwi have long been discussing the issue of land-derived sediments and the effects of sedimentation (more mud) and increased turbidity (reduced water clarity from suspended sediments) on estuaries and coastal waters. The document draws on scientific and empirical evidence and provides guidance for informing users about the impact of sediments, and what happens when the effects of sediments and additional stressors interact with one another in estuaries and coastal waters. The guidance is provided within the context of cumulative effects (CE) and is driven by the need to start managing for CE in a better way.

The document explains how changing turbidity with sea-level rise might impact primary production in coastal waters, and what could happen if turbidity exceeds healthy levels, however it is not a tool for limit setting. It is important to highlight that each location will behave differently, however, it is important to understand that varying combinations of stressors will lead to different consequences; in many cases these can be severe, and without effective management they may not be reversible once a tipping point is exceeded.

Using turbidity nutrient loading and sea-level rise as a focal point, the guidance aims to help people shift their thinking about CE and stressors at different scales and increase awareness of the importance of effectively managing multiple stressors in estuaries and coastal waters.

Application by end-users

The guidance was created for any type of user at any scale, but specifically for managers and decision-makers working on resource consents, policy, and planning.

For more information contact Dr Conrad Pilditch: **conrad.pilditch@waikato.ac.nz**

Further information

Guidance

Managing the impact of turbidity, nutrients and sea level rise on coasts and estuaries **sustainableseaschallenge.co.nz/managing-turbidity-nutrients-and-sea-level-rise-on-coasts**

Monitoring estuaries in a changing world: Lessons for designing long-term monitoring programmes **sustainableseaschallenge.co.nz/lessons-for-designing-long-term-monitoring-programmes**

Monitoring for tipping points in the marine environment **sustainableseaschallenge.co.nz/monitoring-for-tipping-points-in-marine-environments**

Presentation

Thrush S, Paul-Burke K, Carbines M et al (2021). Webinar: Shady business – the problem of mud in our estuaries **sustainableseaschallenge.co.nz/webinar-shady-business**

Summary

Robust, cost effective marine monitoring – how recommendations for designing robust monitoring programmes are being taken up by regional councils **sustainableseaschallenge.co.nz/ics-robust-cost-effective-marine-monitoring**

Completed Project

Tipping points in ecosystem structure, function and services project webpage **sustainableseaschallenge.co.nz/tipping-points**

Academic Publications

Mangan S, Bryan KR, Thrush SF et al (2020). Shady business: the darkening of estuaries constrains benthic ecosystem function. MEPS 647:33–48

Thrush SF, Hewitt JE, Gladstone-Gallagher RV et al (2020). Cumulative stressors reduce the self-regulating capacity of coastal ecosystems. Ecological Applications 31 (1):e02223

Hope JA, Paterson DM and Thrush SF (2019). The role of microphytobenthos in soft-sediment ecological networks and their contribution to the delivery of multiple ecosystem services. Journal of Ecology 108: 815–830

Hewitt J and Thrush S (2019). Monitoring for tipping points in the marine environment. Journal of Environmental Management, 234, 131–137

Using ecosystem service bundles to improve marine management

TYPE Report – Reference material	**DISCIPLINE** Widely ranging
SPATIAL SCALE National	**END-USERS** Decision-makers and researchers

Overview

The concept of ecosystem services (ES) is an effective way of communicating the societal benefits of healthy ecosystems. Numerous and complex ecological processes underpin ES; these processes are not easy to visualise and/or understand but are extremely important to ensuring provision of ES. Therefore, to improve marine ecosystem management and protection, ES need to be measured and mapped to understand where they are being delivered, how they link to ecosystems, and the implications of environmental decision-making to human well-being.

Ecosystem service bundles (ESB) refers to the grouping of associated ES into 'bundles'. ESB has been defined as 'sets of associated services that appear together repeatedly across space and/or time'[1]. The use of the ESB concept enables the translation of the complex ecological knowledge and mechanisms that underpin ES delivery and the relationships between services.

Through measuring and mapping of ES, and understanding their coalescence into bundles, it is possible to better value and protect ecosystems and underlying biodiversity elements that generate and deliver services of benefit to society. ESB serves as an interdisciplinary tool for managers, policy-makers, iwi/hapū, businesses, and communities, and supports resource management decisions. The ES bundles can also act as a framework for further research or modelling and assist in enabling ecosystem-based management.

In Sustainable Seas, the ESB concept was used to exemplify the ecosystem services provided by shellfish populations throughout New Zealand. Shellfish provide several ES, such as food resource/kaimoana, water purification, nitrogen removal, and carbon sequestration. All these services interact with each other causing effects on other ecosystem services (through synergies and trade-offs). If a decision needs to be made that may impact shellfish populations (e.g. through harvest or disturbance), ESB can be used to help quantify the potential effects of the decision in relation to the many services provided by the shellfish.

The ESB tool can be used at different scales (even global), but it is more applicable at local scales. At local scales it is easier to ensure that cultural services, which are local and context-specific, are included. At the local scale, there are also more opportunities to incorporate citizen viewpoints or iwi and hapū, into management decision-making process.

For more information contact Dr Drew Lohrer: **drew.lohrer@niwa.co.nz**

Further information

Guidance

Using ecosystem service bundles to improve marine management **sustainableseaschallenge.co.nz/tools-and-resources/using-ecosystem-service-bundles-to-improve-marine-management**

Academic Publications

Rullens V, Pilditch C, Lohrer A, Townsend M (2019) Ecological mechanisms underpinning ecosystem service bundles in marine environments – a case study for shellfish. Frontiers in Marine Science 6: 409 **doi.org/10.3389/fmars.2019.00409**

Rullens, V., Stephenson, F., Lohrer, A.M., Townsend, M., Pilditch, C.A. 2021. Combined species occurrence and density predictions to improve marine spatial management. Ocean and Coastal Management. **doi.org/10.1016/j.ocecoaman.2021.105697**

Rullens, V., Townsend, M., Lohrer, A.M., Stephenson, F., Pilditch, C.A. (Submitted) Applying ecological principles to predict the spatial distribution of shellfish-generated ecosystem services. Science of the Total Environment

1. doi: 10.1073/pnas.0907284107

Monitoring for tipping points in the marine environment

TYPE Guidance document	**DISCIPLINE** Widely ranging
SPATIAL SCALE Local to regional	**END-USERS** Widely ranging

Overview

Our marine environments are constantly exposed to changes, which can happen rapidly. Unfortunately, there is very little ability to predict these changes and the future consequences.

This guidance document outlines the importance of acknowledging that processes in the environment do not follow linear trends. It is very important to understand the nature of these changes, and how to improve current decision-making processes and current monitoring programmes.

Evidence has shown that cost-effective resource management needs to be strategically designed and include several critical elements that go beyond the current practices, which are mainly focused on limit setting.

These elements include:

- Acknowledging that (1) non-linear change happens in the environment, (2) marine systems are complex and multi-dimensional, and (3) most of our environmental problems are associated with our oceans
- Establishing a well-structured monitoring programme that can be used as a powerful learning and communication tool to help identify early warning signs of tipping points
- Learning to identify and recognise early warning signals to prevent tipping points
- Management strategies that work alongside any socio-ecological systems. People must be involved and engaged. Ideally, getting people thinking about how we (as a society) affect and cause changes in the environment and what the consequences of our decisions are, in order to finally shift the way that we make decisions (increase awareness).
- Focusing on how the ecosystem responds to change, rather than just about what the stressor is
- Where possible, increasing sampling frequency
- Incorporating data from multiple resources, e.g. iwi-based, community-based monitoring
- Involving expert knowledge in the process, including data analysis and interpretation.

This guidance also includes considerations when designing monitoring programmes, along with recommendations for robust monitoring programmes and analyses many of New Zealand's present marine monitoring against these recommendations.

Information provided in this guidance can be applied to any marine ecosystem on a regional scale, therefore, it can help a wide range of users such as iwi, regional councils, and policymakers.

Application by end-users

Researchers from Sustainable Seas have been publicly showing and sharing this information with regional councils.

Some recommendations have already been put into practice by Auckland Council, and are being considered by other regional councils. Currently, researchers are engaging with the Otago, Waikato, Bay of Plenty, Hawkes Bay, and Marlborough Sounds councils.

For more information contact Dr Judi Hewitt: judi.hewitt@auckland.ac.nz or Dr Simon Thrush: **simon.thrush@auckland.ac.nz**

Further information

Guidance

Monitoring estuaries in a changing world: Lessons for designing long-term monitoring programmes
sustainableseaschallenge.co.nz/lessons-for-designing-long-term-monitoring-programmes

Monitoring for tipping points in the marine environment
sustainableseaschallenge.co.nz/monitoring-for-tipping-points-in-marine-environments

Managing the impact of turbidity, nutrients and sea level rise on coasts and estuaries
sustainableseaschallenge.co.nz/managing-turbidity-nutrients-and-sea-level-rise-on-coasts

Presentation

Thrush S, Paul-Burke K, Carbines M et al (2021). Webinar: Shady business – the problem of mud in our estuaries
sustainableseaschallenge.co.nz/webinar-shady-business

Summary

Robust, cost effective marine monitoring – how recommendations for designing robust monitoring programmes are being taken up by regional councils
sustainableseaschallenge.co.nz/ics-robust-cost-effective-marine-monitoring

Completed project

Tipping points in ecosystem structure, function and services project webpage
sustainableseaschallenge.co.nz/tipping-points

Academic publications

Thrush SF, Hewitt JE, Gladstone-Gallagher RV et al (2020). Cumulative stressors reduce the self-regulating capacity of coastal ecosystems. Ecological Applications 31 (1):e02223

Hewitt J and Thrush S (2019). Monitoring for tipping points in the marine environment. Journal of Environmental Management, 234, 131–137

Monitoring estuaries in a changing world:
Lessons for designing long-term monitoring programmes

TYPE Guidance document	**DISCIPLINE** Widely ranging
SPATIAL SCALE Local to regional	**END-USERS** Widely ranging

Overview

This document summarises 7 key lessons for managers to consider when designing long-term monitoring programmes for estuaries in a changing world. These lessons are based on the Manukau Marine Ecology Monitoring Programme (MMEMP) and informed by research from our *Tipping Points* project. The MMEMP has been in place since 1987 and involves on-going monitoring of Manukau Harbour, the second largest harbour in Aotearoa New Zealand, with extensive sandflats covering approximately 40% of the area. The programme focuses on the benthic macrofauna of these intertidal sandflats, as integrators over a range of stressors.

The 7 key lessons:

- Lesson 1: Principles of design to be decided upon at the start of the programme
- Lesson 2: Undertake reviews at fixed time intervals to ensure the monitoring programme is cost-effective, yet provides high quality, robust data
- Lesson 3: Analyses of long-term data can detect multi-year cyclic trends and patterns that short-term data cannot
- Lesson 4: Temporal variability can influence the ability to detect tipping points (TP), so it is important to consider climate patterns in programme design and analyses
- Lesson 5: To detect TP, sampling more than twice per year is an optimal frequency
- Lesson 6: Community analyses are much stronger than single-species analyses for detecting small changes
- Lesson 7: The length, continuity and consistency of a dataset will determine its ability to predict approaching TP or determine whether one has passed

All these lessons, with the possible exception of Lesson 5, will apply to long-term monitoring programmes. More generally, apart from Lesson 5, they will also apply to other variables such as sediment characteristics, water quality and fish communities. Of particular importance for estuarine monitoring networks, would be if long-term continuous time-series collected at some selected sites around Aotearoa New Zealand could be used to set contexts for other less frequently monitored sites.

For more information contact Dr Judi Hewitt:
judi.hewitt@auckland.ac.nz

Further information

Guidance

Monitoring estuaries in a changing world: Lessons for designing long-term monitoring programmes
sustainableseaschallenge.co.nz/lessons-for-designing-long-term-monitoring-programmes

Monitoring for tipping points in the marine environment
sustainableseaschallenge.co.nz/monitoring-for-tipping-points-in-marine-environments

Managing the impact of turbidity, nutrients and sea level rise on coasts and estuaries
sustainableseaschallenge.co.nz/managing-turbidity-nutrients-and-sea-level-rise-on-coasts

Presentation

Thrush S, Paul-Burke K, Carbines M et al (2021). Webinar: Shady business – the problem of mud in our estuaries
sustainableseaschallenge.co.nz/webinar-shady-business

Summary

Robust, cost effective marine monitoring – how recommendations for designing robust monitoring programmes are being taken up by regional councils
sustainableseaschallenge.co.nz/ics-robust-cost-effective-marine-monitoring

Academic Publications

Thrush SF, Hewitt JE, Gladstone-Gallagher RV et al (2020). Cumulative stressors reduce the self-regulating capacity of coastal ecosystems. Ecological Applications 31 (1):e02223

Hewitt J and Thrush S (2019). Monitoring for tipping points in the marine environment. Journal of Environmental Management, 234, 131–137

Decision-making and participatory tools

Collaborative decision making involving many different parties with varying interests (often competing) is a founding principle for EBM in Aotearoa. Making collaborative decisions on the marine and coastal environment is challenging because of the multiple activities and uses that are occurring at the same time, and in turn the cumulative stress these activities place on marine ecosystems.

Tools for informing decision-making can assist with the complex task of incorporating uses-users, activities, and stressors during planning and assessment to ensure the health and functioning of our marine ecosystems. For example, Zonation is a spatially explicit decision-support tool that helps quantify the existing and potential impacts of different policy and management options on ecosystem health. The Aotearoa Cumulative Effects (ACE) framework sets out process and principles for discussions around managing cumulative effects.

Enabling collaborative decision making requires effective processes for enabling participation. EBM provides an inclusive way to manage marine environments. This section includes three participatory tools to assist with planning, engagement and collaboration among diverse participants or end-users during any stage of decision-making processes: Systems mapping for ecosystem-based management; Pātaka Korero to empower kaitiaki; and the Ingredients Tool. More detailed information on objectives and features of these tools is provided in Table 4 (p50) and Table 5 (p54).

EEZ Biodiversity and Hawke's Bay Zonation

TYPE Software – model	**SCENARIOS EXPLORATION** Yes
DISCIPLINE Widely ranging	**COMPLEXITY** Easy
END-USERS Widely ranging	**DATA FLEXIBILITY** High
DIMENSIONS 2D	**COST TO BUILD** $[1]
SPATIAL SCALE Local to national to global	**COST TO RUN** $[1]
TEMPORAL SCALE No	
SKILL NEEDED User friendly through Graphical User Interface (GUI) provided with software. GIS expertise required to prepare input layers	
ABILITY TO INTERPRET AND COMMUNICATE OUTPUTS Easy	

What is it?

Zonation is a software that provides decision support for spatial conservation prioritisation and managing trade-offs between different spatial management objectives. Zonation can be used for managing habitat quality and can account for connectivity. It was originally developed at the University of Helsinki and has been widely used for terrestrial and marine conservation. In Aotearoa New Zealand it has been used to inform freshwater and terrestrial conservation and restoration. Compared with other spatial planning software, Zonation has the capability of running large-scale analysis with millions of data cells, therefore, it can be applied at any spatial scale. The specific tool created by using it depends on the application it is intended for.

Zonation can incorporate biological, physical, economic, or socio-cultural information. Data is typically provided in the form of gridded layers, such as habitat type, species distributions, or economic data such as costs associated with fishing or shipping, though Zonation can also utilise point data such as individual species observations.

Typical analyses look at identifying optimal solutions for prioritising multiple, often conflicting objectives, and the tool includes options to pre-select or pre-block areas where an activity should be permitted or prohibited (e.g. marine reserves, historical sites like Māori Pā, locations of high industry value). Zonation analysis is deterministic, providing one solution per scenario. Outputs include maps of spatial priorities and tables of outputs for individual features.

Zonation has its own graphical user interface (GUI) and provides R code for post-processing (Zonator, available on Github[2,3]); alternatively, outputs can be uploaded into geographic information system (GIS)[4] or other data processing software.

Applications in Sustainable Seas

Zonation was used in Sustainable Seas to develop new approaches to inform prioritisation of marine biodiversity at the scale of New Zealand's Economic Exclusive Zone (EEZ) for decision-making. A key challenge in optimising biodiversity at the EEZ scale is that there are significant spatial biases in sampling of the ocean, and a large portion of the EEZ has had insufficient sampling to assess patterns in biodiversity and community assemblages.

To allow for the whole of the EEZ to be included in Zonation analyses, a Gradient Forest (GF) statistical approach (see p22) was used to create a proxy layer representing community assemblages to help fill data gaps and provide a proxy of biodiversity in the EEZ. Zonation scenarios that used this proxy layer to prioritise areas for biodiversity protection showed similar efficiencies compared with Zonation analyses using 100s of demersal fish modelled layers. The second part of this project related to understanding how uncertainty associated with modelled species distribution layers influences spatial prioritisations in Zonation. Here, the Zonation option of incorporating 'uncertainty maps' was used to 'discount' areas with high uncertainty and explore how priorities change when taking into account areas of high priority, but where models also have high levels of uncertainty. Outcomes from this project provide useful guidance for the use of Zonation to inform spatial management.

See page 39 for footnotes

Our researchers are now applying Zonation in three case studies to provide guidance on how spatial decision support tools can be applied at different scales (national, regional, and local/rohe moana scale) to inform spatial management.

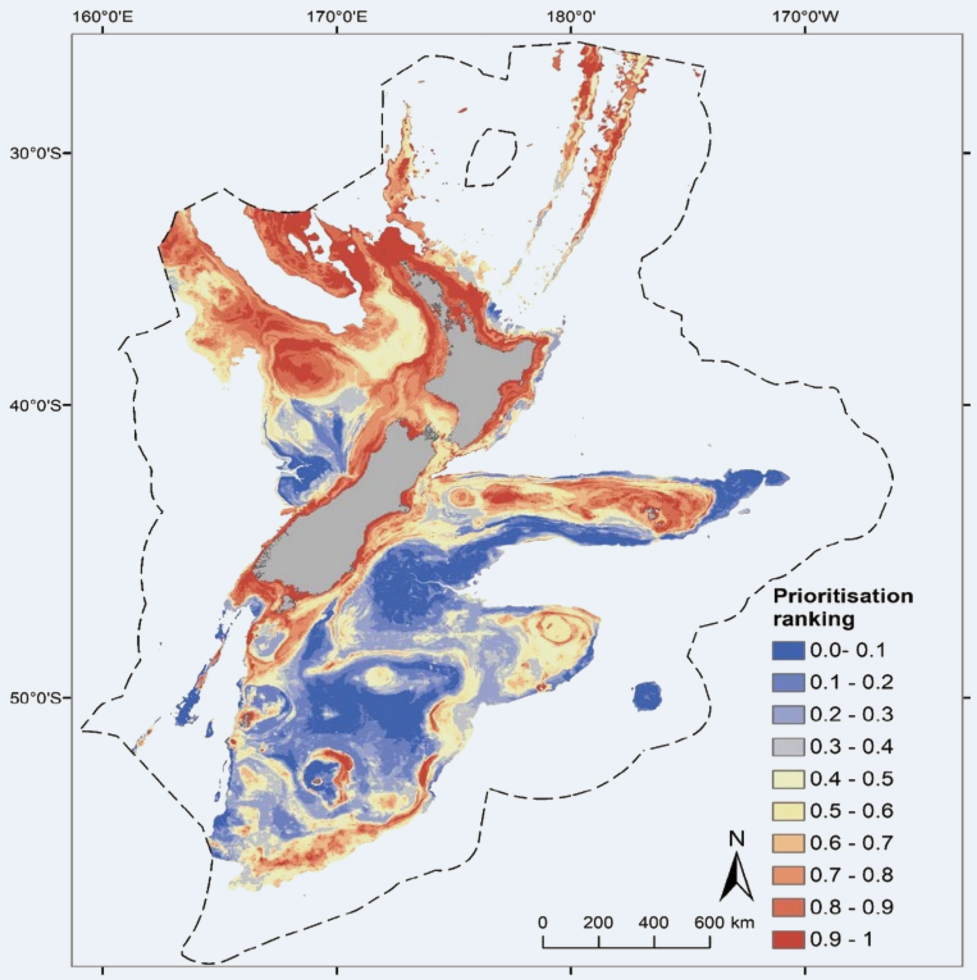
The **national** case study is being developed with stakeholder and national advisory groups, including Department of Conservation, Fisheries NZ, Ministry for the Environment, and the Environmental Protection Authority. Of particular interest to these groups is understanding future impacts and biodiversity patterns in the marine environment under different scenarios of multiple stressors, including climate change. To inform these management challenges, the project team is developing new ways of incorporating cumulative stressors within Zonation scenarios.

At the **regional** scale, researchers are working with Hawke's Bay Regional Council (HBRC) to apply Zonation within the Ahuriri Estuary, and to develop a framework of how spatial tools can be applied to inform spatial planning responsibilities of regional councils. It is expected that the Zonation tool will become highly relevant for marine planning, because the Resource Management Act (RMA) is being repealed and replaced with new laws; one of these will be the Strategic Planning Act (SPA) which will require long-term regional spatial strategies. The regional work with HBRC aims to help familiarise Councils with ways to use this tool and also meet SPA requirements.

The **rohe moana** case study focuses on Ōhiwa Harbour to explore how this tool can be applied to inform decision-making at a local scale, including mātauranga.

How it works

Zonation requires the creation of multiple data layers, which may be generated using data from other models such as species distribution models or predictions of abundance, as well any other data types, such as point records, or qualitative information (e.g. social, economic, cultural, etc). All data layers need to be converted into Zonation input files (raster grids). This step can be done using GIS algorithms or other data processing (e.g. R).



Zonation prioritisation of the New Zealand extended continental shelf to depths of 2000 m, based on distributions of 217 demersal fish species. The highest priority areas for conservation of biodiversity are indicated in red, and the lowest in blue © Carolyn Lundquist, NIWA

Typical resolutions used in Aotearoa New Zealand are 1km x 1km at the EEZ scale, and 250m x 250m in inshore areas.

Zonation's running time depends on the number of layers of information and the number of cells which is determined by model area and the sampling grid. Typical Zonation scenarios for New Zealand biodiversity layers take minutes to hours to process from regional to national scales. Zonation can be run on a standard desktop computer (Windows and Linux operating systems) but is no longer supported on the MacOS[5] operating system.

Outputs from Zonation are mainly summarised in maps, tables and/or graphs, with post-processing typically done with GIS or R Software. Standard software such as Microsoft Excel can also be used. R code for processing the majority of typical outputs is available from the Zonation developers on GitHub.

Build and run time depends on several factors: data availability and cleaning, GIS data analysis, and experience using Zonation. Most of the time is invested in data collection (input layers) and processing (transforming the data into grids of data), and this time will depend on how many layers are processed and the initial state of the data. Once input layers are prepared, Zonation experts can set up, process, and analyse Zonation scenarios in hours to days, though novice users may take longer to set up and debug Zonation files, and process outputs.

Zonation and associated tutorials and output processing files (in R) are available free of cost for non-commercial use on GitHub. Many users may opt to prepare input layers and process outputs in commercial Geospatial software (upwards of $10,000 a year for commercial users of packages such as ESRI[6]).

What it takes to use it

Creating a zonation tool requires a reasonable level of technical knowledge. A good understanding of GIS is required to prepare the data and turn it into raster format for use in Zonation. It is also important to have a good understanding of the mathematics behind Zonation, including the different options available, and what those options mean. Although post-processing of outputs can be done in Excel, it is beneficial to be familiar with R, which makes working with large datasets much more efficient.

Users of Zonation outputs do not require any technical knowledge about Zonation. Outputs are easy to use, interpret, and communicate.

» For more information contact Dr Carolyn Lundquist: **carolyn.lundquist@niwa.co.nz**

Further information

Completed project

Spatially-explicit decision support tools **sustainableseaschallenge.co.nz/spatially-explicit-decision-support-tools**

Active project

Spatially-explicit cumulative effects tools project **sustainableseaschallenge.co.nz/spatially-explicit-cumulative-effects-tools**

Academic publications

Stephenson F, Leathwick J, Moilanen A et al (2021). Species composition and turnover models provide robust approximations of biodiversity in marine conservation planning. Ocean and Coastal Management 212:105855

Rowden AA, Stephenson F, Clark MR et al (2019). Examining the utility of a decision-support tool to develop spatial management options for the protection of vulnerable marine ecosystems on the high seas around New Zealand. Ocean and Coastal Management 170: 1–16

Leathwick J, Stephenson F, Moilanen A et al (in review). Marine spatial planning identifies contrasting trade-offs between conservation and commercial trawling at national versus regional scales. Conservation Science and Practice

External source

Lundquist C, Brough T, McCartain L et al (2021). Guidance for the use of decision-support tools for identifying optimal areas for biodiversity conservation. Prepared for the Department of Conservation, 124 pp.

1. Cost may vary depending on the scenario complexity, knowledge, and/or data needed. For example, simple scenarios (e.g. edit some parameters or force some values, then analyse the flow-on effects) cost will be low ($=<$50k). If more complicated scenarios require bringing in more knowledge and/or data and potentially re-developing some of the model, then it's more likely to be high ($$$ = >$200k).

2. GitHub, Inc. is a provider of Internet hosting for software development and version control using Git. It offers the distributed version control and source code management functionality of Git, plus its own features. github.com

3. rdocumentation.org/packages/zonator/versions/0.6.0

4. A GIS is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface.

5. It is the primary operating system for Apple's Mac computer.

6. ESRI applications provide the backbone for the world's mapping and spatial analysis.

Aotearoa Cumulative Effects (ACE) framework

TYPE Process framework	**SCENARIOS EXPLORATION** Yes
DISCIPLINE Widely ranging	**COMPLEXITY** Easy
END-USERS Responsible for managing cumulative effects	**DATA FLEXIBILITY** High
DIMENSIONS No	**SKILL NEEDED** Cumulative effects background
SPATIAL SCALE Local to national to global	**COST TO BUILD** $[1]
TEMPORAL SCALE No	**COST TO RUN** $[1]
ABILITY TO INTERPRET AND COMMUNICATE OUTPUTS Easy	

What is it?

The Aotearoa Cumulative Effects (ACE) framework has been designed to enable and support conversations among people/agencies who are responsible for managing cumulative effects (CE) from the mountains to the sea. ACE also provides guidance to users in organising ideas about CE management and how to start the process. It is important to highlight that this tool will not answer questions around whether a consent should be granted, or an activity should take place or not.

The ACE framework was co-developed with Māori and stakeholders and is underpinned by the principles of Te Tiriti o Waitangi / Treaty of Waitangi, especially regarding partnership and rangatiratanga.

It would be beneficial to use ACE in conjunction with other tools such as the Ingredients Tool (p47). The ACE framework can be used to promote conversations to move to action[2]. The tool assists users to start collaboratively thinking about questions such as:

- What do they need to do?
- Who do they need to talk to?
- Who should be involved in what?
- What are the common goals?
- What is the vision?
- What sorts of questions do they need to ask?
- What sort of things do they need to think about?

The ACE framework has been successfully tested at a workshop using different examples (scenarios) spanning multiple jurisdictional scales. Agencies normally operate at defined scales and CE goes beyond jurisdictional boundaries; the tool is useful for working across scales in a collaborative, participatory way. The ACE framework provides ways of connecting across national, local, and regional scales.

The framework can be also used for other issues requiring collaborative decision-making and a participatory process. For example, for regional and local councils as they deal with CE management on a daily basis, and/or for community interaction and engagement. Industry could use the ACE framework as part of the process of gaining social license and using the tool as part of their engagement with the wider community. It may also be useful at the national scale for facilitating engagement among agencies; for example, it can help cross-agency work toward managing CE in a participatory and/or collaborative way.

Applications in Sustainable Seas

During its 2014–2019 research, Sustainable Seas generated a considerable amount of knowledge about the nature of CE with respect to difficulties in their management. The ACE framework was developed to bring together this diverse set of knowledge and provide a framework for enabling effective CE management. Using the ACE framework in a workshop involving multiple agencies, it was demonstrated how the collaborative process can lead to improved CE management outcomes.

See page 41 for footnotes

How it works

The ACE framework is designed to be used in an iterative, cyclical manner through a collaborative or participatory process. This tool is question-driven to move to something more strategic. Conversations can be initiated by any organisation or group to identify common goals. The process requires several meetings in person or online, however, face-to-face is preferable as it facilitates a more collaborative environment and decreases contentiousness among participants. The scale of the question/problems or context, vision and goals will determine the number of meetings needed (very likely to be more than one).

After collectively answering the questions in the framework, identified actions should be checked to make sure that they align with the original vision and goals. Although the questions are applicable across all scales, the answers to the questions are likely to change depending on context. Where answers do not align across scales, steps should be taken to negotiate management resolutions based on the overarching CE management principles. This process does not require a leader or facilitator unless the process is not running well, or matters have become contentious.

The ACE framework can be used in many different applications because it is driven by the context of the problem or question being posed. Its application is low cost, as it primarily involves time invested in workshops and meetings.

The ACE framework can be run with or without science content; however, the absence of science expertise can cause limitations in the use of the framework. The tool may also be limited in its use within the legal and policy framework. Therefore, inclusion of science and policy expertise in the process will strengthen its use and potential outcomes.

What it takes to use it

The ACE framework has been designed with the intention that anyone in resource management and policy should be able to make use of the tool. Therefore, the only requirement is some background on CE and an understanding that there are often multiple stressors in the environment that may interact in different ways. No specialist skills are required.

When applying the ACE framework in a collaborative process, it is beneficial to have a wide range of perspectives to make the process effective, and better informed; for example, inclusion of mātauranga Māori, policy and planning expertise, biophysical and social science expertise, and people familiar with the area and the community. Wide participation also encourages a presence of different social values that might be attached to a place.

For more information contact Dr Karen Fisher: k.fisher@auckland.ac.nz

Further information

Guidance

Enabling inter-agency collaboration on cumulative effects **sustainableseaschallenge.co.nz/ace-framework**

Ingredients to catalyse participation in marine decision-making **sustainableseaschallenge.co.nz/ingredients-tool**

Academic Publications

Crease R, Le Heron E, Fisher K et al (2019). How can collaboration improve cumulative effects management practices? Resource Management Journal, 29–34

Davies K, Fisher K, Couzens G et al (2019). Principles for cumulative effects management in Aotearoa New Zealand. Resource Management Journal, 11–15

1. Cost may vary depending on the scenario complexity, knowledge, and/or data needed. For example, simple scenarios (e.g. edit some parameters or force some values, then analyse the flow-on effects) cost will be low ($=<$50k). If more complicated scenarios require bringing in more knowledge and/or data and potentially re-developing some of the model, then it's more likely to be high ($$$ = >$200k).

2. This tool does not provide a single, simple solution but instead is meant to foster collaboration. Then, it requires time to collaborate and discuss with others.

Pātaka Korero to empower kaitiaki

TYPE Web-based	**SCENARIOS EXPLORATION** No
DISCIPLINE Widely ranging	**COMPLEXITY** Easy
END-USERS Widely ranging	**DATA FLEXIBILITY** High
DIMENSIONS No	**SKILL NEEDED** Smartphone technology, internet
SPATIAL SCALE Local to national	**COST TO BUILD** $[1]
TEMPORAL SCALE No	**COST TO RUN** $[1]
ABILITY TO INTERPRET AND COMMUNICATE OUTPUTS Outputs will depend on the knowledge's owner	

What is it?

Pātaka Korero (PK) is a content management system co-developed with hapū and kaitiaki of the Tauranga Moana. The current version is a website; however, it is expected that at the end of this project an intuitive tool will be available in an app format (easier access and user-friendly). Once the tool is finished, it can be used across the whole country and by anyone familiar with using a smartphone and the internet.

The main purpose of the PK is to provide a space to consolidate and manage content digitally, and where Kaitiaki can re-claim, re-frame, synthesise and disseminate datasets, methods, and knowledge. This tool also provides an opportunity to learn and compare how traditional knowledge is being saved and used today. Importantly, the knowledge saved within the tool remains owned by each whānau; therefore, the way the knowledge is used, disseminated, and synthesised is up to each whānau.

In its current state the PK can collate datasets and digital content spatially. This has been utilised to upload datasets from external software programs such as ArcGIS survey123[2] and then exporting and uploading the data into the PK. Whānau have also begun to collate information on specific sites using interviews and drone capture. Once the content is collected, it will be uploaded to the PK to view spatially or within user defined collections. It is expected that PK can be integrated with other tools and provide support to education (e.g. information cards).

Applications in Sustainable Seas

Sustainable Seas research is looking at how the PK tool can contribute to ecosystem-based management. To achieve this, PK has been planned in two main phases: (1) tool development at the local scale (first step), and at the regional and national scale (second step), which includes the development of three case studies as an example of different scenarios and types of uses; and (2) validating the process to use the tool, which includes app development and ensuring it is user-friendly, fast and reliable. This second phase includes development of a user framework, user guide document, options for information exchange, storage capacity, privacy protection, and determining needs around future support and website maintenance once fully developed.

How it works

The PK tool is expected to function through a web-enabled app on a website and is currently under testing. Developers are working on an effective security system to make sure that the information is never lost or misused. A full working tool for kaitiaki and education centres (e.g. kura and wharekura) is expected to be completed by mid-2023.

The only technical requirements for users to use this tool would be familiarity with using a smartphone (or similar) and the internet to upload their information (e.g. photos, korero, etc). Users (individual or community) will be required to set up an account.

See page 43 for footnotes

What it takes to use it

It is expected that this tool will be easy-to-use, fast, and intuitive. The only requirement would be familiarity with the use of smartphone technology and the internet. Development of a user guide is also planned.

For more information contact Caine Taiapa:
caine@teawanui.com

1. Cost may vary depending on the scenario complexity, knowledge, and/or data needed. For example, simple scenarios (e.g. edit some parameters or force some values, then analyse the flow-on effects) cost will be low ($=<$50k). If more complicated scenarios require bringing in more knowledge and/or data and potentially re-developing some of the model, then it's more likely to be high ($$$ = >$200k).

2. ArcGIS Survey123 is a complete, form-centric solution for creating, sharing and analysing surveys. Use it to create smart forms with skip logic, defaults, and support for multiple languages (for more information visit: esri.com/en-us/arcgis/products/arcgis-survey123/overview).

Further information

Digital tool — Pātaka Korero to empower kaitiaki
sustainableseaschallenge.co.nz/pataka-matauranga-to-empower-kaitiaki

Active project — Te Tāhuhu Matatau: Empowering kaitiaki of Tangaroa
sustainableseaschallenge.co.nz/te-tahuhu-matatau-empowering-kaitiaki-of-tangaroa

Completed project — Tāhuhu Matatau Te Ao Tangaroa: Empowering the kaitiaki of Ngā Whare Tokotoru ki Katikati with mātauranga from Aotearoa and beyond project webpage
sustainableseaschallenge.co.nz/our-research/tahuhu-matatau-te-ao-tangaroa-empowering-the-kaitiaki-of-nga-whare-tokotoru-ki-katikati-with-matauranga-from-aotearoa-and-beyond

Tasman/Golden Bay, Hawke's Bay and Blue Economy systems mapping for ecosystem-based management

TYPE Conceptual model and participatory process	**SCENARIOS EXPLORATION** Yes
DISCIPLINE Widely ranging	**COMPLEXITY** Medium
END-USERS Widely ranging	**DATA FLEXIBILITY** High
DIMENSIONS No	**COST TO BUILD** $[1]
SPATIAL SCALE Local to national	**COST TO RUN** $[1]
TEMPORAL SCALE Yes	
SKILL NEEDED *System Dynamics* background; facilitation experience	
ABILITY TO INTERPRET AND COMMUNICATE OUTPUTS Medium (system map + report)	

What is it?

System mapping (sometimes called 'causal loop diagramming') is a method that can help understand the many interconnected causal influences around a particular issue of interest. It is often used in a participatory process setting (as it has been in Sustainable Seas) as this helps build as broad an understanding of an issue from as many perspectives as possible[2]. Within the context of ecosystem-based management (EBM), this tool illustrates cause and effect relationships within and between natural ecological processes and human activities[3].

Systems mapping is based on an academic discipline called System Dynamics. This seeks to understand the network of cause-and-effect relationships (causal relationships) which present as some kind of behaviour over time (or trend) in an area of interest. The network of cause-and-effect relationships is the 'system' that is creating the behaviour of interest and can be made up of both tangible (e.g. sediment loads in rivers) and intangible (e.g. community desire for clean rivers) influences. The approach particularly focuses on the circular nature of causality and articulating feedback loops of influence.
It was originally developed in the late 1950s at Massachusetts Institute of Technology to provide an engineering perspective on business management. Initially, this helped with understanding industrial processes, yet was quickly and widely applied to urban, environmental and socio-ecological systems in the 1970s. Today it is applied to many challenges including complex natural processes and how ecosystems function.

The main qualitative output is called a System Map (or a Causal Loop diagram). The process synthesises a range of knowledge into a broad and visual understanding of an ecosystem and helps to identify the key factors and drivers that are influencing or causing a particular issue or issues. Visualising these inter-relationships not only provides insight into the complexity of their connections, but also gives some idea of the relative strength or impact of certain factors or drivers identified – be they biophysical or socio-economic. This is useful in assisting groups to increase their shared understanding of an issue and importantly, where best to target intervention. The system map can then be used to help develop and/or explore conceptual management interventions. This helps inform decision-making by providing a strong qualitative tool to support participants to progress towards alignment and agreement on what to do or where to explore further or more deeply.

System mapping is useful in supporting decision-making when stakeholders have limited time, budget, and/or information. It can also be a useful method to help introduce a more involved and intensely resourced process, where it can be used to build initial understanding before progressing to more complex modelling/research.

Effective development of a System Map using well-designed participatory processes (usually workshops and/or interviews) can help enable decision-making based on the best information available. Through the engagement process, the method also provides an opportunity to build trust and social capital among participants.

See page 46 for footnotes

The method works best when synthesising multiple influences. Therefore, it can be usefully applied across a variety of scales, from local to national or even a combination. Visual diagrams produced can be used by a wide range of people like government, tangata whenua, iwi/hapū/whānau, industry stakeholders, etc.

Applications in Sustainable Seas

Tasman-Golden Bay (TBGB) case study: A pilot system mapping exercise involving interviews and three workshops was carried out with stakeholders interested in restoring the scallop fishery and seabed health in TBGB. The map and report helped participants gain insights into the factors influencing habitat quality and scallop populations. Importantly, the process itself helped participants increase their shared understanding around the multiple management interventions that likely need to occur, and helped them acknowledge that no one industry or activity is responsible for the decline in the scallop fishery, or similarly, able to be responsible for its recovery.

Hawke's Bay regional study: System mapping was used to understand increased sedimentation and loss of seabed health structure in Hawke's Bay.
A conceptual map visualises the interlinked influences of two main environmental stressors – sediments and disturbance of the seabed. The map is providing a framework for working with multiple stakeholders and various knowledge sources to develop insights about:

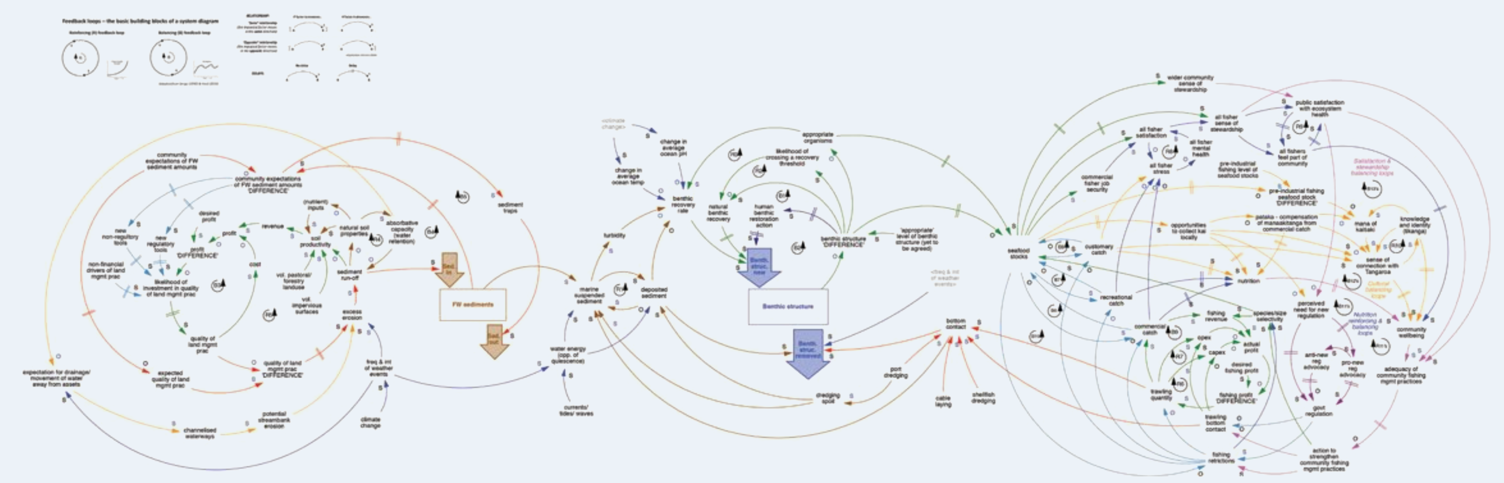
- How to deal with the causes and influences of these stressors
- What sorts of actions or interventions might prove the most useful
- How impactful these interventions might be
- Some insight into the time delays involved for the impacts of action to present
- Who is best placed to take action and respond.

'Blue economy' activities: Conceptual system maps have been used to describe three marine economy activities in Aotearoa New Zealand – wild fisheries, farmed fisheries, and ecotourism. These help explain similarities, differences, and risks among the three systems. The system maps provide a basis for visualising the complexity of the inter-relationships within the economic activities, potential management interventions and opportunities for transitioning to a blue economy.

How it works

System mapping can use various sources of information (such as a literature review), but it is more powerful when the information comes from the diverse knowledge bases of participants in a participatory process. Therefore, the information for developing the system map is best generated from face-to-face facilitated interviews, a working group, or workshops – or ideally, a combination. Online workshops are also possible, but the process will likely take longer and require more skilled facilitation. A minimum of three workshops is recommended, although more are likely to be required depending on the nature of the issue being explored and the dynamics of the group(s) involved. These types of workshops work best with 6 to 12 people. Larger groups can be facilitated, but they would need to be split into smaller groups of no more than 12, requiring multiples sessions. Information produced during the workshop sessions is regularly validated with the participants.

Systems map of increased sedimentation and loss of seabed health structure in Hawke's Bay



System mapping is an adaptative process that is tailored to an issue at hand and to the dynamics of the group involved. It synthesises the best available information to produce a conceptual map, which helps to visually articulate the causal relationships between variables that best explain the behaviour of the system that you are trying to understand. This visual articulation of relationships is known as 'system structure', consisting of several elements such as feedback loops, stock and flow notation, etc. This can then be used to explore the temporal impacts of action (or inaction). The conceptual map can support discussions of different management intervention scenarios and an estimation of their likely impact in the future, in order to support decision-making processes. Once the information is collected, it can be analysed to produce the final output: conceptual maps and reports.

Conceptual maps can be created by hand or with software such as STELLA, KUMU, and Vensim. PowerPoint can also be used but is less suited.

The process can take between two to five months to complete. This time includes at least three workshops and possibly some interviews between them, as well as the completion of conceptual maps and the report or other form of written communication.

What it takes to use it

This method requires a person with a high level of knowledge and practical experience in System Dynamics and mapping, and a facilitator to run the workshops. These may be the same person but do not have to be. Background knowledge for the facilitator around the issues and system being explored is not necessary but may be beneficial. This is because systems mapping provides a process (the mapping) and seeks to involve other subject matter experts – the facilitator is very deliberately not the subject matter expert. If a Te Ao Māori perspective is important to the issue or area of interest being explored, it is highly recommended that the facilitator has a strong grounding or background in Te Ao Māori. Otherwise, strong support from someone with deep knowledge in Te Ao Māori is advised. The conceptual maps produced are best accompanied by a written report and/or explainer videos to aid interpretation. Once created, they can be used and explained by anyone involved in the creation process.

For more information contact Justin Connolly: justin.connolly@deliberate.co.nz

Further information

Reports

Conceptual system maps of 'blue economy' activities report: **sustainableseaschallenge.co.nz/conceptual-system-maps-of-blue-economy-activities**

Systems mapping: Scallop decline in Tasman-Golden Bay report: **sustainableseaschallenge.co.nz/systems-mapping-scallop-decline-in-tasman-golden-bay**

Systems mapping marine stressors in Hawke's Bay report: **sustainableseaschallenge.co.nz/final-report-systems-mapping-in-hawkes-bay-stage-1**

Presentation

Lundquist C, Madarasz-Smith A, Shanahan B et al (2020). Webinar: A systems mapping approach to understanding marine stressors in Hawke's Bay **sustainableseaschallenge.co.nz/mapping-marine-stressors-in-hb-webinar**

1. Cost may vary depending on the scenario complexity, knowledge, and/or data needed. For example, simple scenarios (e.g. edit some parameters or force some values, then analyse the flow-on effects) cost will be low ($=<$50k). If more complicated scenarios require bringing in more knowledge and/or data and potentially re-developing some of the model, then it's more likely to be high ($$$ = >$200k).

2. These conceptual models are not mathematical, but they may help inform further mathematical modelling.

3. This tool can be useful in a Te Ao Māori setting. Yet it should not be assumed to be able to perfectly capture a Te Ao Māori perspective or to be a substitute for it.

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The Ingredients Tool

TYPE Participatory process	**SCENARIOS EXPLORATION** Yes
DISCIPLINE Widely ranging	**COMPLEXITY** Easy
END-USERS Widely ranging	**DATA FLEXIBILITY** N/A
DIMENSIONS No	**SKILL NEEDED** Facilitation experience
SPATIAL SCALE Local to national	**COST TO BUILD** $[1]
TEMPORAL SCALE No	**COST TO RUN** $[1]
ABILITY TO INTERPRET AND COMMUNICATE OUTPUTS Easy	

What is it?

The Ingredients Tool (IT) is an approach that enables integrated, adaptive, and/or collaborative participatory processes (PPs) to address controversial issues in the marine environment. The IT is a key tool for navigating contested spaces, which means grounding thinking and practice when engaging with PPs to allow negotiation through the understanding of shared visions.

The IT was created from a review of 15 PPs, with a further investigation of 5 in-depth case studies of marine PPs:

1. Sea Change Tai Timu Tai Pari Marine Spatial Plan
2. Kaipara Harbour and IKHMG
3. Coalition formation against seabed mining
4. Kaikōura and Te Korowai
5. Awaroa and the Gift Abel Tasman Beach campaign.

These experiences were used to better understand PPs, and to identify features that contributed towards successful negotiated outcomes. Each of these PPs undertook a very different journey with each case study confronting the questions posed in the IT in their own way.

What are participatory processes? PPs are an important component of contemporary governance representing a way of collectively pursuing joint outcomes with many partners and affected or interested parties. PPs are helpful where there are multiple possible outcomes/solutions and contested values and interests. However, each process is different because each process is grounded in a place and time. Consequently, there is no single 'recipe' for how a PP could or should proceed. Further, success is often ascribed to PPs in hindsight – this means it can be difficult to navigate through a process because of the complex context and it is hard to know if the group is on the path to success or not.

Why are PPs important? One of the most important characteristics of PPs is that they create a platform from which difficult issues can be resolved in innovative ways. There are several reasons for this:

- PPs can be flexible in how they are arranged; for example, they can be set within statutory processes or independent of them
- Leadership can originate from government or a community or iwi/hapū collective
- There is freedom to explore diverse outcomes using the wisdom and knowledge of the collective group.

How does the Ingredients Tool help? The tool provides agile, non-prescriptive guidance that enables key questions grouped into themes ('ingredients') to be asked that can help explore new ways of thinking and practicing marine governance. IT supports ongoing discussion across various groups that is invaluable for enabling participation. These ingredients can be combined in ways that work most appropriately for the circumstances and asked in different ways as the PP evolves. By considering the ingredients, often 'invisible' potential 'roadblocks' can be identified and worked though, for example, politics and power, inclusion and exclusion, diversity of knowledge and voices, silences, absences and presences, history and context.

See page 49 for footnotes

Collectively applying the IT allows participants to reflect on their circumstances and to think imaginatively about their collective interests and aspirations for the marine environment, while often working within institutional constraints and seeking to affect innovations in governance. This tool is recommended when there is a need to work collaboratively and when there are many different users or stakeholders involved.

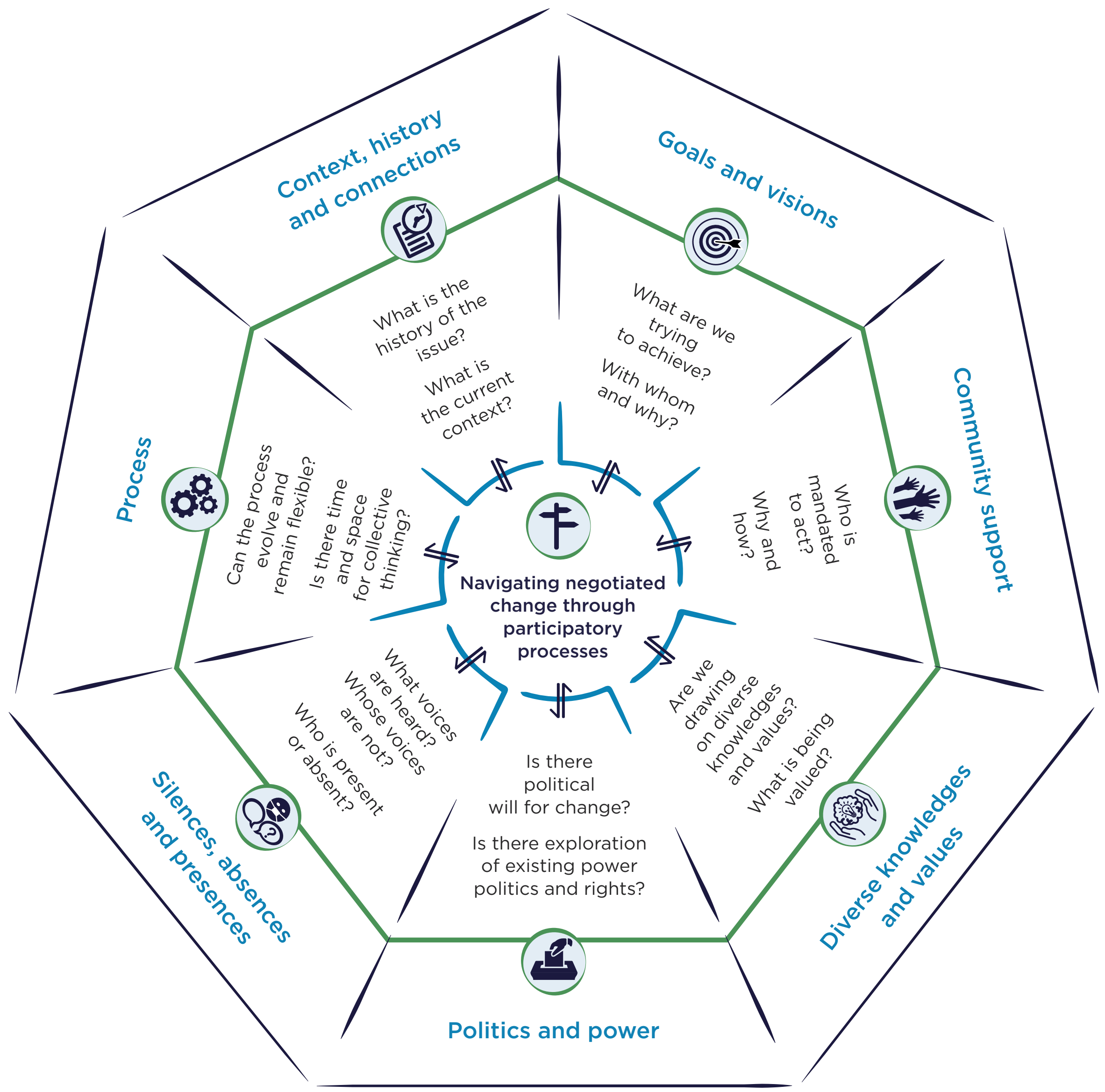
One of the most important characteristics of PPs is that they allow the process to move more independently, but always considering the historical relations among partnerships, as well as including any traditions of the conventional model of governance that have been embraced. In addition, during PPs different cultural values and knowledge from different participants are presented. It is a useful tool to structure conversations and structure discussions to determine agreed goals and encourage deep conversations about challenging issues.

This tool can be adapted to suit local circumstances and priorities; it can be used at any scale. The tool can be used in many situations by different groups, for example, government agencies, communities, iwi and hapū, and industry.

Applications in Sustainable Seas

The tool has been well received at several events; its clarity, simplicity, flexibility and list of ingredients with supporting quotes were features particularly noted. While the tool has been well received, it is expected its full use will occur in 2022/23 as part of the *Policy and legislation for EBM* project, in the Fisheries New Zealand case study.

These ingredients (themes and questions) help people to think about their own circumstances and prompt them to consider the actions they can take that suit their situation, location and community (picture adapted from Le Heron et al. 2019).



How it works

The tool is designed to support PPs by guiding the participants though the key issues that need to be addressed to successfully navigate towards agreed outcomes in a flexible way that is appropriate for the circumstances. As such there is no starting point and users can begin at the question that reflects their most pressing concern.

Key features of the tool are:

- Simplicity – Easy to use, offering key questions to explore at key points in participatory processes.
- Flexibility – Applicable in multiple situations. Every group could use an ingredient in a different way, or a different order as appropriate for their context.
- Catalyst – Enables 'deeper' conversations that probe challenging issues; it is a device to start conversations. In short, it helps people to think about their own circumstances and prompts them to consider other possible kinds of conversations and processes.
- Timing – Questions may be 'time sensitive' and responses may have greater or lesser importance at different stages of the participatory process.
- Synthesis – Collaboration is often the focus of participatory processes, but the tool reminds us that there are many other components to successful initiatives.

A real strength of the IT is that many conversations can be had about each segment, enabling the assembly of a bespoke and relevant approach for each situation.

To use the IT:

- Any question can be the starting point – There is no order in which to ask the questions as it depends on the context: where you are, who is present and what the issue is.
- There are no right or wrong answers – Discussion, rather than the specific answers, help determine agreed goals and move the process towards desired outcomes.
- Adapt to the circumstances – Some questions will be of greater or lesser importance depending on the local situation.

What it takes to use it

The use of this tool requires no special skills other than the ability to critically reflect on the participatory process in question. However, knowledge of the social, economic, cultural and environmental setting in which the participatory process is situated is important. In essence, the tool has been designed to apply to a range of different settings and to be applied by anyone who is leading or involved in an on-going process.

For more information contact Dr Paula Blackett: **paula.blackett@niwa.co.nz**

Further information

Guidance: Ingredients to catalyse participation in marine decision-making **sustainableseaschallenge.co.nz/ingredients-tool**

Completed project: Testing participatory processes for marine management **sustainableseaschallenge.co.nz/testing-participatory-processes-for-marine-management/**

Academic Publications:

Le Heron E, Allen W, Le Heron R et al (2021). What does success look like? An indicative rubric to assess and guide the performance of marine participatory processes. Ecology and Society, 26, 1, 29

Le Heron E, Le Heron R, Blackett P et al (2019). It's not a recipe... but there are ingredients. Navigating negotiated changes through participatory processes in marine spaces. Planning Quarterly 213, 32–37.

Le Heron E., Logie, J, Allen, W et al (2019). Diversity, contestation, participation in Aotearoa New Zealand's multi-use/user marine spaces. Marine Policy, 106, 103536.

Davies K, Fisher K, Foley M et al (2018). Navigating collaborative networks and cumulative effects for Sustainable Seas. Environmental Science and Policy, 83, 22–32.

Le Heron R, Blackett P, Logie J et al (2018). Participatory processes for implementation in Aotearoa New Zealand's multi-use/user marine spaces? Unacknowledged and unaddressed issues. In P. Heidkamp & J. Morrissey (Eds.), Towards coastal resilience and sustainability. Routledge.

1. Cost may vary depending on the scenario complexity, knowledge, and/or data needed. For example, simple scenarios (e.g. edit some parameters or force some values, then analyse the flow-on effects) cost will be low ($=<$50k). If more complicated scenarios require bringing in more knowledge and/or data and potentially re-developing some of the model, then it's more likely to be high ($$$ = >$200k).

Table 4: Summary matrix of tool purpose

Key: **P** Primary function, **S** Secondary function

	Tasman/ Golden Bay (TBGB) Atlantis (p8)	TBGB EwE (p10)	TBGB MSSM (p12)	Ocean Tracker (p15)	BactiMap (p18)	Seabed health and scallop fisheries (p20)	Filling gaps in marine data (p22)	Managing the impact of turbidity, nutrients and sea level rise on coasts and estuaries (p30)	Using ecosystem service bundles to improve marine management (p31)	Monitoring for tipping points in the marine environment (p32)	Lessons for designing long-term monitoring programmes (p34)	EEZ Biodiversity and Hawke's Bay (HB) Zonation (p37)	Aotearoa Cumulative Effects (ACE) framework (p40)	Pātaka Korero to empower kaitiaki (p42)	TBGB, HB and Blue economy systems mapping (p44)	The Ingredients Tool (p47)
Decision-making																
Spatial planning	S			S			P					P				
Policy	P	P	P	S		S		S	S	S	P	P	P	P		P
Conservation	P	P	P			S	S			S		P	S	S	P	P
Managing trade-offs	S					P						P		P	P	
Socio-economic												P	S	P	S	
Knowledge																
Content repository											S			S	P	
Education & awareness	S	S	S	S	S	S		S	S	S	S	S	S	S	P	
Monitoring				S					P	P	P				P	P
Understand ecosystems	P	P	P			P		P	S		S			P	S	
Mātauranga Māori						S		S	S	S		S	S	S	P	
Participatory process																
Facilitate meetings					P	S						S	P	P	S	P
Enable actions						S		S	P	P	P	S	P	P	P	P
Collaboration	S	S			P	S			P	P	P	S	P	P	P	P
Communication						P		P	P	P	P		P	S	P	
Engagement	S	S	S			P				S		S	S	S	P	
Scenario exploration																
Management actions	P	P	P	P		P	P	P	S		S	P	P	P	P	P
Ecological change	P	P	P			S	S	P	S		S				S	
Climate Change									S		S				S	
Risk and uncertainty	S	S			S	P				P	P	S	S	S	P	
Indicators						P			P		P				P	
Cumulative effects																
Tipping points	P	P	P			S		P		P	P					
Single stressor	S	S	S													
Two stressors								P								
Multiple (3+) stressors						P			S	P	P	P	P	P	P	
Early warning signs						S		S	S	P	P				P	

Table 4: Summary matrix of tool purpose (continued)

	Tasman/ Golden Bay (TBGB) Atlantis (p8)	TBGB EwE (p10)	TBGB MSSM (p12)	Ocean Tracker (p15)	BactiMap (p18)	Seabed health and scallop fisheries (p20)	Filling gaps in marine data (p22)		Managing the impact of turbidity, nutrients and sea level rise on coasts and estuaries (p30)	Using ecosystem service bundles to improve marine management (p31)	Monitoring for tipping points in the marine environment (p32)	Lessons for designing long-term monitoring programmes (p34)	EEZ Biodiversity and Hawke's Bay (HB) Zonation (p37)	Aotearoa Cumulative Effects (ACE) framework (p40)	Pātaka Korero to empower kaitiaki (p42)	TBGB, HB and Blue economy systems mapping (p44)	The Ingredients Tool (p47)
Movement																	
Spread of pollution					S											S	
Particle/larval dispersal				S	P												
Population connectivity					P							S				P	
Others																	
Ecotourism	S	S	S			S					S		S	S	S	P	
Fishing	P	P	P			S					P		S	S	S		
Contamination risk	S			P							P	P				S	
Spread disease				P	S											S	
Surveillance of invasives					S							S				P	
Aquaculture	S			P	P	S					P		S		S		

Table 5: Summary matrix of tool features

	Tasman/ Golden Bay (TBGB) Atlantis (p8)	TBGB EwE (p10)	TBGB MSSM (p12)	Ocean Tracker (p15)	BactiMap (p18)	Seabed health and scallop fisheries (p20)	Filling gaps in marine data (p22)	Managing the impact of turbidity, nutrients and sea level rise on coasts and estuaries (p30)	Using ecosystem service bundles to improve marine management (p31)	Monitoring for tipping points in the marine environment (p32)	Lessons for designing long-term monitoring programmes (p34)	EEZ Biodiversity and Hawke's Bay (HB) Zonation (p37)	Aotearoa Cumulative Effects (ACE) framework (p40)	Pātaka Korero to empower kaitiaki (p42)	TBGB, HB and Blue economy systems mapping (p44)	The Ingredients Tool (p47)
Discipline																
Biophysical	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	
Oceanographic	✓			✓	✓	✓	✓					✓	✓		✓	
Socio-economics	✓					✓			✓			✓	✓	✓	✓	
Social	✓					✓			✓			✓	✓	✓	✓	✓
Ecology	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Fisheries	✓	✓	✓			✓	✓			✓		✓	✓	✓	✓	
Economic	✓					✓			✓			✓	✓		✓	
Mātauranga Māori						✓			✓			✓	✓	✓	✓	
End-users																
Government: Central (e.g. policy makers)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Government: Local/Regional (e.g. resource managers)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Public stakeholders	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓
Community	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Iwi/hapū	✓	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓	✓
Project applicants	✓	✓	✓	✓		✓				✓		✓	✓		✓	
Industry: Fishing	✓	✓	✓			✓	✓			✓	✓	✓	✓		✓	
Industry: Aquaculture	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓		✓	
Industry: Tourism	✓	✓	✓			✓	✓			✓	✓	✓	✓		✓	
Industry: Consulting	✓	✓	✓			✓				✓	✓	✓	✓		✓	
Scientist and Research	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
NGO	✓	✓	✓			✓	✓			✓	✓	✓	✓	✓	✓	✓
Skills needed to run the tool																
Not applicable									✓	✓	✓					
Numerical	✓	✓	✓	✓	✓		✓									
Modelling	✓	✓		✓	✓		✓					✓				
Coding	✓	✓	✓	✓	✓		✓									
Physical oceanography	✓			✓	✓											
Bayesian network						✓										

Table 5: Summary matrix of tool features (continued)

	Atlantis Ecosystem model (p8)	Ecopath with Ecosim (EwE) model (p10)	The multi-species size spectrum model (MSSM) (p12)	Ocean Tracker (p15)	BactiMap – Real-time forecasting tool (p18)	Bayesian network tool (p20)	Gradient Forest models: Filling gaps in marine data (p22)	Managing the impact of turbidity, nutrients and sea level rise on coasts and estuaries (p30)	Using ecosystem service bundles to improve marine management (p31)	Monitoring for tipping points in the marine environment (p32)	Lessons for designing long-term monitoring programmes (p34)	EEZ Biodiversity and Hawke's Bay (HB) Zonation (p37)	Aotearoa Cumulative Effects (ACE) framework (p40)	Pātaka Korero to empower kaitiaki (p42)	TBGB, HB and Blue economy systems mapping (p44)	The Ingredients Tool (p47)
Skills needed to run the tool																
Social science						✓								✓	✓	
Basic field sampling														✓		
GIS expertise												✓				
Cumulative effects background								✓					✓			
Facilitation						✓									✓	✓
System Dynamics background															✓	
Basic smart technology					✓									✓		
Basic level of public environmental policy background																
Basic Mātauranga Māori														✓		
Tool support for users																
Yes	✓	✓	✓	✓		✓						✓		✓	✓	
No					✓		✓	✓	✓	✓	✓		✓			✓
Ability to present outputs in different ways																
Yes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
No																✓
Delivery mechanism for tool/model outputs																
Web-based	✓	✓	✓	✓	✓	✓	✓		✓					✓	✓	
Desktop	✓	✓	✓	✓		✓	✓					✓	✓	✓		
Summary reports	✓	✓	✓				✓	✓		✓	✓	✓			✓	✓
Full reports	✓	✓	✓									✓			✓	✓
Workshops	✓	✓	✓			✓						✓	✓		✓	✓
Mobile application	✓			✓										✓		
Skills/knowledge needed to interpret outputs																
No specials skills/knowledge needed				✓	✓				✓			✓	✓		✓	✓
Familiarised with specific ecological concepts	✓	✓	✓			✓	✓	✓		✓	✓	✓		✓		
Familiarised with specific socio-ecological concepts	✓	✓	✓		✓	✓								✓		
Specific Te Ao Māori background														✓		

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