National SCIENCE Challenges

SUSTAINABLE SEAS

Ko ngā moana whakauka

Project 4.2: Options for policy and legislative change to enable EBM across scales

Exploring the use of a system diagram and multi-variate analysis to understand multi-species complexes in fisheries

May 2022

Report by:

Justin D. Connolly — **Director, Deliberate**

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Table of Contents

List of figures

List of tables

Glossary of terms

Table 1. Glossary of terms

Term	Description
ABM	Agent-based model
CAPEX	Capital expenditure
EBFM	Ecosystem Based Fisheries Management
EBM	Ecosystem Based Management
FLA	Flatfish (fisheries code)
FMA	Fisheries Management Area
FNZ	Fisheries New Zealand
GUR	Red Gurnard (fisheries code)
JDO	John Dory (fisheries code)
MVA	Multi-variate analysis
NIWA	National Institute of Water and Atmospheric Research
OPEX	Operating expenditure
RIG	Rig (fisheries code)
SNA	Snapper (fisheries code)
System diagram	A qualitative conceptual diagram based on the tools of System Dynamics that helps to articulate cause and effect, or influence, amongst multiple factors inter-related in a system. Sometimes also called a 'causal loop diagram' (CLD) or a 'system map'.
TAR	Tarakihi (fisheries code)
TBGB	Tasman Bay & Golden Bay
The Challenge	The Sustainable Seas National Science Challenge

Note: The above glossary does not generally include the terms and definitions used in the system diagram described in this report (although there may be some overlap). A comprehensive glossary for that purpose is provided in Appendix 1

Executive Summary

The Sustainable Seas National Science Challenge (the Challenge) seeks to improve decision-making and the health of our seas through ecosystem-based management (EBM). This research forms part of the journey to better understanding tools and processes to support this aim, by seeking to 'road test' the application of a system diagram and supporting multi-variate analysis (MVA) to manage a multi-species complex. This research will also be used to inform a small-scale agent-based model (ABM) which also explores its application to help manage the same multi-species complex. This ABM will be completed and reported in a subsequent report.

This research explored the inter-connectedness between species identified as part of a multi-complex because they are often caught together with snapper. This totalled six species: snapper; tarakihi; John dory; red gurnard; rig; and flatfish (in general).

A system diagram is a conceptual diagram articulating cause and effect across and within a wide range of factors. This visual articulation of the structure of influences and relationships helps to identify feedback loops of influence and infer potential dynamic behaviours from this. The system diagram is drawn from the discipline of System Dynamics and is only intended as a conceptual guide to the complexity contained within a multi-species complex. One of the critical elements of the system diagram approach is the identification of feedback loops of influence. These are indications of endogenous influence on behaviour. There are two types of feedback loops: reinforcing feedback loops – which occur when one influence eventually encourages more of itself, thus 'reinforcing' on itself; and balancing feedback loops – which occur when one influence cancels or 'balances' itself out.

The system diagram does not seek to provide quantitatively rigorous insights and it is stressed that any inferences from the system diagram are conceptual only. These are very useful. They provide a mechanism for exploring inter-connected influences and pathways of influence across a wide range of inter-connected factors, albeit at a high level. This is informed by, and intended to complement, the existing depth of knowledge that exist in many of these subject matter areas.

An overview diagram of the system diagram that was developed in this research is shown below at the end of this executive summary.

A range of important dynamic insights are highlighted by the system diagram. Here, dynamic insights refer to the articulation of cause and effect that can explain trends over time. These are all described in the report individually, yet it is stressed that they will all interact given that they are all part of a complex set of inter-connected influences. Because of these, some of these dynamics may be influenced and/or other dynamics may also be present.

The important individual dynamics highlighted by the system diagram are:

1. The population level of the fishery is dependent on population levels in the earlier life-stages of the species.
2. Habitat functionality supports species viability at each stage of fish life.
3. Bottom contact from human activity directly influences habitat functionality.
4. Low levels of habitat functionality inhibit its natural recovery.
5. The persistence of accumulated sediment is likely to be long lasting.
6. The lower the habitat functionality, the more likely that a recovery threshold for that habitat may be crossed.
7. Human impacts on the ocean are driven by reinforcing loops linked to human benefit and constrained by balancing loops of societal expectations (i.e. what society in general is willing to accept).
8. Delays involved with balancing loops between human impacts and societal pressure are likely to be significant.
9. The QMS operates as a balancing loop, constraining and enabling catch.

10. Within the QMS, both commercial and customary catch operate within balancing loops that self-constrain the corresponding amount of fishing. Commercial is constrained by ACE, customary is constrained by approvals from Kaitiaki.
11. Recreational catch operates within a reinforcing loop that reinforces the amount of fishing based on catch. The amount of fishing is only partly influenced by recreational bag limits.
12. Low levels of habitat functionality are likely to contribute to increased competition for food between species.
13. Market returns are influenced by both market size and their perception of the fishery.
14. Accidental catch (of commercial species) and Bycatch (of other and protected species) are constrained by societal expectations (i.e. what society in general is willing to accept) with long time delays.
15. Activities on land can have a significant impact on the functionality of habitat in the ocean.

Supplementary to these dynamic insights, the MVA provided additional insights. MVA can be used to inform what species are part of a multi-species complex, or what similarities there are within species already grouped in a multi-species complex. Here it was used for the latter. The fact that this was an initial 'road-test' is stressed, data to inform the MVA can continue to be collated, so this provides the opportunity for this to be expanded in the future.

From the bio-physical data available, it was found that all species in the complex had commonality in their exposure and risk to competition for food at each life stage. In addition, there was a high level of overlap between species in terms of their predation risk; and the habitats in which they are found.

Both the process to *use* these tools (participatory and workshop based); as well as the *tools themselves*, were found to have potential benefit in the management of multi-species complexes. A summary of these insights is provided below:

- This 'road test' of the system diagram process and tool coupled with MVA, has demonstrated that this approach can positively contribute to the management of multi-species complexes. They can also strongly contribute to management that may require the input of multiple agencies across both land and ocean.
- System Dynamics is the discipline that informs the system diagram. This is useful for understanding the breadth of impacts within a system and the feedback influence these have at an aggregate level. Within this discipline, one can use qualitative tools like a system diagram (which has been used here), and/or quantitative tools like more rigorous computational computer modelling (which have not been used here).
- A system diagram is generally used to help *elicit causal assumptions* from people involved in a system. More rigorous System Dynamics modelling would be a way of *quantitatively testing those causal assumptions*.
- ABM's are useful for understanding individual interactions and their impact on the overall system. An ABM is currently in development on this project and may contribute further insights to those listed above.
- ABM and System Dynamic models differ in that: ABM's are spatially explicit and look at individual level interactions; while System Dynamic models are not spatially explicit and look at the aggregated interactions.
- An ABM has been used here partly because the case study area is spatially explicit; and partly because there was a focus on multi-species management, which is a more focused area within a wider system. In future applications, there may also a place to consider using System Dynamics models to understand broad dynamics across the system more widely (socio-economic etc), as well as ABM in specific focused areas within that. The system diagram may be a useful tool to communicate the complexity of the inter-connected world to a variety of other stakeholders and agencies.

- The system diagram may be a useful tool to communicate the complexity of the inter-connected world to a variety of other stakeholders and agencies
- While useful, system diagrams do require one to ‘tune in’ to a certain way of thinking. This may be different to the predominant way most people think, and also highlights that this tool can supplement the existing ways that people think.
- The observations in this research are consistent with experiences in both: the pilot application of system diagrams in the Challenge; and a different Challenge case study in the Hawke’s Bay. In particular, that the process helps:
    - participants better understand the perspectives of other participants;
    - participants to identify and consider factors that are not usually considered;
    - the group work together well; and
    - develop a holistic view of the issue which would support workable solutions/interventions.
- The system diagram is generic enough to be applicable across a range of other areas, not only geographic areas, but fish species also.
- The use of MVA in the project suggests a method for transparently highlighting commonalities between species. This can both: help inform *which* species to manage within a multi-species complex; or, if species have already been determined in a complex, help highlight which characteristics of those species may need further investigation to develop appropriate management actions.
- MVA can also help to identify or assess management actions as well as appropriate fishers’ activities. It can also help to identify information gaps that need to be filled in relation to species and/or management actions
- The complexity demonstrated within this system diagram may be useful to other agencies, outside FNZ, and regardless of whether FNZ were to be involved with the policy issue they may be interested in or not.
- The system diagram also presents an opportunity to inform part of the shared understanding that is often required across, between and even sometimes within agencies on differing yet interconnected issues. The ABM currently under development may provide complementary insights.

Figure ES1: Overview of the system diagram developed in this research

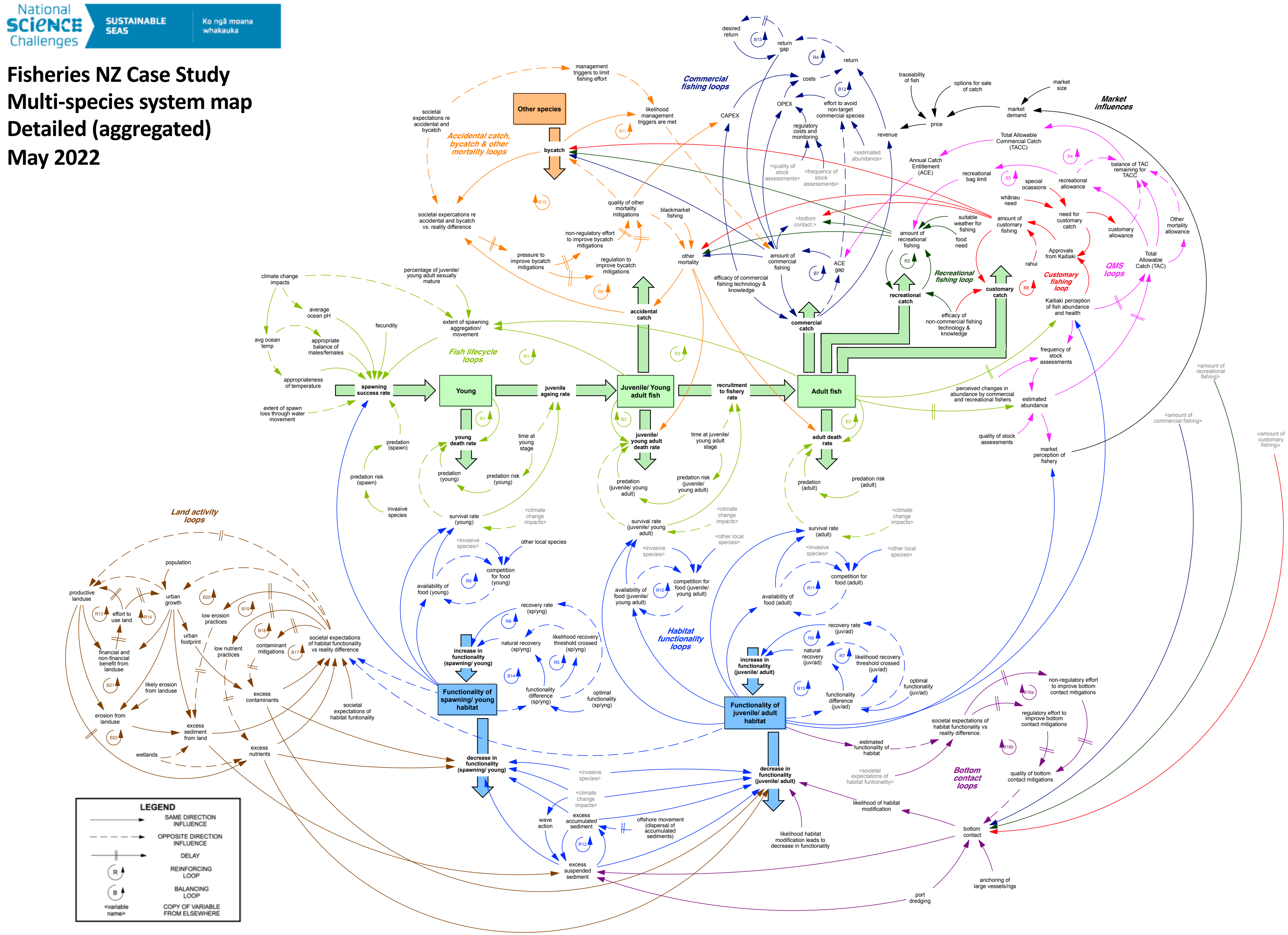
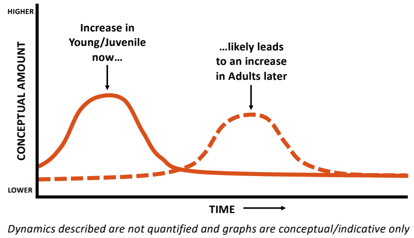
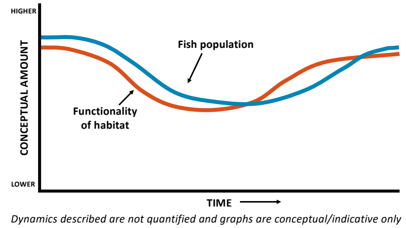
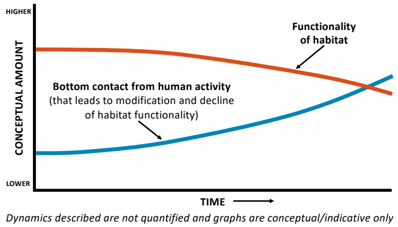
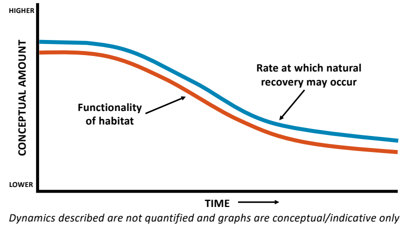
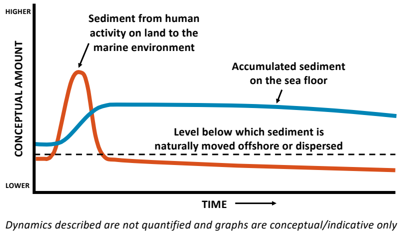
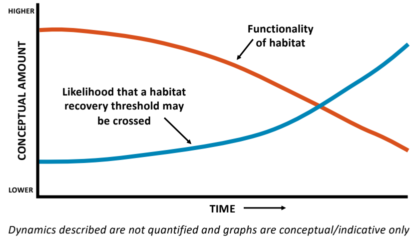
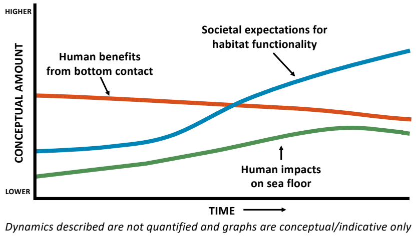
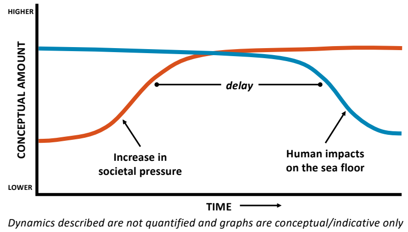
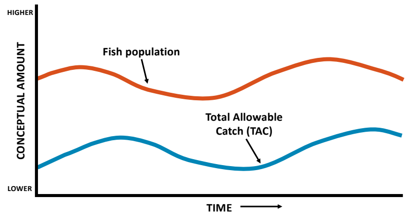
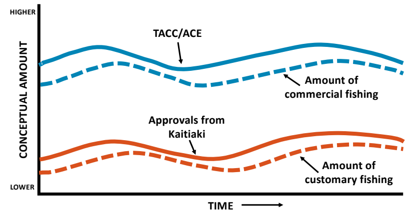
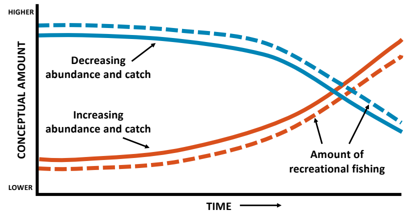
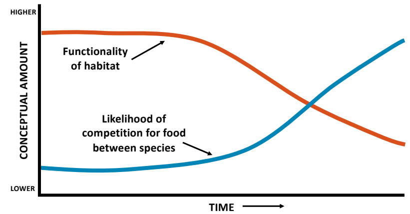
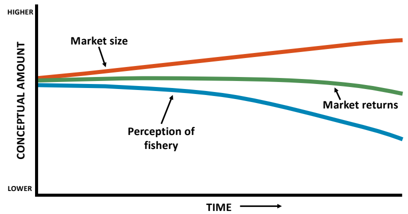
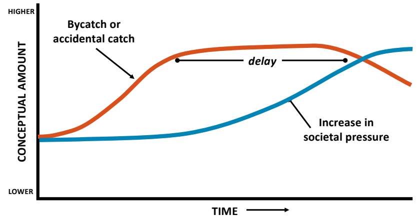
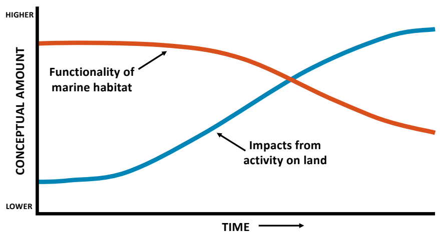


Table ES1: Individual dynamic insights inferred from system diagram

#	Important dynamic insight	Example behaviour over time (all graphs are conceptual only and not quantified)	#	Important dynamic insight	Example behaviour over time (all graphs are conceptual only and not quantified)
1	**The population level of the fishery is dependent on population levels in the earlier life-stages of the species.**		2	**Habitat functionality supports species viability at each stage of fish life.**	
3	**Bottom contact from human activity directly influences habitat functionality.**		4	**Low levels of habitat functionality inhibit its natural recovery.**	
5	**The persistence of accumulated sediment is likely to be long lasting.**		6	**The lower the habitat functionality, the more likely that a recovery threshold for that habitat may be crossed.**	
7	**Human impacts on the ocean are driven by reinforcing loops linked to human benefit and constrained by balancing loops of societal expectations (i.e. what society in general is willing to accept).**		8	**Delays involved with balancing loops between human impacts and societal pressures are likely to be significant.**	

#	Important dynamic insight	Example behaviour over time (all graphs are conceptual only and not quantified)	#	Important dynamic insight	Example behaviour over time (all graphs are conceptual only and not quantified)
9	**The QMS operates as a balancing loop, constraining and enabling catch.**	 *Dynamics described are not quantified and graphs are conceptual/indicative only*	10	**Within the QMS, both commercial and customary catch operate within balancing loops that self-constrain the corresponding amount of fishing. Commercial is constrained by ACE, customary is constrained by approvals from Kaitiaki.**	 *Dynamics described are not quantified and graphs are conceptual/indicative only*
11	**Recreational catch operates within a reinforcing loop that reinforces the amount of fishing based on catch. The amount of fishing is only partly influenced by recreational bag limits.**	 *Dynamics described are not quantified and graphs are conceptual/indicative only*	12	**Low levels of habitat functionality are likely to contribute to increased competition for food between species.**	 *Dynamics described are not quantified and graphs are conceptual/indicative only*
13	**Market returns are influenced by both market size and their perception of the fishery.**	 *Dynamics described are not quantified and graphs are conceptual/indicative only*	14	**Accidental catch (of commercial species) and Bycatch (of other and protected species) are constrained by societal expectations (i.e. what society in general is willing to accept) with long time delays.**	 *Dynamics described are not quantified and graphs are conceptual/indicative only*
15	**Activities on land can have a significant impact on the functionality of habitat in the ocean.**	 *Dynamics described are not quantified and graphs are conceptual/indicative only*			

1 Introduction

This report details exploratory research on using a system diagram and multi-variate analysis to inform a multi-species agent-based model, to help understand multi-species complexes for fisheries management. This report summarises the journey of applying, and the insights from the use of, the first two of these approaches. At the time of writing the agent-based model was in development. This model, and insights from it, will be documented and described in a subsequent report.

This research was undertaken as part of the Sustainable Seas National Science Challenge in late 2021 and early 2022. In collaboration with Fisheries New Zealand (FNZ), the case study focused on a multi-species complex centred around Tasman and Golden bays in Fisheries Management Area 7 (FMA7). To help inform the research FNZ invited a group of individuals with local knowledge and expertise in fisheries management or the marine environment to contribute to the development of the system diagram.

This report is structured in the following way:

Section 2 provides some background to the National Science Challenge and the case study; Section 3 outlines the methodology used, including summary descriptions of that Systems thinking, multi-variate analysis, and agent-based modelling are; while section 4 provides a summary description of the journey for the stakeholders and FNZ, as well as the research team.

Section 5 provides important instruction on how to read a system diagram. This section is necessary reading before the reader moves into either the overview (section 6) or detailed (section 13) descriptions of the system diagram.

Section 6, provides an overview description of the system diagram; while section 7 summarises a series of important dynamics that can be inferred by the structure of influences outlined in the system diagram. It is noted that these are not quantified as this is a qualitative process, yet the influences of factors or their dependencies upon others can be inferred.

Section 8 describes the areas of the System diagram that FNZ has responsibility for, or strong influence over; section 9 described how multi-species were attempted to be represented in system diagrams; while section 10 outlines how multi-variate analysis was used to help infer insight within the multi-species complex; and section 11 describes how this work will inform future agent-based modelling. Section 12 then provides a summary analysis of the benefits of the approach taken in this research.

Section 13 describes the system diagram in significant detail. This has been provided at the end to allow the reader to explore this in line with their interests. A reading of the report up to section 12 will still provide them with good insight into the research and its outputs.

Section 14 provides a summary of the report and a variety of supporting information is provided in the appendices. This includes a full version of the system diagram, as well as: a second version where all life stages and habitats are fully disaggregated (separated from each other), making this *more detailed*; and a third version where all influences have been summarised even further, to highlight the general presence of influence and feedback loop, making this *less detailed*.

2 Background

The case study that this report summarises forms part of the Sustainable Seas National Science Challenge. This section outlines the background to the Challenge and describes the multi-species case study in Nelson/Tasman.

2.1 The Sustainable Seas National Science Challenge

The Sustainable Seas National Science Challenge (the Challenge) (initiated in 2014) is one of 11 Ministry of Business, Innovation and Employment-funded Challenges aimed at taking a more strategic approach to science investment. The Challenge objective is: "*To enhance utilisation of our marine resources within environmental and biological constraints*" and its mission is: "*To transform Aotearoa New Zealand's ability to enhance our marine economy, and to improve decision-making and the health of our seas through ecosystem-based management* (EBM)". EBM is a holistic and inclusive approach to managing marine environments and competing uses for them, demands on them, and the ways New Zealanders value them (Hewitt et al. 2018). While the Challenge does not have the mandate to 'implement' EBM, it will provide underpinning research, tools and case studies to support the design and implementation of an EBM approach tailored to Aotearoa New Zealand. Partnering with central and regional government, industry, other stakeholders, and Māori is critical for the implementation of EBM and the success of the Challenge.

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

2.2 Nelson/Tasman – a case study

As co-development partners to the overarching Sustainable Seas project 4.2 *'Options for policy and legislative change to enable EBM across scale'*, Fisheries New Zealand (FNZ) was approached to be involved in a potential case study. Following a meeting with FNZ, managing multi-species complexes was highlighted as a case study that FNZ would be interested in. The use of system diagrams was suggested to FNZ as a qualitative method for exploring and seeking to understand socio-ecological systems. Subsequently, a system diagram was agreed as the tool to be used and internal FNZ dialogue settled on a case study focused on the Tasman and Golden bays mixed fishery.

Initially, the research plan was to develop a system diagram and then use part of this to inform an exploratory agent-based model. However, during the development of the system diagram the limitations of 'layering' the system diagram described for any single species into a series of multi-tier diagrams to provide multi-species insight, became apparent. The Challenge research team therefore suggested the coupling of a multi-variate analysis with the system diagram. This was added to the work programme to enable insight to the commonalities and differences between species-specific system dynamics within a multi-species complex, which would then help inform the agent-based model.

Therefore, the final outputs of the research are:

- this report, which describes a System Diagram and its supplementary multi-variate analysis, and
- an exploratory agent-based model, which will follow in a later, separate report.

2.3 A note on the participants convened to input to this process

As mentioned above, to help develop the system diagram a group of individuals with local knowledge and expertise in fisheries management or the marine environment was formed. These individuals provided knowledge and experience of:

- Customary, commercial and recreational fishing
- Marine environment and species conservation
- Local government policy and science, and
- Broader community values.

3 Methodology

This section explains the methodological process used to develop the system diagram, multi-variate analysis, and the dynamic insights they provide for multi-species management and EBM.

3.1 The project team

The project team consists of four people from Sustainable Seas and three people from FNZ. The objective of the project team is to collaboratively develop a modelling tool (socio-ecological model) to view the linkages between species caught together in a defined area/fishery, so that FNZ can better take into account multi-species considerations in their analysis and advice.

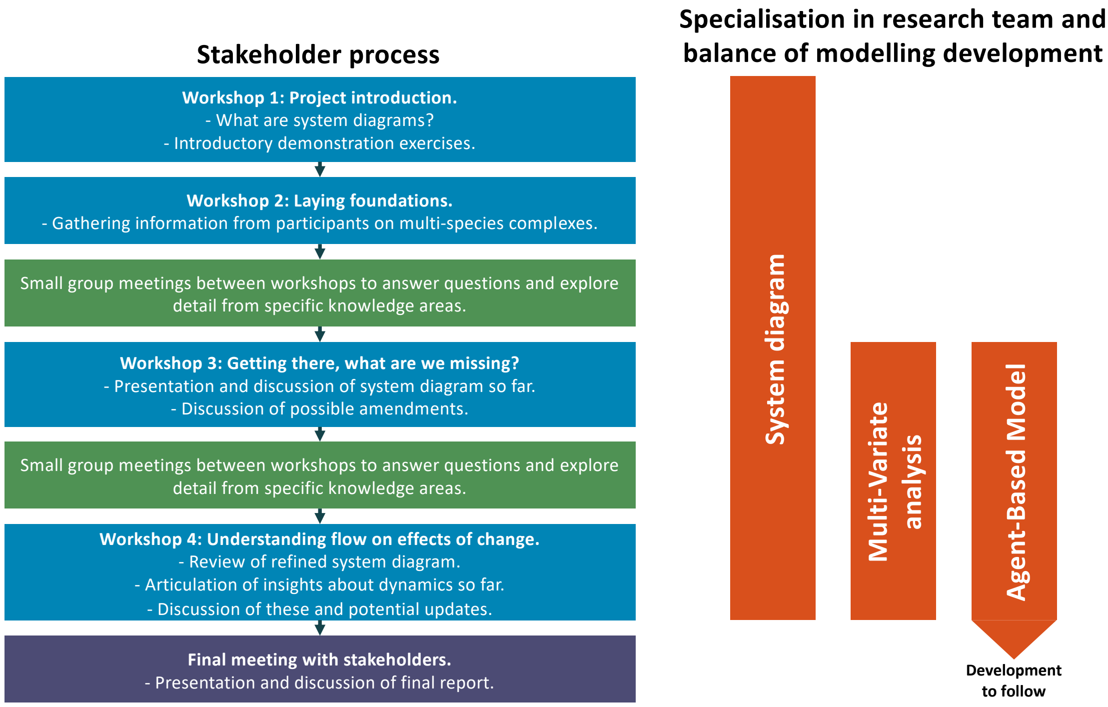
Project team members from the Challenge include: one NIWA one marine ecologist who is a professor in Statistics from The University of Auckland and a NIWA emeritus, who is also a member of the Challenge Leadership Team; one person with extensive fisheries experience and knowledge (who is also a quota owner) contracted to support with project management and relationship management; one NIWA agent-based modeller; and one Deliberate qualitative systems modeller.

Project team members from FNZ include: one Principal Analyst and two fisheries analysis from both Nelson and Auckland offices.

3.2 The case study process

This research followed the process outlined in Figure 1.

Figure 1.System diagram development process



The research was originally designed around a six-workshop process with participants as outlined earlier. However, after three workshops a comprehensive (yet still aggregated) understanding of how any fish species life stages are influenced by habitat functionality, impacts from land, and fishing practices and efforts, was generated from the system diagram. The extent to which inter-connections *between* a complex of species (that could be expanded or scaled) could be represented in a system diagram was challenging. Therefore, multi-variate analysis was added to the methodology to address this aspect. The agent-based modelling is informed by both the system diagram and multi-variate analysis and is being completed outside of the workshop process.

Therefore, the research process was **revised to four workshops and a final meeting with participants** to receive and reflect on the final draft insights and report. This process is shown in schematic form (Figure 1) above.

3.3 What is systems thinking?

The world that we live in is a dynamic interconnected place of cause and effect. The work of policy development often seeks to respond to undesirable behaviour and its cumulative impacts on our natural environment and therefore seeks to influence these causes, to restrict undesirable behaviour and/or enable desired behaviour.

'Systems Thinking' is a name often applied to a range of approaches to thinking about policy issues holistically. One of these approaches is the academic discipline of 'System Dynamics'. System Dynamics originated from the Sloan School of Management at the Massachusetts Institute of Technology, Cambridge, Massachusetts in the late 1960's.

Systems thinking, as articulated by the discipline of System Dynamics, is a conceptual framework and set of tools that have been developed to help clarify patterns of interconnectedness (Senge, 2006)[1]. They help us understand the structure of various interacting factors that generate the behaviour that we are trying to understand. Once these interconnections are articulated, we can better understand which parts of a system are having the most influence on behaviour, allowing us to identify levers of influence.

Where the term systems thinking has been used in this report, it refers to the qualitative concepts articulated by the discipline of System Dynamics (Sterman, 2000). The main qualitative tool that this discipline uses to understand systems is called a causal loop diagram (CLD) or a system diagram. **Throughout this report the term 'system diagram'** has been used.

A system diagram is generally used to help elicit causal assumptions from people involved in a system. More rigorous System Dynamics modelling can be used as a way of *quantitatively testing those causal assumptions* but in this research an ABM was considered a more appropriate modelling tool (see section 3.5).

It should be noted that during the workshop process different terms were often used for the system diagram being developed. It was, at different times, referred to as a 'system map' or a 'system dynamic map' (SDM). Any of these terms may be used and their use varies depending on the practitioner. However, at the time of writing the report, the author decided to avoid the use of the word 'map' to avoid confusion with geographical maps or discrete geographic areas, and to reinforce that these are conceptual diagrams describing influence. Hence the term 'system diagram' is used.

A description of the fundamentals relating to how a system diagram operates is provided in Section 5. This explains the key features of systems thinking and system diagrams – namely the concept of circular causality instead of linear causality. This is shown diagrammatically as either reinforcing or balancing feedback loops. Feedback loops are the basic building blocks of system diagrams.

Note: to fully understand the system diagram presented in the remainder of this report, it will be important for the unfamiliar reader to acquaint themselves with the contents of Section 5.

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

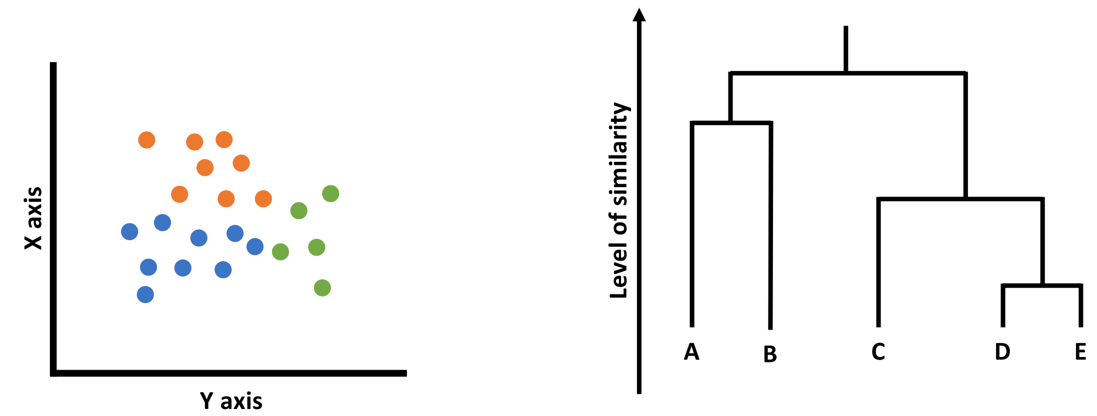
3.4 What is multi-variate analysis?[2]

Much science revolves around understanding the patterns of a single variable (for example single stock assessment, species distribution modelling, biodiversity indices). Multi-variate analysis (MVA) is simply a set of methods used to understand the patterns displayed by many variables at once (e.g., species assemblages), measured in multiple samples. Data for each variable/sample is collated in tabular form (a matrix) with variables generally being rows and samples being columns. For example, a number of cities with their latitude and longitude. Each method is underpinned by a "distance" measure that calculates how similar the samples are based on the variable entries. In the case of the cities, it is simply how far apart they are.

Two different types of analysis are then used to visualise the patterns - clustering or ordination. Clustering literally sorts the samples into groups that are more similar to each other than others, while ordinations seek to display these similarities and groupings in a figure (usually in 2 or 3 dimensions). In order to achieve the display, the ordination needs to determine an axis that pulls out the most variation along it, remove that variation, then determine another axis that pulls out the most of the variation left over, and so on. Clustering is simpler in that results are either just given as groups of a predefined similarity or displayed as a tree, and it is this method that we use here.

For a discussion around how MVA has been used to provide insights into multi-species complexes, please refer to section 10 later in the report.

Figure 2.Two ways of demonstrating insight from MVA – ordination and clustering



ORDINATION: The similarities of elements are highlighted through the proximity and similar colour.

CLUSTERING: The extent to which elements are similar can be represented via a 'tree' diagram.

3.5 What is agent-based modelling?[3]

Agent-based modelling (ABM) is a computational modelling approach for simulating the interactions between autonomous individuals and their impacts on the system. An agent is any autonomous entity that makes decisions (or appears to make decisions) for itself, such as people, fish, and management agencies. ABM is spatially explicit and temporally dynamic, meaning that agent actions can be analysed across space and over time. ABM is an appropriate modelling approach when seeking to understand individual-level interactions rather than aggregated ones, is well-established to help improve system understanding, and is often used in conjunction with participatory processes (in this case study a system diagram).

[2] This sub-section is written by Judi Hewitt.

[3] This sub-section is written by Andrew Allison.

ABMs are usually tested using Monte Carlo analyses, where large numbers (100s-1000s) of simulations are run to understand the behaviour space, or stochasticity, of the model. Statistical testing using generalised linear models can be used to determine statistically significant differences between different model calibrations.

A research question to guide the ABM was developed in the latter workshops. For a discussion around what this is and how it was developed, please refer to section 11 later in the report.

Why has an ABM been used when a system diagram can also be developed into a System Dynamics model?

ABM and System Dynamic models differ in that: ABM's are spatially explicit and look at individual level interactions; while System Dynamic models are not spatially explicit and look at the aggregated interactions.

An ABM has been used here partly because the case study area is spatially explicit; and partly because there was a focus on multi-species management, which is a more focused area within a wider system. In future applications, there may also a place to consider using System Dynamics models to understand broad dynamics across the system more widely (socio-economic etc), as well as ABM in specific focused areas within that. The system diagram may be a useful tool to communicate the complexity of the inter-connected world to a variety of other stakeholders and agencies.

4 Applying systems thinking in multi-species management

This section provides a summary of the journey that was experienced by workshop participants, FNZ and the research team as they navigated the series of workshops and developed the system diagram.

Exploring the use of system diagrams to advance multi-species management was the main objective of this research. As Figure 1 shows, the bulk of the methodology was devoted to this.

The first workshop was an opportunity for the workshop participants to meet (not all had worked together before) and explain what systems thinking was. This was aided by several light-hearted-yet-serious thinking exercises run by the facilitator (the report author). These exercises demonstrated the applicability of systems thinking and helped participants recognise that sometimes things that appear obvious, may in fact operate in a counter-intuitive way. These exercises also highlighted that people think and view the world differently, which highlights the complexity of developing policy and provided a good introduction to discussing participants understandings of how influences operated in the case study area.

The second workshop actively gathered information from the participants about what areas to focus the research on – primarily what multi-species complex. Here it was agreed that the research would focus on species caught with snapper, which were deemed to be five other species: red gurnard; tarakihi; John dory; rig; and flatfish (in general). While smaller numbers of other species were recognised as also sometimes being caught with snapper, this was deemed sufficient for the purposes of exploring the system diagram approach. The balance of that workshop focused on identifying and discussing different factors that influence the snapper population. This was valuable discussion that allowed the author to draft an initial system diagram before the next workshop.

The intention was that the system diagram would provide several things. Firstly, the research sought to develop a generic system diagram that would be applicable for any species and potentially transferable across different locations. This would incorporate components of habitat functionality; influence of land activity on the marine habitat; as well as the various acts of fishing and bycatch. Secondly, the research sought to highlight the value to wider EBM aspirations that incorporating other influences on the marine environment and potential impacts on species abundance might bring. It was recognised that this was a very wide remit.

Components (or part-sections) of the system diagram were tested as they were being developed. The author met with the participants, in between workshops two and three, to discuss their areas of expertise in more detail, and the system diagram approach generally. In workshop three some initial components of a system diagram were presented to the group and discussed. The resulting discussion helped to accept, refine, or reject factors in the system diagram and how they were related, as it was forming.

The process between workshops three and four was like that between workshops two and three. However now the system diagram was more advanced and the discussions helped refine specific areas of interest to the participants.

Throughout the process of delivering workshops three and four, the author and research team began to feel that a purely qualitative representation of multi-species complexity, as had been planned, would be insufficient for demonstrating the complexity sought from workshop participants and FNZ. This was due to a range of reasons: it was the first time a layered system diagram approach was being tested to capture interactions between multi-species; the number of species in a multi-species complex were more numerous than had been anticipated during project planning; and the interactions between species were heavily focused between the various life stages of a fish species and not the other related habitats, fishing practices and land-based influences that had also been mapped. It was realised that for larger numbers of inter-species interactions, this would simply become too confusing. Also, while six species had been agreed within the multi-species complex in this process, it was also important that the tool could potentially be transferrable to a larger complex, as well as other species or other areas in the future.

MVA was suggested as a supplementary tool to highlight common areas of overlap in the system diagram, between species in the multi-species complex. This approach can highlight the amount of similarity that the species within the complex have at different life stages or with different factors in the diagram and thus the extent to which their management within a multi-species complex may be successful. For example, if all the species shared a certain type of habitat at a certain life stage, or had similar spawning/breeding traits, then any activity that may have impacted those habitats or traits would be more likely to impact the other species within the complex. Similarly, species with different habitat requirements or different rates of growth to maturity may confound successful management in the suggested multi-species complex. MVA can also help to identify areas within the system diagram that may benefit from greater attention and discussion or may inform areas within the ABM that might be more important to focus on.

At this point of the project several other things were also recognised and contributed to adjusting the project methodology. Firstly, that less time was required for the development of the system diagram than had originally been scheduled. This was a good indication that the system diagram process was a time-efficient way of developing broad system insights and general agreement and alignment on things that were influencing fish species. Secondly, it was recognised that to take the system diagram to a wider audience to explain and validate the system diagram in a single session (as was originally the intention), was too ambitious due to time and resource constraints. Therefore, the wider audience session was removed from the workshop schedule and the use of other communication techniques and avenues will be considered to inform a wider audience of the project and outcomes.

Workshop four then focused on reflecting on what was deemed to be the final version of the system diagram and the insights from the multi-variate analysis. Some minor points were raised for clarification but there was general support from the workshop group for where the process had landed.

In addition, a question to guide the agent-based modelling was informed by workshop discussions and FNZ’s goal to advance multi-species management.

The following sections now progress into explaining how to read a system diagram, before providing an overview of the current system diagram and the insights gained from it. A detailed description of the diagram is provided in the final section.

5 How to read a system diagram

Before the system diagram is described in the following section, a guide to the symbols and terms used is provided below. An understanding of the concepts outlined in this section is necessary before reading either the overview or detailed description of the system diagram.

At the core of a system diagram is the desire to visually articulate the relationships between factors that best explain the behaviour of the system that you are trying to understand. This visual articulation of relationships is known as 'system structure'.

Following sub-sections outline important fundamental elements of system structure. These are:

- feedback loops;
- how relationships/influences are correctly annotated;
- the use of the 'goal/gap' structure (as this can explain how different loops dominant in a system at different times); and
- understanding how influences can have different effect if they are flowing 'upstream' or 'downstream'.

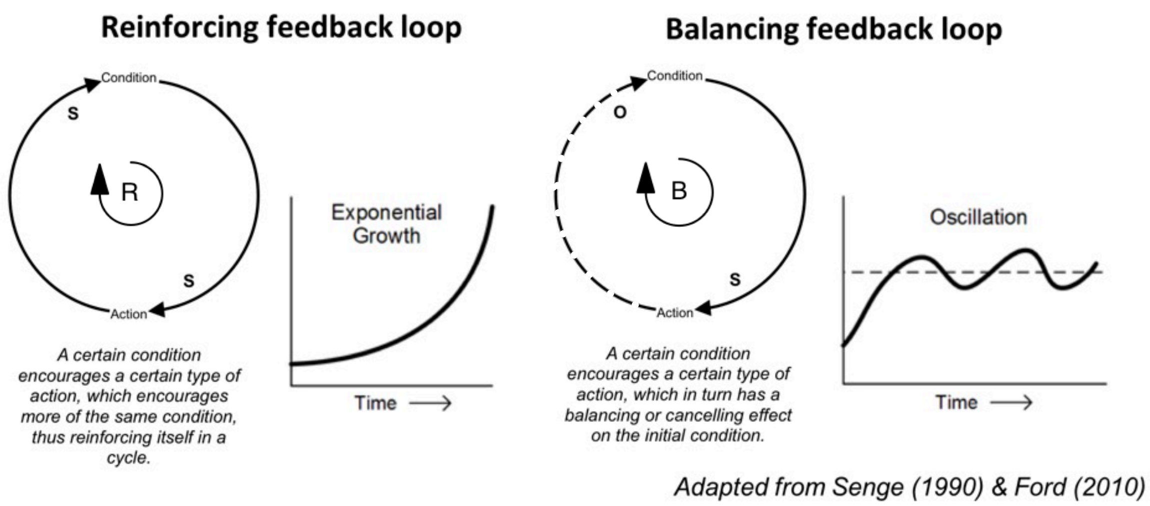
It is recommended that the reader familiarises themselves with these concepts to read the system diagrams in this report and gain insight from them.

The final sub-section outlines different ways that system diagrams can be used.

5.1.1 Feedback loops – the basic building blocks of a system diagram

Systems thinking is especially interested in systems where loops of causality are identified – these are called *feedback loops*. There are two types of feedback loops, *reinforcing* and *balancing* (Senge, 1990). The two types of feedback loop are described in Figure 3.

Figure 3.The two types of feedback loops



In a *reinforcing feedback loop*, the direction of influence provided by one factor to another will transfer around the loop and influence back on the originating factor in the *same* direction. This has the effect of *reinforcing* the direction of the original influence, and any change will build on itself and amplify. For example, (assuming no withdrawals) money in a bank account will earn interest which in turn increases the amount of money in the bank, which in turn enables it to earn more interest. When viewed over time this will present as consistent growth (or decline).

Reinforcing loops are what drive growth or decline within a system.

In a *balancing feedback loop*, the direction of influence provided by one factor to another will transfer around the loop through that one factor (or series of factors) and influence back on the originating factor in the *opposite* direction. This has the effect of *balancing out* the direction of the original influence. For example, a thermostat connected to a heater will turn on if the room is cold, this will heat the room to the desired temperature and which point the thermostat turns the heater off, then the room will begin to cool until such a point as the thermostat turns on again, at which point the cycle begins over again. This will present as an oscillating trend over time.

Balancing loops are what create control, restraint or resistance within a system.

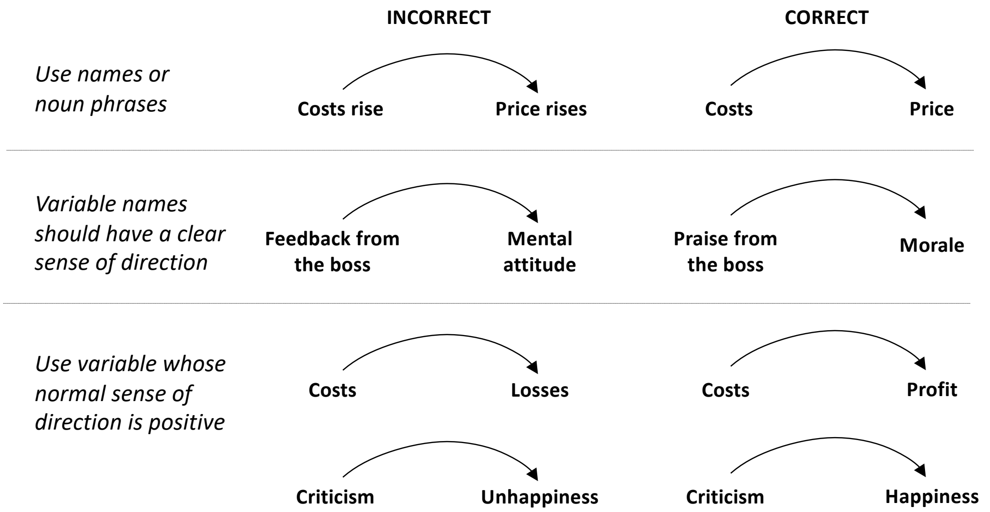
Feedback loops can be made up of more than two variables and can be drawn together to form a system diagram. How these interact provide insight into how a wider system operates.

5.1.2 Labelling factors

An important concept within system diagrams is the concept of accumulation (or decumulation) – where do things build-up (or decrease)? The simple analogy of a bathtub is often used to describe this (for more on this see section 5.1.5).

In system diagrams, this concept of accumulation is captured by describing variables in such a way that their name implies that they can *increase or decrease*. This means that they should be described as *nouns*; have a clear sense of *direction*; and have a normal sense of direction that is *positive*. Examples to demonstrate this are shown in Figure 4.

Figure 4.Labelling variables



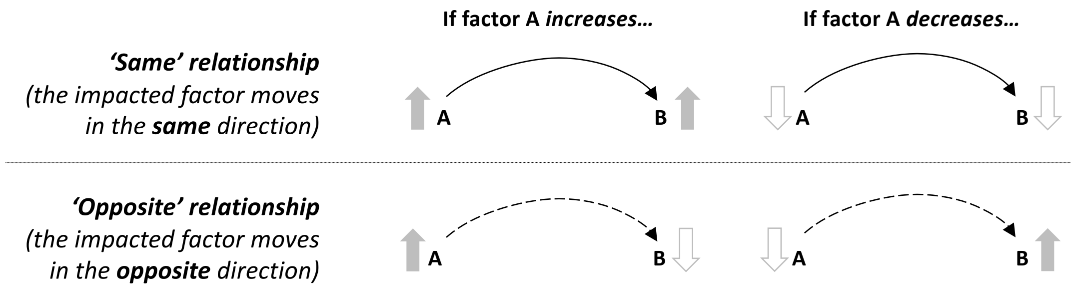
Adapted from Sterman (2000)

5.1.3 Labelling causal relationship arrows

Factors within system diagrams are connected (and made into feedback loops) by arrows, which indicate that one factor has a causal relationship with the next. **'Same'** arrows are drawn with a **solid line**, while **'opposite'** arrows are drawn with a **dashed line**. These terms correspond to the direction of change that any change in the first variable will have on the second variable.

For example, if a directional change in one variable leads to a directional change in the next variable in the *same direction*, it is a *same relationship* (i.e. if A goes up and B goes up, or vice versa). Likewise, if the second variable changes in the *opposite direction*, it is an *opposite relationship* (i.e. if one A goes up and B goes down, or vice versa). See Figure 5 for a visual description.

Figure 5.How arrows are labelled in system diagrams



Adapted from Sterman (2000)

If there is a notable *delay* in this influence presenting in the second variable, when compared to the other influences described in the system diagram, this is annotated as a *double line crossing the arrow*. An example of this is shown in Figure 6. In these diagrams these are conceptual delays and are not quantified.

Figure 6.How delays are annotated on arrows

5.1.4 Goals and gaps – the changing dominance of individual loops.

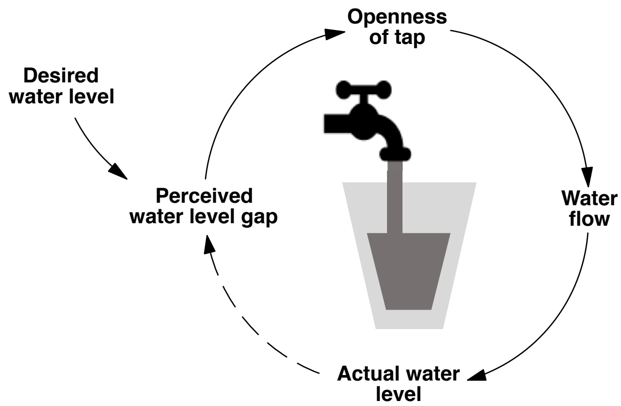
Understanding that multiple loops are operating within a system is the first useful insight of systems thinking. A further useful insight is understanding that not all loops may operate at the same strength all the time. Different loops can dominate the dynamics of a system at different times. For example, a system might be dominated by a period of growth (a reinforcing loop), but when some kind of physical limit is approached (e.g. the available space in a pond for algae to grow) a balancing loop will start to dominate, therefore slowing the rate of growth.

One useful mechanism for gaining insight into the strength of a balancing loop is the *'goal/gap' structure*. This is a structure that combines both a *desired level* of something (a 'goal'), with an *actual level* of something. This *difference between these variables* is the 'gap' between the desired and actual levels.

The higher the desired level and the lower the actual level, **the greater the 'gap' or difference and the greater the dominance** of the loops that this gap influences. The lower the desired level and the higher the actual level, **the lower the 'gap' or difference, and therefore the weaker the dominance** of the loops that this gap influences.

The 'goal/gap' mechanism features in multiple places in the system diagram in this report. A conceptual example is shown in Figure 7 which shows the act of filling a glass of water.

Figure 7.Example of a 'goal/gap' structure in a system diagram – pouring a glass of water



Adapted from Senge (2006)

Initially, while the *gap/difference* between the desired and actual water level is *high*, the tap will be opened more and the strength of the water flow is higher.

As the desired level of water is approached the *gap/difference reduces*, so the tap is closed further, weakening the flow of water (you don't want the water to overflow the glass), until it is fully closed when the water level reaches the desired amount (Senge, 1990).

5.1.5 Stock and flow notation (bathtubs and flows)

The bulk of the system diagram described in this report are made up of variables and arrows as described above. Such variables are the core of system diagrams. However, in some places selected variables are described in a slightly more involved way – they are shown in *stock and flow notation* – which provides a slightly more nuanced level of insight to the behaviour of the system.

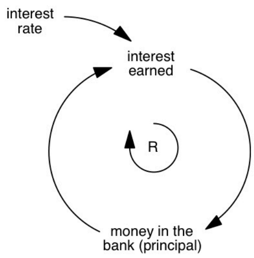
A stock and flow notation is similar to a metaphorical *bathtub* (as mentioned earlier). A stock might be anything that we are interested in – number of people, quality of water, level of morale, etc. **Stocks can ONLY increase through more inflow** (the tap over the metaphorical bathtub), **and ONLY decrease through more outflow** (the drain in the metaphorical bathtub), for whatever you are interested in – just like the level of water in a bathtub. This is reflected in the diagrammatic description of a stock and flow (Figure 8).

Figure 8.Stocks and flows – the more advanced notations used in System Dynamics

Both basic system diagrams and more complicated stocks and flow diagrams explain the same type of behaviour. Yet the inclusion of stock and flow notation within a system diagram allows a greater level of insight to understand whether a change in a key variable (stock) is due to a change in *inflow* or a change in *outflow* (see Figure 9 for an example).

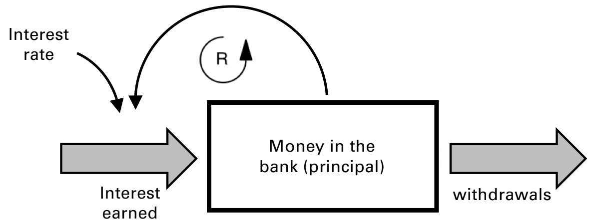
In this report, the use of stock and flow notation has been included for the underpinning central variables of fish life stages, functionality of habitat and bycatch. However, to avoid confusion with the use of 'stock' in fisheries management, the term 'bathtub' will be used.

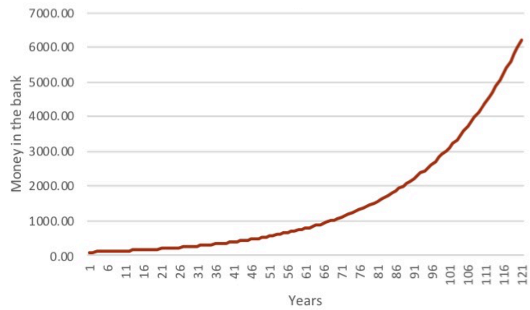
Figure 9. Comparison of reinforcing loops: System diagrams (causal-loop diagrams) vs. Stock and flow diagrams



System diagram reinforcing loop (top)
compared to a
Stock and flow diagram (SFD) reinforcing loop (bottom)

Both cause the exact same behaviour (exponential growth of money in a bank account). *Stock (bathutub) and flow* diagrams allow more insight to whether the stock changes due to a change in *inflow* or a change in *outflow*





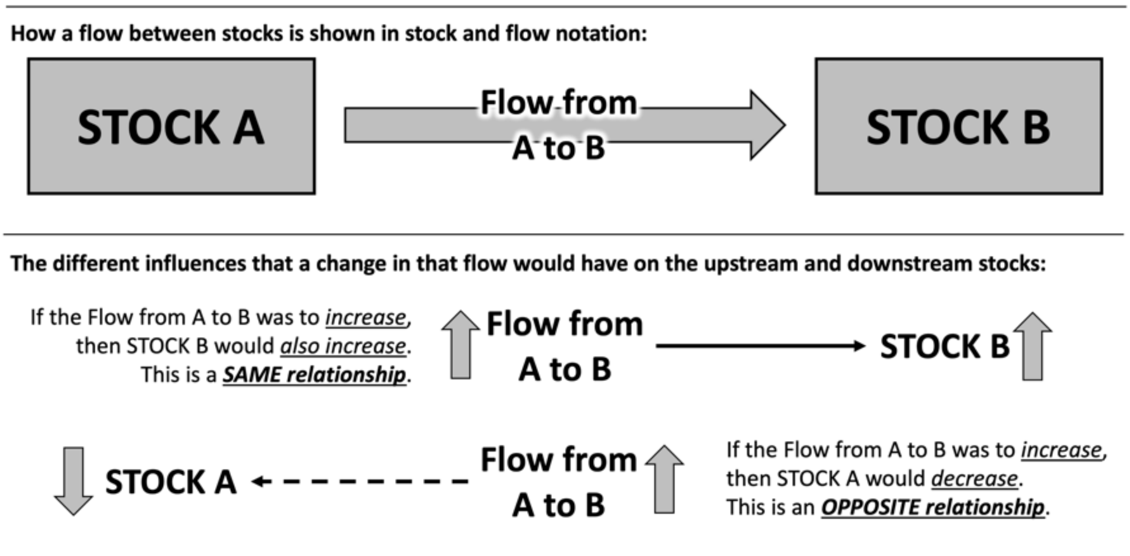
Stocks and flows are the language of simulation modelling in System Dynamics. If any of these diagrams were to be developed into quantitative simulation modelling (in potential future research), then full stock and flow formulation would need to be used. This spectrum of quantitative rigour within the tools of System Dynamics is explained in the next section.

5.1.6 How influence operates differently upstream and downstream of a change in flow

When a diagram is made up partly of variables and arrows of influence, as well as stock (bathtub) and flow notation (as the system diagram in this report is), then the flows themselves often form pathways of influence within feedback loops. When this occurs, the influence can be either *same or opposite*, depending on which way along the flow the influence is travelling.

The flow structure and the variable/arrow influence structure are compared below in Figure 10. Where flow form part of notable feedback loops that are discussed in this report, the influence direction has also been noted.

Figure 10. How influence operates differently upstream and downstream of a change in flow



When a flow forms part of a feedback loop and the influence is travelling ***with the flow*** (i.e. downstream), then that is a ***same influence***. That is, if the flow was to increase (or decrease), then the stock ***to which it is flowing*** would also increase (or decrease), all other things being equal.

When a flow forms part of a feedback loop and the influence is travelling ***against the flow*** (i.e. upstream), then that is an ***opposite influence***. That is, if the flow was to increase (or decrease), then the stock ***from which it is flowing*** would decrease (or increase), all other things being equal.

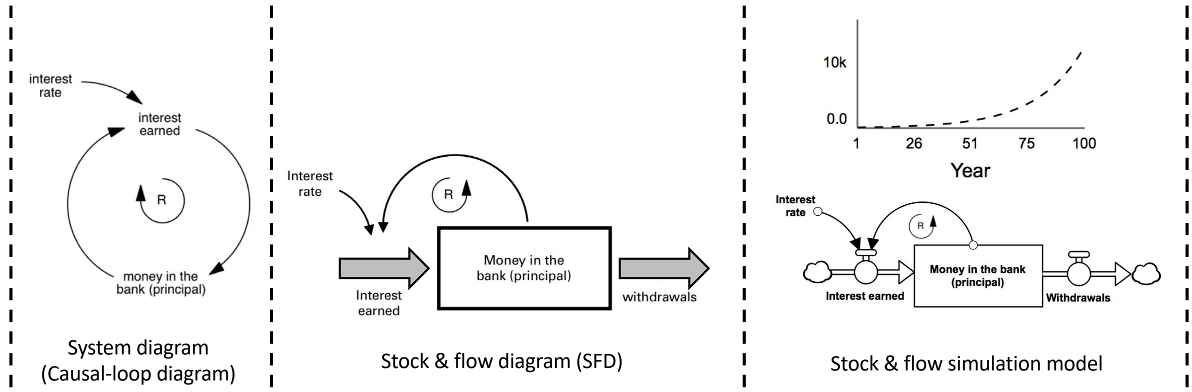
5.1.7 How system diagrams can be used

This section briefly outlines how system diagrams themselves fit within a spectrum of quantitative rigour in the discipline of System Dynamics, and how they may be used in conjunction with other methodological approaches.

System diagrams on the spectrum of quantitative rigour within System Dynamics

The tools of System Dynamics themselves exist on a spectrum of quantitative rigour. These are shown in Figure 11 which highlights how these varying tools can demonstrate the same system, each being able to demonstrate the complexity of that system, yet to differing levels of quantitative rigour or robustness. **This spectrum is also intended to highlight that system diagrams are not the only possible output from the use of SD tools.**

Figure 11. System Dynamics tools exist on a spectrum - System diagrams (or Causal loop diagrams), Stock and flow diagrams, and Simulation modelling.



System diagrams exist at the conceptual (low quantitative rigour) end of this spectrum. These can range from using the simple dynamics of a single feedback loop to demonstrate a type of behaviour, to multiple loop systems (as in this report) – which can demonstrate the high level of complexity of a system.

The next step up in quantitative rigour are Stock and Flow Diagrams (SFD). While some components of the system diagram within this report use stock (bathtub) and flow notation, these diagrams are not considered complete of 'full' SFD. This is because SFD usually contain multiple stocks of interest, not just the focal variables. Although not all factors need to be stocks, their architecture tends to represent a greater level of mathematical functionality (although this may not actually be computed). This is because SFD tend to be qualitative representations of the actual functions and equations that would be represented in a stock and flow model. This level of detail has not been achieved in this report.

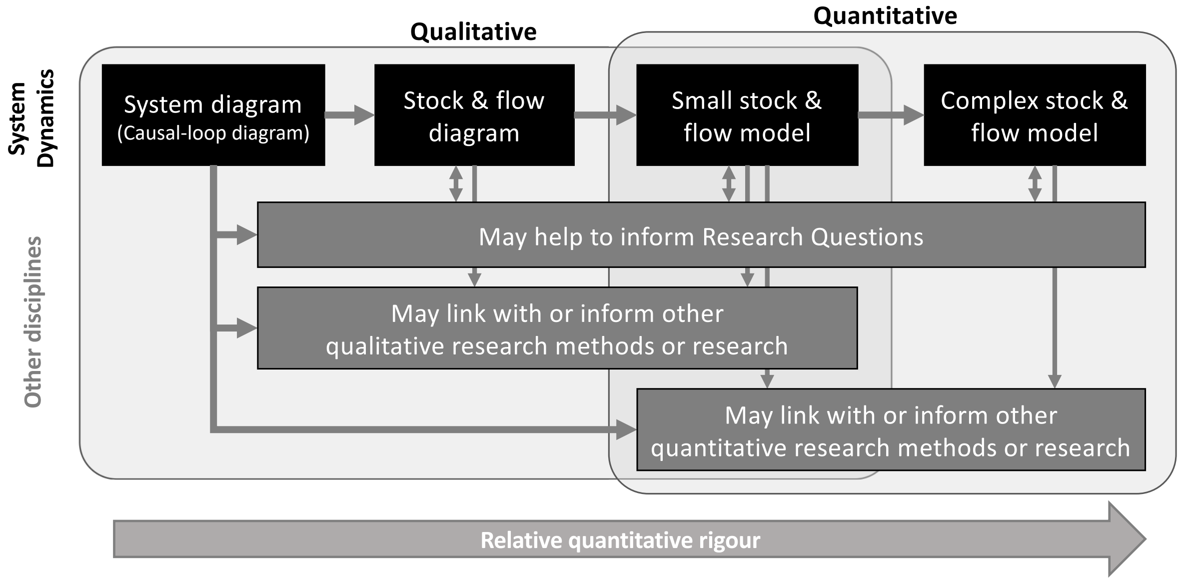
Computer simulation modelling (based on the stock and flow formulation) is the next step in quantitative rigour – that is, turning stock and flow diagrams into simulation models. There is huge variability in the types of simulation models that can be developed, with some people advocating that large system insights can be gained from using small scale models (Meadows, 2008), to others demonstrating the utility of large scale and highly complex simulation models (Sterman, 2000).

A system diagram is generally used to help *elicit causal assumptions* from people involved in a system. More rigorous SD modelling would be a way of *quantitatively testing those causal assumptions*.

How system diagrams may link with other methodological approaches

While system diagrams may result in complex stock and flow diagrams and/or simulation modelling within System Dynamics, it may also link with or inform other methodological approaches within a wider research project. A diagram outlining how this can work is shown below in Figure 12.

Figure 12. How system diagramming can link with other research methodologies



Note: There is an overlap of the qualitative and quantitative areas of application because they are not mutually exclusive. For example, some quantitative relationships in models and their calculations may be informed by research or data, while others may be informed or assumed via some form of participatory process.

The series of *black boxes* across the top of the diagram in Figure 12 represent the increasing quantitative rigour of the System Dynamics tools. The *grey boxes* in the lower part of the diagram represent the research questions that may be generated during research, as well as the different qualitative and quantitative methods that may be employed within the research. All of these may be informed by the system diagramming process, or a more rigorous evolution of a system diagram (for example a small stock & flow model).

For example, a system diagram may provide insight to the nature of relationships within the system that may inform how a research question is framed. It may also inform the types of people who might be involved (as researchers or as research subjects). Further, the nature of the relationships elicited throughout the system diagramming process could also inform other research methods – either qualitative or quantitative – that may be used (as is the case with agent-based modelling in this research).

Please note that the point of explaining this is to highlight that more precise numerical measures tend to give systems theorists the opportunity to specify more precise relationships and thus add layers of quantitative rigour to their models. Yet highly complex systems need not only be represented with tools of high quantitative rigour – these can be articulated with qualitative tools also, as in this report. In fact, in complex worlds, qualitative methods are more likely to capture complexity and make it available for analysis. In complex worlds, systems thinking and causal mapping may be used as a decision-support tool that enables a more holistic view of inter-relationships that may otherwise be missed or excluded from reductionist analyses (Senge, 2006).

6 Overview of the system diagram

Having introduced the reader to the basic concepts of system diagrams in the previous section, this section provides an overview of the system diagram developed in this case study. The complete diagram is shown in Figure 13. A larger version of the same diagram is provided in Appendix 2.

Following this overview section, the sections summarising the feedback loops and dynamic insights identified in the system diagram, the dynamics insights, and the insight from the MVA are all described.

A detailed description of this system diagram follows later in this report (section 13). There, the diagram is built up gradually and the influencing factors, the feedback loops that they form part of, and the potential dynamics they create are explained in detail.

If the reader would prefer to understand the detail of the system diagram before reading the summarised insights, it is recommended that they read the later Section 13, before returning to this point in the report and reading Sections 7 onwards.

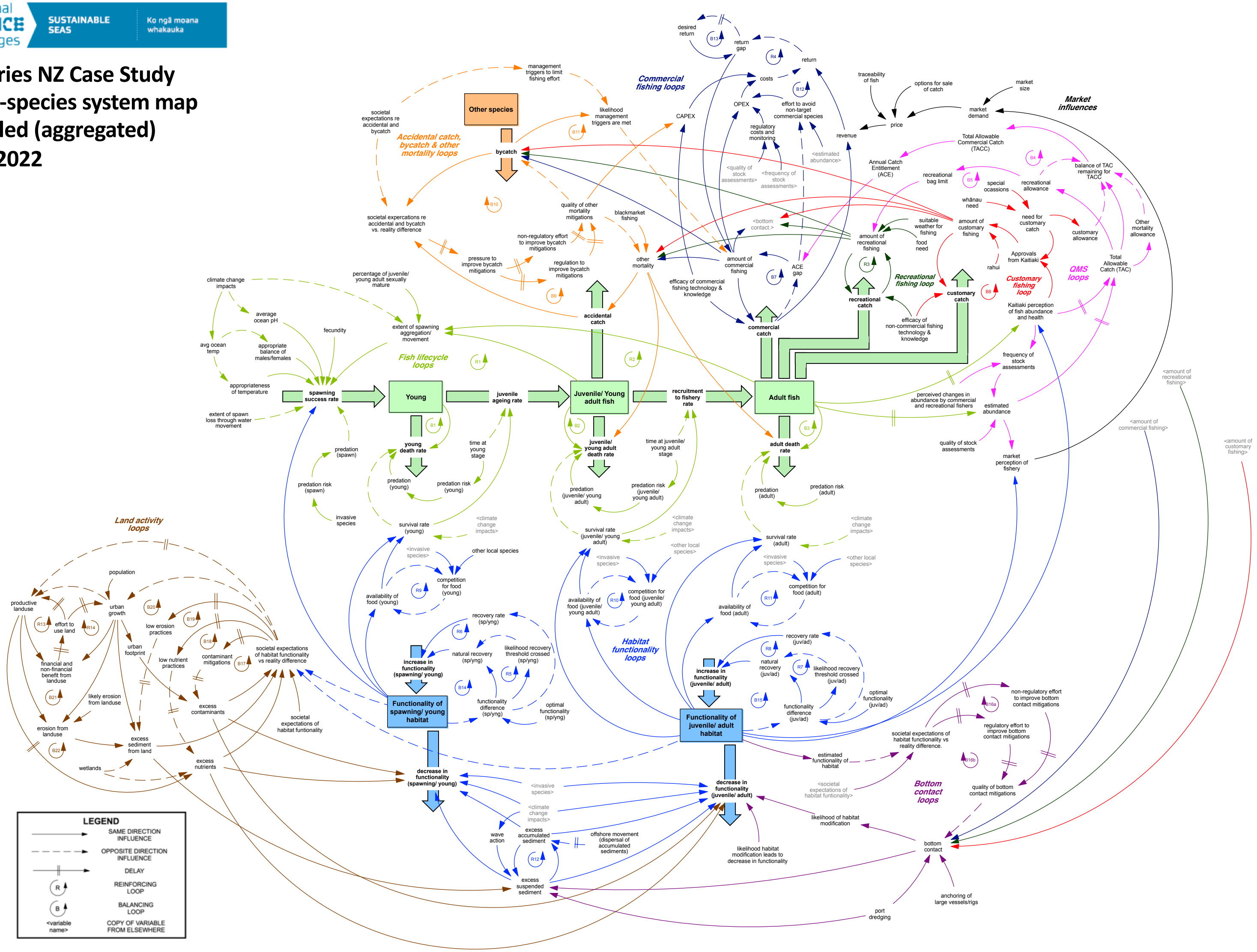
6.1 Summary of what is included the system diagram

A summary of what is included in the system diagram is below. For more detail on any of these, refer to the relevant section in the detailed description of the system diagram (Section 13).

- At the core of the system diagram is a generalised representation of the life stages of a commercial fish species within the multi-species complex. This is made up of three broad life stages or ‘bathtubs’: ‘Young’; ‘Juvenile/Young adult fish’; and ‘Adult fish’. This is shown in green in the centre of the diagram. For more detail see section 13.1.
- The fish life stages are influenced by the ‘Functionality of habitat’ of their various habitats at each life stage. These are grouped into two: 'Functionality of spawning/young habitat’ and ‘Functionality of juvenile/adult habitat’. This is shown in blue in the bottom centre of the diagram. For more detail see section 13.2.
- Activity on the land influences the ‘Functionality of habitat(s)’. This is shown in brown in the bottom left of the diagram. For more detail see section 13.3.
- Bottom contact from human activity also influences the ‘Functionality of habitat’. The different types of bottom contact, their impact, and the drivers of mitigations for this are shown in purple in the bottom right of the diagram. For more detail see Section 13.4
- The Quota Management System (QMS) and the influences on the three types of fishing takes (customary, recreational and commercial) are shown in the top right of the diagram. This also includes a representation of market influences on commercial fishing. The QMS influences are shown in pink; the customary fishing influences are shown in red; the recreational fishing influences are shown in dark green; the commercial fishing influences are shown in dark blue; and market influences on commercial fishing are shown in black. For more detail see Section 13.5.
- Other mortality, accidental catch (of non-target QMS species or undersize target QMS species) and bycatch (protected and other species) are shown in the top centre and top left of the diagram. These are shown in orange. For more detail see Section 13.6.

Figure 13. Complete System Diagram

Fisheries NZ Case Study
Multi-species system map
Detailed (aggregated)
May 2022



7 Important dynamics highlighted by the system diagram

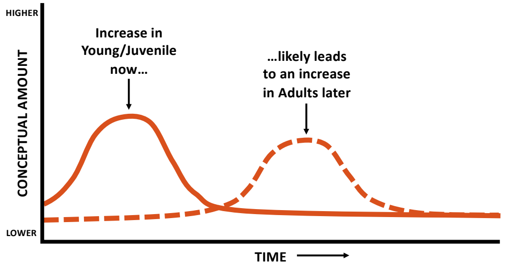
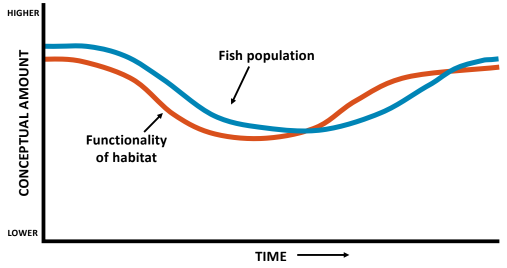
The previous section provided and overview of the system diagram. A detailed description of the system diagram can be found in Section 13 and a summary of the feedback loops can be found in Appendix 3. Reflecting on the system diagram, particularly how the feedback loops, ‘bathtubs’ and ‘flows’ interact with one another, generates useful insights. Feedback loops especially, indicate where influence on the factors of interest is *internal* (endogenous), or from within the ‘system’. This section summarises important dynamics (i.e. the articulation of cause and effect that can explain influence trends over time) that an analysis of the system diagram identifies.

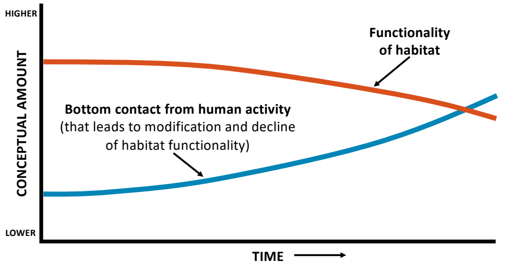
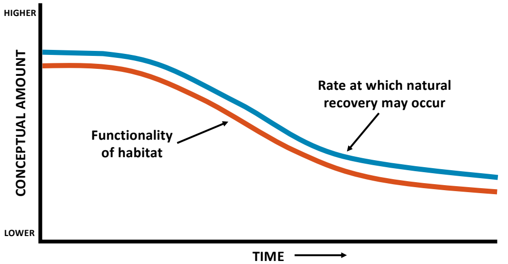
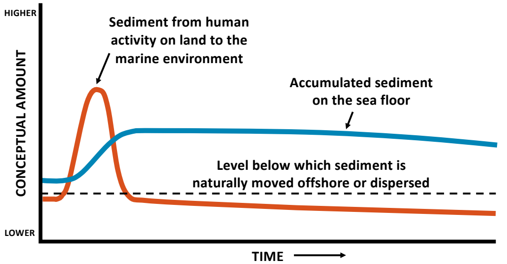
This list is mostly a subset of (or in some cases a combination of) the feedback loops described in Appendix 3. Some insights are primarily descriptions of the ‘bathtubs’ and ‘flows’ identified.

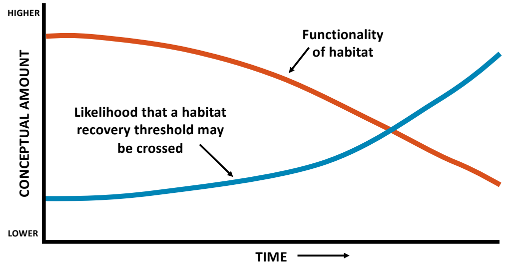
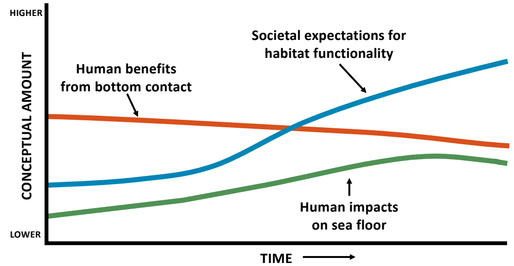
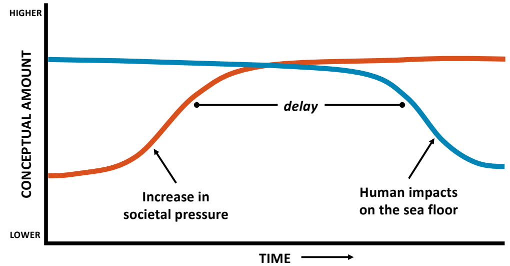
There are several critical points to note before reflecting on the insights contained in the table below. These are:

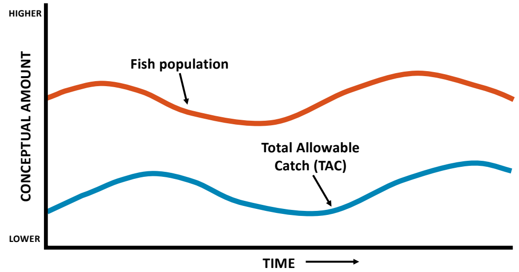
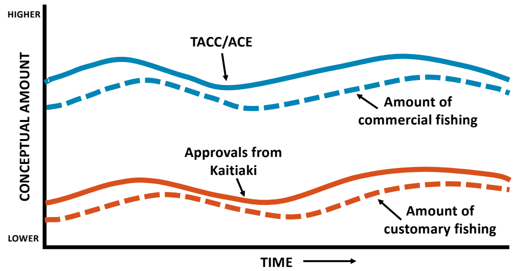
- All the dynamics below are ***described in singular or individual terms***. In reality, many will interact and influence each other. To understand these is beyond the scope of such a conceptual diagram and may be explored in future modelling.
- The ***dynamics described are not quantified***. They are insights observed and inferred from the structure of the relationships in the system diagram only.
- The ***graphs are conceptual only***. They are intended to show the general anticipated *direction* of change. None of the change indicated is quantified and they should not be considered representative of actual levels of change. It is the direction of change from the interactions that is intended to be demonstrated.

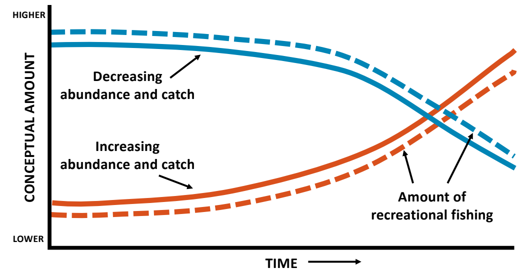
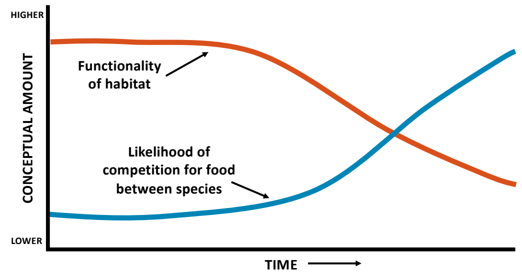
Table 2. Important dynamics highlighted by the System diagram

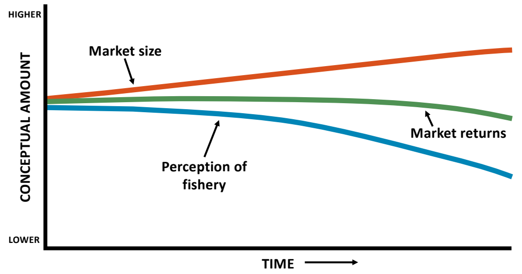
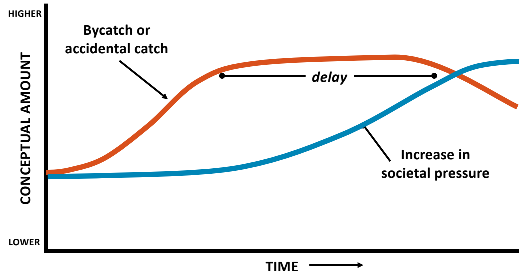
#	Important dynamic insight	Description of dynamic insight	Example behaviour over time (all graphs are conceptual only and not quantified)
1	**The population level of the fishery is dependent on population levels in the earlier life-stages of the species.**	An abundant fish population is dependent on sufficient quantities of the species ageing through all life stages to recruitment into the fishery. Any temporary dominance of lower survival rates will increase the death rate at any life stage, depressing fish population at that stage which will flow through to the older life stages. Any impacts on fish population in the early life stages of a species will flow through the later life stages. If a fisheries population is low, its recovery will be dependent on the remaining number of sexually mature adults, the time it takes that species to mature through their life stages and the strength of the survival rates and/or accidental catch rates at the earlier life stages.	 *Dynamics described are not quantified and graphs are conceptual/indicative only*
2	**Habitat functionality supports species viability at each stage of fish life.**	Habitat functionality is impacted by human activities both on land and in the ocean. The impacts of climate change influence habitat functionality at multiple touch-points. Reductions in habitat functionality are likely to further suppress/impact the ability of species to maintain or recover population levels. Sustained reductions in habitat functionality will have a sustained flow on impact to sustaining or recovering species population levels.	 *Dynamics described are not quantified and graphs are conceptual/indicative only*

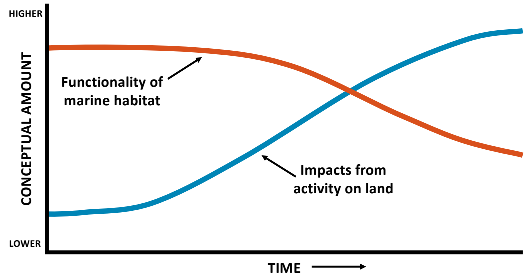
#	Important dynamic insight	Description of dynamic insight	Example behaviour over time (all graphs are conceptual only and not quantified)
3	**Bottom contact from human activity directly influences habitat functionality.**	Bottom contact from human activity leads to habitat modification. If there is a high likelihood that habitat modification leads to a decrease in habitat functionality, then such bottom contact is considered to directly influence habitat functionality. Dependent on whether the habitats of young, juveniles and adults of species managed as a multi-species complex overlap, bottom contact may impact on one or more of these.	 *Dynamics described are not quantified and graphs are conceptual/indicative only*
4	**Low levels of habitat functionality inhibit its natural recovery.**	Sustained reductions in habitat functionality are likely to decrease the rate at which recovery occurs and the likelihood that recovery will occur naturally.	 *Dynamics described are not quantified and graphs are conceptual/indicative only*
5	**The persistence of accumulated sediment is likely to be long lasting.**	The total volume of excess accumulated sediment is likely to persist for a significant time period. The delays involved with the natural offshore movement or dispersal of fine accumulated sediment are significant.	 *Dynamics described are not quantified and graphs are conceptual/indicative only*

#	Important dynamic insight	Description of dynamic insight	Example behaviour over time (all graphs are conceptual only and not quantified)
6	**The lower the habitat functionality, the more likely that a recovery threshold for that habitat may be crossed.**	The lower the habitat functionality, the greater the likelihood that a recovery threshold for that habitat will be crossed. This may inhibit the ability of a habitat to recover naturally.	 *Dynamics described are not quantified and graphs are conceptual/indicative only*
7	**Human impacts on the ocean are driven by reinforcing loops linked to human benefit and constrained by balancing loops of societal expectations (i.e. what society in general is willing to accept).**	The impacts of human activity on the ocean are constrained by balancing loops of societal expectations. These are likely to involve long time delays (see dynamic insight #8). At the same time the activities causing those impacts are driven by reinforcing loops. Human benefit derived from such activities tends to drive a desire for more activities. The total level of human activities that impact the ocean are determined by the net impact of these competing loops. If the reinforcing loop dominates, more activity will occur. If the balancing loop dominates, the activity (and its impacts) will plateau.	 *Dynamics described are not quantified and graphs are conceptual/indicative only*
8	**Delays involved with balancing loops between human impacts and societal pressures are likely to be significant.**	The delays involved with balancing loops between human impacts and societal pressures are likely to be significant. This is because many things are assumed along this pathway of influence. For example, it may take time for human impacts to become known, then to become quantified, then to be become accepted by a significant enough number of people to be able to influence change. The flow on impacts on the dynamics in these loops are likely to be relative to the strength of societal pressure. *NOTE: It is important to note that if the delay is too long, recovery may be impossible without some intervention not presently in the diagram included*	 *Dynamics described are not quantified and graphs are conceptual/indicative only*

#	Important dynamic insight	Description of dynamic insight	Example behaviour over time (all graphs are conceptual only and not quantified)
9	**The QMS operates as a balancing loop, constraining and enabling catch.**	At its simplest, the QMS operates as a balancing loop, constraining or enabling an overall volume of catch. This is made up of customary, recreational, and commercial catch.	 *Dynamics described are not quantified and graphs are conceptual/indicative only*
10	**Within the QMS, both commercial and customary catch operate within balancing loops that self-constrain the corresponding amount of fishing. Commercial is constrained by ACE, customary is constrained by approvals from Kaitiaki.**	Both the commercial and customary catch operate within balancing loops. These are separate, but related, to the QMS loops. **For commercial catch:** A balancing loop of the QMS sets the Total Allowable Commercial Catch (TACC). This loop is likely to operate over multiple years. Nested within (or related to) the larger QMS loop is a balancing loop with the Annual Catch Entitlement (ACE), which constrains the amount of commercial fishing. This loop operates over a single year. **For customary catch:** A balancing loop where Kaitiaki perceptions of population levels enable or constrain the issuing of approvals from Kaitiaki is the balancing loop that constrains the customary catch. This likely operates within seasonal, annual and longer contexts. This may also include the use of Rahui.	 *Dynamics described are not quantified and graphs are conceptual/indicative only*

#	Important dynamic insight	Description of dynamic insight	Example behaviour over time (all graphs are conceptual only and not quantified)
11	**Recreational catch operates within a reinforcing loop that reinforces the amount of fishing based on catch. The amount of fishing is only partly influenced by recreational bag limits.**	The recreational catch operates within a reinforcing loop nested within a balancing loop of the QMS. A balancing loop of the QMS sets the Recreational allowance which, along with sustainability concerns, are used to determine the Recreational bag limit. This loop is likely to operate over multiple years (the timeframe over which bag limits could be adjusted). Nested within (or related to) the larger QMS loop is a reinforcing loop linking the amount of recreational fishing and recreational catch. This operates on a much shorter timeframe (e.g. daily, weekly, seasonally). In times of plenty this will tend to operate in an upward direction, resulting in increased amounts of recreational fishing and catch. In times of scarcity this will tend to operate in a downwards direction, resulting in lower amounts of recreational fishing and catch. As bag limits only apply to a single day, generally (unless specified in regulation for specific species for multi-day trips) there is not a formal local or individual method for constraining cumulative recreational catch by any individual. Therefore, the intensity and success of this loop is more likely to be determined by population level than by societal pressures.	 *Dynamics described are not quantified and graphs are conceptual/indicative only*
12	**Low levels of habitat functionality are likely to contribute to increased competition for food between species.**	The availability of food is linked in a reinforcing loop with competition for food between and within species groups. When food is plentiful there is likely less competition, when food is scarce, competition increases (all other things being equal). Availability of food is part of habitat functionality, therefore, when habitat functionality is low, this is likely to constrain available food (all other subfactors being constant) and mean that the reinforcing loop operates in a 'downward' way – increasing competition between species and further lowering levels of available food.	 *Dynamics described are not quantified and graphs are conceptual/indicative only*

#	Important dynamic insight	Description of dynamic insight	Example behaviour over time (all graphs are conceptual only and not quantified)
13	**Market returns are influenced by both market size and their perception of the fishery.**	Market demand and price are a function of both market size and the perception of that market of the fishery. The market perception of the fishery is likely to be based on perceptions of both its population levels and habitat functionality. Delays involved with market perception may mean that perceptions (good or bad) may persist for some time beyond such perceptions no longer reflecting reality.	*Dynamics described are not quantified and graphs are conceptual/indicative only*
14	**Accidental catch (of commercial species) and Bycatch (of other and protected species) are constrained by societal expectations (i.e. what society in general is willing to accept) with long time delays.**	Accidental catch and bycatch (see the description of terms for the system diagram for a description of accidental catch and bycatch) are constrained by balancing loops involving societal expectations with long time delays. These are largely driven by public perceptions which are likely influences on process improvements (which may also be influenced by market forces, not shown here), albeit after delays. (For an example of this, see dynamic insight #8 ‘Delays involved with balancing loops between human impacts and societal pressure are likely to be significant’ above). These loops compete with the amount of commercial and recreational fishing. The stronger of these loops will dominate – if overall societal expectations are stronger then constraints on accidental and bycatch will likely increase, if drivers of the amount of commercial and recreational fishing are stronger, bycatch and accidental catch is likely to continue.	*Dynamics described are not quantified and graphs are conceptual/indicative only*

#	Important dynamic insight	Description of dynamic insight	Example behaviour over time (all graphs are conceptual only and not quantified)
15	**Activities on land can have a significant impact on the functionality of habitat in the ocean.**	Activities on land can have a significant impact on the functionality of different habitats in the ocean. While land and marine activity are often managed discretely or separately, there is a strong link between the two. This dynamic refers to the presentation of impacts from activity on land to the functionality of habitat in the ocean. This is assumed to present relatively quickly (e.g. sediment smothering an area). This does not describe any delays that may be involved in the dispersal of that impact. See dynamic #5 for an example of the persistence of the impact of sediment.	 *Dynamics described are not quantified and graphs are conceptual/indicative only*

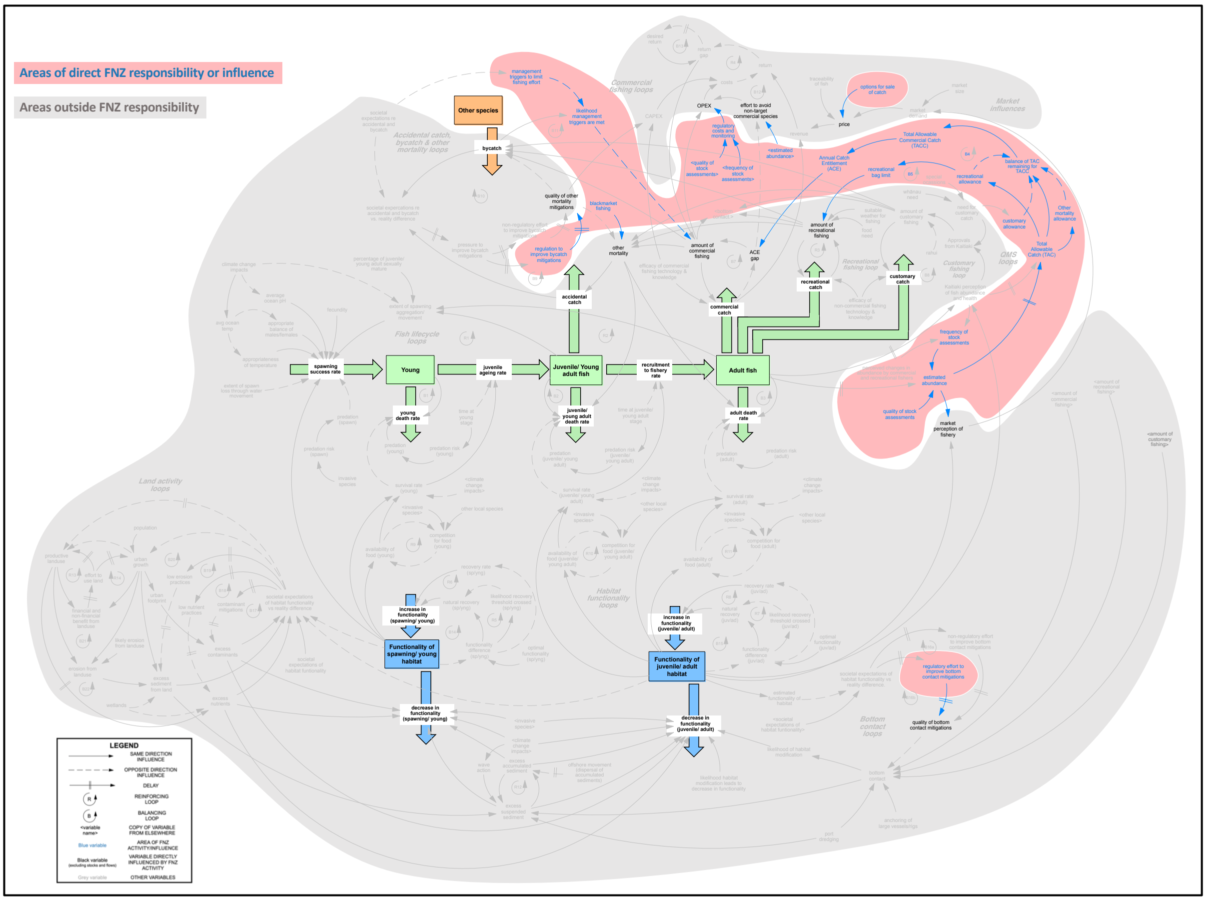
8 Where Fisheries New Zealand has influence over factors in the System diagram

This section provides an overview of where in the system diagram, FNZ has direct responsibility or influence. This is provided to highlight the areas of influence that FNZ both has and does not have, over many of the factors identified as influencing different areas of the marine environment and species abundance.

The areas identified in the system diagram that FNZ has responsibility for are shaded in light red in Figure 14. Those where FNZ has no responsibility are shaded in grey. Please note that this diagram is not intended to be readable, it is a visual prompt to highlight the **relative difference in the size of the grey areas versus the light red areas**.

Areas where FNZ's responsibility may have a *flow on influence* are the factors in black writing that can be seen in the grey areas (again, not intended to be read, more for illustrative purposes as these are also shown in the other figures in this section.).

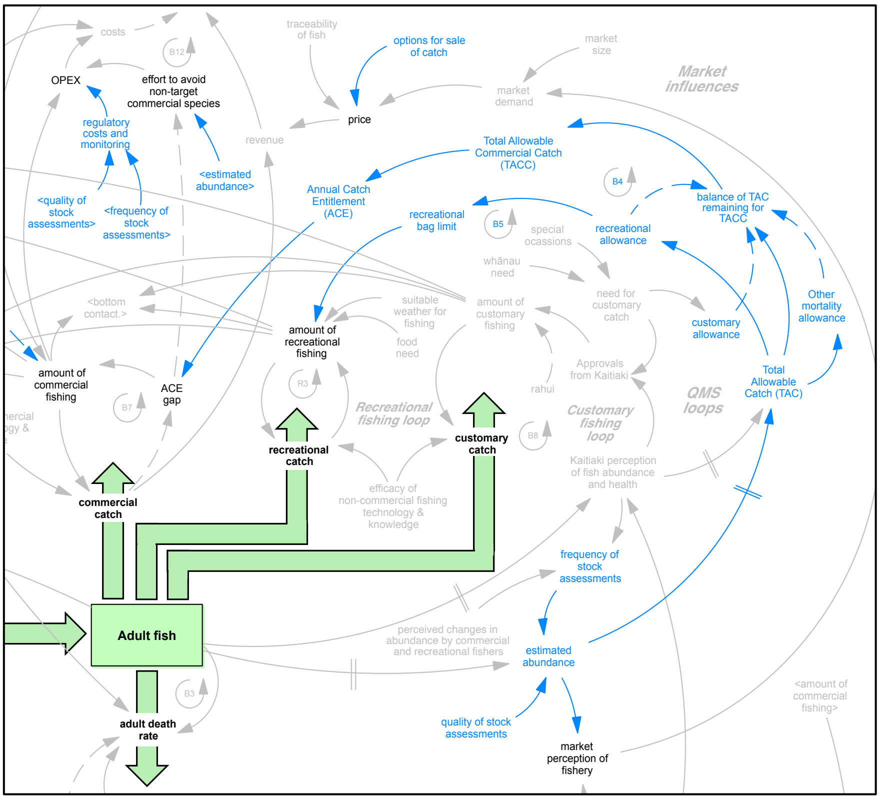
Figure 14. Overview of the system diagram highlighting Fisheries New Zealand's influence/ responsibility



These are examined in more detail in following figures.

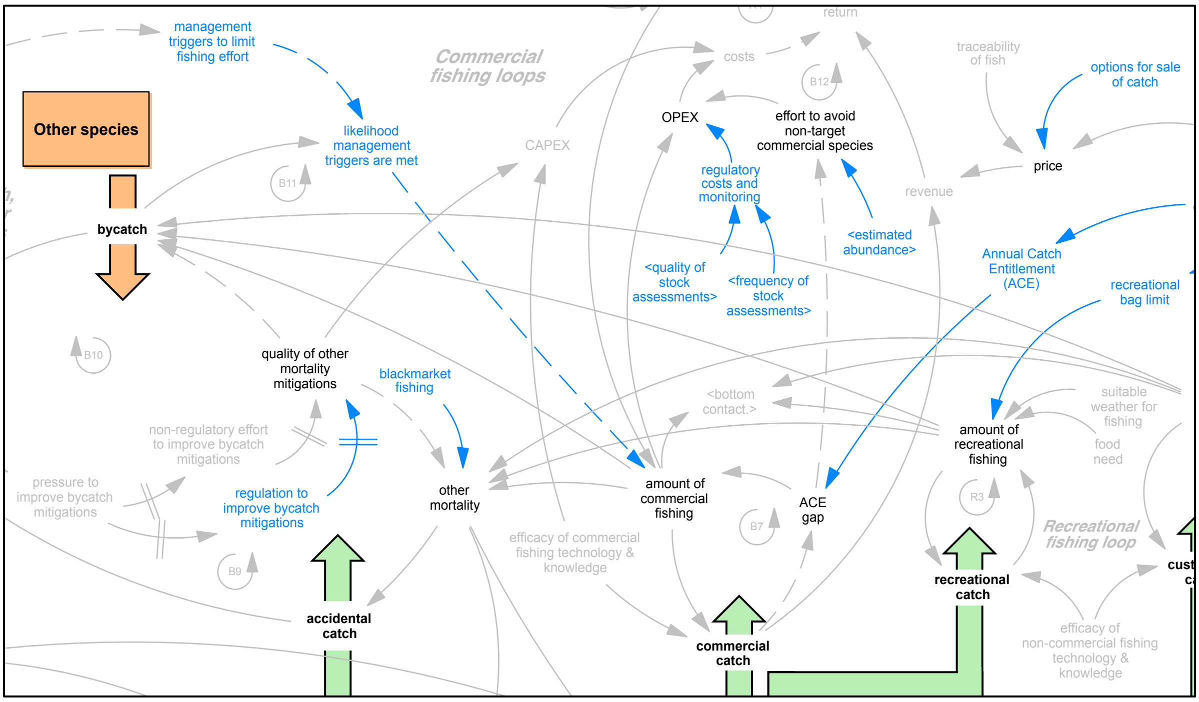
FNZ has responsibility for estimating the abundance of fish stocks and determining the QMS limits. These are shown in the factors highlighted blue in Figure 15.

Figure 15. FNZ: estimating abundance and QMS limits



Many of FNZ's responsibilities are shown in Figure 16. These include cost recovery for stock assessments from commercial fishers, as well as managing the other regulatory costs of commercial fishing such as licensing and monitoring fees. They are also responsible for the legislation that provides a range of options for the sale of catch (most is via licenced fish receivers; a small amount is via direct wharf sales).

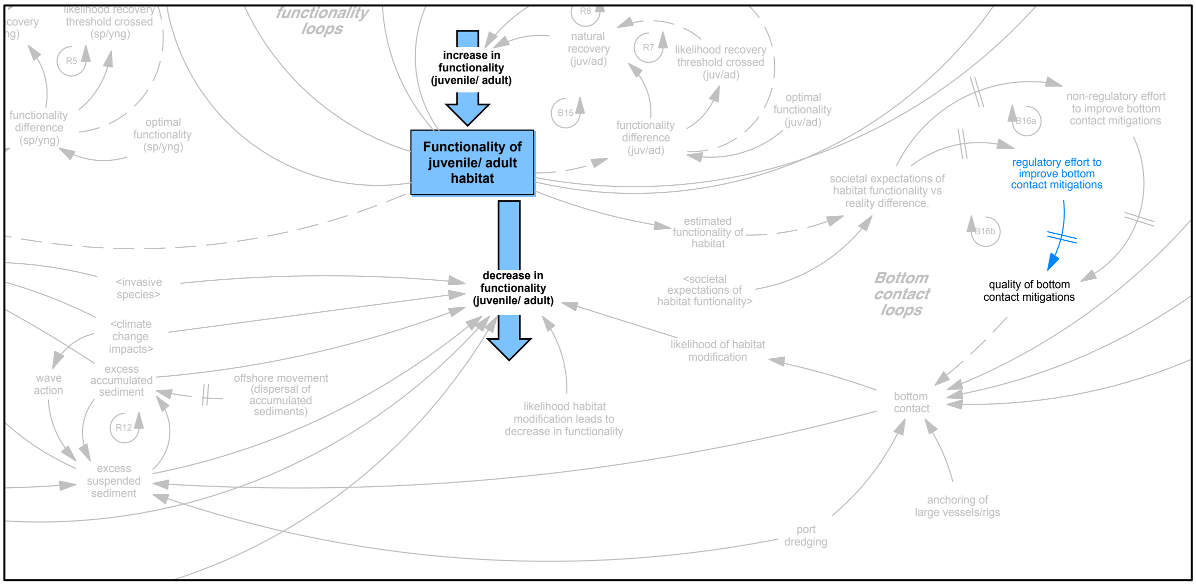
Figure 16. FNZ: cost recovery, catch sale options, other mortality, bycatch and blackmarket fishing



Further, they are also responsible for a range of activities involved with monitoring and managing bycatch of protected species in collaboration with the Department of Conservation. They have a regulatory power to mandate improved bycatch mitigation if this is necessary, although they are not in control of the act of fishing itself. They have an important role to play in developing, implementing and monitoring management triggers that are designed to limit bycatch. They also have responsibility for monitoring and enforcing compliance in relation to blackmarket (illegal) fishing.

Finally, FNZ also have the regulatory power to enforce certain levels of minimum standards in relation to fishing gear, these improve the quality of bottom contact mitigations (see Figure 17).

Figure 17. FNZ: bottom contact mitigations

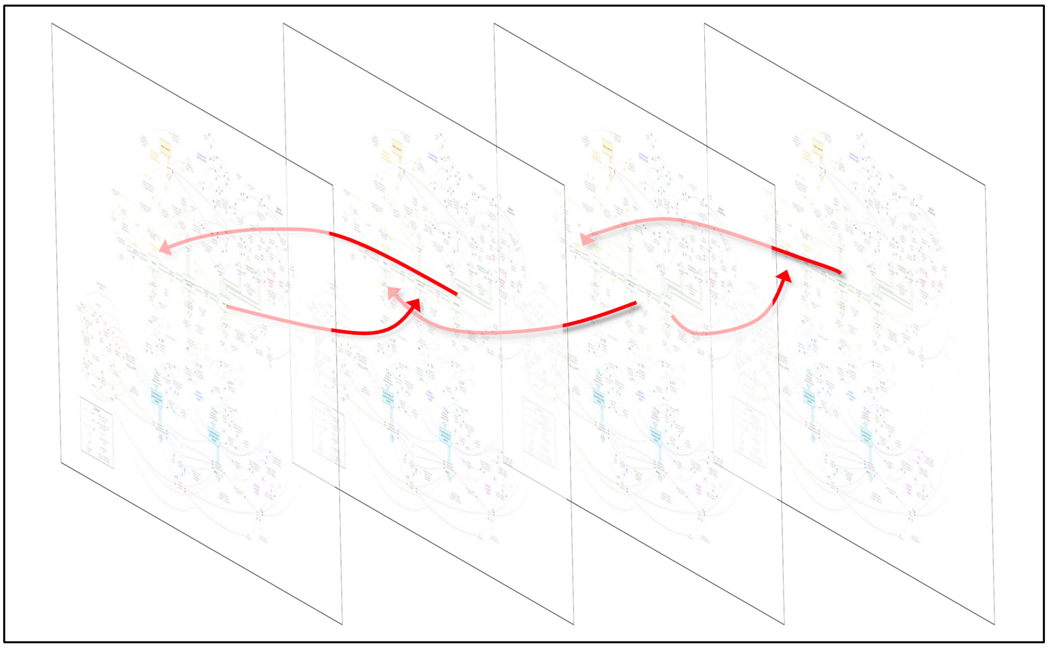


9 Representing multi-species complexes in a system diagram

Section 6 provides an overview of the system diagram for a single species (and it is explained in detail in Section 13). That diagram has been developed in such a way that different versions of the same diagram for different species could be ‘layered’ on top of each other and different connections made between the species.

During the development of the research plan, it was anticipated that this would be done. It was expected that influences between species in a multi-species complex may be able to be represented simplistically by drawing conceptual links *between* individual species versions of the system diagram. A conceptual demonstration of this is shown in Figure 18.

Figure 18. Conceptual demonstration of how influence between species were anticipated to be represented



As the research progressed, it became apparent that this would not likely be a useful way of demonstrating such interconnectivity. This was for three main reasons:

- It would be quite challenging to demonstrate this visually,
- Technically, most species were at risk of predation from most other (carnivorous) species, even their own, resulting in a situation where ‘everything was preying on everything’ and nuanced insights of connectivity between species was unlikely, and
- FNZ had the desire to potentially scale up the number of species included in such an analysis. Being able to add further species was a pre-requisite to any approach devised.

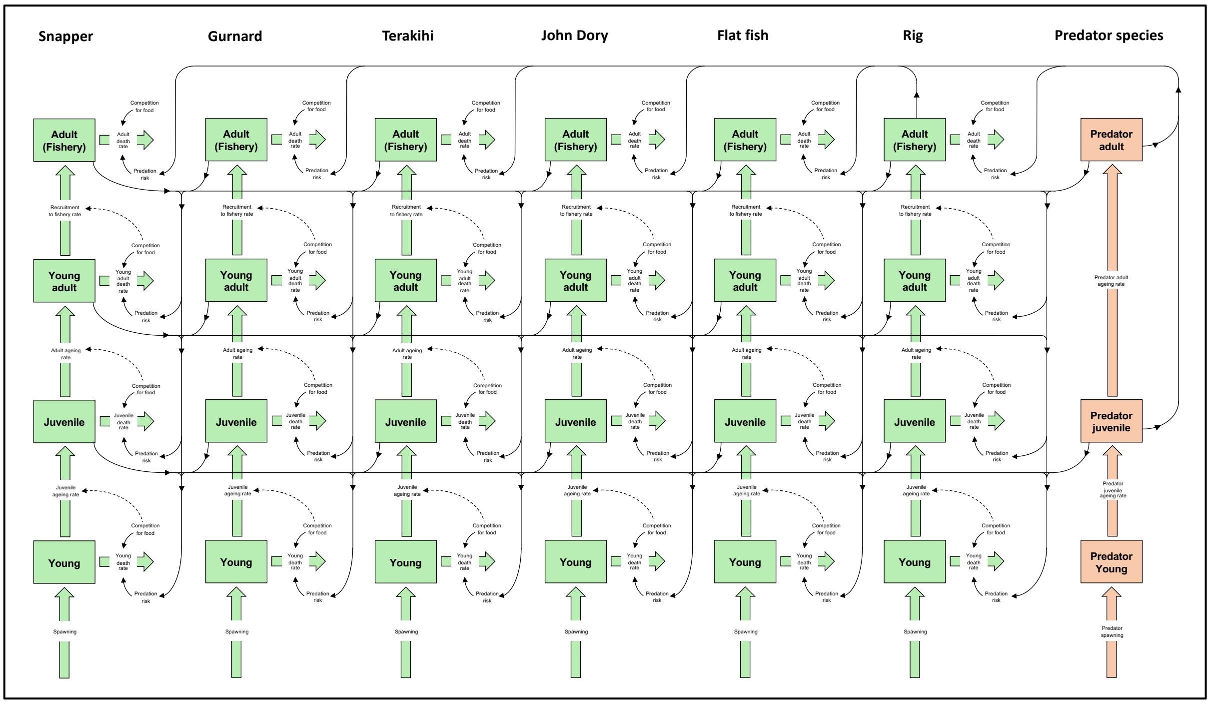
For these reasons, the intention of representing the influences between species in the multi-species complex visually, like in Figure 18, was abandoned. Instead, the use of MVA was added to the methodology.

That said, one diagram representing only the potential interactions between the species of the multi-species complex caught with snapper was created. When this was discussed with workshop participants there were two main views on it:

- **It was too complicated** to derive any useful understanding of the dominance of influences between species in the complex, yet
- **It was still useful** to demonstrate, simply, the complexity of the multi-species complex itself and how much influence there is between all of the species.

Therefore, this diagram is provided here as a demonstration of the latter of these two observations.

Figure 19. Connections between the different life stages of species in the multi-species complex



This diagram recreates the four life stages of a generic fish species and demonstrates the potential for fish at each stage of that fish species life stages to predate on other fish within the multi-species complex. Basically, all fish at an earlier life stage may be predated upon by fish at later life stages of its own or other species. In other words, most fish are at risk of being eaten by anything larger than them.

A conceptual predator species has also been included. This is one where juvenile and adult of that species may also prey on fish within the multi-species complex at the *same or later* life stages. In other words, it might eat anything larger than it.

10 Supporting the system diagram with multi-variate analysis[4]

Throughout the discussions, the need for a way to demonstrate areas of similarity between species that might form a multi-species complex, as well as differences between species biology, required habitats and response to external stressor factors such as sedimentation and climate change impacts, arose on many occasions.

Multi-variate analysis is well-proven in its ability to summarise patterns of similarities and differences, so it was decided to trial its use as a support both for the system diagram and the decision of which species could be well managed as a multi-species complex. The latter was expected to fall out of similarities between the species, as the more dissimilar species are in their biology and response to external factors, the less likely that a management decision would be adequate for safely and sustainably fishing all of them.

At present this analysis does not include social, management and economic components, however, a similar process should be used for these.

There were three steps in the development of this proof of concept:

- Determining the variables that would be useful
- Sourcing the data and creating the data table (matrices)
- Analysing and displaying the similarities

10.1 Determining variables to be used

These were based on the factors used in the system diagram, where either species-specific similarities were expected (e.g., spawning aggregations), or where the factor was an aggregate (e.g., habitat functionality). For each factor, a list of categories expected to be important was created (see Table 3). In the case of the aggregate factors, there were two levels of categories – high level categories which could have been separate factors in a more complicated system diagram – and low-level categories within each of the high level ones (see Table 4). Categories were initially created by FNZ staff, supplemented by an ecologist, and then checked and added to by two NIWA fisheries scientists. It would be useful to have these categories further checked and added to by those with local experiences.

Table 3. Factors from the system diagram with their categories

Factor	Categories
Do they aggregate to spawn? *(this factor is based on the factor 'extent of spawning aggregation/movement' in the system diagram)*	N
	Y
Duration at 'Young' life stage	1-2 weeks
	1 month - 6 months
	7-12 months
'Risk of predation': Adult; Juvenile/young adult; and Young	High
	Medium
	Low

[4] This section has been written by Judi Hewitt with contributions from Justin Connolly.

Factor	Categories
'Competition for food': Adult, Juvenile/young adult and Young	Low diet overlap (with 0-1 other species)
	Mod diet overlap (with 2-4 other species)
	High diet overlap (with 5-6 other species)
'Functionality of habitat': Adult, Juvenile/young adult, Young and Spawning	Sediment type - Erect 3D structure
	Sediment type - water
	Sediment type - mud
	Sediment type - sand
	Sediment type - rock
	Depth range - shallow <30m
	Depth range - mid 30-200m
	Depth range - deep >200m
	Temperature range
	Current range
	High microalgal biomass
	High zooplankton biomass

Table 4. Supporting factors with their categories

Factor	Categories
Reproductive location	Leaves management area/map
	Within a specific location/habitat
	Within normal adult location
Reproductive frequency	Once only
	Seasonal short
	Seasonal but protracted
	Multi-year event driven- skipping
	Continuous
Reproductive strategy	Bearers/brooders
	Guarders
	Broadcast spawners
Feeding/trophic level: Adult, Juvenile/young adult and Young	Predator on other species adults
	Predator on juvenile fish,
	Predator on zooplankton,
	Predator on infauna/epifauna
	Benthic herbivore

Factor	Categories
	Predator on algae/bacteria
	Does not feed
Maximum age/size	<3yr - 3-6yr
	6-10yr - 10-20yr
	20-40yr - >40yr
Size at maturity	<20cm
	20-30cm
	30-50cm
	50cm-1m
	1-1.5m
Competition/Competitive behaviour: Adult, Juvenile/young adults and Young	Territorial
	Aggregative/schooling
	Neutral

10.2 Creating the data table

Data for each species was sourced by FNZ staff and converted into a data table whose entries were the probability of the species exhibiting that behaviour or meeting that characteristic (see example data table, Table 5). Generally, these entries were 1 (the species exhibits that behaviour or meets that characteristic) or 0 (the species does not exhibit that behaviour/characterisation). Yet some species could exhibit more than one type of behaviour or meet more than one characteristic category. For example, some species were found across a wide range of depths. For those species where this applies, probability values between 0 and 1 were used. Again, using depth as an example, if a species spent most of its time in shallow areas but sometimes were found in moderate depths then the shallow depth category would have a "0.8", moderate would have a "0.2" and deep would have "0" allocated. Conversely, if the species could be found throughout shallow, moderate and deep with no known preferences then the shallow, moderate and deep categories all received "0.33" values.

An example table data demonstrating how categories within each factor apply to species within the multi-species complex, is shown in Table 5.

Table 5. Example data table for a simple component in the MVA

factor	Category	John dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
Do they aggregate to spawn?	No		0	0	0	0	
	Yes		1	1	1	1	
Duration at 'Young' life stage	1-2 weeks			1	0	0	
	1mo-6mo	?	?	0	0	0	
	7-12mo			0	1	1	

Legend: Empty cells occur when no information was available. Question marks ("?") occur when this was anticipated to be the likely category but there was no confirmation.

For many factors, no information was available for at least one (and often many of) the species (see table). These factors were not analysed further for this report and extra information was not collected as the use of MVA here was only a “proof of concept”. For use in actual management, much of this information would be critical. While some of this information may be really “unknown”, much is probably held by local fishers.

Collection of the data for the multi-variate analyses was useful to define more factors and sub-factors. For example, the data collected for habitat functionality revealed that for most species the juveniles had different requirements to the adults, preferring shallower, often sheltered waters with the presence of 3-dimensional habitat structure on the seafloor. While the young adults sometimes demonstrated a preference for a transition between the “juveniles” and the “adults”, their requirements were more like the older “adults”.

The data collected for recruitment frequency highlighted that while all the species exhibited seasonal patterns extending over two seasons, for four of the species this was the spring-summer period, while the other two were winter-spring and summer-autumn respectively. This is likely to be important when trying to manage the species together and suggested the need to include “time” as well as “frequency”.

This highlighted that in some technical instances, a greater level of disaggregation in the system diagram might be useful. Therefore, an additional version of the system diagram has been provided in Appendix 6 of this report. In that version, all four generic fish life stages have been separated (Juvenile and Young adult have been split out), and all four generic habitats have been split out (spawning, Young, Juvenile and Adult).

10.3 Displaying similarities between species

After the data gathering there was information on habitat requirements (3-dimension habitat structure, sediment type and depth range), competitive behaviour, predation risk, dietary overlaps (a surrogate for competition for food), size at sexual maturity, duration at young, maximum age, reproductive strategy and frequency, and whether they aggregated for spawning. Similarity between species was calculated separately for each of the aggregated factors using a bray-curtis similarity measure[5]. Groups of similar species were defined as being 60% similar based on average linkage clustering (see Figure 20).

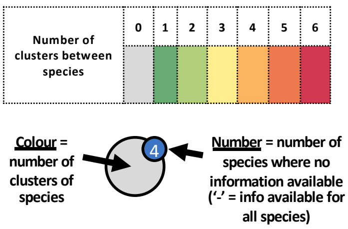
[5] The Bray-Curtis index is a modified version of the Sørensen index which calculates the similarity (or difference) between pairs of samples as a percent that runs from 1 (totally similar) to 0 (totally different). Usually used for species count data, the values it is calculated from must be non-negative, and it has the benefit that variables that share “0” values are as important as those that share positive values. If MVA is to be taken further, with a more complete set of information, some trials as to the effect of various similarity measures would be important.

Figure 20. Example clustering used to determine groupings: Adult and juveniles habitat

Once this clustering was determined, it was represented on the system diagram using a 'heat mapping' approach, as shown below in Figure 21. This was a novel attempt to visually represent the insights from the MVA on the relevant areas of the system diagram, in a way that enabled readers to easily identify and understand the importance of certain parts of the system diagram on the multi-species complex.

Figure 21. Guide to 'heat mapping' of MVA insights on system diagram

'Heat map' guide to multi-variate analysis insights:
When individual species maps are overlaid, how many clusters of species are there at important nodes?



Example	No. species WITH avail. info	No. CLUSTERS amongst species with avail. info	# species WITHOUT avail. info	Example 'heat bubble' on diagram
A	4	1	2	2
B	6	2	0	0
C	5	4	1	1

A series of colour coded circles were used to highlight the number of clusters associated with relevant factors on the system diagram (see Figure 21). Here one large, coloured circle is placed around the factor of interest on the map and one small circle is placed on the edge of this large circle. The colour in the large circle indicates the number of clusters of species associated with that factor. These colours are on a scale ranging from dark green (indicating that all species for which there is information have the same category in common within that factor), through to red (indicating that each species within the cluster is in its own category within that factor). The lower the number of clusters, the greater the commonality of that feature across species. For example, a cluster of 1 means that all species for which information was available had that component of the diagram in common.

The number in the small circle indicates the number of species within the cluster for which there was no information available. For example, if there was no information for one species in the cluster, a '1' would be in the small circle; if information was available for all species within the cluster, then a '-' will appear in the small circle.

These common factors were then shown visually on the System diagram (see Figure 22).

The commonality of habitat functionality was shown separately for the different habitats: spawning and young; and juvenile and adult.

The coloured circles in Figure 22 highlight that, for the information available, the most commonality between species (all in one cluster) is their aggregation or moving at spawning, and the competition for food. There were two clusters relating to their predation risk and the commonality of habitat for spawning and juvenile life stages. While there were three clusters relating to how long species spent at the 'Young' stage as well as three clusters for each of the young and adult habitat.

10.4 How multi-variate analysis can be then used

This research is interested in whether a system diagram and MVA can support in the management of multi-species complexes. A multi-species complex is a grouping of fish that have been identified as being able to be managed together. That is, management actions undertaken on complex apply to all the species in it, or at least take all their characteristics into consideration.

So how can MVA be used to support this? Primarily, it is a tool to identify which species would fit most comfortably into a multi-species complex. It would help identify those species similar enough in their use of space; their habitat requirements; and temporal dynamics (life stages), that changes in extraction amounts or fishing effort should not produce unforeseen or detrimental impacts.

This research has assumed the potential of a multi-species complex. In this instance it has been determined as six species that are caught together. However, there may be other ways of determining a complex, and being caught together is only one characteristic that fish share.

MVA can quickly summarise the similarity in many characteristics across hundreds of species. So, it may add value by being applied across more (or all?) species within the management area.

In this research, the system diagram has helped to inform the list of characteristics which would be important for management of a potential multi-species complex.

If an MVA was applied using these characteristics, then where species have high and low levels of similarity can be identified. Species that are highly similar in their characteristics are more likely to be successfully managed as a multi-species complex. Inversely, those with less similarity may be more challenging to manage as a multi-species complex.

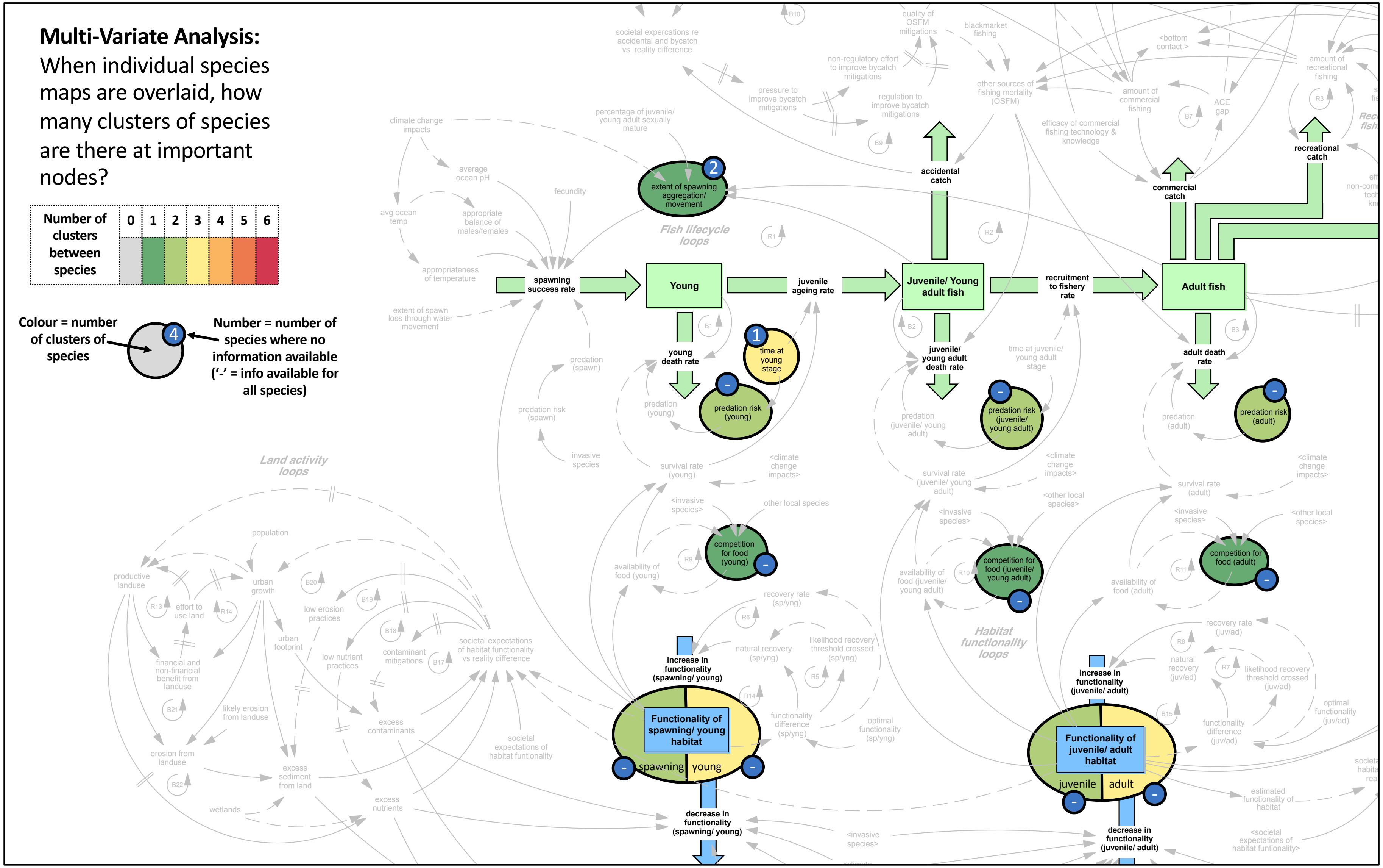
Where species lack similarity, the MVA insights can be used to identify which characteristics may contribute to the differences and thus the places in the systems diagram where these differences lie. The system diagram can then inform both: what other factors influence those characteristics; and what other factors those characteristics themselves go on to influence. This can help fisheries managers understand some of the flow on implications of their management actions.

Both the MVA and the system diagram can also be used to inform more detailed modelling such as agent-based modelling, multiple coupled population dynamic models or Atlantis models.

MVA can also be used:

- As a first step in the assessment of potential management actions. For example, if the spatial extent of management were to change; or if councils were to change policies relating to land use practices.
- As a first step in the assessment of changes in fishers' activities. For example, gear types and preferred locations.
- To identify information gaps that may need to be filled: to achieve a more robust assessment of the state of a multi-species complex; regarding the potential effects of the management of other multi-species complexes; and for the progression of movement towards ecosystem-based fisheries management (EBFM).

Figure 22. Diagram of MVA heat mapping



11 How this work informs future Agent-based modelling[6]

As outlined at the beginning of this report, this work has sought to couple a variety of methods: A system diagram; MVA, and an agent-based model (ABM). This report details the work of the system diagram and the MVA. The ABM is currently in development and will be completed at a later date. This section provides an outline of how the process described in this report has informed the ABM process and how the insight and data generated by the system diagram and the MVA will inform the ABM.

11.1 Agent-based modelling question formulation

During the first three workshops, the project team considered the discussions between the group and the interests of the group members, FNZ and Sustainable Seas. Areas of focus and interest for all/most parties were identified and questions were generated that could be both: investigated using ABM; and had the potential to inform or advance multi-species management.

As ABM is spatially explicit and temporally dynamic (operates over a pre-defined spatial area and runs scenarios within that area over time), the focus question for the ABM needed to have spatial and temporal components. An iterative process was then followed where the project team formulated, discussed, and refined questions that could be tested using ABM.

In iteration one, four preliminary scenario questions were drafted after Workshop 2, informed by the workshop discussions and systems mapping. These focussed on:

a) stock abundance variability,
b) management options,
c) managing stocks to a higher abundance, and
d) market feedbacks to fisher behaviour. The project team discussed these and ruled out option d based on the absence of a spatial component.

In iteration two, four questions were drafted. Three focused on integrating stock assessment, inter-species interactions and TAC and investigating their impacts on the multi-species complex:

a) considered volumetric changes,
b) considered spatial changes and
c) considered temporal changes.
d) a fourth option, was based around market pressures and governance/regulatory influences on fisher behaviour, with flow on effects on fish stocks.

In iteration three, two questions were drafted for discussion with the participants at Workshop 4:

Option A	*How might a change in management arrangements (TAC / legal sizes / fishing seasons / area managed / deemed values) impact on the multi-species complex, fisher behaviour and/or commercial viability? And what if the change happens at different times within the abundance cycles of different species?*
Option B	*How might a spatial change in management arrangements (e.g. trawl corridor) impact on the multi-species complex?*

Option A focused on the immediate interests of FNZ, while B was of greater interest to the wider Sustainable Seas challenge. As this project aims to assist FNZ in advancing multi-species management, the preferred option of the project team was A, with scope for feedback from the group on what

[6] This section has been provided by Anderw Allison with contributions from Justin Connolly.

changes in management arrangements they would like to consider, and whether they would like to investigate the impacts on the multi-species complex, fisher behaviour, or commercial viability.

These final two questions were presented to the group in Workshop 4. The objective and considerations of both FNZ and the Sustainable Seas Challenge made outlined to the group.

After discussion with participants in Workshop 4, the group decided to focus on option A, with some refinements. There were several reasons for this:

- Option A is the more dynamic question; it is more likely to reveal unknown aspects of the system and uncover relationships within the multi-species complex.
- Option A is more flexible; workshop participants can choose one (or more) of the hypothetical management arrangements to test *as well as* the impacts on the multi-species complex and commercial viability (workshop discussion ruled out exploring fisher behaviour, as this would require gathering further information that has not been generated during the workshop series). Option B only gives the participants the choice of a single change in spatial management arrangements.
- Option A is more likely to demonstrate the strengths of ABM (improving system understanding, revealing emergent behaviour, exploring directions of system change, etc.) to FNZ than option B.

There remained scope to determine what hypothetical change in management arrangements the group would like the model to focus on: TAC, legal sizes, area managed or deemed values. Fishing seasons was ruled out as this is not a management intervention; rather it is something that may occur because of a management intervention. While investigation of area managed or deemed values would have to occur in isolation, it would be possible to model changes in both TAC and legal sizes in one model.

As a result of the discussion during Workshop 4 and in an email thread including the research team and all workshop invitees, the final question was determined over the following week:

Final question for Agent-based modelling	***How might a change in TAC of one or two primary/dominant stocks impact on the multi-species complex and commercial viability? And what if the change happens at different times within the abundance cycles of different species?***

11.2 How the system diagram and the multi-variate analysis will inform the agent-based model

The model is currently under development. The system diagram was used to determine the structure of relationships between fish and habitat and between fishers and fish. First a prototype was developed to encode the relationships:

- between different species
- between species and fishers
- between species and the environment, and
- between fishers and the environment

The next step is to use data generated from the multi-variate analysis to populate these relationships.

12 Analysis of the approach

This report has so far described a process and the resulting outputs of exploring the use of the system diagram tool from System Dynamics to help understand multi-species complexes. In the course of this research this was coupled with MVA and both will further inform ABM work that is still progressing.

Earlier sections in this report have described how the journey evolved as it progressed. As this was a process that sought to utilise the input and knowledge of workshop participants, as well as ‘road test’ the system diagram tool with them, it is important to recognise that the journey was just as important a part of the research as were the resulting outputs. To this extent, the journey and process was found to be useful and satisfactory. Anecdotal and informal feedback from workshop participants has been that the system diagram approach has been useful and that it could help to inform a wide range of other knowledge areas and resource management discussions, not just multi-species management. Yet it was also noted as still being quite high level. The extent to which it will be useful in multi-species management will depend on how the general dynamics insights, MVA insights, and how the ABM (still being developed) may be applied.

It was also found that there are extra things that could be done with the system diagram.

It has been recognised as a potential useful tool in communicating the complexity of our inter-connected world to a variety of other stakeholders and agencies. However, at the same time it was noted both by members of the project team and some workshop participants, that it does require one to ‘tune in’ to the way of thinking. This highlights both that this tool can supplement the existing ways that people think; and that, at the same time, the way that this tool operates is a little different to the predominant way that people think.

These observations are consistent with the findings of a pilot in the use of system diagrams earlier in the Challenge. In that pilot, there was generally strong agreement amongst participants that the process helped: participants better understand the perspectives of other participants; participants to identify and consider factors that are not usually considered; the group work together well; and develop a holistic view of the issue which would support workable solutions/interventions.

These observations are also consistent with the anecdotal experiences of the Deliberate system diagram specialist, and their experience on another Challenge case study in the Hawke’s Bay. There, a system diagram was developed to explore the causal connections between important stressors on seafloor health. The experience of participants in that case study were also that it was a different type of thinking, yet once ‘tuned in’, it provided participants a useful and holistic way of viewing the issues they were dealing with.

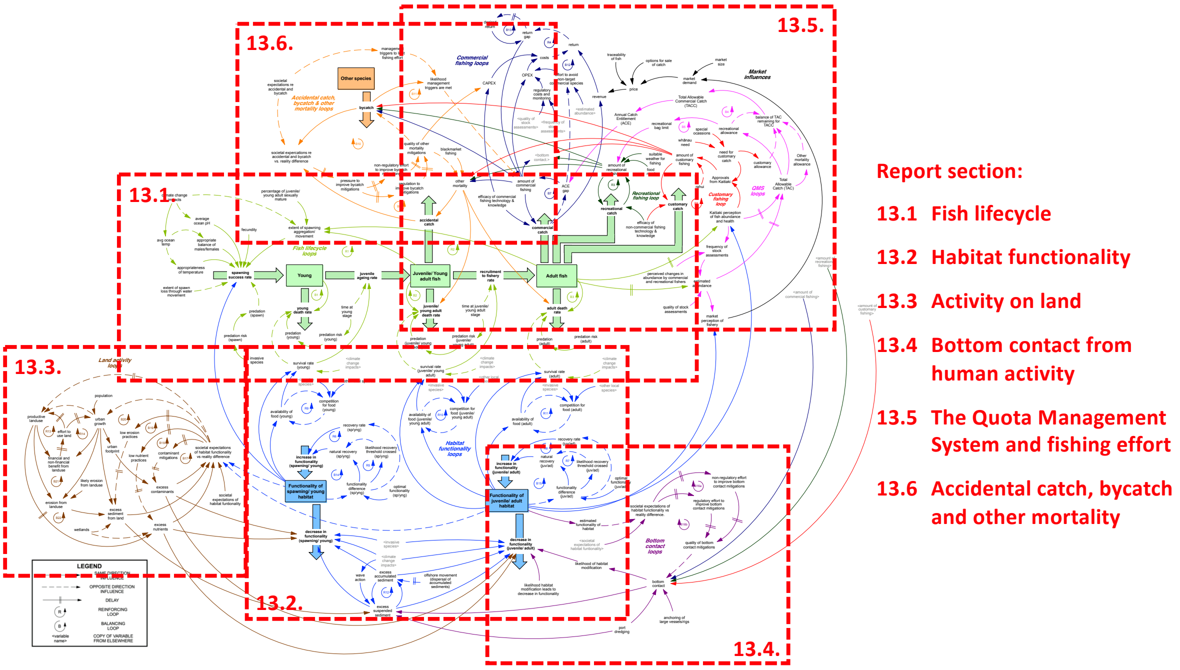
It is recognised that what has been developed here is generic enough to be applicable across a range of other areas, not only geographic areas, but fish species also. This was partly the intent when developing it, so it is noted that this intention has been successful. Moreover, the use of MVA in the project, while not initially planned, does suggest a method for transparently highlighting commonalities between species selected for management within a multi-species complex in habitat requirements, behavioural characteristics and sensitivities to other human activities. Factors where species within the complex are not similar can be investigated for the likelihood of these differences to affect successful management as a single complex.

Finally, it is recognised that some of the complexity that has been demonstrated within this system diagram may be useful to other agencies, outside FNZ, and regardless of whether FNZ were to be involved with the policy issue they may be interested in or not. This presents an opportunity for this system diagram to inform part of the communal understanding that is often required across, between and even sometimes within agencies. It is provided to all stakeholders who helped develop it with that understanding in mind, and it is of course recognised that the additional ABM currently under development also has the potential to provide complementary insights.

13 Detailed description of the system diagram

This section provides a detailed description of the system diagram developed with the group. It is made up of seven sections. It contains following six sub-sections each discuss different areas of the system diagram in detail. These are shown in the diagram below.

Figure 23. The six sections of the system diagram discussed in detail



A list describing all of the terms used in the system diagram is provided in Appendix 1. A full reproduction of the diagram is provided in Appendix 2.

Different colours have been used throughout the system diagram to indicate where loops and influences tend to go together or operate as part of one section of the diagram, or related activity. While these provide a useful help to reading the diagram, it should be noted that many arrows form part of several loops, so the colour used is not a firm indication of the loop that the relationship is part of.

It is strongly noted that the use of colour in no way infers or indicates any prioritisation of any areas of the system diagram. Nor does it indicate any attempt to weight the relationships within the diagram, or imply judgement or aspersions about or on any part of the diagram. Rather, it is simply an attempt to aid the reader to focus on related areas and to avoid the diagram becoming overwhelming if all in one colour.

Other things that are stressed to the reader are as follows:

- Regular reference is made to the conceptual ‘bathtub’ used in systems thinking to describe where things accumulate. In systems language this is often referred to as a ‘stock’, however since this research deals with fisheries management, the term ‘stock’ has been avoided to avoid confusion with the regular use of that term to refer to the overall stocks of specific fish species.
- When influences are being described in the detailed description of the system diagram, they are described from the point of view of ‘all other things being equal’. Any actual change in a factor will usually be the result of multiple influences. How these influences interact have not be described when only individual influences are being described. In reality, multiple influences act together to create change in downstream factors.

- Not everything articulated in a system diagram can (or should) be measured. Therefore, the extent to which something is measurable is not a pre-requisite for inclusion in the system diagram.
- Perception is an important component in system diagrams. Being able to represent how things are perceived or understood by people at an aggregate level is an important feature of system diagrams. Such diagrams are a tool for exploring how people understand influence to interact to generate behaviours of interest. Many of these important influences will be sociological, such as attitudes, levels of knowledge or desires, and it is important to be able to represent these – regardless of whether they might be considered 'good' or 'bad'.

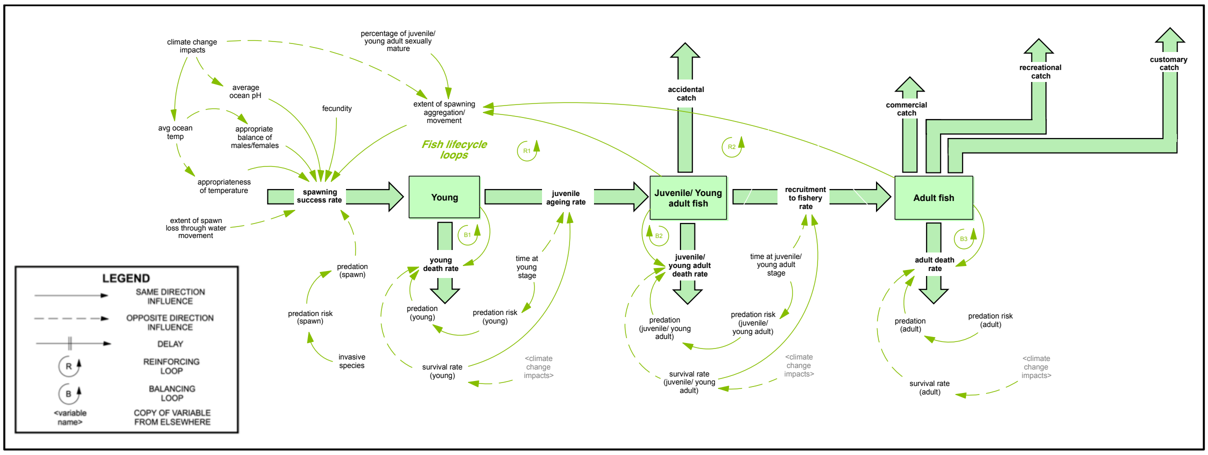
It should be noted that when the system diagram is being described, when a factor represented in the diagram is being referred to, it is written in single quotation marks – for example: 'Adult fish'. When emphasis is being applied by the author to a particular word or sentence, italics are use – for example: the *higher* the level of factor A, the *lower* the level of factor B.

13.1 The fish lifecycle – putting fish at the centre of the diagram

This research focused on multi-species complexes. The system diagram, however, is based around a single species to first develop an understanding of the inter-relationships between multiple socio-ecological factors and this affects one fish species, before extending this to multiple fish species. How multiple species may be represented in a system diagram has been discussed in section 9.

Yet while multiple species and the socio-ecological factors that influence them are the interest of this research, to enable appropriate focus on fisheries management, the generic fish lifecycle is placed at the core of the system diagram. This is shown in Figure 24 and is explained in more detail in the following sub-sections.

Figure 24. Overview of the fish lifecycle

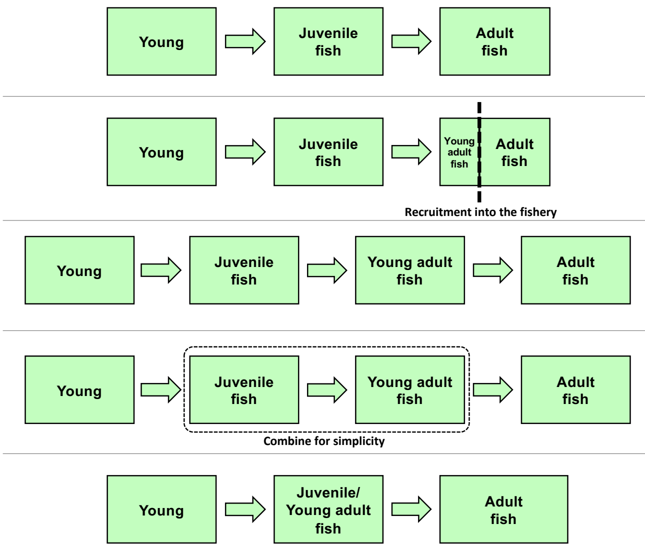


13.1.1 The generic life stages of fish used in this diagram

Not all fish species go through the same life stages. The intent of this system diagram is to represent these as simply as possible while still allowing for insight to be gained from the structure of the diagram (highlighting the interactions of various relevant socio-ecological factors.

The life stages of most fish species can be divided into three general categories: Young (which represents the phase of eggs and larvae, before they become recognizable fish), Juvenile and Adult. Adult fish are sexually mature. Yet in fisheries management, adult fish are considered to 'recruit into the fishery' after a certain period of sexual maturity. This boundary is determined by fisheries managers and scientists to allow for stock regeneration and does not reflect a biological step in their lifecycle. Figure 25 below describes how the three fish life stages were determined and used in the system diagram.

Figure 25. How the three fish life stages used in the system diagram were determined



The life stages of most fish species can be divided into three general categories: Young, Juvenile and Adult.

Young are early life stages for a species; Juvenile fish are fish that are not yet sexually mature; Adult fish are sexual mature. (see glossary in appendix)

Yet in fisheries management, adult fish are considered to 'recruit into the fishery' after a certain period of sexual maturity. This boundary is determined by fisheries managers and scientists. This differs across species to allow for stock regeneration.

It does not reflect a biological step in their lifecycle.

In this system diagram then, we *refer to four stages* of a fish's lifecycle. Separating Young adult fish that are sexually mature but NOT eligible for the fishery, from Adult fish that are sexually mature AND ARE eligible for the fishery.

Yet, when using system diagrams, we always try to synthesise things to be as simple as possible without losing the focus of what we are trying to understand. Therefore, as these maps focus on fisheries management, Juvenile fish and Young adult fish have been combined and represented as one group ('bathtub' in system thinking terms).

This means that the three main life stages of fish are represented by the three groups ('bathtubs') the system diagram in this report: 'Young', 'Juvenile and Young adult', and 'Adult'.

Both Young adult and Adult fish are sexually mature. (see glossary in appendix for more detail)

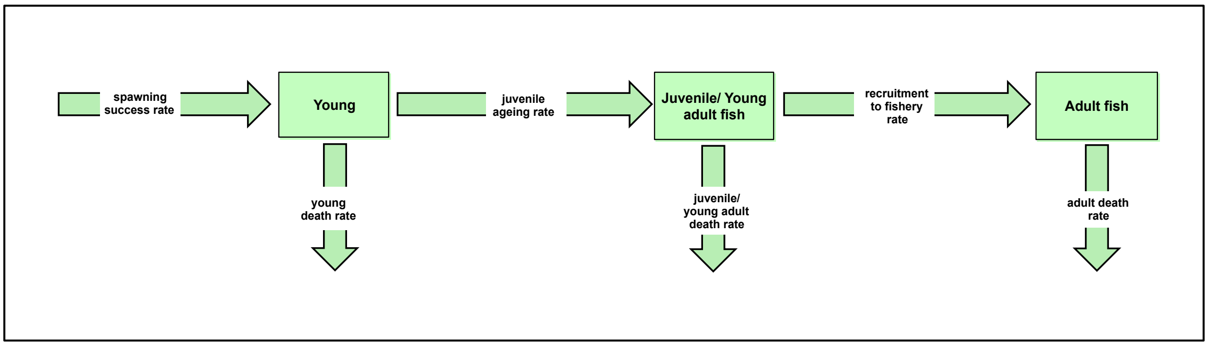
13.1.2 Ways of moving into and out of each life stage

These three life stages form the main ageing chain of the fish species life cycle. The boxes in the diagram are metaphorical *bathtubs* (or life stages) where fish accumulate for a time. They move into or out of these *bathtubs* through *flows* which are represented with solid arrows.

The only way a fish can enter or leave a *bathtub* is via one of these *flow* arrows.

Without considering catch or other activity by humans, the standard flow of fish through this lifecycle is shown in Figure 26 and explained below.

Figure 26. The three generic lifecycles of fish species (excluding human catch /extraction)



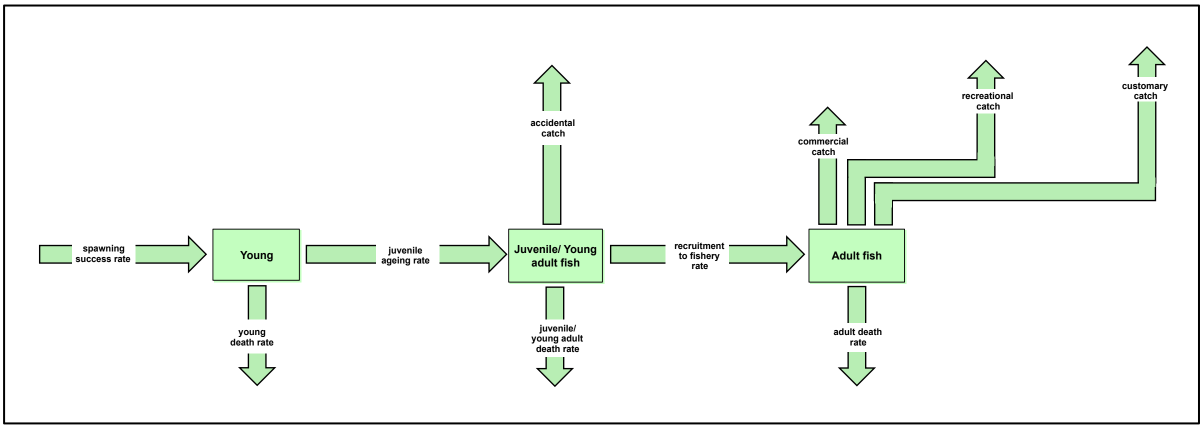
Firstly, Young of fish species are a result of successful spawning, therefore the flow 'spawning success rate' flows into 'Young'. This 'spawning success rate' *flow* includes fertilisation and the amount of spawn that makes it to the 'Young' life stage. From here, 'Young' will either: successfully age and become 'Juvenile fish' (and eventually 'Young adult fish'), via the flow labelled 'juvenile ageing rate'; or they will die, therefore flowing out of the 'Young' bathtub via the flow labelled 'young death rate'.

Secondly, from the 'Juvenile/Young adult fish' bathtub, fish will either: successfully age and become 'Adult fish' (and therefore be deemed to have recruited into the fishery), via the flow labelled ‘recruitment to fishery rate’; or they will die, therefore flowing out of ‘Juvenile/Young adult fish’ via the flow labelled ‘juvenile/young adult death rate’.

Finally, as there are no ageing stages after the ‘Adult fish’ bathtub, fish will only flow out of this life stage through mortality, represented by the ‘adult death rate’.

Human activity impacts the volume of fish in any one of these life stages (or bathtubs). This is either: indirectly, by impacting the death rate from any one life stage (see discussion of impacts on Habitat functionality in Section 13.2 and that on Other Sources of Fishing Mortality in Section 13.6); or directly through the extraction of fish from any of these *bathtubs*. As the focus here is fisheries management, the system diagram includes extraction of fish from the ‘Adult fish’ life stage via the three main types of catch (‘commercial catch’, ‘recreational catch’ and ‘customary catch’); and as ‘accidental catch’ from the ‘Juvenile/Young adult fish’ life stage. These catch flows are shown in Figure 27.

Figure 27. The three generic lifecycles of fish species (including human catch /extraction)

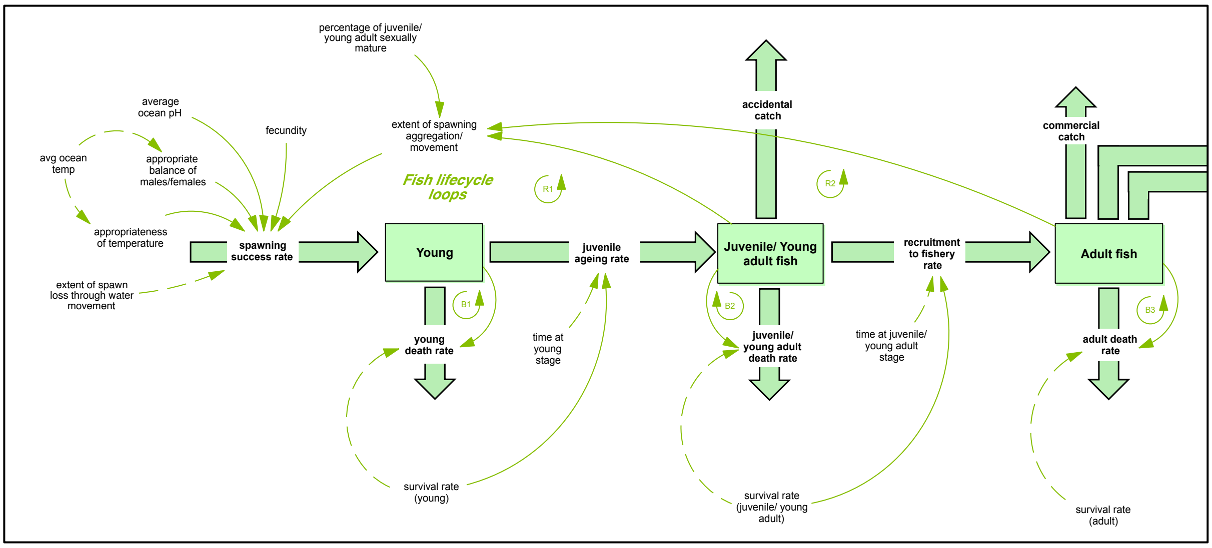


These are the main life stages (or bathtubs) and how fish progress into/from/between them (flows) for any one fish species at the centre of the system diagram.

13.1.3 The fish lifecycle loops of influence – reproduction and mortality

Having described the life stages of a fish species and how these are represented, this section now explains the fundamental way that these influence each other. This generates feedback loops of influence relating to reproduction (reinforcing loops) and mortality (balancing loops). These are shown in Figure 28 and explained in the subsections below.

Figure 28. The fish lifecycle loops of influence – reproduction (reinforcing) and mortality (balancing)



13.1.3.1 The reinforcing feedback loops of reproduction

There are two reinforcing feedback loops for reproduction – **R1** and **R2**.

The 'spawning success rate' of any species is dependent on the number of sexually mature fish there are and their 'extent of spawning aggregation/movement' (here, this factor represents the physical amount or coverage of a spawning aggregation by a particular species. The solid arrows from the 'Juvenile/Young adult fish' and 'Adult fish' boxes to 'extent of spawning aggregation/movement' represent a same relationship – all other things being equal, the larger the numbers of adult fish the greater the extent of their spawning aggregation. The 'percentage of juvenile/young adult sexually mature' refers to the percentage share of sexually mature adults in the middle life stage bathtub. The higher this is, the higher the 'extent of spawning aggregation/movement', as both sexually mature 'Young adult' fish as well as 'Adult' fish will contribute to the extent of any spawning aggregation.

The greater the 'extent of spawning aggregation/movement', the greater the 'spawning success rate' (a same relationship). Additionally, the 'spawning success rate' is also influenced with by same relationships from 'fecundity' (or the volume of spawn produced), whether there is an 'appropriate balance of males/females'*,* and the 'appropriateness of the temperature'. The greater these factors the greater the 'spawning success rate'.

The greater the 'spawning success rate', the greater the chances of the numbers of 'Young' in that bathtub increasing and the greater the chances of fish progressing to the other life stages (juvenile, adult), thus *reinforcing* the likelihood of 'spawning success' in the future. Hence, these are the pathways for reinforcing loops **R1** and **R2** as shown in Figure 28.

The balancing feedback loops of mortality of fish can occur at any of the life stages and is represented by a balancing loop at each life stage (**B1** for 'Young', **B2** for 'Juvenile/Young adult fish', and **B3** for 'Adult fish'). Each of these indicate that, all other things being equal, the mortality ('death rate') at any life stage is dependent on the number at that stage and the 'survival rate'. Therefore, if the numbers of fish were to *increase* in any life stage and the survival rate *remain constant*, then the *absolute* mortality numbers would also increase. Any mortality removes fish from the relevant life stage, which in turn *decreases* its numbers. Therefore, these loops balance (or cancel) themselves out.

The time each species spends at each life stage has an influence on how long they remain exposed to the mortality risk for each life stage. This therefore has an *opposite relationship* with the flows between stocks. This is shown by the dashed line between 'time at [life] stage' and both the 'juvenile ageing rate' and the 'recruitment to fishery rate'.

The survival rate also influences this flow, but as a *same relationship* – the better the survival rate, the higher the flow of fish to the next stage of life. This therefore is shown by a solid line between 'survival rate' and both the 'juvenile ageing rate' and the 'recruitment to fishery rate'.

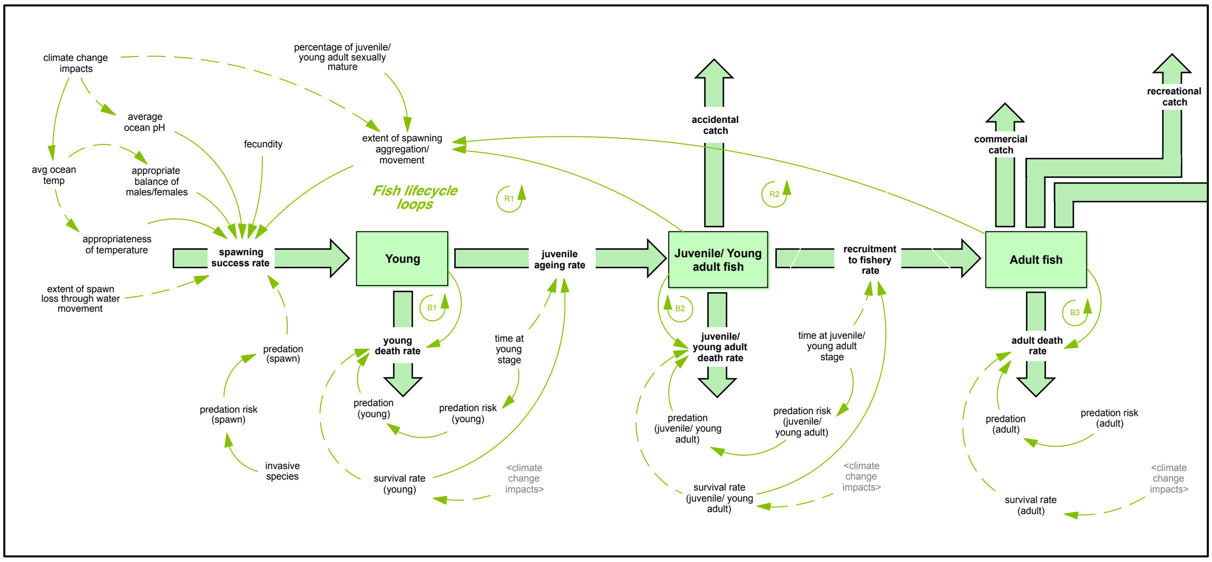
13.1.3.2 Other proximal factors influencing the reproduction and mortality feedback loops

Many proximal factors also influence these reproduction and mortality loops (see Figure 29).

Beginning with the 'spawning success rate', many factors influence this both directly and indirectly.

For example, 'invasive species' has an opposite influence on 'spawning success rate' – the more invasive species there are the lower the spawning success rate due to predation of spawn. 'Average ocean temperature' also has an opposite relationship with factors that influence 'spawning success rate'*.* For example: the higher the 'average ocean temperature' the less the 'appropriateness of [the] ocean temperature' for spawning (this will differ across species but is assumed as a general influence here) and the less likely there will be an 'appropriate balance of males/females', because for some species sex is influenced by ocean temperature.

Figure 29. Other factors influencing reproduction and mortality



Predation of spawn from other (and often their own) species also impacts the 'spawning success rate'. Therefore, this shown as an *opposite* relationship on 'spawning success rate'. The greater the predation, the lower the spawning success. Predation at the spawning stage ('predation (spawn)') is influenced the predation risk at the spawning stage ('predation risk (spawn)'), which is also influenced by the number of 'invasive species'.

'Climate change impacts' in the system diagram are defined as impacts that are deemed to be undesirable and a negative consequence of climate change – for example, more frequent and intense storm events, or a higher average temperature. This has been assumed because, while subtle changes in the short-term may be beneficial or detrimental, most changes in the long term are likely to be detrimental (e.g. a small increase in temperature in the short term may increase spawning likelihood, but sustained long-term increases will likely be detrimental to most species).

'Climate change impacts' influences many proximal factors. It has an opposite relationship with the 'extent of spawning aggregation/ movement' because, for example, increased and more extreme storm events and water movement may increase turbidity and decrease the ability of fish to aggregate. It also has an opposite influence on the 'average ocean pH' (a measure of ocean acidity), which for the purposes of this diagram has been bundled with climate change. In other word, the greater the 'climate change impacts', the greater the ocean acidity. 'Climate change impacts' also have a same influence on the 'average ocean temperature' – the greater the impacts, the higher the average temperature.

Other factors also influence the 'death rate' at each life stage. The structure for these influences is similar across the three stages of the life cycle.

Firstly, in the longer-term 'climate change impacts' (the negative impacts of climate change) will also have an opposite impact on the 'survival rate' at each life stage[7]. The greater the 'climate change impacts' the lower the 'survival rate'.

Predation from other (and often their own) species also impacts the 'death rate'. It is important to note here that 'survival rate' is environmental and does not include predation. Therefore, the greater

[7] It is noted that, like many relationships that have been simplified in this diagram, the relationship between the impacts of climate change and the survival rate of fish at each life stage is likely to be non-linear. That is, a small amount of warming, like that which will occur in the initial stages of climate warming, may actually result in an increased survivial rate. However, in the longer term this is likely to reverse and become a detrimental effect. Therefore, when discussing climate change impacts, the longer-term and detrimental impact is assumed.

the level of 'predation' at any life stage the greater the 'death rate'. At any life stage, 'predation' is influenced by the 'predation risk', which is a conceptual measure of the likelihood that fish at any life stage are exposed to predation from their own or other species. This risk remains while a fish is at that life stage, therefore 'time at [life] stage' has a same relationship with 'predation risk' (the higher the former, the higher the latter).

13.2 Functionality of habitat – supporting the fish lifecycle

This previous section outlined how the main stages of a generic fish lifecycle has been represented in this system diagram (see Figure 24). This section outlines how the functionality of habitats that supports fish has been represented in the system diagram.

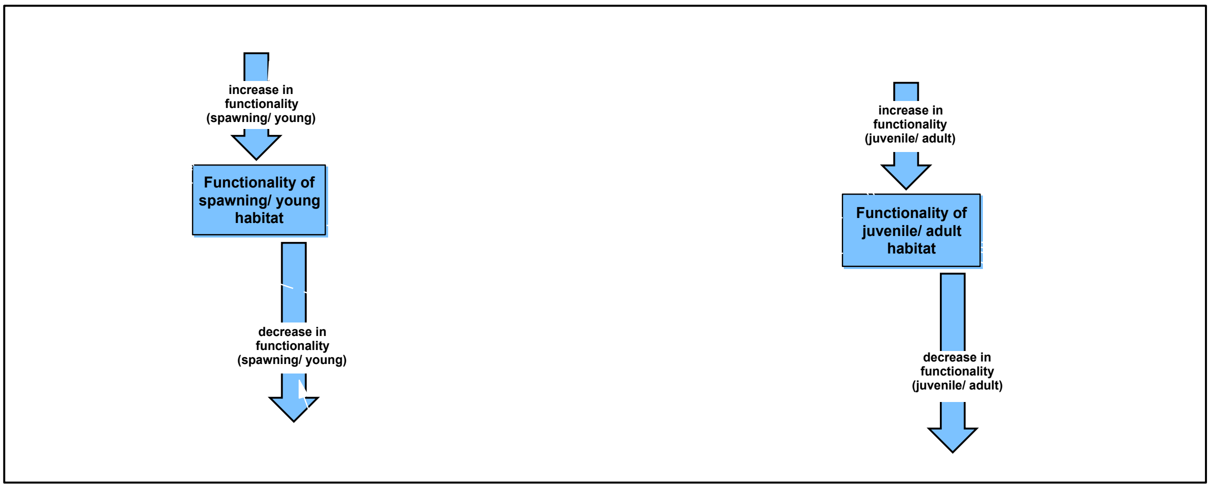
13.2.1 Representing functionality of habitat as a metaphorical bathtub

Healthy and functioning habitat is the critical ecological and environmental factor that supports abundant fish species. There are, of course, many different types of habitats that support many different types of fish. Because this diagram is designed for a generic fish species, it avoids describing the different types of habitats that exist in the ocean, their individual quantity, and the level of quality that each may be experiencing. To attempt this would in part be an exercise attempting to recreate detailed knowledge that exists elsewhere into a system diagram, which is not the intent of this diagram, and likely make it far too complex to navigate as a qualitative diagram. Rather, the system diagram is intended as a tool that helps users understand the range of relationships between factors, so that important areas can be understood and incorporated into consideration in fisheries management. Both detailed knowledge that informs this system diagram (yet is held outside of it) and the insights of this system diagram, are intended to support fisheries management.

Instead, the term 'functionality of habitat' has been used to describe both the quantity and quality of habitat, and how well it is functioning, in relation to how it would support the focus species of the diagram, in a non-human-impacted world. This term is a conceptual amalgam of quantity, quality and functionality and therefore has a high level of flexibility in relation to the things that can be included in it.

Importantly, 'Functionality of [life stage] habitat' is also represented as a conceptual *bathtub*. We are interested in whether the functionality of habitat is increasing (accumulating) or decreasing (decumulating). See Figure 30.

Figure 30. Representing Functionality of habitat as bathtubs



When this is represented in *bathtub* and *flow* format, a *flow into* the bathtub of 'Functionality of [life stage] habitat' is shown and labelled as a flow arrow of 'Increase in functionality ([life stage])'. This represents any marginal increase in the functionality of habitat as an *addition to* (a flow into) the existing level (bathtub) of 'Functionality of [life stage] habitat'. Similarly, any marginal decrease in the functionality of habitat is shown as a *removal from* (a flow out of) the level (bathtub) of 'Functionality of [life stage] habitat'.

For simplicity, the 'Functionality of spawning and young habitats' have been combined into one bathtub, as they are often similar or proximal; as have the 'Functionality of juvenile and adult habitats' for similar reasons. This does not mean that they are the same habitats. This is simply conceptually representing them as similar for the purposes of maintaining a simplified diagram. When the user of the system diagram is reflecting on what these bathtubs represent, they can replace them with a range of things that will be relevant for the specie(s) that they are interested in.

13.2.2 Functionality of habitat recovery feedback loops

Several feedback loops influence the recovery (or not) of the functionality of habitat. These loops are all driven by a **goal/gap** structure as outlined in section 5 (specifically, see section 5.1.4). **Once again, the reader is advised to familiarise themselves with section 5 before reading the rest of the detailed description of the system diagram.**

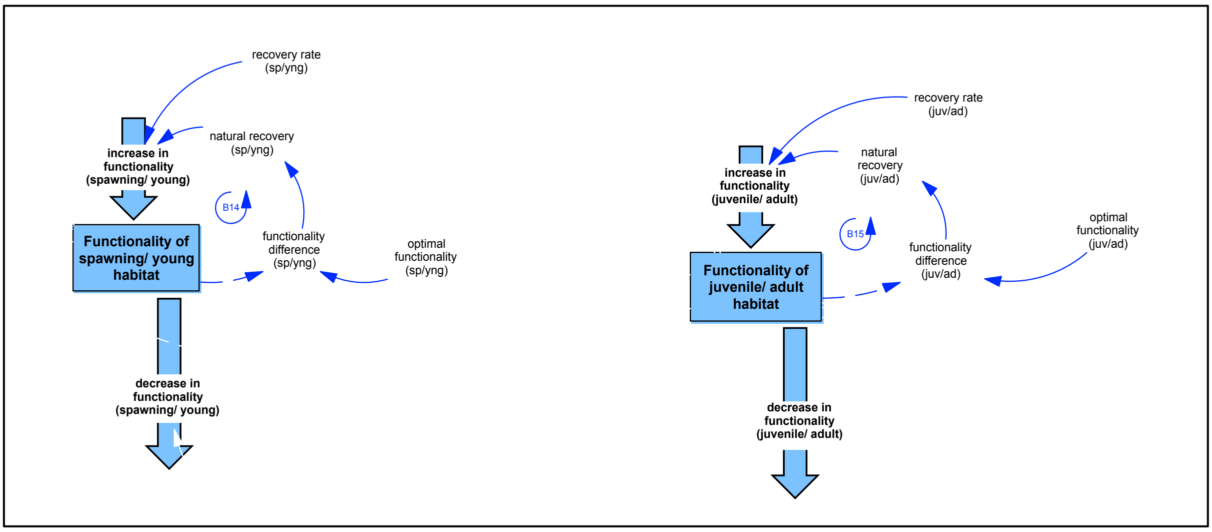
The **goal/gap** structure that drives these loops compares an *actual* level of the functionality of habitat to a conceptual *optimal* level, resulting in a factor called the 'functionality difference' for that bathtub. This factor is an indication of how *out of balance* the functionality of habitat currently is from its possible optimal functionality. The greater the difference, the greater the process of 'natural recovery' for that bathtub will occur, leading to any 'increase in functionality' for that bathtub.

13.2.2.1 The natural recovery feedback loop

'Natural recovery' is a conceptual representation of the varied biological, ecological and natural processes that act to create the functionality of that habitat. For example, such processes may be: the process(es) by which water is filtered or clarified and turbidity is reduced; the process(es) by which biogenic habitat recovers and grows; or the process(es) by which excess sediment is dispersed. In short, this represents the natural recovery processes which occurred uninhibited prior to human influence. See Figure 31.

This recovery process operates as a balancing loop (**B14** and **B15**) with the **goal/gap** structure. If there is a large gap (or 'functionality difference') this prompts greater 'natural recovery' which, in turn, leads to an 'increase in functionality' and an overall increase in the 'Functionality of [life stage] habitat'. This assumes that all other things are equal – i.e. that there is no corresponding 'decrease in functionality'.

Figure 31. Functionality of habitat – natural recovery balancing feedback loop

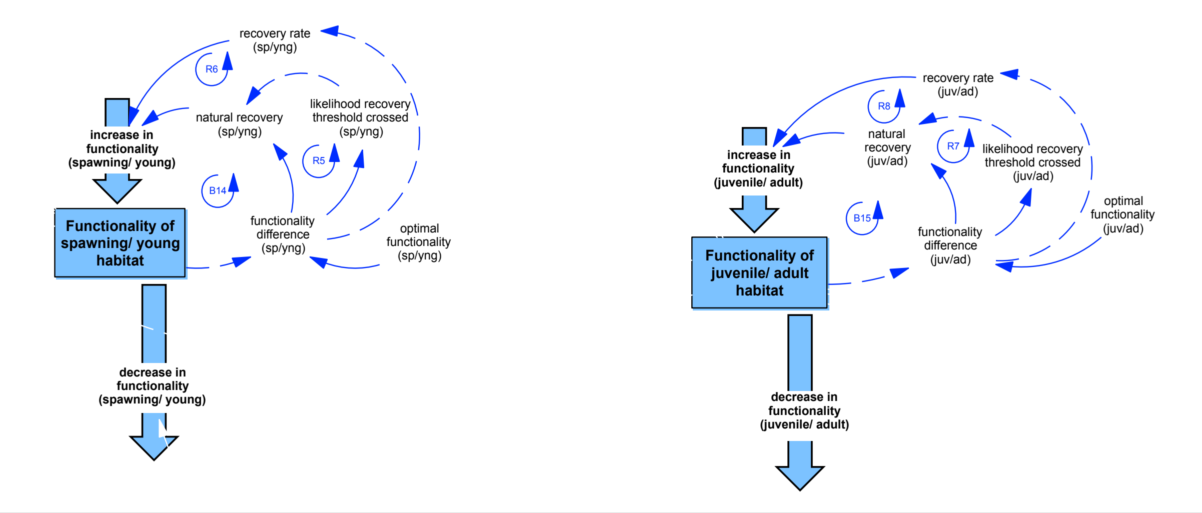


The rate at which this recovery occurs is influenced by the 'recovery rate'. The higher the rate of recovery the faster the process of 'natural recovery' will be. For example, all other things being equal, a recovery rate of 5% will result in faster recovery than a rate of 3%.

13.2.2.2 Feedback loops suppressing natural recovery

Importantly however, the ability for natural recovery to occur and the rate at which it occurs is influenced by two other feedback loops. These suppress natural recovery (Figure 32).

Figure 32. Functionality of habitat – feedback loops suppressing recovery



Firstly, the size of the 'functionality difference' may suppress the 'recovery rate' (loops **R6** and **R8**). In other words, if the functionality of habitat is a long way out of balance, then that functionality may still recover naturally, but the rate at which it recovers may be *slower* as the size of the imbalance may suppress the 'recovery rate'. This is shown by the opposite relationship (dashed line) from 'functionality difference' to the 'recovery rate'.

Secondly, the greater the 'functionality difference', the greater the likelihood that a recovery threshold will be crossed. This is represented by the factor 'likelihood recovery threshold crossed', which is a conceptual reference to the concept of *tipping points* – where habitat functionality may reduce to the point where it gets so out of balance that it is impossible for it to recover naturally. This is represented by the loops **R5** and **R7**. Here, the greater the 'functionality difference' the greater the 'likelihood recovery threshold crossed' (a same relationship), the greater the 'likelihood recovery threshold crossed' the less 'natural recovery' (an opposite relationship). The less 'natural recovery', the less 'increase in functionality', resulting in sustained low levels of the 'Functionality of [life stage] habitat' which, in turn, maintains (or reinforces) a large 'functionality difference', or gap.

13.2.2.3 How these feedback loops work together

While described here independently, these loops all influence each other and the actual level of 'Functionality of [life stage] habitat' is a result of those combined interactions. Different loops may dominate at different times. For example, the natural recovery feedback loop (**B14** and **B16**) will likely dominate if functionality is only slightly out of balance; while the likelihood of crossing a recovery threshold loop (**R5** and **R7**) may dominate if the gap between actual and optimal functionality is sustained for too long.

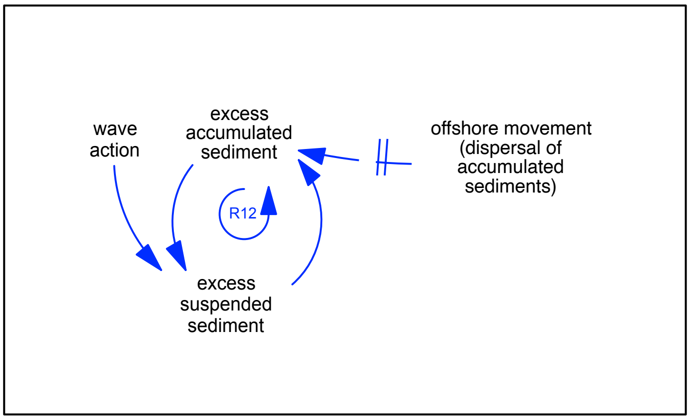
These loops and influences provide a conceptual guide to the forces at play in relation to the functionality of habitat.

13.2.3 Impacts that decrease the functionality of habitat

Declines in the functionality of habitat are represented by flows *out* of the bathtub of the 'Functionality of [life stage] habitat' through the flow labelled 'decrease in functionality'. If this flow is activated it is *drawing down* the amount of functionality of the habitat, thus reducing it. A range of factors influence this flow.

Firstly, two factors relating to excess sediment are represented. These are 'excess suspended sediment' and 'excess accumulated sediment'. As both suspended and accumulated sediment are naturally occurring phenomenon in the ecosystem, these factors have been represented as *excess*, indicating that they broadly and consistently exceed what would be considered the range of *normal* for an ecosystem delivering functionality of habitat within an optimal range. These two factors have a reinforcing relationship with each other – the more suspended sediment there is the greater the likelihood this will result in more accumulated sediment once it settles out of the water column. Similarly, the more accumulated sediment there is, the greater the likelihood that this will be resuspended (through 'wave action') into suspended sediment. This is shown as a reinforcing loop (**R12**) in Figure 1.

Figure 33. The reinforcing relationship between excess suspended and accumulated sediment



The factor labelled 'offshore movement (dispersal of accumulated sediments)' represents the currents and water movement that, over the longer term, may work to disperse accumulated sediments from inshore to deeper offshore areas. These will be different in different areas and operate over long timeframes. Hence the influence arrow has a *double line crossing it* – indicating that this influence would take a longer time to present, relative to others in the diagram.

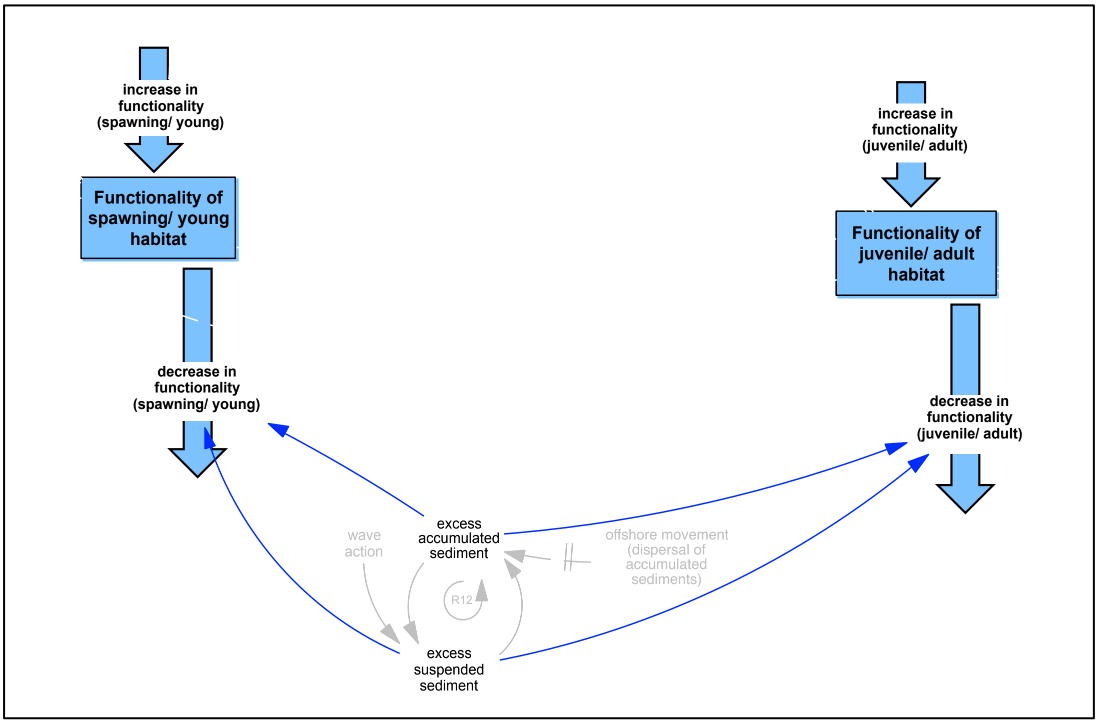
These are, of course, qualitative factors. Yet they have been included to represent the impact that excess amounts of both suspended and accumulated sediment can have on any 'decrease in functionality'. Consequently, both 'excess suspended sediment' and 'excess accumulated sediment' have same relationships (solid line) with 'decrease in functionality' – if there is greater excess sediment, there is a greater decrease in functionality (see Figure 34).

Other factors may also influence the 'decrease in functionality'. These are represented in the diagram as 'climate change impacts' and 'invasive species'.[8]

Climate change impacts have already been described elsewhere – this refers to the detrimental impacts of climate change such as increased storm frequency and intensity. This may directly impact the functionality of habitat through things like destroying or altering benthic structure. Indirectly it may also impact through increased wave action which increases excess suspended sediment.

[8] Both 'climate change impacts' and 'invasive species' are represented in this part of the diagram in angular parentheses (<example>). This simply means that this factor also appears elsewhere in the system diagram. Such factors are often represented several times in the diagram, this minmises the arrows that would otherwise need to cross the diagram and create confusion.

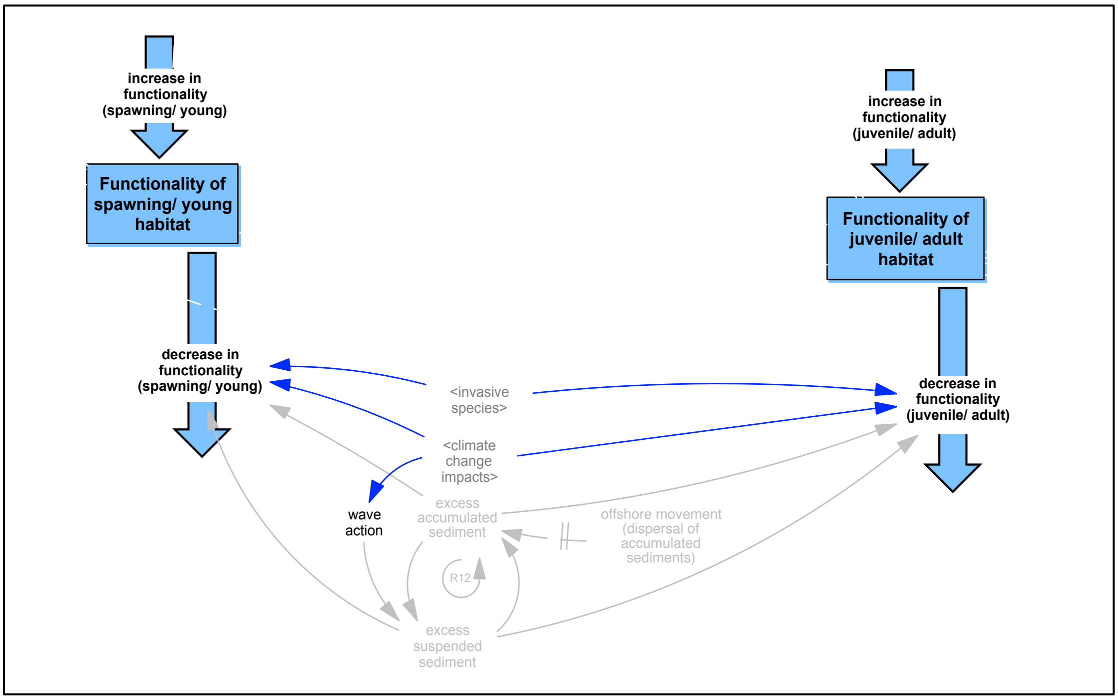
Figure 34. How excess sediment can decrease the functionality of habitat



Invasive species is a factor to indicate that exotic species can often be introduced to the local ecosystem. This may occur through multiple pathways such as from foreign shipping, through escape or release of pest plants and animals, etc. This factor assumes that *invasive species* are not conducive to the balance of the local ecosystem and are detrimental to it.

Both these factors have a same relationship with *decrease in functionality*. If either were to escalate, so would the *decrease in functionality*. See Figure 35.

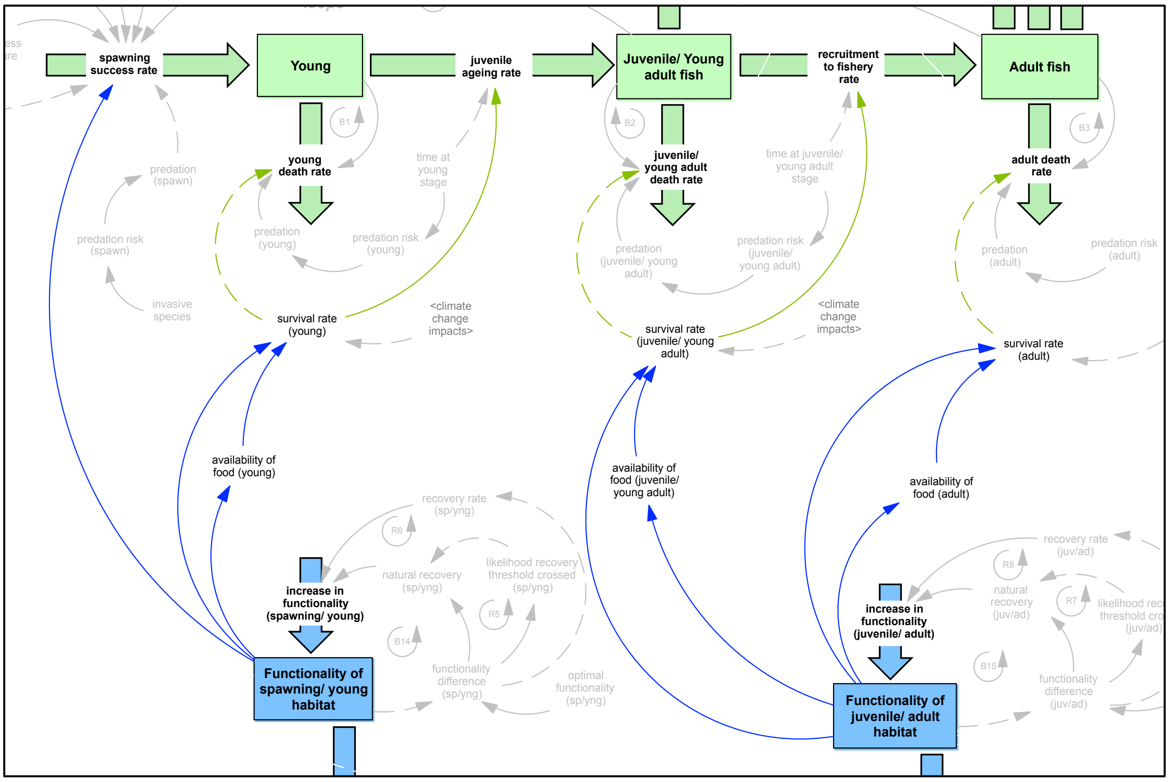
Figure 35. Other factors that decrease the functionality of habitat



13.2.4 How the functionality of habitat supports the fish lifecycle

This section explains the connection between the functionality of habitat and how this supports the fish lifecycle.

Figure 36. How the functionality of habitat supports the fish lifecycle



As noted earlier, the 'Functionality of [life stage] habitat' is a critical ecological enabler of abundance within different fish life stages. Therefore, there is a direct same relationship from the level of this functionality (represented by the bathtub or box) and the success/survival rates associated with the various life stages of the fish species. The better the functionality the better the relevant success/survival rate. These are shown in Figure 36.

Each of the life stages are influenced by a direct same influence from 'functionality of [life stage habitat' to '*survival rate*'*.* This represents the environmental conditions such as the quality of water, the availability of structure on the sea floor (if appropriate), visibility etc.

These influences are as follows. Firstly, functional spawning habitat supports 'spawning success rate'. This is the critical first life stage in the fish life cycle. Secondly, functional youth habitat supports the 'survival rate (young)' at this life stage. Thirdly, functional juvenile and young adult habitats supports the 'survival rate (juvenile/young adult)' at this life stage. And finally, functional adult habitat supports the 'survival rate (adult)' at this life stage.

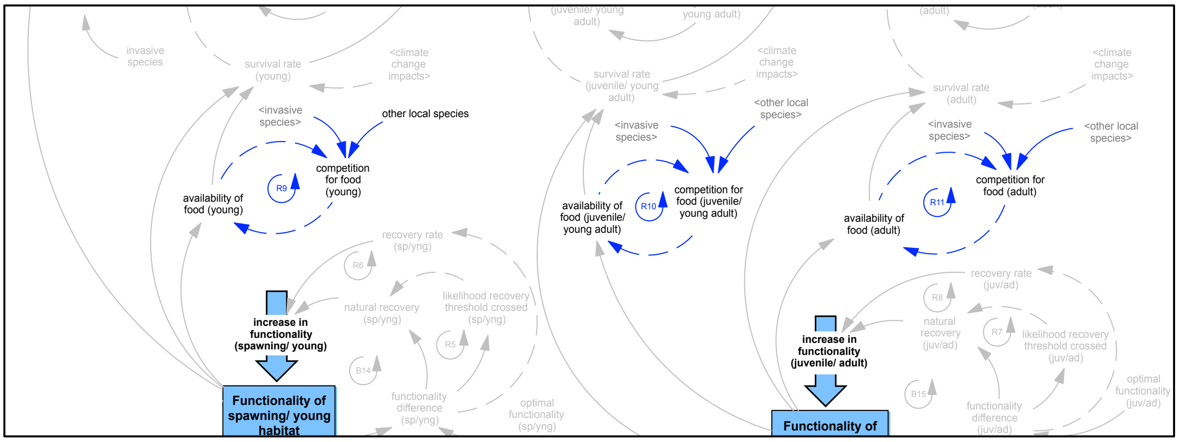
In addition to the above direct influences, each of the 'Young', 'Juvenile/Young adult fish' and 'Adult fish' life stages are influenced by a second pathway of influence from 'Functionality of [life stage] habitat'. Here, 'Functionality of habitat' also supports the 'availability of food ([life stage])' with a same relationship, which in turn also has a same relationship with the 'survival rate' for that life stage.

The availability of food was separated out so that the influence of competition for food could be explicitly captured. This was to allow for the potential of this factor to be an important in attempting to understand multi-species fish complexes, given the dynamics of food availability with other local and invasive species.

13.2.4.1 Competition for food feedback loops

This competition for food is shown as reinforcing loops (**R9**, **R10** and **R11**) in Figure 37. Here, the greater the 'availability of food' at any life stage means there is less 'competition for food' at that life stage. Similarly, the less 'competition for food' the greater the 'availability of food'.

Figure 37. Competition for food with local and invasive species



In addition, the 'competition for food' may also be influenced by 'other local species' and 'invasive species', as well as fish of the same species (which is not shown for simplicity). The greater the numbers of these, the greater the 'competition for food', reducing its availability.

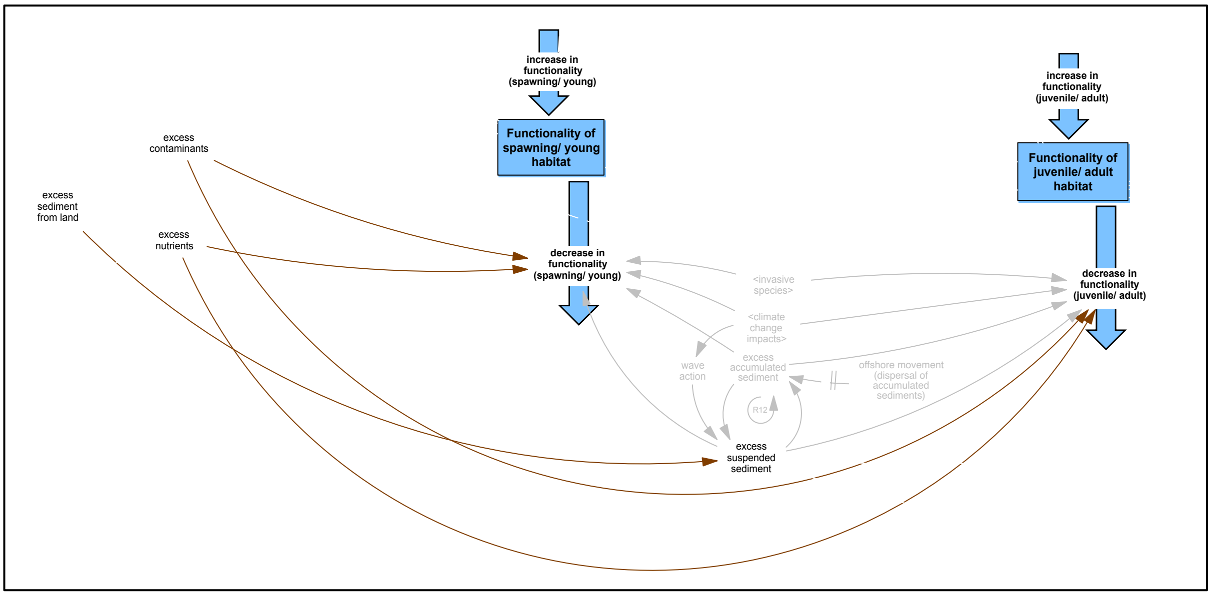
13.3 Activity on land and impact on the functionality of habitat

This section describes the impacts that from activity on land and the loops associated with that activity.

13.3.1 The three main impacts from activity on land

During the workshop, three main aggregated impacts from activities on land were discussed and represented in the system diagram. These are: 'excess nutrients', 'excess sediment from land', and 'excess contaminants'. These three impacts are shown in Figure 38.

Figure 38. The three main impacts from activity on land



Like suspended and accumulated sediment described in earlier sections, these impacts are naturally occurring, yet are accentuated by human activity. Therefore, in the diagram, these are also framed in terms of excess levels. Excess levels of these factors can contribute to a 'decrease in functionality', and therefore the 'Functionality of [life stage] habitat', either directly or indirectly.

'Excess sediment from land' describes the sediment that is eroded from land into the ocean. This is predominantly as sediment load in rivers but may also occur directly from coastal erosion. This has a same relationship with 'excess suspended sediment'. If the first one increases, then so does the second. This is again predominantly because the bulk of sediment load is delivered to the ocean as suspended sediment in river flow. This will impact functionality indirectly as it will either flow on as an impact via 'excess suspended sediment' or 'excess accumulated sediment', both described earlier.

'Excess nutrients' describes a range of nutrients that occur naturally but may be at elevated levels. This may include (but is not limited to) nutrients such as nitrogen, phosphorous, and/or faecal matter from wild and farmed animals (for this the presence of *E. coli* is used an indicator).[9]

'Excess contaminants' describe a range of contaminants that occur naturally but may be at elevated levels, or contaminants that are unlikely to occur naturally. In the instance of the latter, even a small amount would be considered 'excess'. This may include (but is not limited to) contaminants such as heavy metals (zinc, copper, magnesium), (micro)plastics, and/or tarseal/oil/rubber residue from roads.

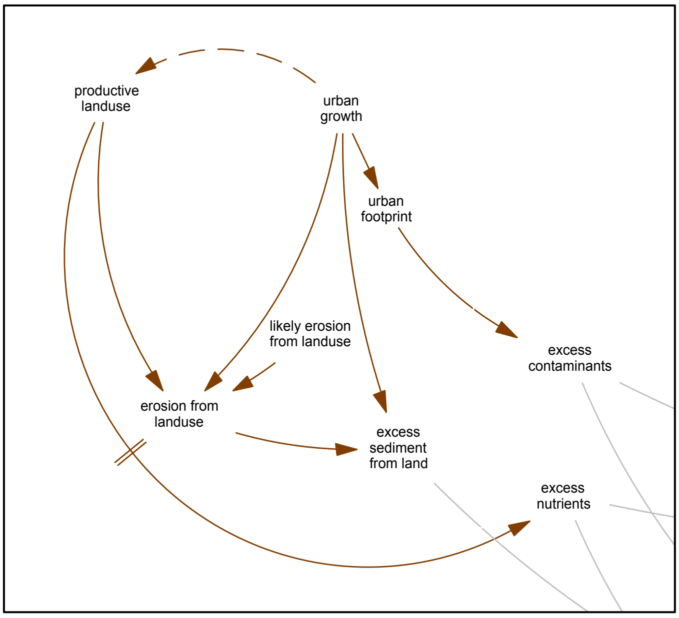
'Excess nutrients' and 'excess contaminants' both impact 'decrease in functionality' directly, as excess levels of these are considered to have a detrimental impact on the 'functionality of habitat'.

13.3.2 Productive landuse and the urban footprint

The three impacts from activity on land (nutrients, sediment and contaminants) can be summarised as originating from two broad types of human activity on land – 'productive landuse' and the 'urban footprint' (which is increased through 'urban growth'). These and their associated influences can be seen in Figure 39.

'Productive landuse' describes land used for productive human purposes such as farming, forestry, viticulture, orchards, horticulture etc. 'Urban footprint' describes the size of the urban area, which includes residential, commercial, retail, industrial and other forms of land use that would be deemed to fall within a broad infrastructural urban footprint.

Figure 39. Productive landuse and the urban footprint



Land currently considered 'conservation estate' or similar, where it remains in a high level of bush cover or a low level of productive use and is likely to stay that way, is not considered in this system

[9] In this diagram 'nutrients' is used as a term that related to nutrient contamination, usually associated with productive land use. 'Contaminants' is used as a term related to contaminants that are usually associated with urban infrastructure, such as heavy metals etc.

diagram. This is because it is unlikely to be converted to productive landuse or urban form. However, this does not preclude this from happening and if it did this would be seen to increase to either of these bathtubs of landuse.

13.3.2.1 Productive landuse

'Productive landuse' has a same influence on both 'erosion from landuse', which then impacts excess sediment from land, and *'excess nutrients'* directly. At a high level this recognises that productive landuse often involves the application of additional nutrients in the form of fertiliser; as well as the potential for erosion due to the historical clearance of bush and use of the land for production (e.g. livestock of tillage). Each individual type of landuse will have its own profile in relation to the level or intensity of inputs (e.g. fertiliser). Profiling all of these is not the intent of this report, but it is recognised that they are not homogenous. The erosion from landuse is also influenced by the 'likely erosion from landuse', which is a factor intended to conceptualise the erosion risk profile for any area of land.

'Urban footprint' describes the size of the urban area described by the uses above, within a broad infrastructural urban footprint. The infrastructural footprint (roads, drains etc) is important here, as this is viewed as the main pathways (or vectors) by which excess contaminants make their way to the marine environment. Therefore, 'urban footprint' has a same influence on 'excess contaminants'.

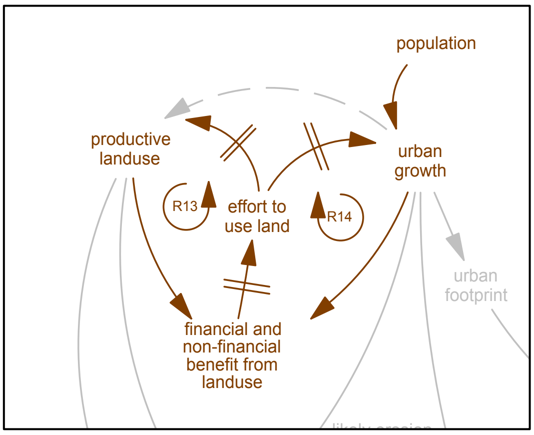
'Urban footprint' is also influenced by a same influence from 'urban growth'. 'Urban growth' is the active expansion of the 'urban footprint' through the conversion of land to urban form and, importantly, the addition of the infrastructural footprint described above (roads, drains etc). The act of 'urban growth' often involves earthworks for road building, subdivision etc. This means that any increase in 'urban growth' can lead to an increase in 'erosion from landuse' (even if only temporarily – i.e. in the act of conversion) and an 'excess of sediment from land'. 'Urban growth' therefore influences these two factors with a same relationship.

Because 'urban growth' is often assumed to occur through the conversion of productive land to urban form, 'urban growth' influences 'productive landuse' in an opposite direction – the more 'urban growth', the less 'productive land'.

13.3.3 Drivers of productive landuse and the urban footprint

This part of the system diagram focuses on 'productive landuse' and 'urban growth' as the main sources of impacts on land. These are shown in Figure 1.

Figure 40. Drivers of productive landuse and the urban footprint



The drivers of these two landuses can be summarised into the amount of 'effort to use land' (for human purposes), which is in turn driven by the 'financial and non-financial benefits from landuse' that are realised by humans. In effect this means that, because humans have a vested interest in using land they will tend to use more of it, which in turn continues to give them benefit, which in turn continues to encourage them to use it. These are reinforcing loops (**R13** and **R14**) and they tend to have delays associated with the effort to use land.

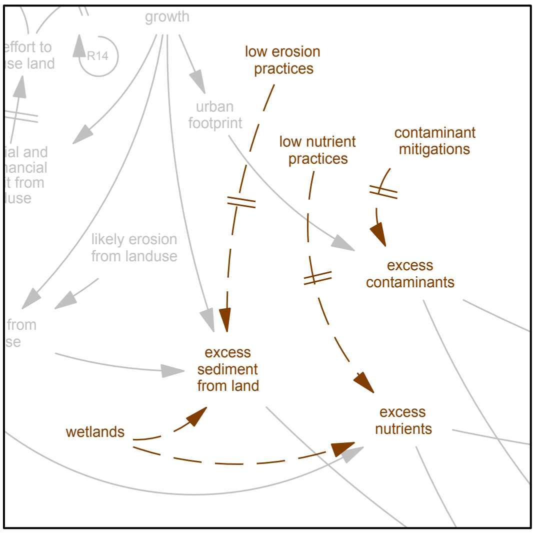
'Urban growth' is also influenced by the size of the 'population' – the greater the 'population' the greater the 'urban growth'.

13.3.4 Mitigating impacts from landuse

A range of mitigations exist to reduce the 'excess contaminants', 'excess nutrients' and 'excess sediment from land'. These have been represented in a range of aggregated ways (see Figure 1).

These aggregated representations include: '*low erosion practices*' in both '*productive landuse*' (e.g. on farms/plantations) and in the act of '*urban growth*' (e.g. mitigation measures in relation to earthworks); '*low nutrient practices*' on productive farmland; '*contaminant mitigations*' such as mitigations to capture and/or filter contaminants within existing urban infrastructure; '*wetlands*' to help reduce both '*excess sediment from land*' and '*excess nutrients*' from farmland. These are shown in Figure 1 as opposite relationships because an increase in any of them will result in a decrease in the impacts.

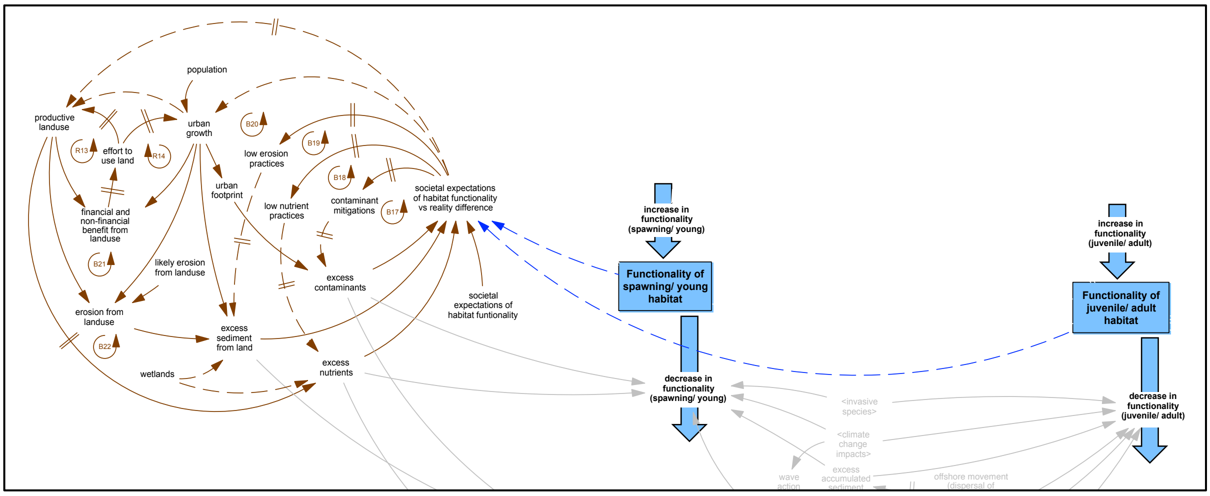
Figure 41. Means of mitigating impacts from landuse



13.3.5 Activity on land and societal expectations

Both the two main sources of impacts from land ('productive landuse' and 'urban growth') and the three main mitigation activities ('low erosion practices', 'low nutrient practices' and 'contaminant mitigations') are all driven by feedback loops relating to societal expectations. This final sub-section describes these relationships and loops (see Figure 42).

Figure 42. Activity on land and societal expectations



The main structural component here is a **goal/gap** relationship between the levels of habitat functionality that we as a society *expect* (represented by 'societal expectations of habitat functionality'); and the *actual* levels of habitat functionality (as represented by the two bathtubs of 'Functionality of [life stage] habitat').

The word ‘societal’ is used in the broadest sense and is intended to include all people in society, whether they are actively aware of the marine habitat and its functionality or not. It includes people who are actively involved in the use and/or management of the ocean area, and people from all perspectives and opinions within those areas.

The word ‘expectations’ as used here describes the aggregate level of expectations of what the functionality of the habitat *should* be. This is not a clearly articulated position statement on what level of functionality there should be, it is quite the opposite. This factor recognises that people have many different views and that some will have no views at all – there is unlikely to be any single, clear, public articulation of what these expectations are. Rather, this factor describes the combined aggregate level of those expectations, which may be evident in the way that people vote in relation to issues, the level of press coverage that such discussion might have, and the nature of the opinions that people hold and the discussion that people have.

This *expectation* is represented in the diagram by the ‘societal expectations of habitat functionality’. The *actual* level of habitat functionality is represented in the diagram by: the actual levels of the ‘functionality of [life stage] habitat’; and, as proxies, the levels of the different impacts that occur from land (‘excess contaminants’, ‘excess nutrients’, ‘excess sediment from land’).

The difference between the *actual* level of habitat functionality and the *expected* level of habitat functionality, determines how far out of balance reality is with expectations. This is, of course, impossible to measure and it is not intended that it could or should be. Rather, these conceptual factors are intended to represent how in or out of balance the health and wellbeing of the marine environment is with societal expectations. Representing these factors on the system diagram is intended as a prompt for users of the diagram to recognise the connection between broader societal expectations and their influence on activity that influences the marine environment. This is an important factor of socio-ecological systems and highlights the role that human perceptions and desires have on influences that impact the marine environment.

This is represented in the system diagram as another **goal/gap relationship**, where the difference between *expectations* and *reality* are represented by the factor labelled ‘societal expectations of habitat functionality vs reality difference’ (also called ‘difference’). If this difference is *small*, then reality is *virtually in line* with the expectations. If this difference is *large*, then the reality is *out of line* with expectations. This difference then influences other factors.

The ‘difference’ factor has an opposite relationship with the ways land is used (‘productive landuse’ and ‘urban growth’). If the ‘difference’ decreases (i.e. habitat functionality is *in line with* expectations) then this may result in an increase in land use activities. Conversely, if the ‘difference' was to *increase* then this would increase pressure to *reduce* the land use activities of ‘productive landuse’ and ‘urban growth’. These influences take far longer to present and so are represented with delays (double lines across the arrows).

At the same time, the ‘difference’ factor has a same relationship with the various low impact and mitigation practices (‘low erosion practices’, ‘low nutrient practices’, and ‘contaminant mitigations’). These relationships also have a delay so do not present straight away. If the ‘difference’ is small (i.e. habitat functionality is in line with expectations) then there will be minimal pressure to establish or increase such practices as they may not be deemed necessary. Conversely, if the ‘difference’ is large then this may lead to increased pressure to establish or expand low impact or mitigation practices.

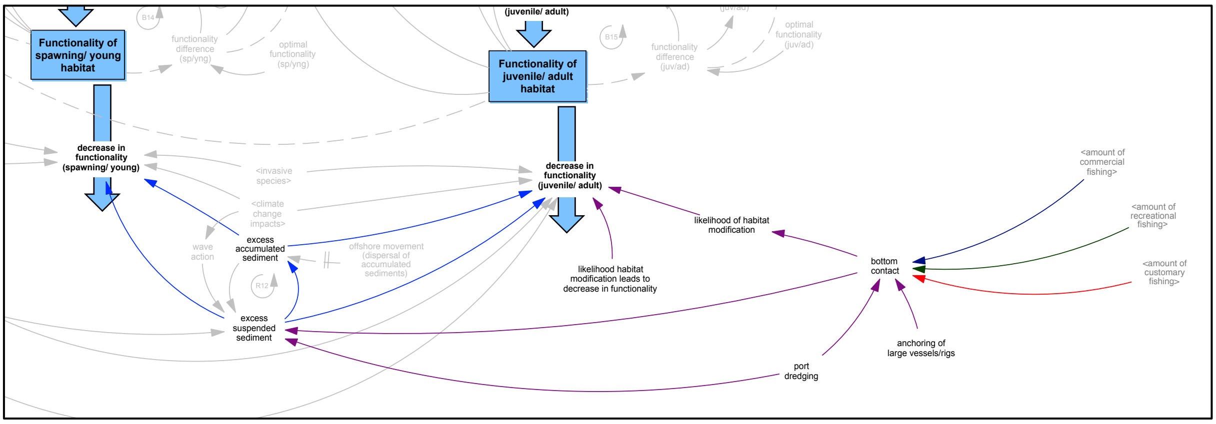
13.4 Ocean bottom contact, impact, and drivers of mitigation

This section describes the variety of ways that human activity has direct contact with the ocean floor (represented by the factor ‘bottom contact’) and how these impacts influence ‘decrease in [life stage] functionality’. It also describes the pathways of influence which counteract or mitigate these impacts.

13.4.1 Types of bottom contact and their potential impact on the functionality of habitat

There are a range of ways in which bottom contact from human activity occurs in the marine environment including port dredging, anchoring of large vessels/rigs, the 'amount of commercial fishing', the 'amount of recreational fishing', and the 'amount of customary fishing'. These relationships are shown in Figure 43.

Figure 43. Types of ocean bottom contact and their impact on the functionality of habitat



'Bottom contact' describes human activity that results in contact with, and potential modification of, the ocean floor. This does not include small scale gear like sinkers and light anchors. It is deemed to include any dredging (for sediment clearance or fishing purposes) and the dragging of gear (fishing or otherwise) across the ocean floor. 'Bottom contact' may occur to varying intensities depending on the nature of the activity.

The impact that 'bottom contact' can have on 'decrease in functionality' occurs via two pathways. Firstly, any 'bottom contact' can lead to more 'suspended sediment' which can lead to a 'decrease in functionality'. Secondly, any 'bottom contact' can lead to an increased 'likelihood of habitat modification' which, may lead to a 'decrease in functionality'. The extent to which any modification may lead to a decrease in functionality is determined by the 'likelihood habitat modification leads to a decrease in functionality'. The potential extent of any impacts will differ according to the location and type of 'bottom contact' that occurs. It is beyond the scope of this report to determine what these are.

'Port dredging' describes the act of dredging in relation to the port. This is constrained to the area where the dredging occurs and where the dredging spoil is disposed. This factor has two potential pathways of influence to 'decrease in functionality', both are represented as same influences. Firstly, the more 'port dredging' the more 'bottom contact' and the greater the 'likelihood of habitat modification'; and secondly, the more 'port dredging' the more 'excess suspended sediment' there will be – both through the act of dredging resuspended sediment off the ocean floor and through the disposing of the dredge spoil in other parts of the bay. This 'excess suspended sediment' may lead to an increase in 'excess accumulated sediment' as that dredge spoil settles on the ocean floor. Both excess suspended and accumulated sediment can lead to a 'decrease in functionality'.

The four other factors that influence the 'bottom contact' factor are: 'Anchoring of large vessels/rigs'; the 'amount of customary fishing', the 'amount of recreational fishing' and the 'amount of commercial fishing'.

'Anchoring of large vessels/rigs' describes the act of temporarily anchoring large vessels or oil rigs in the bay – as described here their large anchoring gear may create reasonable contact with the ocean floor.

The 'amount of customary fishing', 'amount of recreational fishing' and 'amount of commercial fishing' all describe the volume and intensity of these types of fishing. All are assumed to have the potential for ‘bottom contact’ with the ocean floor at reasonable scale. However, these occur at different scales: commercial trawling is known to occur at scale; and at the same time, it is acknowledged that customary and recreational fishing activities may involve techniques that involve reasonable scale bottom contact (for example shellfish dredging).

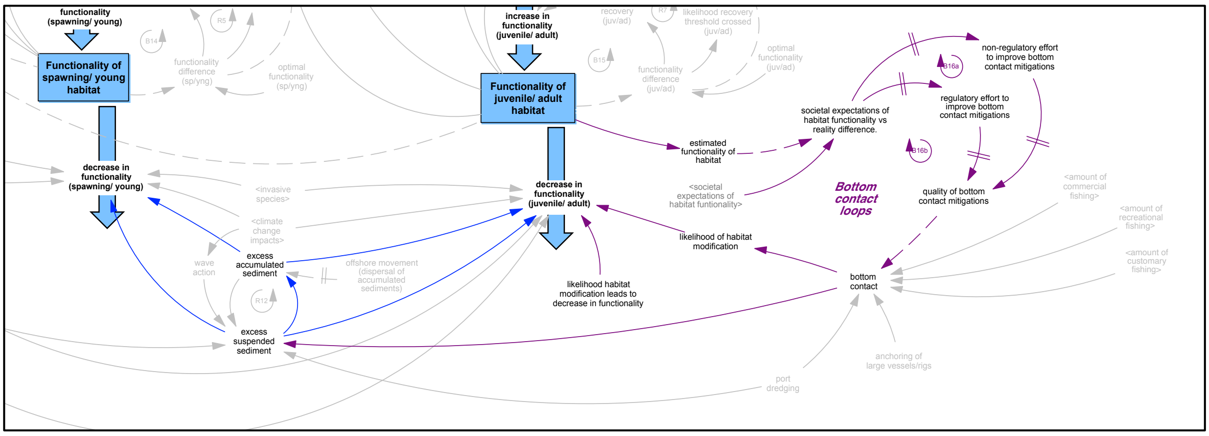
Assessing the relative impact of such techniques is not within the scope of this report. The drivers of mitigations to reduce the impact of bottom contact activities and how they create balancing loops is discussed in the following sub-section.

13.4.2 The drivers of mitigations to reduce bottom contact

When considering bottom impacts, it is important to recognise the drivers of mitigations to reduce bottom contact also (see Figure 44).

In summary, as the ‘Functionality of juvenile/adult habitat’ reduces and falls out of line with societal expectations of what that functionality *should* be, over time this may lead to efforts to improve bottom contact mitigations. For example, adapting gear to reduce the impact of bottom contact activity or avoiding important habitats. This could occur via a voluntary or regulatory pathway.

Figure 44. The loops driving mitigations of bottom contact



The pathways from ‘bottom contact’ to reduced ‘Functionality of juvenile/adult habitat’ have been described in the previous section. From reduced functionality, the pathway to voluntary or regulatory activity is driven again by a **goal/gap** relationship with ‘Societal expectations of habitat functionality’. This concept of societal expectations has already been described in section 1.1.1 in relation to landuse activity and the same descriptor applies here. A comparison of the actual ‘functionality of habitat’ with the *societal expectations* of what that habitat should be determines the *difference* between the two (represented by the factor ‘societal expectations of habitat functionality vs reality difference’ (also described as ‘difference’)). If this ‘difference’ is low (i.e. reality is roughly in line with expectations), there is unlikely to be significant pressures to increase the ‘quality of bottom contact mitigations’. However, the larger this difference becomes, the more out of line with expectations, the greater the pressure to increase the ‘quality of bottom contact mitigations’.

Any increase in the ‘quality of bottom contact mitigations’ may occur via a voluntary (non-regulatory) or a regulatory pathway. These represented by the factors ‘non-regulatory effort to improve bottom contact mitigations’ and ‘regulatory effort to improve bottom contact mitigations’. Any increase in the ‘quality of bottom contact mitigations’ is expected to *reduce* the level of bottom contact – therefore the loops that these create are *balancing* loops (**B16a** (non-regulatory) and **B16b** (regulatory)).

13.5 The Quota Management System (QMS) and customary, recreational, and commercial fishing effort

This section outlines the factors and feedback loops that represent setting catch limits and allowances with the Quota Management System (QMS) at an aggregated level, in the diagram. This includes the overall loops of setting a total allowable catch (TAC) that helps to keep the fish stocks sustainable; as well as the three types of catch that are recognised in the Fisheries Act 1996 – customary, recreational and commercial catch.

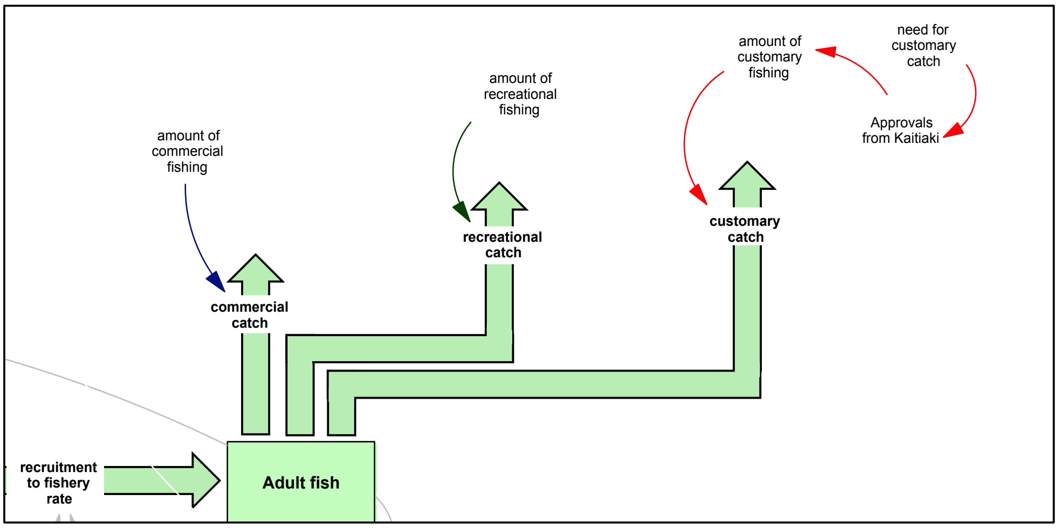
13.5.1 An overview of the loops that represent the QMS

Three fishing sectors are recognised in the QMS enabling legislation: customary; recreational and commercial. A description of how these are represented in the system diagram follows.

13.5.1.1 The three types of catch in the QMS

The three types of catch (customary, recreational and commercial) are shown in Figure 45, along with some of the drivers of customary catch shown in more detail (more drivers for all catch types will be described in the following sub-sections).

Figure 45. The three main types of catch in the QMS



'Customary catch' is the aggregate representation of catch by Māori with the permission of local Kaitiaki (customary guardians). This is a process whereby Kaitiaki permit any catch or collection of kaimoana (seafood), in the diagram this is represented by the factor 'approvals from Kaitiaki'. Approvals by Kaitiaki are only issued if the Kaitiaki perceives the kaimoana/fish populations are abundant enough – this is not shown in Figure 45, but is explained in more detail in section 13.5.2. The greater a community's 'need for customary catch', the greater the 'Approvals from Kaitiaki', the greater likelihood of applications for customary permits. The greater the issuing of 'approvals from kaitiaki', the greater the 'amount of customary fishing'. These factors form a feedback loop that is not shown in Figure 45, yet is fully described in in section 13.5.2, and where approvals by Kaitiaki are only enabled if the Kaitiaki perceives the seafood/fish stocks to be abundant enough.

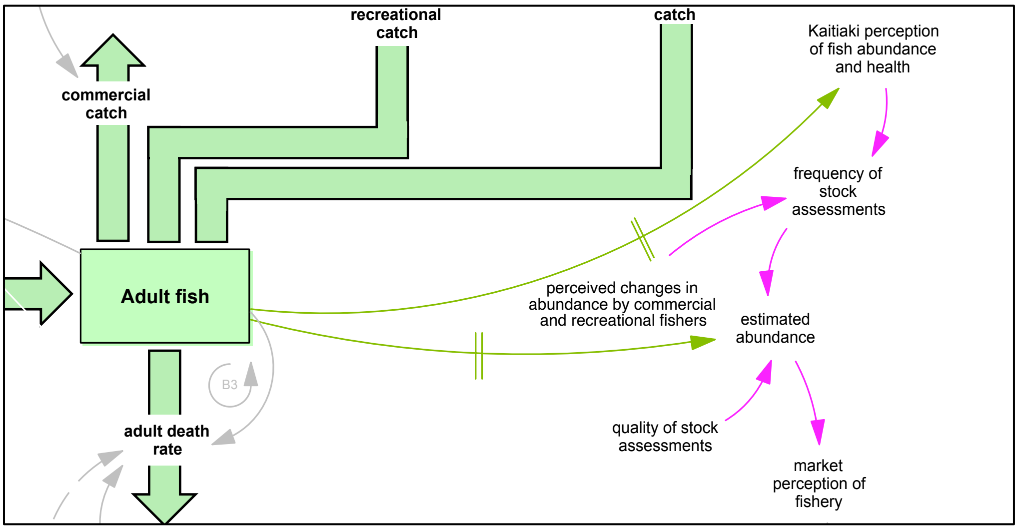
'Recreational catch' is the aggregate representation of catch by any people who choose to go out and fish for personal use (e.g., not for barter or trade). This will mostly be local people who fish recreationally at differing frequencies, yet may also include tourist fishers (including those on amateur fishing trips) who also fish under the recreational bag limit. The recreational bag limit is not shown in Figure 45, this is explained in detail in section 13.5.3.

‘Commercial catch’ is the aggregate representation of catch by licenced commercial fishers. Other factors that influence commercial fishing are described in sections 13.5.4 to 13.5.8.

13.5.1.2 Estimating abundance

The QMS provides a mechanism for the overall combined catch from these three main types of catch, and all other mortality caused by fishing, to be accounted for within the estimated sustainable catch from the fishery/ies. To determine the total limit within which the various catches must remain to ensure sustainability, it is first necessary to estimate the abundance of the (various) fish stock(s). The different influences on the estimation of abundance are shown in Figure 46.

Figure 46. Estimating abundance



FNZ uses scientific assessments of fish stocks to determine abundance and sustainable catch levels. This is represented by the ‘estimated abundance’ factor which indicates the level of abundance that is thought to exist and the level of confidence in this estimate.

‘Estimated abundance’ is informed by many things. Primarily it is informed by the level of fish stocks that are in the ocean (the green line from the ‘Adult fish’ bathtub). This has a delay to represent that this is not an immediate influence – it takes time to make estimates and they are not formally undertaken every year. FNZ commissions formal stock assessments and both the frequency and quality of these assessments have an influence on the estimated abundance. These are represented by the factors ‘frequency of stock assessments’ and ‘quality of stock assessments’. The influence of these factors should not be interpreted as saying that undertaking stock assessments more frequently will mean there is more abundance, rather it will *increase the confidence* in the estimation of abundance.

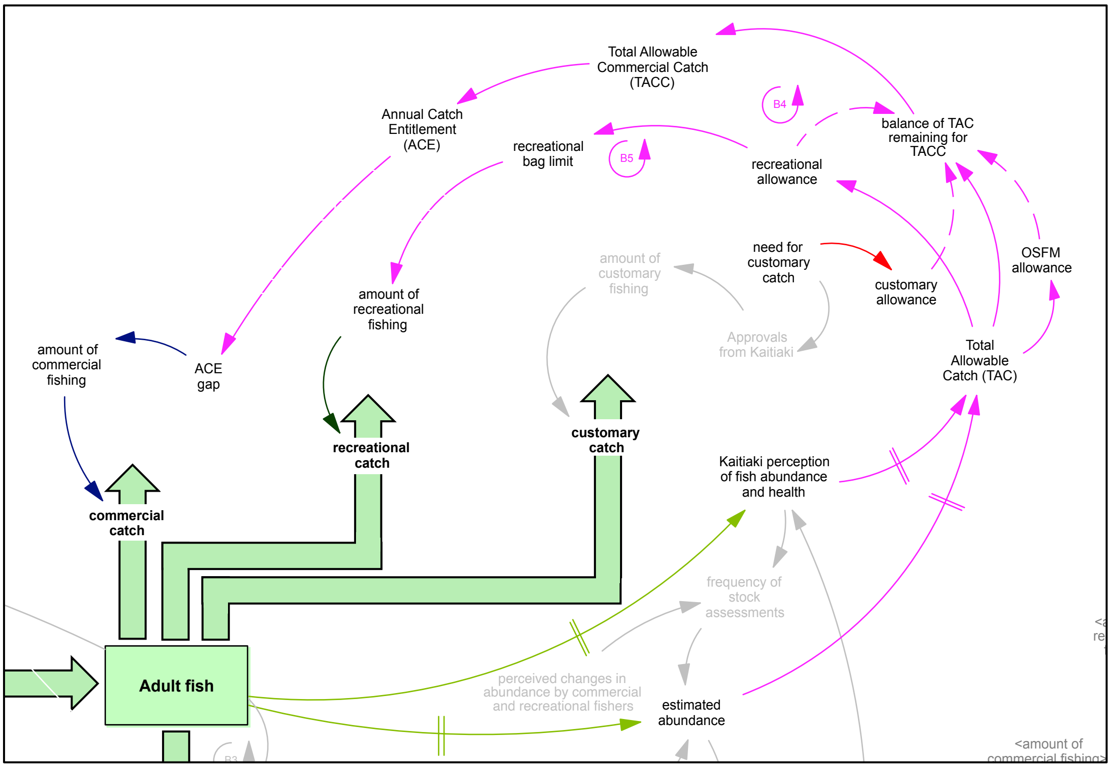
Commercial and recreational fishing bodies, as well as local Kaitiaki, also contribute knowledge to FNZ in the process of estimating abundance.

The factor ‘perceived changes in abundance by commercial and recreational fishers’ describes the perceived changes that people actively involved in fishing may observe (either commercial or recreational) which, when fed back to FNZ, may prompt more frequent stock assessments. Similarly, if there is a change in the ‘Kaitiaki perception of abundance and health’ of fish stocks, then this may also be fed back to FNZ and may prompt more frequent stock assessments.

13.5.1.3 The main QMS balancing feedback loops

Once abundance has been estimated, this informs the process of determining the catch limits within the QMS, as does input from Kaitiaki. The below description and diagram (Figure 47) are not intended to be a comprehensive explanation of how the QMS works. Other sources of information are better placed to do this. However, the influences described below provide a high-level summary of the influences operating within the QMS.

Figure 47. **The main QMS balancing feedback loops**



These influences are listed below.

- The 'estimated abundance' determines the 'Total Allowance Catch (TAC)' in the QMS. This is a same influence – the greater the abundance the greater the TAC. The delay lines on this influence arrow indicate that this process takes time. (Note: this relationship forms art of both reinforcing loops, so does not operate independently of the actual abundance)
- The 'need for customary catch' determines the 'customary allowance' – the greater the need the greater the allowance (hence a same relationship). This is the annual level of catch that Māori advise FNZ they expect to need. This is taken from the TAC before other fisheries allowances are determined.
- After the 'customary allowance' has been taken out of the TAC, the 'recreational allowance' and an allowance to account for Other mortality ('other mortality allowance') are determined and taken out of the TAC. The other mortality is an allowance made within the TAC to account for unseen fish deaths through the act of fishing. This includes (but may not be limited to): illegal take; under-reporting; death of fish required to be returned to the sea; "ghost fishing" by lost gear and burst nets. Unlike the customary catch, these two allowances are directly determined by the TAC. So, the TAC has a same relationship with these two factors – the greater the TAC the greater the potential greater ability for the Minister of Fisheries increase the 'recreational allowance', while assuming the rate that assumes other mortality remains the same, any increase in TAC would also result in an increase in the 'Other mortality allowance'.
- Once the customary allowance has been advised and the recreational and other mortality allowances determined, the 'balance of the TAC remaining for TACC' (the Total Allowable Commercial Catch) can be determined. Same and opposite relationships influence this node. The greater the TAC the *greater* the 'balance of TAC remaining for TACC', because there is more to be allocated (a same relationship). Yet at the same time, the greater the customary,

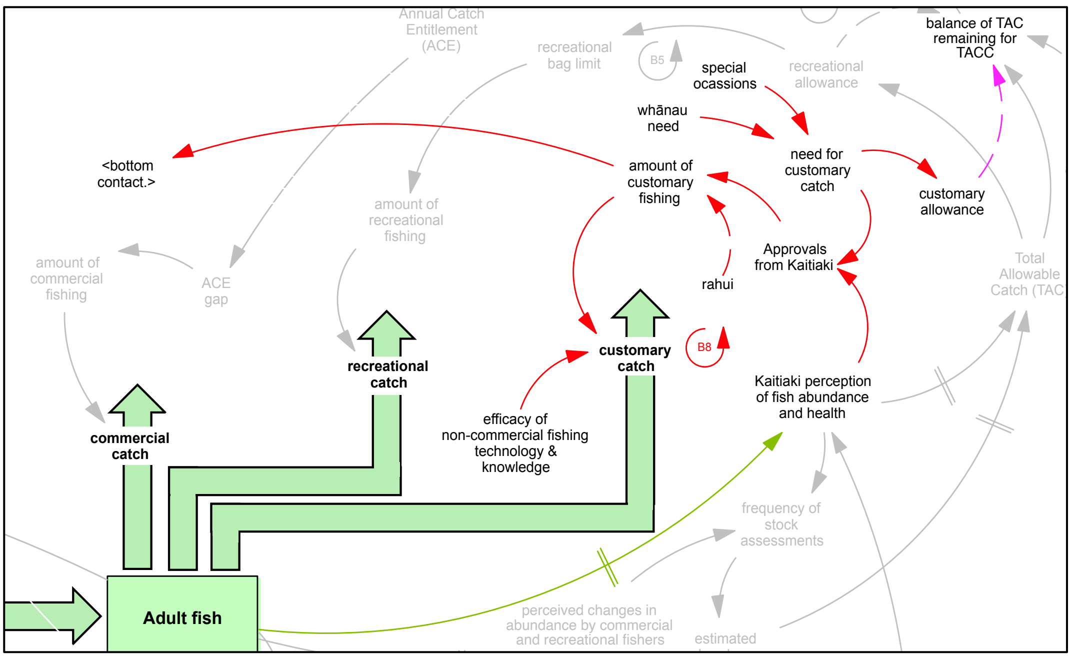
recreational and other mortality allowances, the *lower* the 'balance of TAC remaining for TACC' because these allocations have taken more of the available TAC (opposite relationships).

- Once the balance available for the TACC has been determined, the Total Allowable Commercial Catch is determined, which is represented by the factor of the same name. This represents the allowable catch by quota owners.
- The 'recreational allowance' informs the 'recreational bag limit' (same relationship) which is one important driver (or constraint) on the 'amount of recreational fishing'. This is also a same relationship – the greater the bag limit, the greater the 'amount of recreational fishing', and vice versa (this is explained in more detail in section 13.5.3). Like all catch, 'recreational catch' removes fish from the population and so has the potential to reduce the numbers of fish in the 'Adult fish' bathtub, which may eventually be reflected in revised 'abundance estimates' and revised 'Total Allowable Catch (TAC)'. **This influence pathway completes the first of the two important balancing loops in the QMS** (**B5** in Figure 47).
- The 'Total Allowable Commercial Catch (TACC)' determines the total 'Annual Catch Entitlement (ACE)' which is available to quota owners. Each quota owner receives an allocation of ACE in proportion to the TACC and the quota held for a fish stock. Quota owners may fish their ACE if they are commercial fishers or may make ACE available to other fishers and licensed fish receivers (via a range of methods). . The total ACE for a fish stock is the maximum annual entitlement for a fish stock that any fisher may catch (without incurring deemed value penalties), so the gap between this *allowance* and their *actual* catch is important and is represented by the factor 'ACE gap', which is an important influence on the 'commercial fishing effort'. Like all catch, 'commercial catch' removes fish from the population and so has the potential to reduce the numbers of fish in the 'Adult fish' bathtub, which may eventually be reflected in revised 'abundance estimates' and revised 'Total Allowable Catch (TAC)'. **This influence pathway completes the second of the two important balancing loops in the QMS** (**B6** in Figure 47).

13.5.2 The drivers of customary catch

The overarching loops of the QMS are described above. This section outlines other specific influences on customary catch and the balancing loop that it itself operates within. These are shown in Figure 48.

Figure 48. The customary catch loop



As noted earlier, the 'need for customary catch' is what informs the 'customary allowance' within the TAC. This need is also the driver of applications for customary permits used by Kaitiaki. Customary permits are represented by 'Approvals from Kaitiaki' in the system diagram. The need for 'Approvals from Kaitiaki' is itself influenced by the need for kai generated by 'whānau need' and 'special occasions'. The 'whānau need' factor describes the need of whānau and hapu for nutrition and sustenance; while the 'special occasions' factor describes the types of special occasions that might require harvesting of customary catch in order to provide kai – for example, weddings, tangihanga, significant milestone birthdays (e.g. a 70th birthday).

The 'Approvals from Kaitiaki' are also informed by the 'Kaitiaki perception of fish abundance and health'. If Kaitiaki don't believe that the fish are abundant and healthy, they are less likely to issue permits. This is represented with a same relationship (the better the abundance the greater the approvals). 'Approvals from Kaitiaki' directly informs the 'amount of customary fishing' (same relationship). The 'amount of customary fishing' is also influenced by 'rahui' – which is a mechanism of placing temporary bans on harvesting/fishing for different reasons.

While the main driver of 'customary catch' is the 'amount of customary fishing' and the number of fish in the *bathtub*, it is also important to note that this is also influenced by the efficacy of technology and practices. This is represented with the factor 'efficacy of non-commercial fishing technology & knowledge' which is intended to capture the tools, skills and knowledge that can help improve 'customary catch' for the same amount of effort. For example, fish finders, more powerful engines, and boats with greater range potential, etc.

Together, these influences make a balancing loop (**B8**) because: The better the Kaitiaki perception of abundance, the more approvals, the more fishing occurs and the greater catch. Over time, the more catch, the less fish in the *bathtub* and, if sustained, this would eventually adjust the Kaitiaki perception of abundance, thus balancing out the loop.

It is important to note that while the statutory role of Kaitiaki is recognised in the Fisheries Act, this balancing loop operates independently of the Total Allowable Catch (TAC) that is determined in the QMS.

Finally, the 'amount of customary fishing' also has a same relationship with the level of 'bottom contact', if this is part of the fishing method, then more fishing means more bottom contact.

13.5.3 The drivers of recreational catch

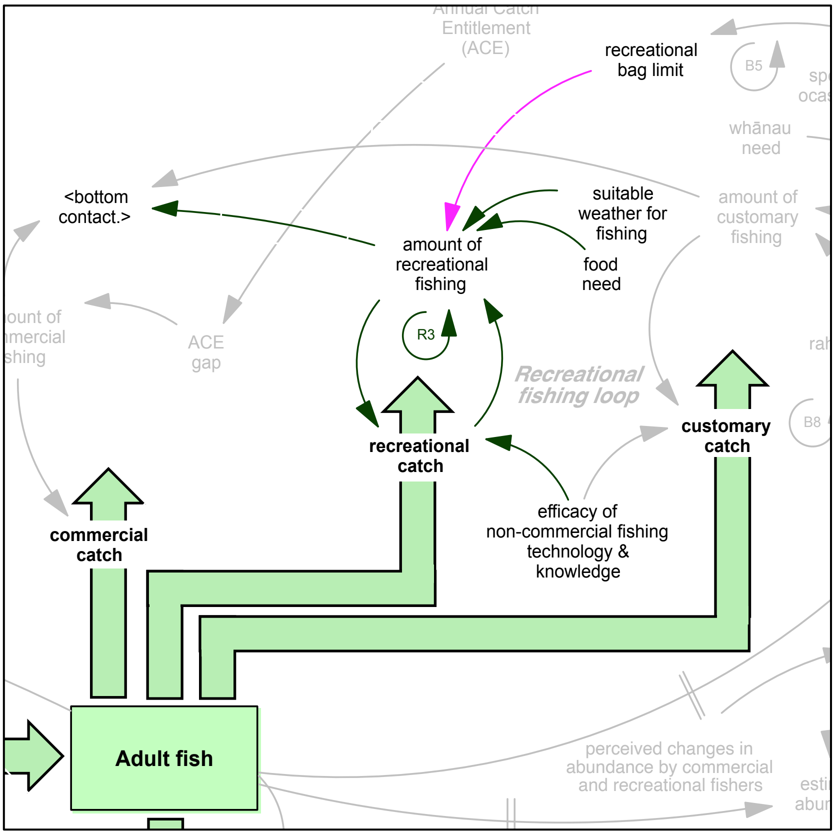
This section describes the drivers of the amount of recreational fishing and catch. These are shown in Figure 1.

The 'recreational bag limit' is one of the influences on the 'amount of recreational fishing'. The 'recreational bag limit' itself is influenced by the other factors already described within the main QMS feedback loops, this provides the overall daily catch limit for recreational fishers. So here, a larger bag limit is considered to be a greater driver of the 'amount of recreational fishing' (among other things). There is no restriction on how many days in a year that recreational fishers can catch that limit.

Other factors that influence the 'amount of recreational fishing' include fisherpersons experience of recent fishing successes – if they have been experiencing good catch (abundance) then they are more likely to fish again. This is represented by a same relationship from 'recreational catch' (the amount actually caught) to the 'amount of recreational fishing'. Other influences include 'suitable weather for fishing', and also the 'food need' of fisherpersons and their family (i.e. do they need to fish to eat?).

It is recognised that some 'amount of recreational fishing' may also result in 'bottom contact' on the ocean floor, depending on the gear used. So, this is represented with a same relationship from 'amount of recreational fishing' to 'bottom contact'. The exact strength of this remains undetermined and may be quite low. This is not suggesting that the intensity of ‘bottom contact’ from the ‘amount of recreational fishing’ is comparable to that of commercial fishing.

Figure 49. **The drivers of recreational catch**



Like customary fishing, while the main driver of ‘recreational catch’ is the ‘amount of recreational fishing’, it is also important to note that this is also influenced by the efficacy of technology and practices. Therefore, the factor of ‘efficacy of non-commercial fishing technology & knowledge’ is an influence on ‘recreational catch’, and is intended to capture the tools, skills and knowledge that can help improve ‘recreational catch’ for the same amount of recreational fishing. For example, fish finders, more powerful engines, and boats with greater range potential, etc.

It is important to note that because the ‘recreational bag limit’ is a daily limit, there is effectively no constraining mechanism on the overall cumulative level of the ‘amount of recreational fishing’ and ‘recreational catch’. Therefore, these two factors form a reinforcing loop (**R3**) and when catch is high this will reinforce effort in an upward direction; and when catch is low this will reinforce effort in a downward direction.

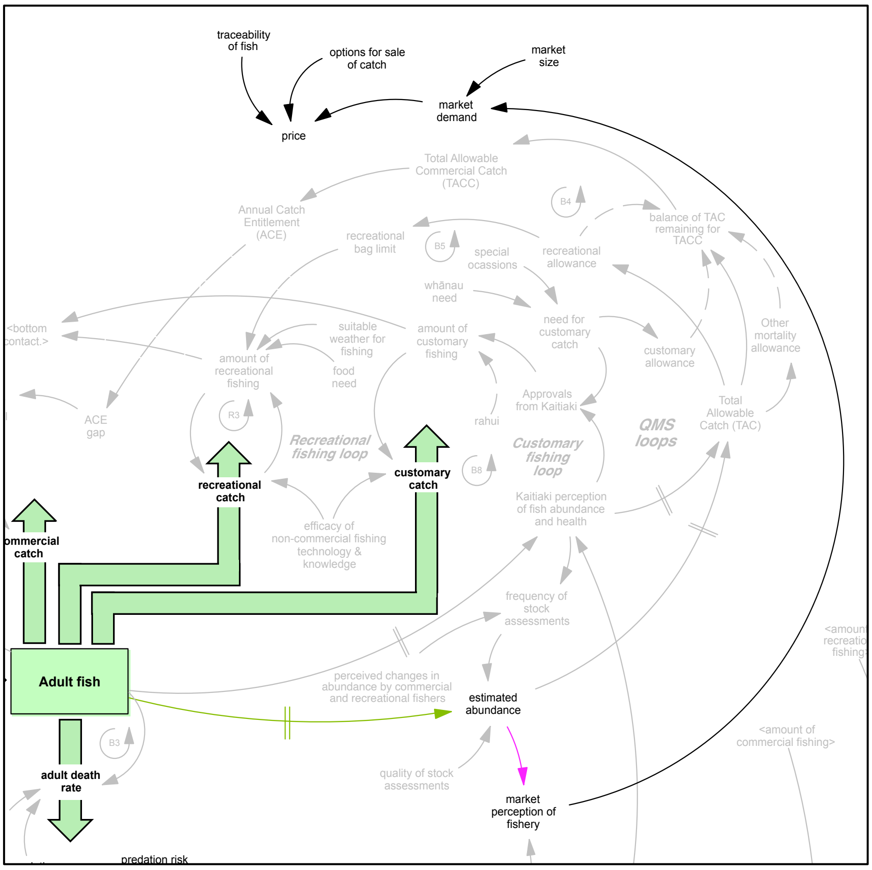
13.5.4 Commercial revenue – market influences on the price of fish

The remaining sub-sections in this section describe a variety of factors relating to influences on commercial catch. This section describes market influences on price and revenue. These are shown in Figure 1.

At the simplest level, there is a same influence from ‘price’ to ‘revenue’, because if all other things remained equal, if price increased so would revenue.

‘Price’ is influenced by three factors in the diagram: ‘market demand’; ‘options for sale of catch’; and ‘traceability of fish’. ‘Market demand’ refers to the demand for fish, both domestically and internationally. ‘Options for sale of catch’ describes the options available to licenced fishers for how they might sell their catch – the more options fishers have for selling their fish, then the greater their opportunity to realise the best price. Examples of options for sale of catch include (but may not be limited to) being able to sell directly off the wharf (this is a relatively small amount in reality); and being obliged to sell to a variety of licenced fish receivers. The ‘traceability of fish’ describes the ability to trace the provenance of fish and therefore potentially realise a greater premium for it in the market.

Figure 50. **Market influences on price**



Finally, 'market demand' is influenced by two summary factors in this diagram: 'market size' and 'market perception of fishery'. 'Market size' describes the demand that exists for the fish – the greater the 'market size' the greater the 'demand'. The 'market perception of fishery' describes the influence on demand from the market perception of the state of the environment supporting the fishery – if the functionality of habitat is low and the market knows it is low, this is likely to reduce the perception and the demand (and vice versa).

13.5.5 Representing the complexity of the act of fishing

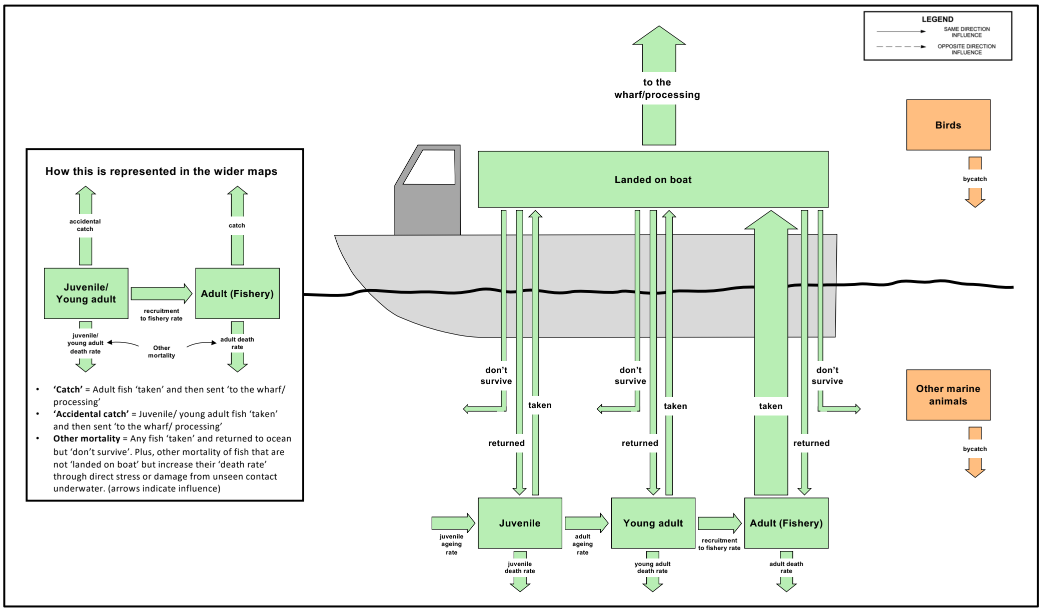
The physical act of fishing is itself a complicated collection of many different things. It is not possible to represent in the system diagram all the subtle ways in which fish are brought onto a boat and then brought to the wharf for process or, in some case, legally returned to the ocean. To do so is not the intent of the system map and would be replicating detailed knowledge already in existence within FNZ and the fishing industry. Therefore, this section describes how the various activities in the act of fishing have been simplified and represented in *bathtub* and *flow* structure at the core of this system diagram.

As like elsewhere in this report, this is not intended as a detailed explanation of how fisheries management works but demonstrates aggregated systems thinking.

13.5.5.1 A Detailed representation of the act of fishing

Figure 51 demonstrates the various ways that fish can be caught and, in some cases, legally returned to the ocean. While the target is 'Adult fish' (those deemed to be *in the fishery*), sometimes 'Juvenile' and/or 'Young adult' may be brought on to the boat. These are all represented as the 'taken' flows from each of these life stages. Some fish from different fisheries may be legally returned to the ocean and these may survive (the 'returned' flow back to the bathtub of fish), or may not survive (the 'don't survive' flow, effectively a flow out of the bathtub of fish).

Figure 51. A detailed representation of the act of fishing



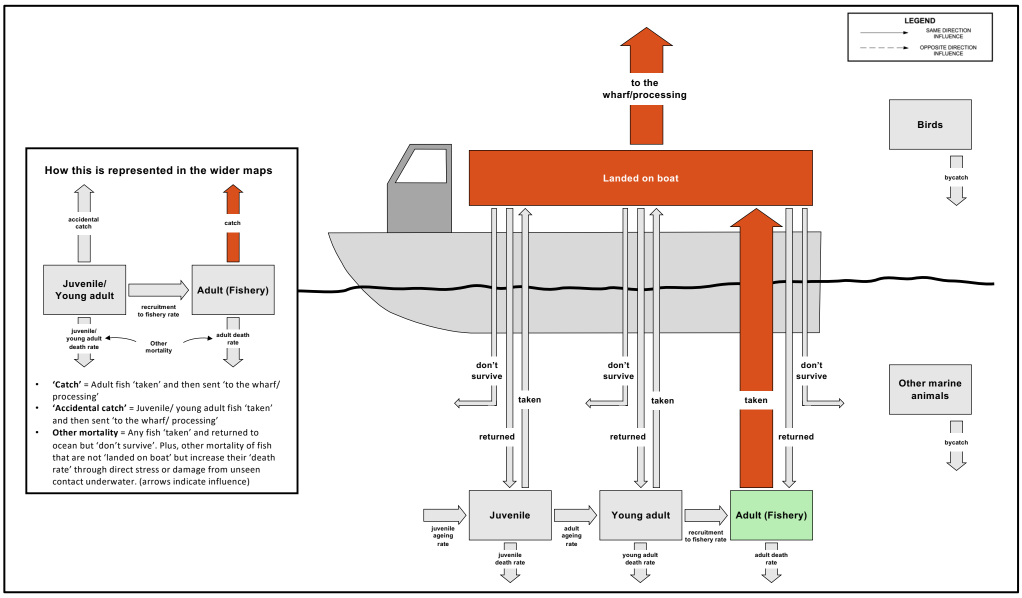
How these are represented in the system diagram is shown in the breakout box in Figure 51. These are each explained in more detail in the following sub-sections and diagrams.

Bycatch is represented by the two broad *bathtubs* of 'Birds' and 'Other marine animals' (this includes species of fish, mammals, reptiles and corals) – protected and otherwise.

13.5.5.2 How all types of catch are represented in the system diagram

All types of catch (customary, recreational and commercial) are represented as a flow in the system diagram *out of* the bathtub of 'Adult fish' (those deemed to be in the fishery'). This flow represents all target species fish of legal size that are taken from the ocean, 'landed' on the boat, and then sent to the wharf or for processing. This is shown in the inset of Figure 52.

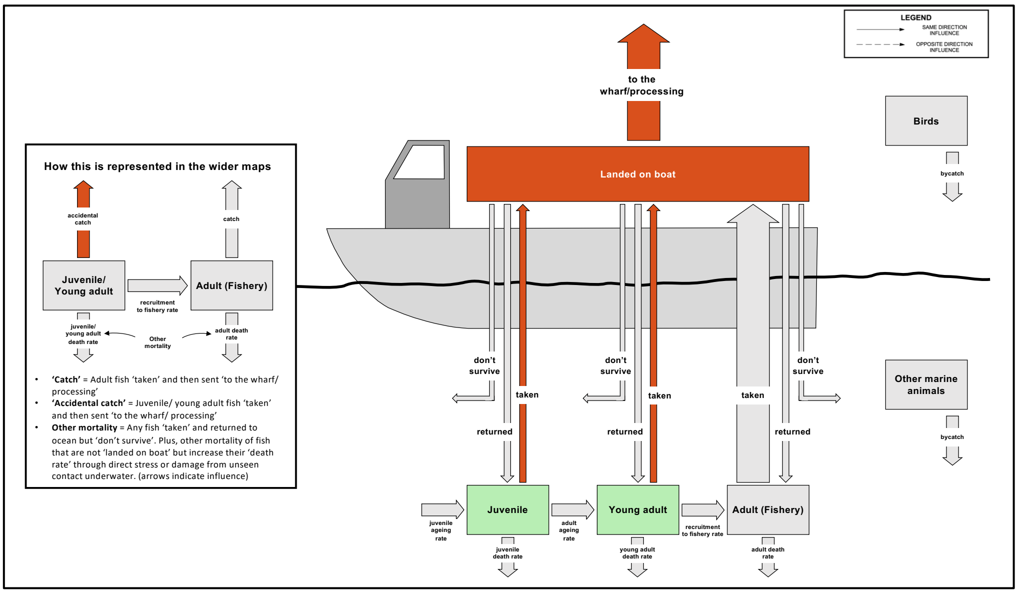
Figure 52. Representing all types of catch in the system diagram



13.5.5.3 How accidental catch are represented in the system diagram

Accidental catch is represented in the system diagram as a flow out of the bathtub of 'Juvenile/Young adult fish'. See the inset in Figure 53.

Figure 53. Representing accidental catch in the system diagram



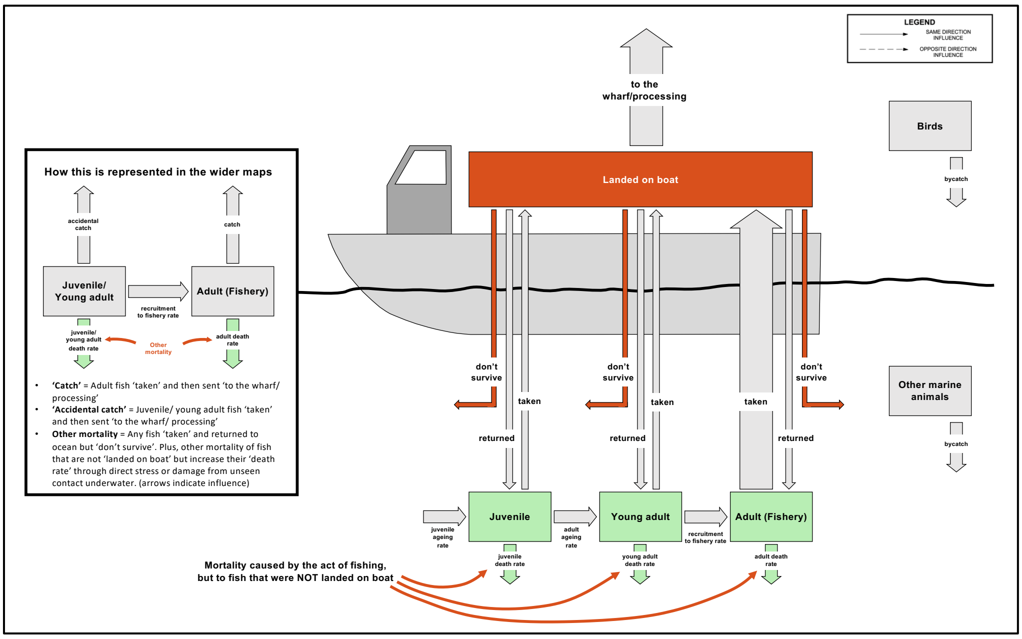
This flow represents all target species fish of *below legal size* that are taken from the ocean – these may be sexually mature ('Young adult' not yet 'recruited' to the fishery) or 'Juvenile' (not yet sexually mature). After these are 'landed' on the boat, they are then *either* legally returned to the ocean (and assumed to survive) *or* sent to the wharf for reporting. These flows are shown in orange in Figure 53.

13.5.5.4 How other mortality is represented in the system diagram

Other mortality is represented in the system diagram as an influence on the 'death rate' at each fish life stage. See the inset in Figure 54.

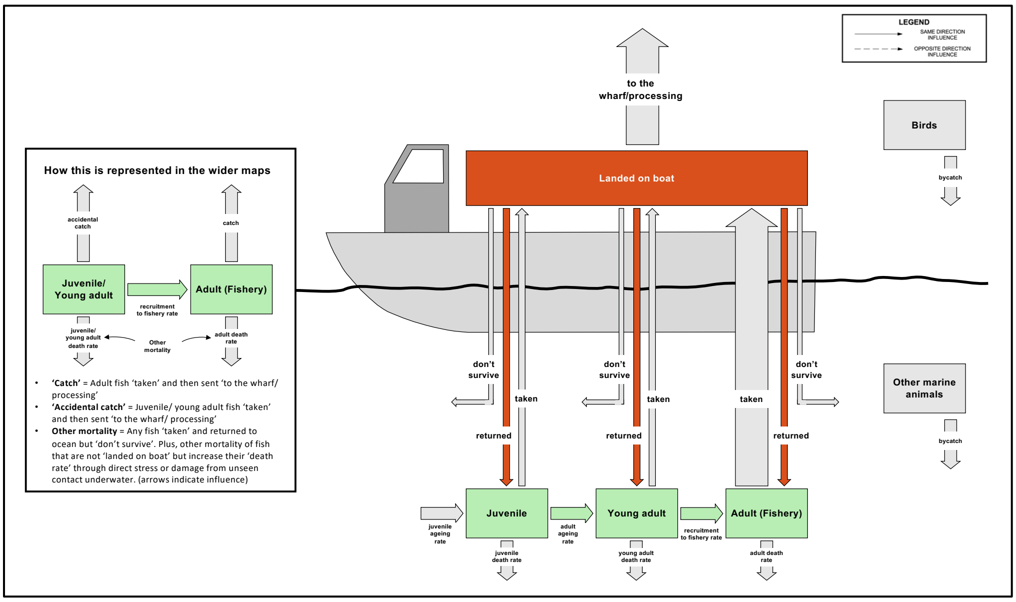
In the detail of the act of fishing this could be either a fish that is landed on boat and then legally returned to the ocean; or as a trauma that occurs to fish that are never landed on a boat.

Figure 54. Representing other mortality in the system diagram



For those fish that are landed and then returned, they may be: returned dead; or returned alive at first but assumed to die soon after due to trauma obtained in landing.

Figure 55. Representing fish landed on boat and legally returned to the ocean



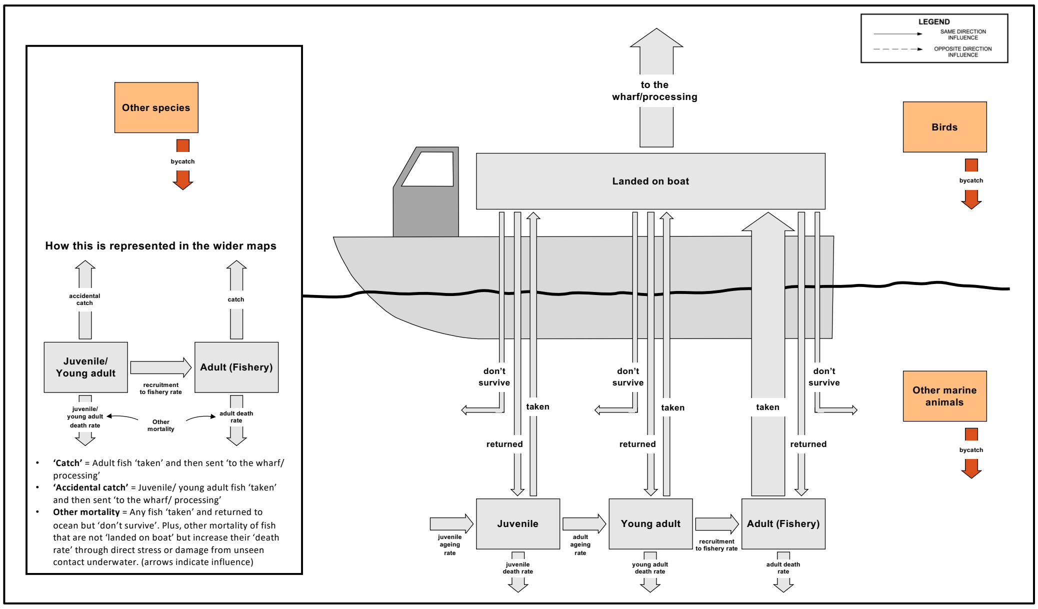
For those that may experience trauma but not be landed, this includes fish that may be killed by the gear used for fishing, even though they are not landed by on a boat with that gear.

Fish that are legally landed on boat, legally returned to the ocean, and assumed to live, are not represented in the system diagram at all. This is because they are not deemed to have been permanently taken from the bathtub of fish in that life stage – they are still in the ocean. Importantly, returning these fish to the ocean ***does not add*** to the number of fish in the ocean. Rather, it simply ***does not reduce*** the fish in that life stage. In the actual act of fishing, these are the 'returned' flows shown in Figure 55.

13.5.5.5 How bycatch is represented in the system diagram

Bycatch is represented in the system diagram as a bathtub of 'other species' and a flow of animals out of these bathtubs, as any bycatch is a removal from these 'other species'. This is shown in the inset in Figure 56. In the detailed act of fishing these are shown as two separate bathtubs – one representing 'Birds' and one representing 'Other marine animals'.

Figure 56. Representing bycatch



No direct connections are made to these 'bycatch' flows in the detailed representation of fishing, as that will depend on the method used and all methods are assumed to have different types of bycatch impact profiles.

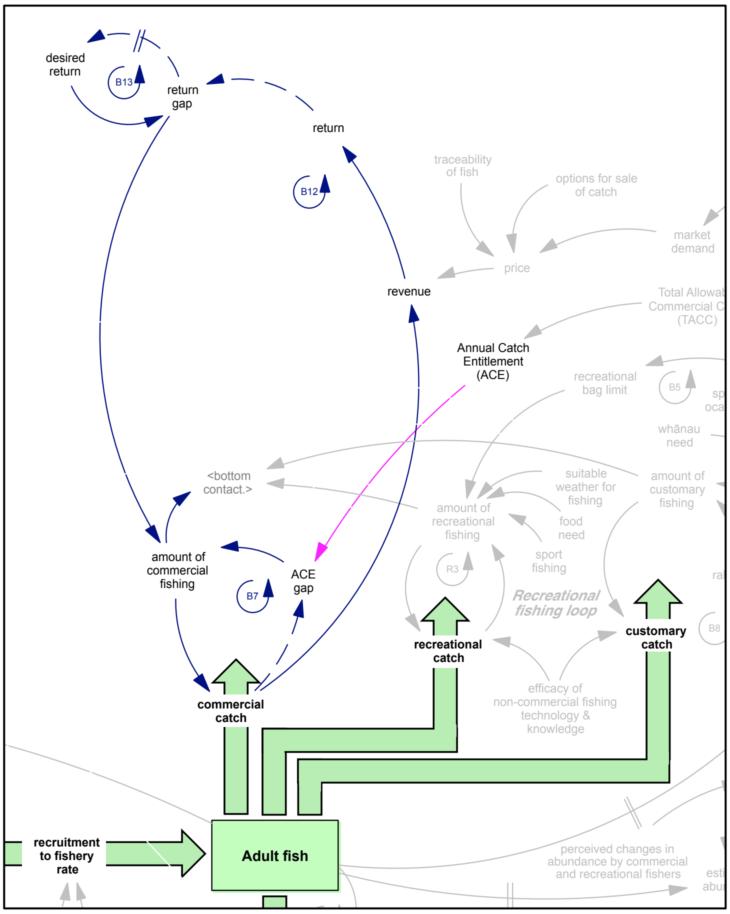
Having described how the detailed act of fishing is represented in the system diagram, the following sub-sections now return to the different drivers of commercial catch.

13.5.6 The drivers of commercial catch – revenue

Section 13.5.4 detailed the market influences on 'price' and 'revenue' from commercial fishing. This section details the commercial fishing loop (**B7**) which is an important determinant of commercial catch, and how this interacts with the revenue loop (**B12**) and the desired return loop (**B13**). These are all shown in Figure 1.

Firstly, commercial fishing loop (balancing loop **B7) is described**. The 'commercial catch' is determined by the 'amount of commercial fishing', the efficacy of the fishing technology (this is not represented here yet, this is added and discussed in Section 13.5.7), and the abundance of the fishery (the number of fish in the bathtub of 'Adult fish').

Figure 57. The drivers of commercial catch – revenue



When drawn in conjunction with the 'Annual Catch Entitlement (ACE)' set under the QMS, this forms another **goal/gap** structure with 'commercial catch' being the *actual* catch, in relation to the *permissible* ACE limit. How close these two factors are, is represented by the factor 'Ace gap'. This gap influences the 'amount of commercial fishing' – the closer those two levels then the closer fishers are to catching their 'Annual Catch Entitlement (ACE)'. If the 'Annual Catch Entitlement (ACE)' is exceeded, then deemed values will be incurred by the fisher. The ACE therefore provides a constraint on the 'amount of commercial fishing', therefore balancing catch within the TACC.

Secondly, the revenue loop (balancing loop **B12)** is described. The 'amount of commercial fishing' also forms part of this larger loop. This also has a **goal/gap** structure which compares the *actual return* ('return') to the *desired return* ('desired return'). This results in a 'return gap'. If this gap is small the fishers' 'desired return' is close to being met, which in turn is likely to reduce the 'amount of commercial fishing'. However, if this gap is large then this is likely to increase commercial fishing effort to compensate. Any increase in effort is, of course, also constrained by the limit of the 'Annual Catch Entitlement (ACE)'.

Finally, the desired return loop (balancing loop **B13**) is described. Here, the 'desired return' also forms a balancing loop with the 'return gap'. The 'return gap' has a delayed and opposite influence on the 'desired return'. This is to represent the influence where, if the 'return gap' was to remain *low for a sustained period* (that is, the fisher **is meeting** their revenue goals on a sustained basis) then they are likely to increase their 'desired return' (i.e. they are likely to desire more). Conversely, if the 'return gap' was to remain *high for a sustained period* (that is, the fisher **is not meeting** their revenue goals on a sustained basis) then they may decrease their 'desired return' (i.e. they are likely to adjust their expectations).

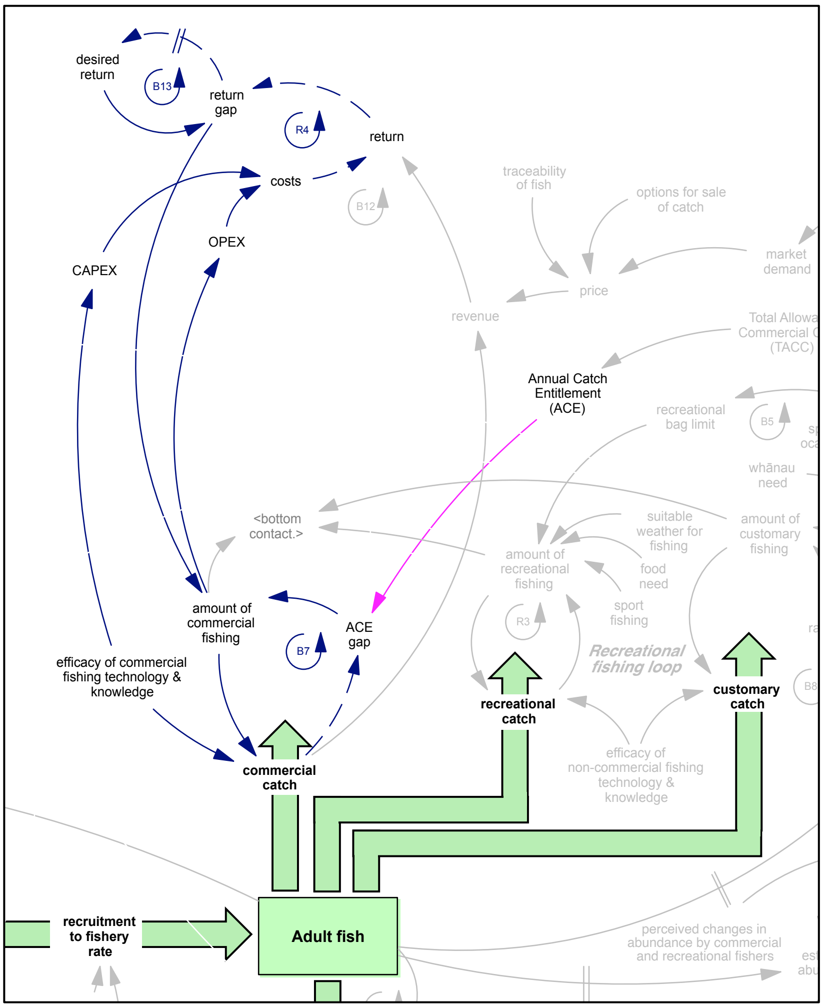
The complexity of these loops highlights the multiple ongoing tensions and influences at play within commercial fishing revenue.

The factors and loops influencing cost are explored in the following subsection.

13.5.7 The drivers of commercial catch – costs (opex and capex)

'Return' is represented in this system diagram simply as revenue minus costs. The greater the 'revenue' the greater the 'return' (a same relationship – this was explained in the previous section). The greater the 'costs' the lower the 'return' (an opposite relationship – this and it's supporting influences are explained in this section. See Figure 1.

Figure 58. The drivers of commercial catch – costs (opex and capex)



Overall 'costs' that feed into the 'return' equation are made up of two types – Capital expenditure ('CAPEX') and Operating expenditure ('OPEX'). 'CAPEX' in this diagram describes major capital upgrades or expenditure, mostly on gear, machinery, and boats. 'OPEX' in this diagram describes everyday operating costs such as labour, fuel, other consumables, and repairs and maintenance.

'OPEX' is part of a reinforcing loop (**R4**) where the greater the 'OPEX', the greater the overall 'costs' and lower the 'return' and the greater the 'return gap' (i.e. the fisher is not making the return they want to make).

A sustained return gap is likely to influence an additional 'amount of commercial fishing'[10] (so long as this is within their ACE limit – balancing loop **B7**) to increase 'commercial catch' and 'revenue'. Yet this additional effort only further increases 'OPEX', further increasing 'costs' – hence this loop reinforces on itself.

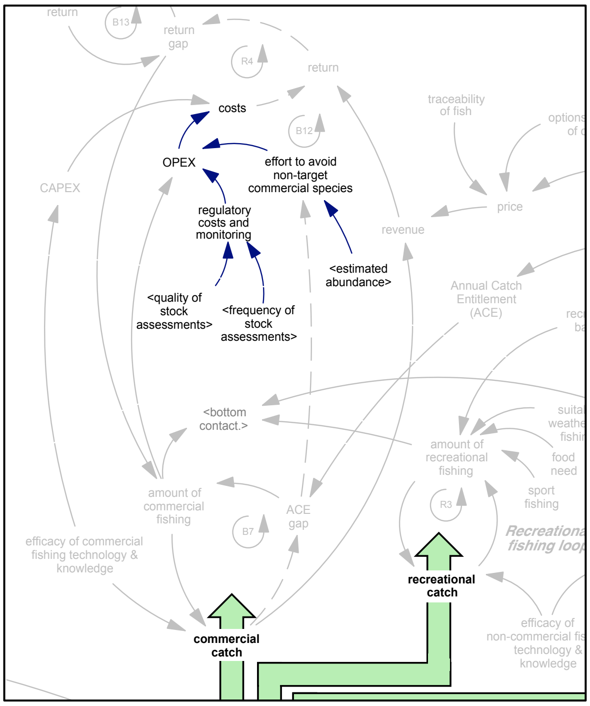
The daily balance of whether fishers make sufficient return will be the result of how the loops described in the previous *revenue* section and this *costs* section interact. This will be a constant tension.

'CAPEX' is not part of a loop but will be influenced by whether new gear or boats are required. The need for additional 'CAPEX' is influenced by the factor called 'efficacy of commercial fishing technology & knowledge'. Like customary and recreational fishing described earlier, 'commercial catch' is determined by the 'amount of commercial fishing', the 'efficacy of commercial fishing technology & knowledge', and the abundance of the fishery. The factor of 'efficacy of commercial fishing technology & knowledge' is intended to describe the tools, skills and knowledge that can help improve 'commercial catch' for the same 'amount of commercial fishing'. For example, this includes the trawl (or other) gear, the quality and size of the boats and the power of their engines, as well as things like management practices based on knowledge (including abundance and distribution) that help improve fishing efficacy. An increase in 'efficacy of commercial fishing technology & knowledge' may increase catch without any change in the 'amount of commercial fishing'.

13.5.8 The drivers of commercial catch – other costs

Several other forms of costs were also drawn in the diagram. These can be summarised as costs imposed by the regulator and costs incurred when attempting to *avoid* fish species. These are captured in Figure 1.

Figure 59. The drivers of commercial catch – other costs



Costs imposed by the regulator are described by the factor 'regulatory costs and monitoring'. This has a same influence on 'costs'. This factor captures the licencing costs of fishing and the levy costs paid to the regulator to cover things like stock assessments and monitoring. The 'frequency of stock assessments' and the 'quality of stock assessments' also have a same influence on 'regulatory costs and monitoring'. If they were to increase, so would the overall regulatory costs.

The diagram also captures the influence of abundance in certain species and the effort required to *avoid* that species, when its ACE is nearly at its limit. This is described by the factor labelled 'effort to avoid non-target commercial species' and this factor increases when the 'ACE gap' is low (i.e. the ACE has almost been reached).

[10] A sustained return gap may also mean that a particular fisher exits from the fishery – this is not shown as a particular factor as it is assumed that their quota or ACE will be taken up by another fisher.

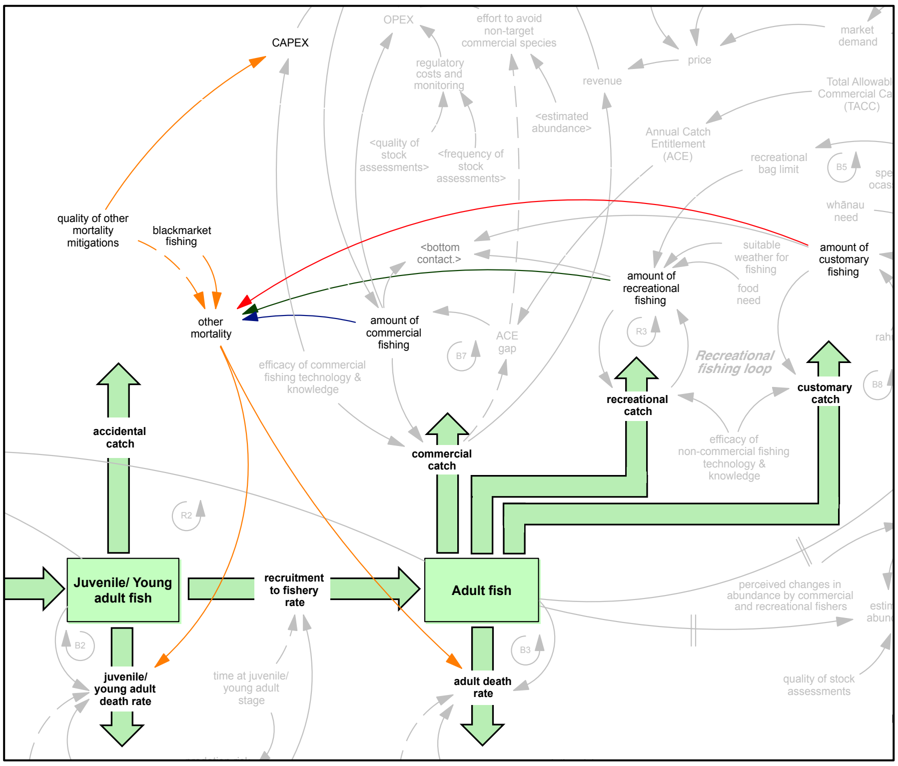
13.6 Other mortality, accidental catch and bycatch

This section describes the sections of the diagram that deal with other mortality, accidental catch and bycatch.

13.6.1 Other mortality

As noted earlier, the other mortality is an allowance made within the TAC to account for unseen fish deaths through the act of fishing[11]. This includes (but may not be limited to): illegal take; under-reporting; death of fish required to be returned to the sea; "ghost fishing" by lost gear and burst nets. These are represented different ways in the system diagram see Figure 1.

Figure 60. How other mortality is represented in the diagram



Firstly, mortality may occur when fish encounter fishing gear yet are not caught or brought onto the boat. This may be through such things as: damage to the fish from gear (e.g. burst nets or by encountering gear but not being caught in it), or "ghost fishing" by gear that is lost at sea. Both of these are represented as same influences on the 'death rate' of both the 'Juvenile/Young adult' and 'Adult fish' bathtubs. This means they *flow out* of that bathtub of fish through death rather than catch.

Other mortality also includes target species fish that have a minimum legal size (not all fisheries have one) that are caught and brought onto the boat, but that are not technically 'in the fishery' (e.g., of legal size). This is represented by the same influence on 'accidental catch'.

Finally, other mortality also includes illegal fishing (called 'blackmarket fishing' in the diagram). This is shown as a same influence on other mortality – the greater the illegal fishing the greater the other mortality.

Importantly however, the actual level of other mortality is also influenced by the 'quality of other mortality mitigations'. This is a factor that describes the *quality of mitigations* designed to reduce or eliminate other mortality. These may be technical (e.g. a certain type of gear) or practice (the way an activity is undertaken). This has an *opposite* influence on other mortality as the higher the 'quality of other mortality mitigations', the lower the 'other mortality'.

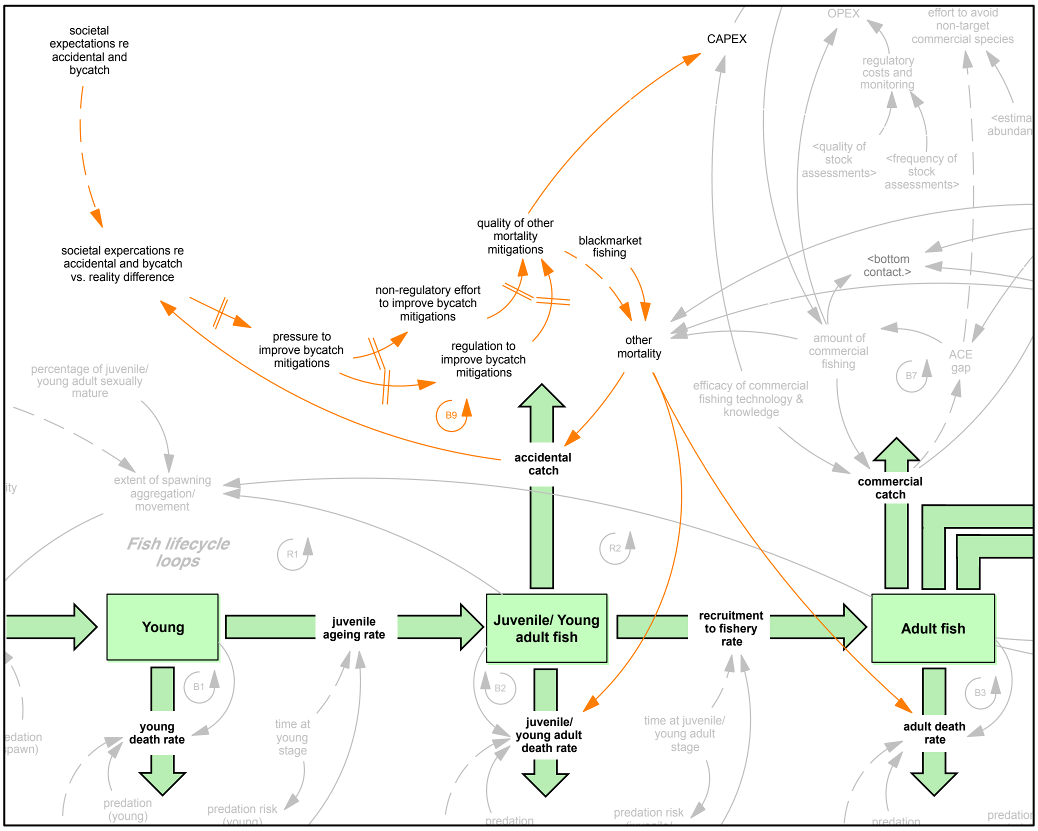
[11] Specifically, this refers to 'all other mortality caused by fishing' (Section 21(1)(b) of the Act).

There is also a same relationship from the ‘quality of other mortality mitigations’ to ‘CAPEX’. This represents the impact that any new or upgraded gear will have on capital expenditure in commercial fishing.

13.6.2 Other mortality through accidental catch

The influence of societal expectations has already been described in several places in the system diagram (see Section 13.3 for a discussion of the impact of societal expectations on activity on land, and Section 13.4 for the impact of societal expectations on mitigations to reduce bottom contact). Societal expectations also play an important part in other mortality through accidental catch (as well as bycatch, which is described in Section 13.6.3). How this impacts other mortality is shown in Figure 61.

Figure 61. Other mortality and societal expectations



As explained earlier, societal expectations is a very high-level term that describes the aggregate level of expectations that people have in relation to what something will be (in this case, accidental catch and bycatch). This is not intended to represent a clearly articulated position statement around what such a level should be, rather it is a conceptual factor that describes the combined aggregate level of a wide number of expectations – in short, the level of something that society is willing to accept, whether this is explicitly articulated or not.

Here this is represented in the factor ‘societal expectations re accidental and bycatch’ and this is part of a **goal/gap** relationship with the *actual* level of ‘accidental catch’. When these two factors are compared, this determines the ‘societal expectations re accidental and bycatch vs reality difference’ (the ‘difference’). This ‘difference’ has a delayed influence on the ‘pressure to improve bycatch mitigations’ which represents the broad public and societal pressure that will be on fishers to act on this ‘difference’. Sustained pressure to improve mitigations would be expected to eventually lead to greater effort to improve these. This is shown via two pathways: ‘non-regulatory effort to improve bycatch mitigations’ (which represents *voluntary* efforts); and ‘regulation to improve bycatch mitigations' (which represents *mandated* efforts). Both pathways have a same relationship with the 'quality of other mortality mitigations' – the greater the pressure and the effort, the greater the eventual quality of mitigations.

Both pathways are also shown with delays as this pressure, effort and eventually mitigations, all take time to manifest.

These influences eventually form a *balancing* feedback loop (**B9**) as any improvements in the 'quality of other mortality mitigations' then *reduce* (opposite relationship) the actual other mortality and the accidental catch.

13.6.3 Bycatch

Bycatch is the accidental capture of non-target commercial species, as well as protected species including species of seabird, mammal, fish, corals and reptiles, that can become hooked or entangled in fishing gear. These are all represented as a generic bathtub of 'Other species' in the system diagram, with a flow *out* of that bathtub representing any 'bycatch' that might be caught. This is shown in Figure 62.

Figure 62. Representing bycatch in the system diagram

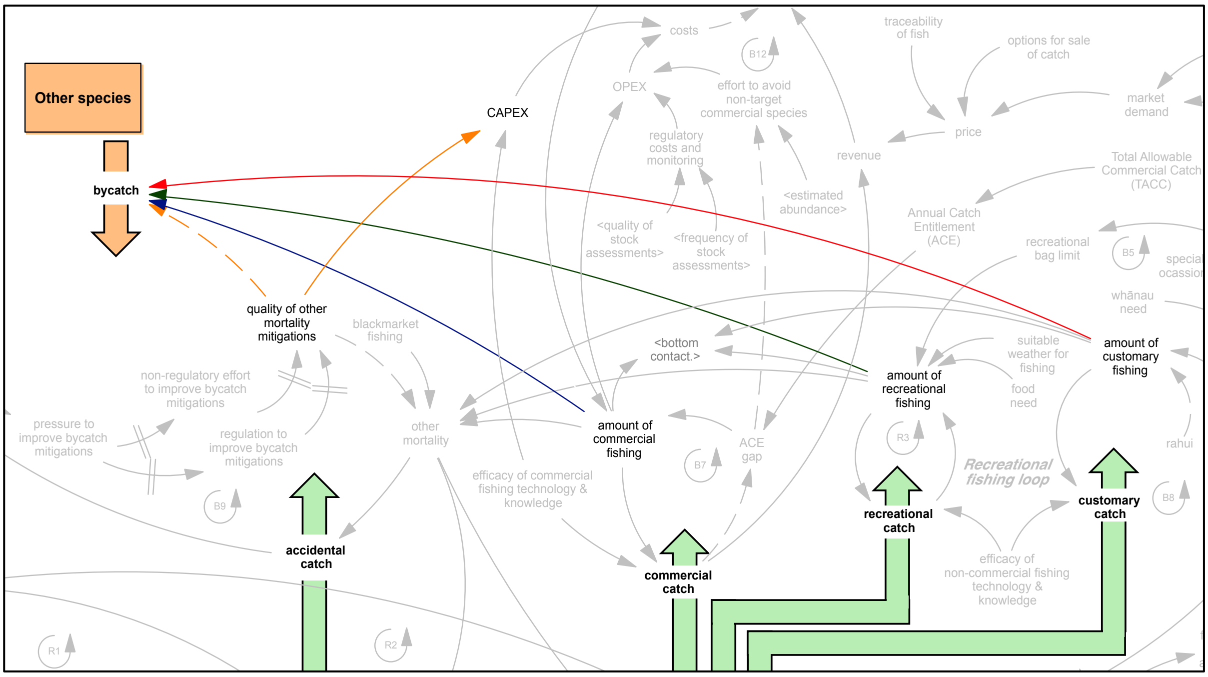
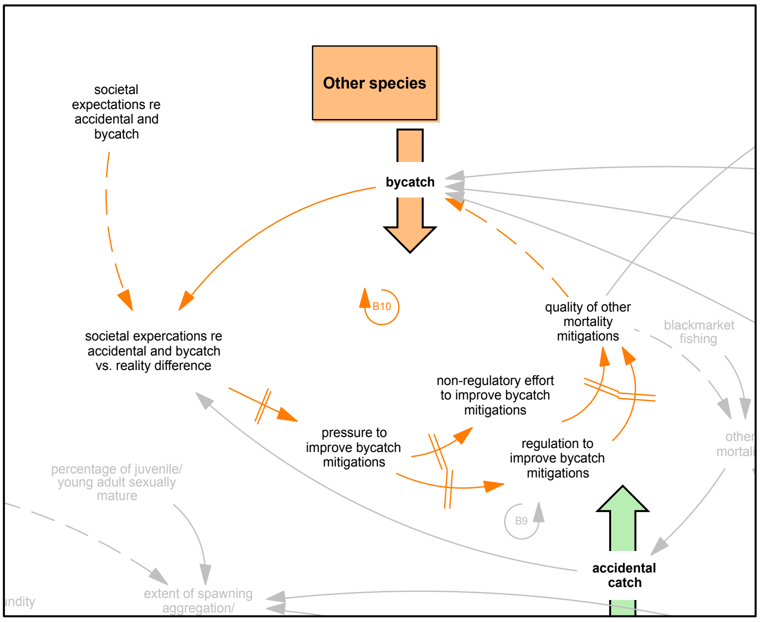


Figure 62 also shows how the amounts of customary, recreational and commercial fishing all affect the level of bycatch. All other things being equal, the greater the amount of any fishing, potentially the greater the bycatch, so this is represented with a *same* relationship. However the 'quality of other mortality mitigations' discussed in the previous subsection can also reduce the bycatch, so this is shown with an *opposite* relationship – the better the mitigations the lower the catch (from the same amount of fishing).

Once again, 'quality of other mortality mitigations' has a same relationship with 'CAPEX' for commercial fishers. This represents the cost that new or upgraded gear has on commercial fishers. This relationship has not been represented with customary or recreational fishers as it is unlikely to be as large.

The quality of other mortality mitigations and bycatch are also influenced by a balancing feedback loop (**B10**) involving the 'societal expectations re accidental and bycatch'. This is shown in Figure 1.

Figure 63. **Bycatch and societal expectations**



Here, the same **goal/gap** relationship that drives the voluntary and mandated efforts to improve other mortality mitigations (described in section 13.6.2) operates. It just also influences bycatch via a separate balancing loop.

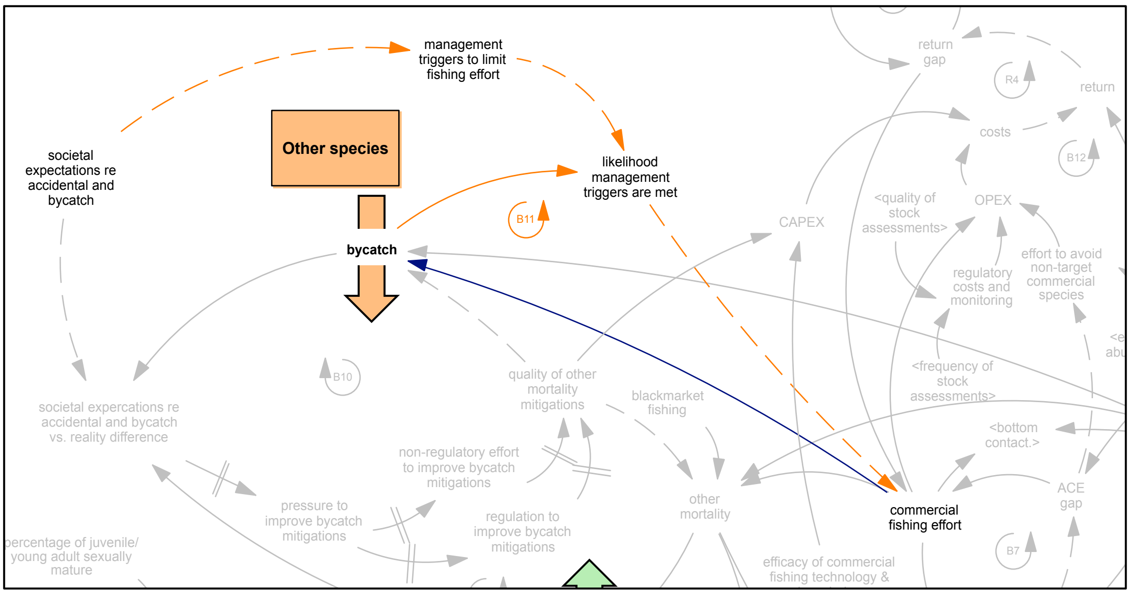
Finally, one other important feedback loop is represented in the system diagram. This is the feedback loop that involves management triggers relating to bycatch that can directly impact the amount of commercial fishing (see Figure 64).

Management triggers here is a term used to describe different mechanisms by which commercial catch may be directly limited due to bycatch thresholds being met or exceeded. This may include (but not be limited to) plans that specifically manage threatened or endangered species, as well as plans that relate to any species.

Here, the greater the bycatch from commercial fishing, the greater the 'likelihood management triggers are met' (same relationship). The greater that likelihood (or, in other words, the greater the likelihood that a threshold is met/triggered) then the less 'commercial fishing effort', hence this is represented as an opposite relationship.

The 'societal expectations re accidental and bycatch' will have an influence on the levels at which 'management triggers to limit fishing effort' are set. The lower the 'management triggers to limit fishing effort' are set, the higher the 'likelihood management triggers are met'. Therefore these two influences are shown as an opposite relationship.

Figure 64. **Bycatch management triggers that limit commercial fishing effort**



14 Summary and insights from this research

This report has described a research project that explored the application of a system diagram and multi-variate analysis (MVA) to the management of multi-species complexes. This work will also inform exploratory agent-based modelling (ABM) that is being undertaken to see if that is useful in multi-species complexes.

It has described the context that it sits within in the Sustainable Seas National Science Challenge and has outlined the methodological approach used. Originally a six-workshop process focused only on the development of a system diagram, this was adjusted to a four-workshop process part way through that delivered a system diagram and supporting MVA.

Guides to both how to read and use a system diagram are provided early in this report (sections 5) and are necessary reading for anyone wanting to read either the overview or detailed descriptions of the system diagram. The overview description of the system diagram is provided in section 6; followed by a description of the important dynamics that may be inferred from the structure of the system diagram in Section 7. Section 7 provides useful insight to different dynamics in various parts of the diagram.

The areas of the system diagram that FNZ has influence over are described in Section 8; then an attempt at representing inter-species relationships is described in Section 9. The results of the supplementing MVA are provided in Section 10; while the focus and direction of the ABM is described in Section 11.

Section 12 provides an anecdotal analysis of the approach used in this research and its usefulness. Following this, a detailed description of the system diagram and the feedback loops within it are provided in Section 13. This detailed description was provided at the end to give readers the choice of whether they wanted to read that level of detail or not.

A summary of the insights from both the participatory research process (workshops) and the tools used (system diagram and MVA), are provided below:

- This 'road test' of the system diagram process and tool coupled with MVA, has demonstrated that this approach can positively contribute to the management of multi-species complexes. They can also strongly contribute to management that may require the input of multiple agencies across both land and ocean.
- System Dynamics is the discipline that informs the system diagram. This is useful for understanding the breadth of impacts within a system and the feedback influence these have at an aggregate level. Within this discipline, one can use qualitative tools like a system diagram (which has been used here), and/or quantitative tools like more rigorous computational computer modelling (which have not been used here).
- A system diagram is generally used to help *elicit causal assumptions* from people involved in a system. More rigorous System Dynamics modelling would be a way of *quantitatively testing those causal assumptions*.
- ABM's are useful for understanding individual interactions and their impact on the overall system. An ABM is currently in development on this project and may contribute further insights to those listed above.
- ABM and System Dynamic models differ in that: ABM's are spatially explicit and look at individual level interactions; while System Dynamic models are not spatially explicit and look at the aggregated interactions.
- An ABM has been used here partly because the case study area is spatially explicit; and partly because there was a focus on multi-species management, which is a more focused area within a wider system. In future applications, there may also a place to consider using System Dynamics models to understand broad dynamics across the system more widely (socio-

economic etc), as well as ABM in specific focused areas within that. The system diagram may be a useful tool to communicate the complexity of the inter-connected world to a variety of other stakeholders and agencies.

- The system diagram may be a useful tool to communicate the complexity of the inter-connected world to a variety of other stakeholders and agencies
- While useful, system diagrams do require one to ‘tune in’ to a certain way of thinking. This may be different to the predominant way most people think, and also highlights that this tool can supplement the existing ways that people think.
- The observations in this research are consistent with experiences in both: the pilot application of system diagrams in the Challenge; and a different Challenge case study in the Hawke’s Bay. In particular, that the process helps:
    - participants better understand the perspectives of other participants;
    - participants to identify and consider factors that are not usually considered;
    - the group work together well; and
    - develop a holistic view of the issue which would support workable solutions/interventions.
- The system diagram is generic enough to be applicable across a range of other areas, not only geographic areas, but fish species also.
- The use of MVA in the project suggests a method for transparently highlighting commonalities between species. This can both: help inform *which* species to manage within a multi-species complex; or, if species have already been determined in a complex, help highlight which characteristics of those species may need further investigation to develop appropriate management actions.
- MVA can also help to identify or assess management actions as well as appropriate fishers’ activities. It can also help to identify information gaps that need to be filled in relation to species and/or management actions
- The complexity demonstrated within this system diagram may be useful to other agencies, outside FNZ, and regardless of whether FNZ were to be involved with the policy issue they may be interested in or not.
- The system diagram also presents an opportunity to inform part of the shared understanding that is often required across, between and even sometimes within agencies on differing yet interconnected issues. The ABM currently under development may provide complementary insights.

15 References

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Fisheries Act 1996

Appendix 1
Definitions of factors in the system diagram

This appendix contains a list of definitions for the factors named in the system diagram.

When reading the definitions of factors in the system diagram, most will be found to be of a higher-level of abstraction that they may usually be referred to, or they may even be highly subjective. This is intentional. The purpose of the system diagram is to provide a 'lens' through which to look at various different situations and/or geographic locations. Therefore, the factors have been worded in such a way that they can be used in various situations.

Some examples are noted below to demonstrate this:

- **Excess sediment from land:** Erosion of sediment from land is a natural and ongoing process. *Excess sediment from land* is an articulation of a level of sediment that is in excess of what would be considered natural or should be considered acceptable in the current environment.
- **Societal expectations of habitat functionality:** This represents the societal expectations of the quality level at which ocean habitat should function. Even though the general public are unlikely to know specifically what habitat functionality is (or should be), this node speaks to a level of public expectation around the quality of the ocean habitat and its ability to sustain life.
- **Predation risk:** This represents the risk of predation by their own or other species, that any one species may be exposed to at various life stages. This is likely to be a changeable variable dependent on a number of conditions including species abundance.

Definitions of factors in the systems diagram

Factor name	Description
Land activity (lower left-hand side of map)	
Excess sediment from land	Erosion of sediment from land is a natural and ongoing process. Yet the volume has been impacted by human activity over long time periods. Excess sediment is an articulation of a level of sediment that exceeds what would be considered natural or should be considered acceptable in the current environment.
Excess nutrients	The run-off of nutrients from land to the ocean is a natural and ongoing process. Nutrients as used here are defined as things like (but not limited to) nitrogen, phosphorous and *E*. coli. E. coli is not a nutrient itself but is used as an indicator of nutrient contamination, especially faecal matter. The volume of these nutrients lost from land has changed with human activity over long time periods. Excess nutrients are an articulation of a level of nutrients that exceeds what would be considered natural or should be considered acceptable in the current environment.
Excess contaminants	The run-off of contaminants from land to the ocean is usually a process that is a result of human activity, although small amounts can occur naturally, depending on the contaminant. Contaminants as used here are defined as things like (but not limited to) heavy metals, plastics, and chemical contaminants. The volume of these contaminants lost from land is usually associated with human activity over long time periods, particularly in association with (but not limited to) urban areas.

Factor name	Description
	Excess contaminants are an articulation of a level of nutrients that exceeds what is considered acceptable (or natural if naturally occurring) in the current environment.
Societal expectations of habitat functionality	This represents the societal expectations of the quality level at which ocean habitat should function. Even though the general public are unlikely to know specifically what habitat functionality is (or should be to sustain abundant fish species), this node speaks to a level of public expectation around the quality of the ocean habitat and its ability to sustain life.
Societal expectations of habitat functionality vs reality difference	This is a ***goal/gap equation***. It describes the difference between the *desired* and *actual* levels the habitat functionality and those factors that are known to impact it (excess sediment, nutrients and contaminants). The *lower* this difference then the *closer* actual habitat functionality will be to the expected habitat functionality. If this difference is *high*, then the actual habitat functionality is *further away* from the expected habitat functionality.
Low erosion practices	This represents the actual level of a broad range of possible land management practices to reduce erosion and sediment loss from land. These will vary across different landuses.
Low nutrient practices	This represents the actual level of a broad range of possible land management practices to reduce nutrient loss from land. These will vary across different landuses.
Low contaminant practices	This represents the actual level of a broad range of possible land management practices to reduce contaminant loss. These will vary across different landuses yet are largely considered to represent urban mitigations such as infrastructure and containment processes. Practices may also occur in non-urban areas.
Erosion from landuse	The actual amount of sediment that runs off from land into waterways.
Likely erosion from landuse	A factor indicating the likelihood or risk of erosion from land into waterways, for any particular areas or landuse.
Wetlands	The volume and quality of wetlands that operate as ways of mitigating both sediment and nutrient loss from land.
Financial and non-financial benefit from landuse	This node recognises the benefit, both financial and non-financial, that humans derive from various forms of landuse (whatever that might be).
Effort to use land	The effort that humans invest to actively manage and/or use land for their own benefit. This generally excludes areas of native bush held in reserve or conservation, so long as it is not actively used for productive purposes by humans.
Productive landuse	The volume and intensity of landuse for productive purposes by humans. This generally excludes areas of native bush held in reserve or conservation, so long as it is not actively used for productive purposes by humans.
Urban footprint	The volume and intensity of land in urban form for use by humans. This includes all general 'non-rural' activities such as residential, industrial and commercial. Broadly, this is a way of capturing the area

Factor name	Description
	of land where excess sediment, nutrients and contaminants are predominantly experienced within 'hard' infrastructure, rather than diffuse discharges (although this is also still possible)
Urban growth	The process of converting rural land to urban land. Be that residential, industrial or commercial.
Population	The total population of the area, especially in urban areas.
Fish lifecycle (centre of map)	
Spawning success rate	The number of fish eggs that are successfully fertilised (either in or outside of fishes' bodies) and that make it through to the 'Young' life stage. This is a volumetric *flow* of new fish into the species life cycle.
Young	The number of Young of a species. This is a numerical *bathtub* of Young in the species life cycle.
Juvenile ageing rate	The number of Young successfully ageing to Juvenile/ Young adults in the species life cycle. This is a numerical *flow* of fish advancing from Young to the Juvenile/Young adult fish stage in the life cycle.
Juvenile/ Young adult fish	The number of Juvenile/ Young adult fish. This is a combination of two parts of the life cycle – Juvenile and the first part of adulthood (post sexual maturity). Sexual maturity will be reached for fish while resident in this bathtub. This is a numerical *bathtub* of Young in the species life cycle.
Recruitment to fishery rate	The number of Juvenile/ Young successfully ageing to Adults that are considered part of the fishery. It is important to recognise that this is a human categorisation, not an ecological one. Consequently, this may change over time if the definition of recruitment to the fishery changes. This is a numerical *flow* of new fish advancing from Juvenile/Young adult to the Adult fish stage in the life cycle.
Adult fish	The number of Adult fish. Adults in this bathtub are defined as fish that have been recruited into the fishery – however that is determined. It is important to recognise that this is a human categorisation, not an ecological one. Consequently, this may change over time if the definition of recruitment to the fishery changes. This is a numerical *bathtub* of Adult fish in the species life cycle.
Young death rate	The number of young that die at this stage of the species life cycle. This is a numerical *flow* of new fish out of the species life cycle.
Juvenile/ young adult death rate	The number of juvenile/ young adult that die at this stage of the species life cycle. This is a numerical *flow* of new fish out of the species life cycle.
Adult death rate	The number of adults that die at this stage of the species life cycle. This is a numerical *flow* of new fish out of the species life cycle.

Factor name	Description
Percentage of juvenile/ young adult sexually mature	The percentage of the fish in the Juvenile/ Young adult box (bathtub) that are sexually mature at any one time. In effect, this is the percentage of this bathtub that are in the Young adult category. These fish will be sexually mature but have not yet been recruited into the fishery.
Extent of spawning aggregation/ movement	The extent (both quantity and geographic spread) of any spawning aggregation of sexually mature members of the species. This in part depends on the volume of the species that are sexually mature.
Extent of spawn loss through water movement	A parcel of water containing 'Spawn' (fertilised eggs and larvae) can be moved to or from areas suitable for further development and can result in the loss of spawning products.
Fecundity	The fecundity, or fertility, of the fish species.
Average ocean pH	The average ocean pH level.
Appropriate balance of males/females	The appropriate balance of males/females required for spawning. Male/female sex ratio.
Appropriateness of temperature	The appropriateness of the ocean temperature for spawning.
Invasive species	The volume of invasive species. Invasive species is defined as species that have been introduced or migrated to the local environment. It is also considered that they are likely to compete with local species for habitat and food, thus are considered an undesirable introduction.
Average ocean temperature	The average ocean temperature.
Climate change impacts	The frequency and severity of climate change impacts. The more frequent and severe, the higher the impacts, (and vice versa).
Predation (spawn)	The actual predation of spawn of the species by other animals in the ocean. This includes other fish of the same species.
Predation risk (spawn)	The risk of predation of the spawn of this species by other animals in the ocean. This includes other fish of the same species.
Predation (young)	The actual predation of young of the species by other animals in the ocean. This includes other fish of the same species.
Predation risk (young)	The risk of predation of the young of this species by other animals in the ocean. This includes other fish of the same species.
Survival rate (young)	The likelihood that young will survive this stage of life and progress into the next stage.
Time at young stage	The time that young of this species will spend at this stage of life.
Predation (juvenile/ young adult)	The actual predation of juvenile/ young adult of the species by other animals in the ocean. This includes other fish of the same species.
Predation risk (juvenile/ young adult)	The risk of predation of the juvenile/ young adult of this species by other animals in the ocean. This includes other fish of the same species.
Survival rate (juvenile/ young young)	The likelihood that juvenile/ young adult will survive this stage of life and progress into the next stage.
Time at juvenile/ young adult stage	The time that juvenile/ young adult of this species will spend at this stage of life.

Factor name	Description
Predation (adult)	The actual predation of juvenile/ young adult of the species by other animals in the ocean. This includes other fish of the same species.
Predation risk (adult)	The risk of predation of the juvenile/ young adult of this species by other animals in the ocean. This includes other fish of the same species.
Survival rate (adult)	The likelihood that adult will survive this stage of life, thus reaching their full life expectancy.
Habitat functionality (bottom of map)	
Functionality of spawning/ young habitat	The functionality of habitat where this species spawns and its young live for that phase of their life. This factor is an amalgam of many things that make up 'habitat functionality' which may change depending on the species. This may include (but not be limited to) things such as: prevalence and integrity of 3D structure; water quality and clarity; abundance of food sources, etc. This is a *conceptual bathtub* representing the collection of things that represent the actual current level of the functionality of spawning/ young habitat.
Increase in functionality (spawning/ young)	This is a *conceptual flow* representing any increase in the current level of the functionality of spawning/ young habitat.
Decrease in functionality (spawning/ young)	This is a *conceptual flow* representing any decrease in the current level of the functionality of spawning/ young habitat.
Optimal functionality (sp/yng)	The optimal level of functionality for a healthy and abundant fish population at this stage of life. This is a conceptual node, representing an aspirational or desirable level for optimal functionality.
Functionality difference (sp/yng)	This is a ***goal/gap equation***. It describes the difference between the optimal level of habitat functionality and the actual level of habitat functionality. This difference is a conceptual representation and represents how in or out of balance the habitat functionality is. The larger the difference the more out of balance, and vice versa.
Natural recovery (sp/yng)	This node represents the *process* of natural recovery of habitat functionality.
Recovery rate (sp/yng)	This is the recovery rate at which natural recovery will occur. This is likely to be a percentage recovery rate.
Likelihood recovery threshold crossed (sp/yng)	This is a conceptual node that represents the likelihood that a recovery threshold or 'tipping point' might be crossed. If this is crossed, it is likely to have a strong opposite impact on the process of natural recovery.
Availability of food (young)	The availability of food for the young at this stage of life.
Competition for food (young)	The competition with other animals for food at this stage of life. This includes competition with its own species as well as other animals.
Other local species	The number and volume of other local (i.e., non-invasive) species.
Functionality of juvenile/ adult habitat	The functionality of habitat where the juvenile/ young adult of this species live for that phase of their life. This factor is an amalgam of many things that make up 'habitat functionality' which may change depending on the species. This may include (but not be limited to)

Factor name	Description
	things such as: prevalence and integrity of 3D structure; water quality and clarity; abundance of food sources, etc. This is a *conceptual bathtub* representing the collection of things that represent the actual current level of the functionality of juvenile/ young adult habitat.
Increase in functionality (juvenile/ adult)	This is a *conceptual flow* representing any increase in the current level of the functionality of juvenile/ young adult habitat.
Decrease in functionality (juvenile/ adult)	This is a *conceptual flow* representing any decrease in the current level of the functionality of juvenile/ young adult habitat.
Optimal functionality (juv/ad)	The optimal level of functionality for a healthy and abundant fish population at this stage of life. This is a conceptual node, representing an aspirational or desirable level for optimal functionality.
Functionality difference (juv/ad)	This is a ***goal/gap equation***. It describes the difference between the optimal level of habitat functionality and the actual level of habitat functionality. This difference is a conceptual representation and represents how in or out of balance the habitat functionality is. The larger the difference the more out of balance, and vice versa.
Natural recovery (juv/ad)	This node represents the *process* of natural recovery of habitat functionality.
Recovery rate (juv/ad)	This is the recovery rate at which natural recovery will occur. This is likely to be a percentage recovery rate.
Likelihood recovery threshold crossed (juv/ad)	This is a conceptual node that represents the likelihood that a recovery threshold or ‘tipping point’ might be crossed. If this is crossed, it is likely to have a strong opposite impact on the process of natural recovery.
Availability of food (juvenile/ young adult)	The availability of food for the juvenile/ young adult at this stage of life.
Competition for food (juvenile/ young adult)	The competition with other animals for food at this stage of life. This includes competition with its own species as well as other animals.
Availability of food (adult)	The availability of food for the adult at this stage of life.
Competition for food (adult)	The competition with other animals for food at this stage of life. This includes competition with its own species as well as other animals.
Excess suspended sediment	Sediment suspected in the ocean is a natural occurring phenomenon. This node refers to the volume of *excess sediments suspended in the ocean*.
Excess accumulated sediment	Sediment accumulated on the ocean is a natural occurring phenomenon and process. This node refers to the volume of *excess sediments accumulated on the ocean floor*, which can be more than reasonably occurs naturally.
Wave action	Wave action as describe here is a proxy for water movement in the water column. This is usually generated by wave action but also includes water movement from currents etc.
Offshore movement (dispersal of accumulated sediments)	This node represents the process of gradual offshore movement of deposited sediments in the ocean. This is a natural and slowly

Factor name	Description
	occurring process whereby water movement and currents naturally and gradually disperse sediments offshore. This will vary in intensity and speed in differing areas of the ocean.
Bottom contact (bottom right of map)	
Estimated functionality of habitat	The estimated functionality of the habitat. This is the estimation of habitat functionality by humans from scientific surveys and observations, as well as local knowledge. This is also intended to capture the perceived functionality, it may not be possible to actually measure the functionality of all habitats.
Bottom contact	The actual amount of contact with the sea floor from human activities, which can modify the sea floor and stir up deposited sediments. Examples include fishing methods such as dredging and trawling, as well as non-fishing methods such as anchoring of large vessels and rigs, port dredging, and cable laying.
Likelihood of habitat modification	The likelihood that bottom contact on the sea floor results in habitat modification.
Likelihood habitat modification leads to decrease in functionality	The likelihood that any habitat modification will lead to a decrease in habitat functionality.
Anchoring of large vessels/rigs	The act of anchoring large vessels and oil rigs on the sea floor.
Port dredging	The act of dredging the port and shipping channels As well as the disposal of dredge spoils to another area in the ocean.
Quality of bottom contact mitigations	The quality of bottom contact mitigations. That is, the extent to which technology and fishing gear can minimise contact with the sea floor.
Societal expectations of habitat functionality vs reality difference	This is a ***goal/gap equation***. It describes the difference between societal expectations of habitat functionality versus the reality.
Regulatory effort to improve bottom contact mitigations	Effort to improve bottom contact mitigations that may be prompted by or realised via *regulatory pathways* by those doing the bottom contact. This regulation may be by FNZ or other regulators.
Non-regulatory effort to improve bottom contact mitigations	Effort to improve bottom contact mitigations that may be prompted by or realised via *voluntarily pathways* by those doing the bottom contact. This is also known as non-regulatory pathways.
Accidental catch, bycatch and other mortality (top left of map)	
Other species	The number and volume of other species that may sometimes be caught as bycatch in the act of fishing. This includes (but is not limited to) birds, marine mammals, sharks and fish.
Bycatch	Bycatch is the accidental capture of non-target commercial species, as well as protected species including species of seabird, mammal, fish, corals and reptiles, that can become hooked or entangled in fishing gear. It is noted that not all bycatch is required to be reported, so this node is a conceptual one and does not assume that all bycatch is measured or reported.

Factor name	Description
Accidental catch	The accidental catch of target fish species that have not yet been recruited into the fishery. In other words, undersized fish of the target species.
Societal expectations re accidental and bycatch	The societal expectations as to what is an acceptable level or number of bycatch of other species. This is a conceptual node intended to represent a broad level representing all people in society (including fishers), rather than a specific number. This includes the consideration of perceived risk on some bycatch population dynamics, that may be able to sustain a certain level of deaths regardless of whether this is viewed as unacceptable to some sectors or interests.
Societal expectations re accidental and bycatch vs. reality difference	This is a ***goal/gap equation***. It describes the difference between societal expectations of what is an acceptable level of bycatch and the actual bycatch. If this gap is large it will tend to have a strong influence on other factors that it influences, if it is low, it will have a lesser influence.
Pressure to improve bycatch mitigations	This describes the societal pressure to improve bycatch mitigations of fishing, to minimise or eliminate bycatch.
Regulation to improve bycatch mitigations	Any regulation intended to improve or determine the required level of bycatch mitigations.
Non-regulatory effort to improve bycatch mitigations	Any voluntary change intended to improve or determine the required level of bycatch mitigations.
Other mortality	Other mortality describes any mortality to fish from the act of fishing that is not from landing the fish on the wharf. This includes (but is not limited to) fish that are caught and returned that then die; and fish that may be mortally stressed or wounded by fishing but not actually caught. This node represents the *actual amount* of this that occurs.
Quality of other mortality mitigations	This describes the quality of other mortality mitigations used in fishing by any sector (customary, recreational or commercial). Such mitigations reduce the other mortality that occurs.
Management triggers to limit fishing effort	There are many ways that bycatch may trigger management interventions to reduce fishing effort and reduce bycatch. These are all represented here as 'management triggers'. These include but are not limited to, threat management plans for endangered species and voluntary management plans by industry.
Likelihood management triggers are met	This describes the likelihood that bycatch will trigger any of the management triggers outlined above, thus reducing or temporarily stopped commercial fishing effort.
Blackmarket fishing	This node represents the amount of fish that are taken illegally through blackmarket fishing. This is unlikely to be quantified.
Quota Management System (QMS) (top right of map)	
Estimated abundance	The human estimates of abundance of the fish stock. This is determined by scientific stock assessments and catch information.
Frequency of stock assessments	The frequency at which stock assessments are carried out.

Factor name	Description
	Stock assessments inform the TAC. These can be industry-initiated (paid for by industry) or initiated by FNZ (cost-recovered).
Quality of stock assessments	The comprehension and quality of scientific stock assessments.
Total Allowable Catch (TAC)	The Total Allowable Catch (TAC) means a total allowable catch as set or varied for that stock by notice in the *Gazette* that applies to each fishing year and is set to a level that maintains (or alters catch levels to achieve) maximum sustainable yield. .
Customary allowance	The estimated catch of the species taken for customary food gathering. This is determined by Kaitiaki and advised to FNZ.
Other mortality allowance	Other mortality describes any mortality to fish from the act of fishing that is not from landing the fish on the wharf. This includes (but is not limited to) fish that are caught and returned that then die; and fish that may be mortally stressed or wounded by fishing but not actually caught. This node represents the *allowable limit* for this set under the QMS.
Recreational allowance	This is an estimate of what the recreational catch could be.
Recreational bag limit	The individual bag limit for the species per recreational fishers.
Balance of TAC remaining for TACC	The different fishing allowances are determined sequentially. The estimated allowances for customary, recreational and other mortality are determined, then the remaining proportion of the TAC is available to be allocated to the TACC.
Total Allowable Commercial Catch (TACC)	The Total Allowable Commercial Catch (TACC) is the total commercial catch allowed to be caught by quota owners in any given year.
Annual Catch Entitlement (ACE)	The Annual Catch Entitlement is an entitlement of catch allocated to individual fishers. The ACE are made up from the quota held by the various quota owners, but the fisher does not need to be a quote owner to have ACE. They can purchase this.
Recreational fishing (top right of map)	
Suitable weather for fishing	The suitability of weather for recreational fishing, as a driver of fishing effort.
Food need	The food needs of the recreational fisher and their family/whānau.
Amount of recreational fishing	The total amount of recreational fishing. This is a conceptual representation and no metric is assumed for this in the map as it is likely to be made up of multiple factors. For example (but not limited to), the number of fishers as well as the time spent fishing. 2 fishers spending an hour fishing is less ‘effort’ than the same 2 fishers spending 4 hours fishing. It is noted that some forms of recreational catch are required to report their catch (e.g. charter operators), while others do not (most general recreational fishing effort).
Recreational catch	The total recreational catch.
Efficacy of non-commercial fishing technology & knowledge	The efficacy of non-commercial fishing technology and knowledge as an aid in fishing success.
Customary fishing (top right of map)	

Factor name	Description
Special occasions	The number of specials occasions that may require need of customary commercial fishing allowances. For example, weddings, major birthdays, tangihanga.
Whānau need	The need of whānau for food.
Need for customary catch	The total need of whānau for food from customary catch.
Amount of customary fishing	The amount of customary fishing. This is a conceptual representation and no metric is assumed for this in the map as it is likely to be made up of multiple factors. For example (but not limited to), the number of fishers as well as the time spent fishing. 2 fishers spending an hour fishing is less 'effort' than the same 2 fishers spending 4 hours fishing.
Customary catch	The total customary catch.
Kaitiaki perception of fish abundance and health	The Kaitiaki's perception of the abundance and health of the fishery. This is the driver of approvals for customary take by Kaitiaki.
Approvals from Kaitiaki	The actual approvals for customary take issued by Kaitiaki.
Rahui	A customary fishing mechanism of placing temporary bans on harvesting/fishing for different reasons. These are not enforceable by law but are often partially enforceable through moral suasion.
Commercial fishing (top centre of map)	
Amount of commercial fishing	The amount of commercial fishing. This is a conceptual representation and no metric is assumed for this in the map as it is likely to be made up of multiple factors. For example (but not limited to), the number of fishers as well as the time spent fishing. 2 fishers spending an hour fishing is less 'effort' than the same 2 fishers spending 4 hours fishing.
Commercial catch	The total commercial catch (at the wharf).
ACE gap	This is a ***goal/gap equation***. It describes the difference between the Annual Catch Entitlement (ACE) and the actual catch. If this gap is large it will tend to have a strong influence on other factors that it influences, if it is low, it will have a lesser influence. If the 'Annual Catch Entitlement (ACE)' is exceeded, then deemed values will be incurred by the fisher.
Efficacy of commercial fishing technology & knowledge	The efficacy of commercial fishing technology and knowledge as an aid in fishing success.
Revenue	Revenue earned from the sale of fish.
CAPEX	Capital expenditure. This includes (but is not limited to) fishing boats, gear, including investment in new and experimental gear.
OPEX	Operating expenditure. This includes (but is not limited to) fuel, labour, compliance costs, other consumables.
Costs	Total costs incurred in the act of fishing.
Return	Revenue earned from fishing minus the costs incurred from fishing. This is a simple representation of the complex financial realities of the fishing business. It is not intended to represent CPUE (Catch Per Unit Effort), or other specific financial measures used in the industry.
Desired return	The financial return desired by the fishing enterprise.

Factor name	Description
Return gap	This is a ***goal/gap equation***. It describes the difference between the desired return and the actual return. If this gap is large it will tend to have a strong influence on other factors that it influences, if it is low, it will have a lesser influence.
Regulatory costs and monitoring	This is a conceptual node that captures the regulatory costs associated with being a commercial fisher as well as commercial fishing's required contribution to the cost of monitoring. This covers: • Commercial fishing permits, vessel registration and other administration fees. • Costs recovered via levies to cover stock assessments and surveys, including conservation services on behalf of DoC, as well as monitoring of fishing activities. As noted in *frequency of stock assessments*, stock assessments inform the TAC. These can be industry-initiated (costs covered by industry) or initiated by FNZ (cost-recovered).
Effort to avoid non-target commercial species	Effort taken by fishers to avoid non-target species. This can lead to increases in OPEX.
Market (top right of map)	
Market perception of fishery	The international and local market perceptions of the fishery.
Market demand	The market demand for fish. An aggregate of all demands, domestic and international.
Market size	The size of the market served.
Price	The price for fish.
Traceability of fish	This represents the extent to which the provenance of fish are traceable. This is considered a value-add trait in some markets and can increase the price realised for fish.
Options for sale of catch	The options available to fishers with ACE for selling their catch. This acknowledges that this needs to be through licenced fish receivers and that direct wharf sales are possible. This is a conceptual node to indicate the number of options available to fishers (thus giving them greater options for earning).

Appendix 2
The complete system diagram

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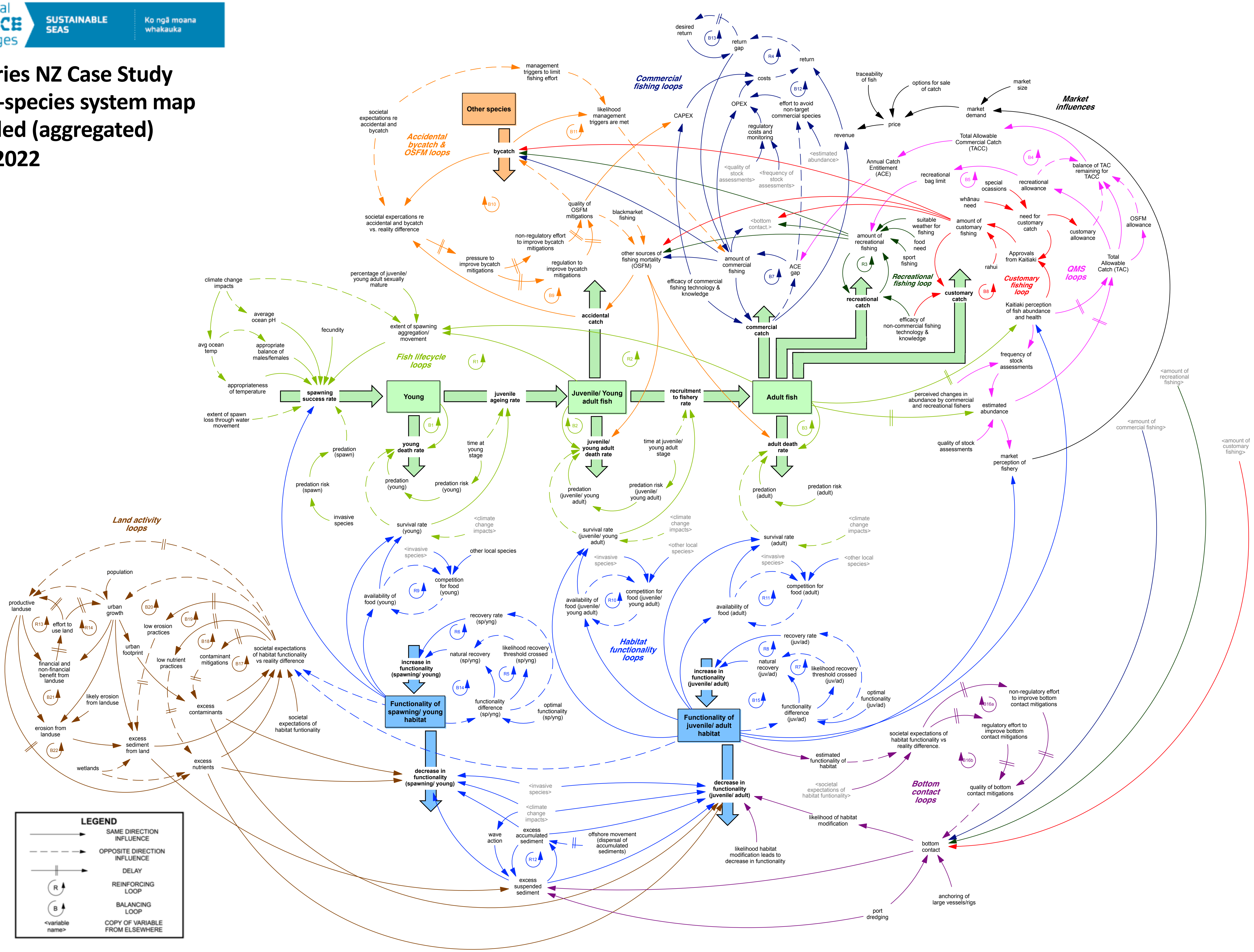
Fisheries NZ Case Study
Multi-species system map
Detailed (aggregated)
May 2022



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Appendix 3
List of feedback loops identified in the system diagram

This section summarises all the feedback loops that were identified in the system diagram. This is a tabulated summary of those described in detail in section 13.

For ease of reading, it is recommended that this list in read in conjunction with viewing the full-sized system diagram in Appendix 2.

Table 6. List of feedback loops identified in the system diagram

Feedback loop number	Label/Description For brevity, loops are described in one direction only but also operate in the other direction (i.e. if the initial factor is described as *increasing*, then the opposite will occur if the initial factor is described as *decreasing*). All loops are described in the context of 'all other factors being equal' (i.e. no outside influences are assumed).
Reinforcing feedback loops	
R1	Young adult fish reproduction loop An increased number of sexually mature adults (who *have not yet been* recruited into the fishery) increases the likelihood spawning aggregation/movement and successful spawning, eventually increasing the young adult fish population.
R2	Adult fish (in the fishery) reproduction loop An increased number of sexually mature adults (who *have been* recruited into the fishery) increases the likelihood spawning aggregation/movement and successful spawning, eventually increasing the young adult fish population.
R3	Recreational fishing effort-catch loop All other things being equal, an increase in recreational fishing effort will likely lead to an increase in recreational catch. Further, recreational effort is largely based on previous lived experience, so if fishing has been good, effort will likely continue.
R4	Cost-fishing effort loop Greater costs result in lower return and less likelihood of meeting desired financial goals. This drives further fishing effort, thus increasing costs.
R5 ***(R5a & R5b on some maps)***	Habitat recovery threshold (spawning/young) loop The lower the habitat functionality the less likely it is to have optimal functionality and the more likely to cross a natural recovery threshold, lowering any recovery and continuing to depress habitat functionality. *Where shown as R5a and R5b on disaggregated maps: R5a relates to the likelihood of spawning habitat crossing a recovery threshold and R5b relates to the likelihood of young habitat crossing a recovery threshold.*

Feedback loop number	Label/Description **For brevity, loops are described in one direction only but also operate in the other direction (i.e. if the initial factor is described as *increasing*, then the opposite will occur if the initial factor is described as *decreasing*).** **All loops are described in the context of 'all other factors being equal' (i.e. no outside influences are assumed).**
R6 ***(R6a & R6b on some maps)***	Habitat recovery rate (spawning/young) loop The lower the habitat functionality the less likely it is to have optimal functionality, and the lower the percentage rate at which the habitat recovers. This will delay habitat functionality recovery. *Where shown as R6a and R6b on disaggregated maps: R6a relates to the percentage recovery rate of spawning habitat and R6b relates to the percentage recovery rate of young habitat.*
R7 ***(R7a & R7b on some maps)***	Habitat recovery threshold (juvenile/adult) loop The lower the habitat functionality the less likely it is to have optimal functionality and the more likely to cross a natural recovery threshold, lowering any recovery and continuing to depress habitat functionality. *Where shown as R7a and R7b on disaggregated maps: R7a relates to the likelihood of juvenile habitat crossing a recovery threshold and R7b relates to the likelihood of adult habitat crossing a recovery threshold.*
R8 ***(R7a & R7b on some maps)***	Habitat recovery rate (juvenile/adult) loop The lower the habitat functionality the less likely it is to have optimal functionality, and the lower the percentage rate at which the habitat recovers. This will delay habitat functionality recovery. *Where shown as R8a and R8b on disaggregated maps: R8a relates to the percentage recovery rate of juvenile habitat and R8b relates to the percentage recovery rate of adult habitat.*
R9	Competition-availability of food (young) loop The less food there is available the greater the competition for it, further decreasing the available food.
R10	Competition-availability of food (juvenile/young adult) loop The less food there is available the greater the competition for it, further decreasing the available food.
R11	Competition-availability of food (adult) loop The less food there is available the greater the competition for it, further decreasing the available food
R12	Suspended-accumulated sediment loop The more suspended sediment the more potential there is for accumulated sediment, which in turn increases the likelihood of suspended sediment.
R13	Productive landuse loop Productive landuse generates both financial and non-financial benefits. This encourages further efforts to use land in a similar way, leading to more productive landuse. There are likely to be delays in this loop.

Feedback loop number	Label/Description For brevity, loops are described in one direction only but also operate in the other direction (i.e. if the initial factor is described as *increasing*, then the opposite will occur if the initial factor is described as *decreasing*). All loops are described in the context of 'all other factors being equal' (i.e. no outside influences are assumed).
R14	Urban growth loop Urban landuse generates both financial and non-financial benefits. This encourages further efforts to use land in a similar way, leading to more urban growth. There are likely to be delays in this loop.
Balancing feedback loops	
B1	Young mortality loop At a consistent survival rate, the more young there are the more young will die (in absolute numbers). This mortality reduces the absolute number of young, in turn reducing the absolute number of them that will die.
B2 ***(B2a & B2b on some maps)***	Juvenile/ Young adult fish mortality loop At a consistent survival rate, the more juvenile/young adult fish there are the more juvenile/young adult fish will die (in absolute numbers). This mortality reduces the absolute number of juvenile/young adult fish, in turn reducing the absolute number of them that will die. *Where shown as B2a and B2b on disaggregated maps: B2a relates to juvenile mortality and B2b relates to young adult mortality.*
B3	Adult fish mortality loop At a consistent survival rate, the more adult fish there are the more adult fish will die (in absolute numbers). For example, a 95% survival rate of 100 fish means that 5 fish will die; a 95% survival rate of 1,000 fish means that 50 fish will die. This mortality reduces the absolute number of adult fish, in turn reducing the absolute number of them that will die.
B4	QMS commercial loop Increased abundance in the fishery leads to an increased estimated abundance which leads to an increased Total Allowable Catch (TAC). In general terms this leads to an increased Total Allowable Commercial Catch (TACC), and increased Annual Catch Entitlement (ACE) and more commercial fishing effort. Increased effort increases the commercial catch, therefore removing fish from the current abundance. Any changes in abundance as a result of this increased effort (e.g. sustained or decreased abundance) will, over time, flow on to impact the estimated abundance and eventually the TAC, hence the loop constrains of 'balances' itself. There are likely to be delays in this loop, particularly between the actual abundance and the estimated abundance; and the estimated abundance and the setting of the TAC.

Feedback loop number	Label/Description For brevity, loops are described in one direction only but also operate in the other direction (i.e. if the initial factor is described as *increasing*, then the opposite will occur if the initial factor is described as *decreasing*). All loops are described in the context of 'all other factors being equal' (i.e. no outside influences are assumed).
B5	QMS recreational loop Increased abundance in the fishery leads to an increased estimated abundance which leads to an increased Total Allowable Catch (TAC). In general terms this leads to an increased Non-Commercial allowance, recreational bag limit and recreational fishing effort. Increased effort increases the recreational catch, therefore removing fish from the current abundance. Any changes in abundance as a result of this increased effort (e.g. sustained or decreased abundance) will, over time, flow on to impact the estimated abundance and eventually the TAC, hence the loop constrains of 'balances' itself. There are likely to be delays in this loop, particularly between the actual abundance and the estimated abundance; and the estimated abundance and the setting of the TAC.
B6	QMS Customary loop Increased abundance in the fishery leads to an increased estimated abundance which leads to an increased Total Allowable Catch (TAC). In general terms this leads to an increased Non-Commercial allowance, the customary allowance and customary fishing effort. Increased effort increases the customary catch, therefore removing fish from the current abundance. estimated abundance and eventually TAC. There are likely to be delays in this loop.
B7	Commercial fishing effort loop The commercial fishing effort is constrained by the difference between the Annual Catch Entitlement (ACE) and the actual commercial catch. If this difference is high (i.e. the ACE is a long way from being met) then there is a greater likelihood of commercial fishing effort, if this is low (i.e. the ACE is close to being met) then there is less likelihood of commercial fishing effort. In reality, rather than a high effort at the beginning of the year and a low effort at the end of the year, commercial fishers will spread their effort across the year in anticipation of what they anticipate catching and when. The influence of the difference between the ACE on the intensity of catch effort as described above, is more likely to be a feature towards the end of the ACE time cycle. In other words, if there is still lots of ACE left and time is running out, more effort may be put into that species; and vice versa.
B8	Customary fishing effort loop The customary fishing effort is enabled by written approvals from Kaitiaki. If the level of the customary catch increases, the actual adult fish abundance reduces. The lower the Kaitiaki perception of fish abundance and health, the less likely they are to issue written permits.

Feedback loop number	Label/Description For brevity, loops are described in one direction only but also operate in the other direction (i.e. if the initial factor is described as *increasing*, then the opposite will occur if the initial factor is described as *decreasing*). All loops are described in the context of 'all other factors being equal' (i.e. no outside influences are assumed).
B9 ***(B9a & B9b on some maps)***	Accidental catch-other mortality mitigations loop The accidental catch is determined by other mortality (which is in turn influenced by commercial and recreational fishing effort). The greater the accidental catch the greater the difference between societal expectations of accidental catch and reality. A sustained difference here over time increases pressure to improve accidental catch mitigations, eventually leading to improved other mortality mitigations, which reduces other mortality. There are likely to be delays in this loop. *Where shown as B9a and B9b on disaggregated maps: B9a relates accidental catch of juveniles and B9b relates to accidental catch of young adults.*
B10	Bycatch- other mortality mitigations loop The bycatch is determined by recreational and commercial fishing effort in conjunction with the quality of other mortality mitigations. The greater the bycatch catch the greater the difference between societal expectations of bycatch and reality. A sustained difference here over time increases pressure to improve bycatch mitigations, eventually leading to improved other mortality mitigations, which reduces bycatch. There are likely to be delays in this loop.
B11	Threat management plan loop Threat Management Plans exist for certain species. These outline a bycatch threshold for these species that, if met, will enable limitations on commercial fishing effort to be imposed. Therefore, the greater the bycatch, the greater the likelihood of such a threshold being met, leading to a reduction in commercial fishing effort which, in turn, reduces bycatch.
B12	Revenue loop Revenue is represented simplistically in the map as function of commercial catch and price. The greater both the catch and/or the price in combination, the greater the revenue and consequently the return (profit) once costs have been taken into account. The greater the return the less the gap between the desired return and the actual return (i.e. the closer one is to making their desired return). The smaller this gap (i.e. the closer to making their desired return), then the less commercial fishing effort required to achieve the current desired return and therefore correspondingly, the less commercial catch required. *See also B13 'desired return loop'.*
B13	Desired return loop The greater ones desired financial return the greater the likelihood that there will be a gap between that and the actual return. If this gap is sustained (i.e. the return is consistently not as much as desired), then over time there is likely to be pressure to reduce the desired return. There is likely to be a delay in this loop. *See also B12 'revenue loop'.*

Feedback loop number	Label/Description For brevity, loops are described in one direction only but also operate in the other direction (i.e. if the initial factor is described as *increasing*, then the opposite will occur if the initial factor is described as *decreasing*). All loops are described in the context of 'all other factors being equal' (i.e. no outside influences are assumed).
B14 ***(B14a & B14b on some maps)***	Habitat natural recovery (spawning/young) loop Natural recovery describes the process of habitat returning to some level of optimal functionality by natural means, if it is ever damaged or thrown out of balance. Optimal functionality is a conceptual node that represents an aspirational or desirable level of functionality to support abundant life of the species of interest. It is important to note that this is natural process and occurs even without the influence of humans. If habitat functionality is reduced, the difference between the optimal functionality and the reality is increased, the larger this gap the more natural recovery is needed, the longer time this will take. *Where shown as B14a and B14b on disaggregated maps: B14a relates to the process of natural recovery of spawning habitat and B14b relates to the process of natural recovery of young habitat.*
B15 ***(B15a & B15b on some maps)***	Habitat natural recovery (juvenile/adult) loop Natural recovery describes the process of habitat returning to some level of optimal functionality by natural means, if it is ever damaged or thrown out of balance. Optimal functionality is a conceptual node that represents an aspirational or desirable level of functionality to support abundant life of the species of interest. It is important to note that this is natural process and occurs even without the influence of humans. If habitat functionality is reduced, the difference between the optimal functionality and the reality is increased, the larger this gap the more natural recovery is needed, the longer time this will take. *Where shown as B15a and B15b on disaggregated maps: B15a relates to the process of natural recovery of juvenile habitat and B15b relates to the process of natural recovery of adult habitat.*
B16	Bottom contact mitigations loop Bottom contact is a function of the recreational/commercial fishing effort and the quality of bottom contact mitigations – the higher the mitigations the lower the contact and/or the effects of contact. If there is a high level of bottom contact there is a greater likelihood of habitat modification and (if that modification is likely to lead to it) a resulting decrease in habitat functionality. Lower levels of habitat functionality increase the gap between societal expectations of habitat functionality and the reality, which over time increases pressure to improve bottom contact mitigations which over time leads to improved mitigations and less bottom contact.
B17	Excess contaminant mitigations loop Greater levels of excess contaminants from land getting into the ocean lead to a decrease in habitat functionality and an increasing gap between societal expectations of habitat functionality and the reality. Over time this will lead to more contaminant mitigations being put in place which over time will lead to less excess contaminants getting into the ocean. There are likely to be delays in this loop.

Feedback loop number	Label/Description For brevity, loops are described in one direction only but also operate in the other direction (i.e. if the initial factor is described as *increasing*, then the opposite will occur if the initial factor is described as *decreasing*). All loops are described in the context of 'all other factors being equal' (i.e. no outside influences are assumed).
B18	Excess nutrient mitigations loop Greater levels of excess nutrients from land getting into the ocean lead to a decrease in habitat functionality and an increasing gap between societal expectations of habitat functionality and the reality. Over time this will lead to more excess nutrient mitigations being put in place which over time will lead to less excess nutrients getting into the ocean. There are likely to be delays in this loop.
B19	Excess sediment mitigations loop Greater levels of excess sediment from land getting into the ocean lead to a decrease in habitat functionality and an increasing gap between societal expectations of habitat functionality and the reality. Over time this will lead to more excess sediment mitigations being put in place which over time will lead to less excess sediment getting into the ocean. There are likely to be delays in this loop.
B20	Urban growth loop Urban growth (the conversion non-urban land into urban land) is one way that excess sediment makes its way into the ocean. It also increases the total urban footprint, which is correlated with excess contaminants getting into the ocean. Therefore, urban growth can be linked to decreasing habitat functionality via these two pathways. Decreases in habitat functionality increase the gap between societal expectations of habitat functionality and the reality. Over time this will lead to more pressure to resist and even limit urban growth. There are likely to be very long delays in this loop.
B21	Productive landuse-excess sediment loop Productive landuse is one way that excess sediments make their way into the ocean. Therefore, productive landuse can be linked to decreasing habitat functionality. Decreases in habitat functionality increase the gap between societal expectations of habitat functionality and the reality. Over time this will lead to more pressure to resist and even limit productive landuse. There are likely to be very long delays in this loop.
B22	Productive landuse-excess nutrients loop Productive landuse is one way that excess nutrients make their way into the ocean. Therefore, productive landuse can be linked to decreasing habitat functionality. Decreases in habitat functionality increase the gap between societal expectations of habitat functionality and the reality. Over time this will lead to more pressure to resist and even limit productive landuse. There are likely to be very long delays in this loop.
Balancing feedback loops (on some summarised maps only)	

Feedback loop number	Label/Description For brevity, loops are described in one direction only but also operate in the other direction (i.e. if the initial factor is described as *increasing*, then the opposite will occur if the initial factor is described as *decreasing*). All loops are described in the context of 'all other factors being equal' (i.e. no outside influences are assumed).
B23	Excess contaminants, nutrients, and sediment mitigation loop (summarised version) This loop is summary loop that combines loops B17, B18, B19 listed in the more detailed/ disaggregated maps. Greater levels of excess contaminants, nutrients, and sediment from land getting into the ocean lead to a decrease in habitat functionality and an increasing gap between societal expectations of habitat functionality and the reality. Over time this will lead to more contaminant, nutrient and sediment mitigations being put in place which over time will lead to less excess contaminants, nutrients, and sediment getting into the ocean. There are likely to be delays in this loop.
B24	Urban growth loop (summarised version) This loop is similar to B20 listed in the more detailed/ disaggregated maps. Urban growth (the conversion non-urban land into urban land) is one way that excess sediment makes its way into the ocean. (In this loop, sediment is combined into the node 'excess contaminants, nutrients and sediment'). It also increases the total urban footprint, which is correlated with excess contaminants getting into the ocean. Therefore urban growth can be linked to decreasing habitat functionality via these two pathways. Decreases in habitat functionality increase the gap between societal expectations of habitat functionality and the reality. Over time this will lead to more pressure to resist and even limit urban growth. There are likely to very long delays in this loop.
B25	Productive landuse-excess nutrients and sediment loop (summarised version) This loop is summary loop that combines loops B21 and B22 listed in the more detailed/ disaggregated maps. Productive landuse is one way that excess nutrients and sediments make their way into the ocean. (In this loop, nutrients and sediment is combined into the node 'excess contaminants, nutrients and sediment'). Therefore productive landuse can be linked to decreasing habitat functionality. Decreases in habitat functionality increase the gap between societal expectations of habitat functionality and the reality. Over time this will lead to more pressure to resist and even limit productive landuse. There are likely to be very long delays in this loop.

Appendix 4
The System diagram highlighting areas Fisheries New Zealand has influence or responsibility

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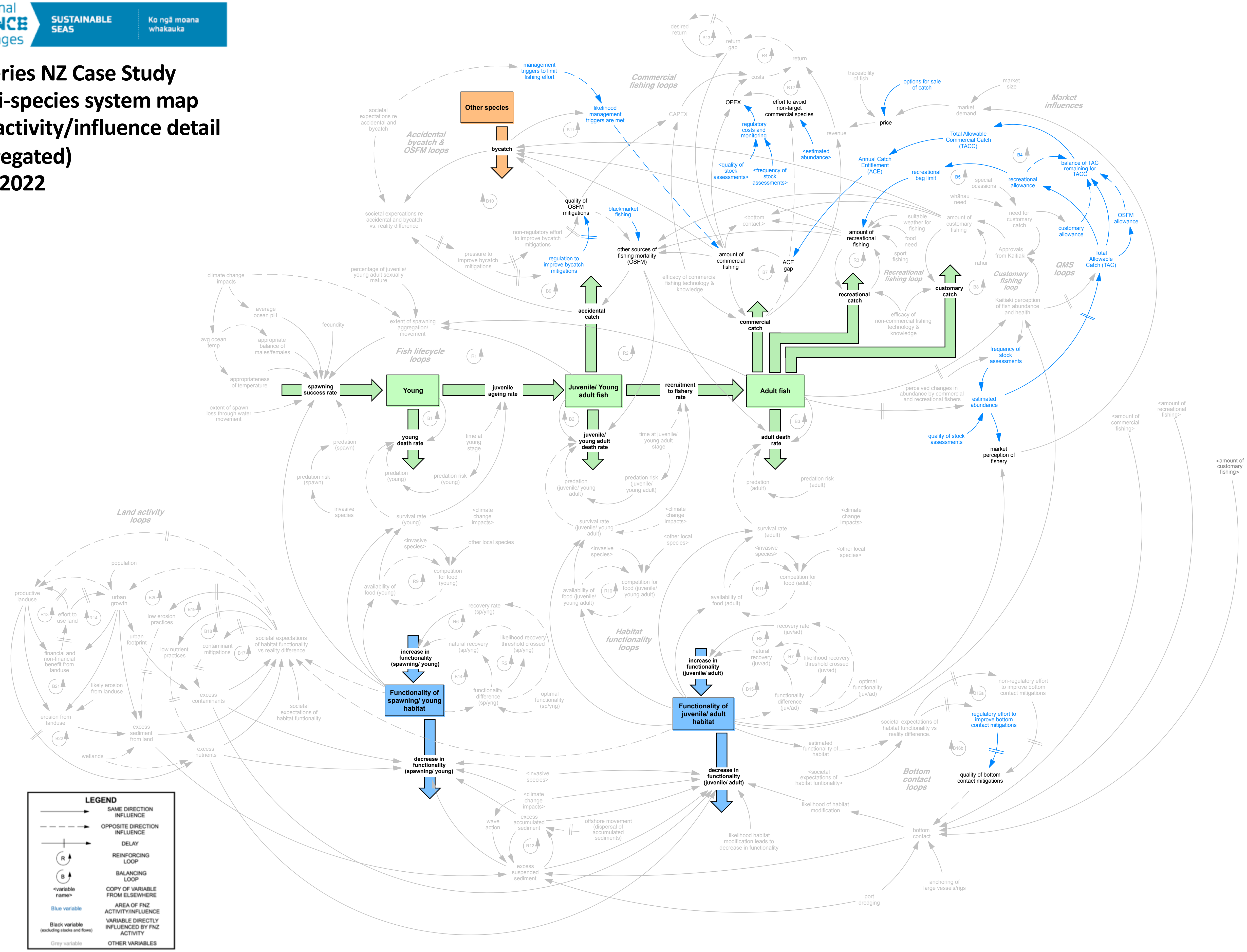
Fisheries NZ Case Study
Multi-species system map
FNZ activity/influence detail (aggregated)
May 2022



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Appendix 5 Multi-variate analysis data tables

This appendix provides the data for the MVA that was available for each species within the multi-species complex. This information was correct at the time of writing and should be considered a 'live' document which can be continually updated as more information becomes available.

It shows the development of the matrix for MVA from: raw data and initial categories; through refined categorisation, to; final matrix available for heat mapping analysis.

Table 7. MVA data – raw data and initial categories

Factor	Matrix categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
spawning aggregation	**no spawning aggregation**						
	aggregation local (within spatial area of management/map)		inshore TBGB,	inshore TBGB,	aggregate inshore during spring and summer to mate; known pupping area around Farewell Spit	Three main spawning grounds ID'ed, one of which is WCSI- Jackson Bay	
	aggregation not local	Large aggregations known to occur in mid water possibly for spawning		not all spawning snapper undertake large movements		Three main spawning grounds ID'ed, one of which is WCSI- Jackson Bay	offshore
Reproductive frequency	**Semelparous**						
	seasonal				spring/summer	Aggregate in summer/autumn to spawn	
	Annual protracted	Dec thru Apr?	spring and summer	spring and summer	spring and summer	summer/autumn	winter-spring
	Multi-year event driven						
	continuous						
Reproductive strategy	**Bearers/brooders**				live young birthed in shallow coastal waters during spring/summer		
	Guarders						

Factor	Matrix categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
	Non-guarders- open substrate spawners broadcast spawners brood hiders	large pelagic eggs??	pelagic eggs	large pelagic eggs?? Short planktonic phase 1 -2 weeks		pelagic eggs and larvae	pelagic eggs
Reproductive location	**Leaves management area/map to reproduce**					Three main spawning grounds id'ed, one of which is WCSI- Jackson Bay	
	Reproduces within management area/map but aggregates in a specific location/habitat			Inshore TBGB Tasman Sea.	Adults move into shallow coastal waters during spring and summer to birth young and mate		offshore
	Reproduces within its normal adult location		widespread inshore in TBGB				offshore
feeding/trophic level- adult	**other species adults**	yes		yes			small Fish,
	juvenile fish	(visual?) predator on juvenile fish,		yes			small Fish,
	zooplankton			sometimes salps			
	infauna/epifauna	squid, crabs, molluscs, kina	shellfish, crustaceans and worms	crustaceans, polychaetes, echinoderms, molluscs	invertebrates	worms, crustaceans, mollusks and echinoderms	squid, crabs, molluscs,
	benthic herbivore						
feeding/trophic level- juvenile/young adult	**juvenile fish**	yes					juvenile fish,
	zooplankton	predator on zooplankton		young post-settlement stage (a few months, until 6 cm in size) being predominantly a predator of zooplankton			predator on zooplankton, as for adult?

Factor	Matrix categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
	infauna/epifauna		shellfish, crustaceans and worms	larger juveniles predominantly an infauna/epifauna predator.	crustaceans	crustaceans <15cm, worms>15cm	squid, crabs, molluscs,
	benthic herbivore						
feeding/trophic level- young	**zooplankton**	predator on zooplankton,		larvae feed on zooplankton		?	predator on zooplankton, as for adult?
	algae/bacteria					?	
	carries food stores with it		period of at least eight days before larvae start feeding.				
	NA- born live						
	does not feed						
Maximum age/size	**Categories then made from this information**	max age observed 12 years, females larger than males; mature 29-35cm and 23-29cm resp	10-20yr, max = 15	>60yr with low rates of natural mortality (0.075)	>20??	Max age of 40+ years	3-6yr for flounders, soles. 10-20yr, for brill and turbot
Duration young	**Categories then made from this information**	eggs take 12-14 days to hatch; reach 12-18 cm in first year;	eggs at least 8 days to hatch larvae 1yr+ (10-20cm)	1-2 weeks.	11 mo gestation	7-12 months old	
Duration/size juvenile/young adults	**Categories then made from this information**	mature at 29-35 cm but no age noted	2-3yr, sexual maturity (length about 23 cm)	3-4yr, sexual maturity (length 20-28 cm)	Males mature at 5-6 years, 85 cm TL; avg max length of 126 cm TL, Females mature at 7-8 years, 100 cm TL; avg max length of 151 cm TL	Juveniles reach 25 cm FL at 4 years of age, 50% maturity at 33 cm FL and 6 years of age	
risk of predation -adult	**high**						
	medium					medium- hapuka eat them	medium- kingfish and ?birds
	low	low					

Factor	Matrix categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
	unknown				??? Not eaten by others in this exercise	??? Not eaten by others in this exercise	
risk of predation -juvenile/young adult	**high**						
	medium	medium				medium, ???	medium
	low						
	unknown				???		
risk of predation -Young	**high**	high					high
	medium						
	low						
	unknown				NA	???	
competition-adult	**territorial**			yes			
	aggregative/schooling					aggregative,	
	neutral				??? Unknown		
competition-juvenile/young adult	**territorial**						
	aggregative/schooling			aggregate around 3D structure	??? Unknown	aggregative,	
	neutral						
competition-Young	**territorial**						
	aggregative/schooling						
	neutral				??? Unknown	neutral	
Functionality of habitat – spawning	**Erect 3D structure**						
	sediment type	release sperm and eggs into the water to fertilize.	muddy or sandy bottoms	adjacent to estuaries and harbours			
	depth range		shallow surface waters	shallow	inshore during spring and summer to give birth and mate		

Factor	Matrix categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
	temperature range			Spawning is initiated when water temp reaches 14.8-16 degrees. Water temp is important to larval period, abundance and survival.		gonad maturation related to a drop in seawater temperature.	
	current speed range						
Functionality of habitat young	**Erect 3D structure**						
	sediment type	water		water			
	depth range	inshore	egg and larval development occurs in surface waters.	move inshore only when ready to settle		Pelagic, offshore waters 50-100m. Found in surface waters at night.	offshore
	temperature range			Australian research suggests optimum temperature growth is 18-20 degrees- unknown for NZ.			
	current speed range						
	high microalgal biomass			Wind driven upwelling can result in greater primary productivity, prey abundance and higher larval snapper survival.			
	high zooplankton biomass						
Functionality of habitat juvenile/young adult	**Erect 3D structure**	weed and kelp	rough or weed covered	use 3D structure to feed around and escape predation		Settle on three-dimensional structure in cold water	

Factor	Matrix categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
	sediment type	reef to open sand and mud	sediment type, in habit ground that is unable to be trawled (e.g., rough or weed covered ground) in shallow embayment's.	reef to open sand/mud	Nursery for new-born juveniles turbid estuaries		muddy or sandy bottoms
	depth range	juveniles common inshore	shallow embayments, juveniles common inshore	juveniles common inshore <200m depth, 10-70mm in estuaries, harbours and sheltered coastal areas	- bays, surf beaches and open coastline waters less than 10 m deep may function as nursery areas (from HoPSFM table)	Juvenile nursery areas in shallow, inshore waters, Juveniles move out into deeper waters at 25 cm FL, age 3-4 years	estuaries <50m
	temperature range		warm	18-20?	- muddy substrata in turbid parts of harbours which have a significant freshwater component especially support high abundances of 0+ rig		
	current speed range			Disperse to less sheltered coastal areas as they grow older.	young grow rapidly in shallow coastal waters during first summer, then move into deeper waters in autumn when waters cool		
	high microphytobenthic biomass						
	high zooplankton biomass						
Functionality of habitat adult	**Erect 3D structure**	weed lines and kelp beds				weed lines or reef edges over sandy/muddy ground	
	sediment type	reef to open sand and mud	gravel and sandy sediment	reef to open sand/mud	Found mainly over soft sediment	school over open seafloors	muddy or sandy bottoms

Factor	Matrix categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
	depth range	inshore to 200m	depth range, inshore in 10 to 200m, older fish generally further offshore	inshore to 200m but most abundant in 16-60m.		deeper waters of 50 to 250m, rarely seen in waters above 15-20m (except round the South Island, where they can be found in the 5 to 10 metre range).	estuaries <50m
	temperature range	warm waters		18-20?	make extensive coastal migrations (females migrate further than males, mature further than immature)		
	current speed range						
	high microphytobenthic biomass						
	high zooplankton biomass						

Table 8. MVA data – refined categorisation

Factor	Matrix categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
Likelihood of spawning aggregation	N						
	Y	?	Y	Y	Y	Y	?
Reproductive location	Leaves management area/map	?				Y	?
	Within a specific location/habitat with management area/map	?		Y	Y?		?
	Within normal adult location	?	Y				N?
Reproductive frequency	Semelparous						
	seasonal short						
	Seasonal but protracted	Y	Y	Y	Y	Y	Y
	Multi-year event driven-skipping						
	Continuous						
Reproductive strategy	Bearers/brooders				Y		
	Guarders						
	Non-guarders	Y	Y	Y		Y	Y
feeding/trophic level- adult	other species adults	Y		Y			Y
	juvenile fish	Y		Y			Y
	zooplankton			sometimes salps			
	infauna/epifauna	squid, crabs, molluscs, kina	shellfish, crustaceans and worms	crustaceans, polychaetes, echinoderms, molluscs	invertebrates	worms, crustaceans, mollusks and echinoderms	squid, crabs, molluscs,
	benthic herbivore						
feeding/trophic level- juvenile/young adult	juvenile fish	Y		Y			Y
	zooplankton	Y		Y			Y
	infauna/epifauna	crustaceans	shellfish, crustaceans and worms	shellfish, crustaceans and worms	crustaceans	crustaceans <15cm, worms>15cm	squid, crabs, molluscs,

Factor	Matrix categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
	benthic herbivore						
feeding/trophic level- young	zooplankton	Y	?	Y		?	Y?
	algae/bacteria					?	
	does not feed						
max-age/size	1yr						
	2-3yr						
	3-6yr						Y
	6-10yr						
	10-20yr	Y	Y				Y
	20-40yr				Y		
	>40yr			Y		Y	
Duration young	1-2 weeks			y			
	1mo-6mo	?	?				
	7-12mo				y	y	
size mature at	<20cm						
	20-30cm (Gur snapper)		Y	Y			
	30-50cm (Tar John Dory)	Y				Y	
	50-1m						
	1-1.5m (Rig)				Y		
risk of predation -adult	high						
	medium					Y	Y
	low	Y					
risk of predation - juvenile/young adult	high						
	medium	Y				?	Y
	low						
risk of predation -Young	high	Y					Y
	medium						
	low						
	territorial			Y			

Factor	Matrix categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
competition-adult	aggregative/schooling					Y	
	neutral				?		
competition-juvenile/young adult	territorial						
	aggregative/schooling			Y	?	Y	
	neutral						
competition-Young	territorial						
	aggregative/schooling						
	neutral				?	?	
competition for food- adult	low diet overlap 0-1 other species						
	mod diet overlap 2-4 species						
	high diet overlap 5-6 species	Y	Y	Y	Y	Y	Y
Diet overlaps	specific to species being considered	shellfish and crust with all, squid and crabs with flatfish and sna	shellfish and crust with all, worms with sna and tar	shellfish and crust with all, worms with gur and tar, squid and crabs with jdo and sna	shellfish and crust with all	shellfish and crust with all, worms with gur and sna	squid and crabs with JDO and sna, shellfish with rest
competition for food - juvenile/young adult	low diet overlap 0-1 other species						
	mod diet overlap 2-4 species						
	high diet overlap 5-6 species	Y	Y	Y	Y	Y	Y
Diet overlaps	specific to species being considered	crust with all, juv fish and zooplankton with sna and flat	crust with all, worms with sna, tar and flat, shell with sna and flat	crust with all, worms with gur, tar and flat, shell with gur and flat and zooplankton with jdo and flat	crust with all	crust with all, worms with gur, sna and flat	crust with all, worms with gur, tar and sna, shell with sna and gur, and zooplankton with sna and jdo
competition for food -Young	low diet overlap 0-1 other species						
	mod diet overlap 2-4 species	Y	Y	Y	NA	Y	Y

Factor	Matrix categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
	high diet overlap 5-6 species						
Diet overlaps	specific to species being considered	?gur, sna,?tar, ?flat	?jdo, sna,?tar, ?flat	?gur, jdo,?tar, ?flat		?gur, sna,?jdo, ?flat	?gur, sna,?tar, ?jdo
Functionality of habitat-spawning	sediment type- Erect 3D structure						
	sediment type water	Y	Y	Y	Y	Y	Y
	sediment type mud				Y		
	sediment type sand				Y		
	sediment type rock						
	depth range- shallow <30m		Y	Y	Y		
	depth range- mid 30-200					?	?
	depth range- deep >200						
	temperature range			14.8-16			
	current range						
Functionality of habitat young	sediment type- Erect 3D structure						
	sediment type water	Y	Y	Y		Y	Y
	sediment type mud						
	sediment type sand						
	sediment type rock						
	depth range- shallow <30m	Y	?				
	depth range- mid 30-200			Y		Y	Y
	depth range- deep >200						
	temperature range			18-20?			
	current range						
	high microalgal biomass			Y			
	high zooplankton biomass			Y			
Functionality of habitat juvenile/young adult	sediment type- Erect 3D structure	weed and kelp	rough or weed	Y		Y	
	sediment type water	Y	Y	Y	Y		
	sediment type mud	Y		Y	Y		Y

Factor	Matrix categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
	sediment type sand	Y		Y			Y
	sediment type rock	Y		Y			
	depth range- shallow <30m	Y	Y	Y	Y	Y	Y
	depth range- mid 30-200			Y		Y	
	depth range- deep >200						
	temperature range		warm	18-20?	WARM	COLD	
	current range						
	high microphytobenthic biomass						
	high zooplankton biomass						
Functionality of habitat adult	sediment type- Erect 3D structure	weed lines and kelp beds				weed lines or reef edges	
	sediment type water	Y	Y	Y	Y	Y	
	sediment type mud	Y		Y	Y	Y	Y
	sediment type sand	Y	Y	Y	Y	Y	Y
	sediment type rock	Y		Y		Y	
	depth range- shallow <30m	Y	Y	Y	Y		Y
	depth range- mid 30-200	Y	Y	Y	Y	Y	?
	depth range- deep >200					?	
	temperature range	warm					
	current range						
	high microphytobenthic biomass						
	high zooplankton biomass						

Table 9. MVA data – final matrix available for heat mapping analysis

Factors	Matrix sub-factors and categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
Likelihood of spawning aggregation	not spawning	0.5					
	spawning	0.5	1	1	1	1	1
Reproductive location	Leaves management area/map	0.3			0.1	1	0.4
	Within a specific location/habitat	0.4		1	0.8		0.5
	Within normal adult location	0.3	1		0.1		0.1
Reproduction timing	spring summer		1	1	1	1	
	summer autumn	1					
	winter spring						1
Reproductive strategy	Bearers/brooders				1		
	Guarders						
	Non-guarders	1	1	1		1	1
Adult feeding	other species adults	0.3		0.2			0.3
	juvenile fish,	0.3		0.2			0.3
	zooplankton,			0.1			
	infauna/epifauna	0.4	1	0.5	1	1	0.4
	squid	0.25			0.2		0.3
	crustaceans	0.25	0.3	0.25	0.2	0.25	0.4
	shellfish	0.25	0.4	0.25	0.2	0.25	0.3
	echinoderms	0.25		0.25	0.2	0.25	
	polychaetes		0.3	0.25	0.2	0.25	
Juvenile feeding	juvenile fish,	0.25		0.25			0.25
	zooplankton,	0.25		0.25			0.25
	infauna/epifauna	0.5	1	0.5	1	1	0.5
	squid						0.33
	crustaceans	1	0.3	0.33	1	0.5	0.34
	shellfish		0.3	0.34			0.33
	polychaetes		0.4	0.33		0.5	

Factors	Matrix sub-factors and categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
Young feeding	zooplankton,	1	0.8	1		0.5	0.8
	algae/bacteria		0.1			0.5	0.2
	does not feed		0.1		1		
Maximum age	3-6yr,						0.5
	10-20yr,	1	1				0.5
	20-40yr,				1		
	>40yr			1		1	
Duration young	1-2 weeks			1			0.25
	1mo-6mo	1	1				0.5
	7-12mo				1	1	0.25
Size mature at	<20cm,						0.2
	20-30cm		1	1			0.6
	30-50cm	1				1	0.2
	1-1.5m				1		
risk of predation - adult	high,		0.2				
	medium,		0.6	0.2	0.2	1	1
	low	1	0.2	0.8	0.8		
risk of predation - juvenile/young adult	high,		0.8	0.1	0.1	0.1	
	medium,	1	0.2	0.8	0.8	0.8	1
	low			0.1	0.1	0.1	
risk of predation - Young	high,	1	0.8	0.8		0.8	1
	medium,		0.2	0.2	0.2	0.2	
	low				0.8		
competition- adult	territorial,	0.8	0.3	1			0.3
	aggregative/schooling,		0.3		0.2	1	0.3
	neutral	0.2	0.4		0.8		0.4
competition- juvenile/young adult	territorial,	0.2	0.2		0.2		0.2
	aggregative/schooling,	0.2	0.2	1	0.6	1	0.2
	neutral	0.6	0.6		0.2		0.6

Factors	Matrix sub-factors and categories	John Dory	Red gurnard	Snapper	Rig	Tarakihi	Flatfish
Functionality of habitat- spawning *	sediment type, water	1	1	1	0.3	1	1
	sediment type, mud				0.4		
	sediment type, sand				0.3		
	depth range- shallow,<30m	0.5	1	1	1	0.2	0.2
	depth range- mid 30-200	0.5				0.8	0.8
Functionality of habitat -young *	sediment type, water	1	1	1		1	1
	depth range- shallow,<30m	1	0.8		1		
	depth range- mid 30-200		0.2	1		1	1
Functionality of habitat- juvenile and young adults *	sediment type- Erect 3D structure	0.6	0.5	0.6		1	
	sediment type, water	0.1	0.5	0.1	0.5		
	sediment type, mud	0.1		0.1	0.5		0.5
	sediment type, sand	0.1		0.1			0.5
	sediment type, rock	0.1		0.1			
	depth range- shallow,<30m	1	1	0.5	1	0.5	1
	depth range- mid 30-200			0.5		0.5	
Functionality of habitat- adults *	sediment type- Erect 3D structure,	0.3				0.3	
	sediment type, water	0.1	0.5	0.25	0.4	0.3	
	sediment type, mud	0.1		0.25	0.3	0.1	0.5
	sediment type, sand	0.3	0.5	0.25	0.3	0.1	0.5
	sediment type, rock	0.2		0.25		0.2	
	depth range- shallow,<30m	0.5	0.5	0.5	0.5		0.8
	depth range- mid 30-200	0.5	0.5	0.5	0.5	1	0.2

**** Habitat functionality is comprised of a number of subfactors which have been listed in the earlier tables: sediment type, depth, temperature, current speed, temperature range, water clarity, high microalgal biomass and high zooplankton biomass. There was only enough information for sediment type and depth to create categories for the MVA. In this table only these two sub-factors where information was available have been included. Here, each subfactor has been shaded as the weightings in each subfactor adds up to 1. This is not the case for the other factors in the table.***

Appendix 6

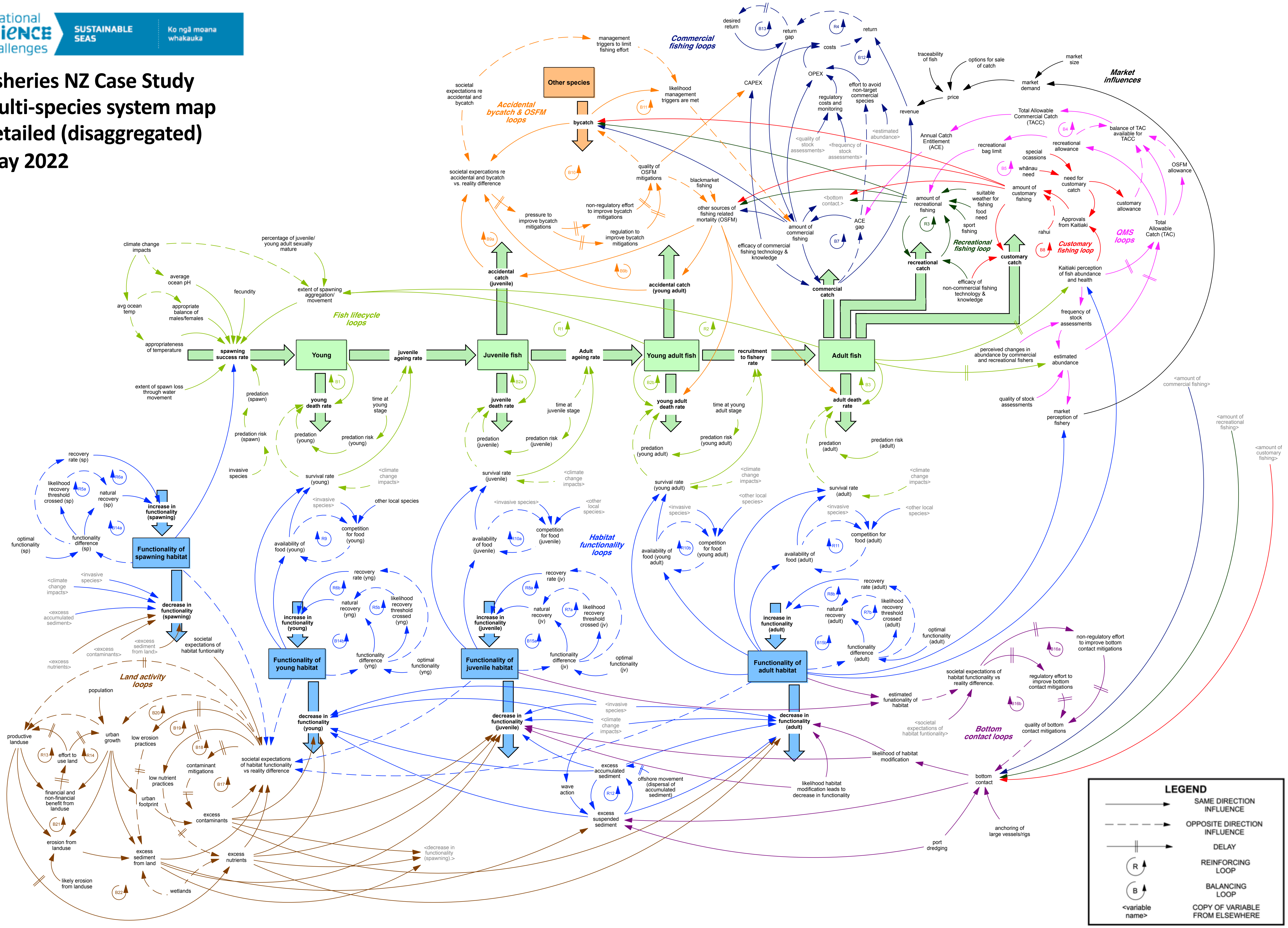
Alternative (more detailed) version of the System Diagram

This version of the System Diagram is provided for background information. It presents fully disaggregated life stages and functionality of habitats in case this is of use for any technical audience interested in this report.

Here, the three life stages in the generic system diagram have been more formally separated into four: Young; Juvenile fish; Young adult fish; Adult fish. The demarcation between Young adult fish and Adult fish is the human determined step of 'recruiting into the fishery'.

All other relationships remain the same, they have just been replicated across bathtubs that have been disaggregated.

Fisheries NZ Case Study
Multi-species system map
Detailed (disaggregated)
May 2022



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Appendix 7
Alternative (less detailed) version of the System Diagram

This version of the System Diagram is also provided for background information. It presents a simplified version of generic system diagram of a fish species.

Here, the life stages and functionality of habitats in case this is of use for any technical audience interested in this report.

All other relationships remain the same, they have just been replicated across bathtubs that have been disaggregated.

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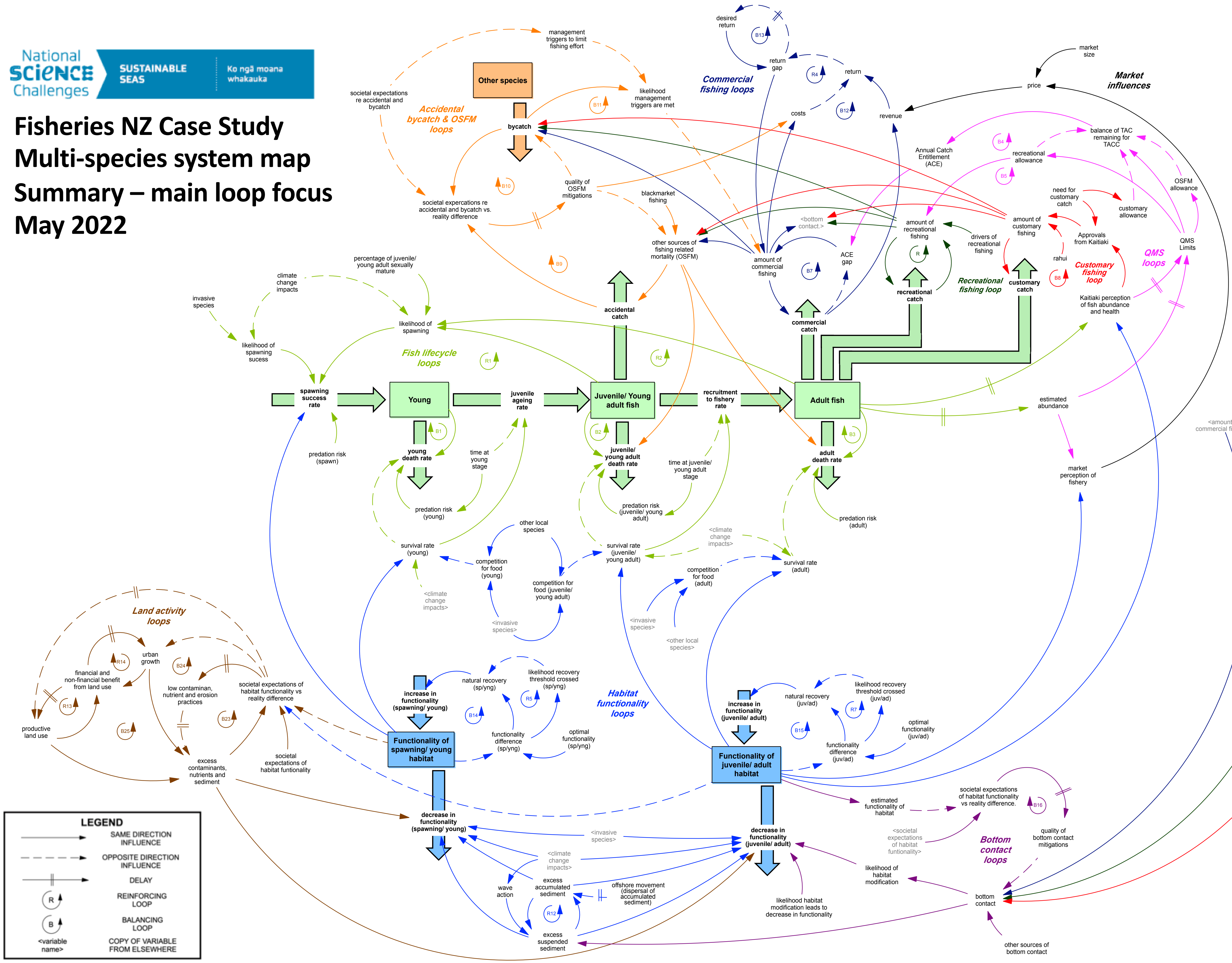
Fisheries NZ Case Study
Multi-species system map
Summary – main loop focus
May 2022



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