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Kaitohutohu Mātanga Pūtaiao Matua ki te Pirimia

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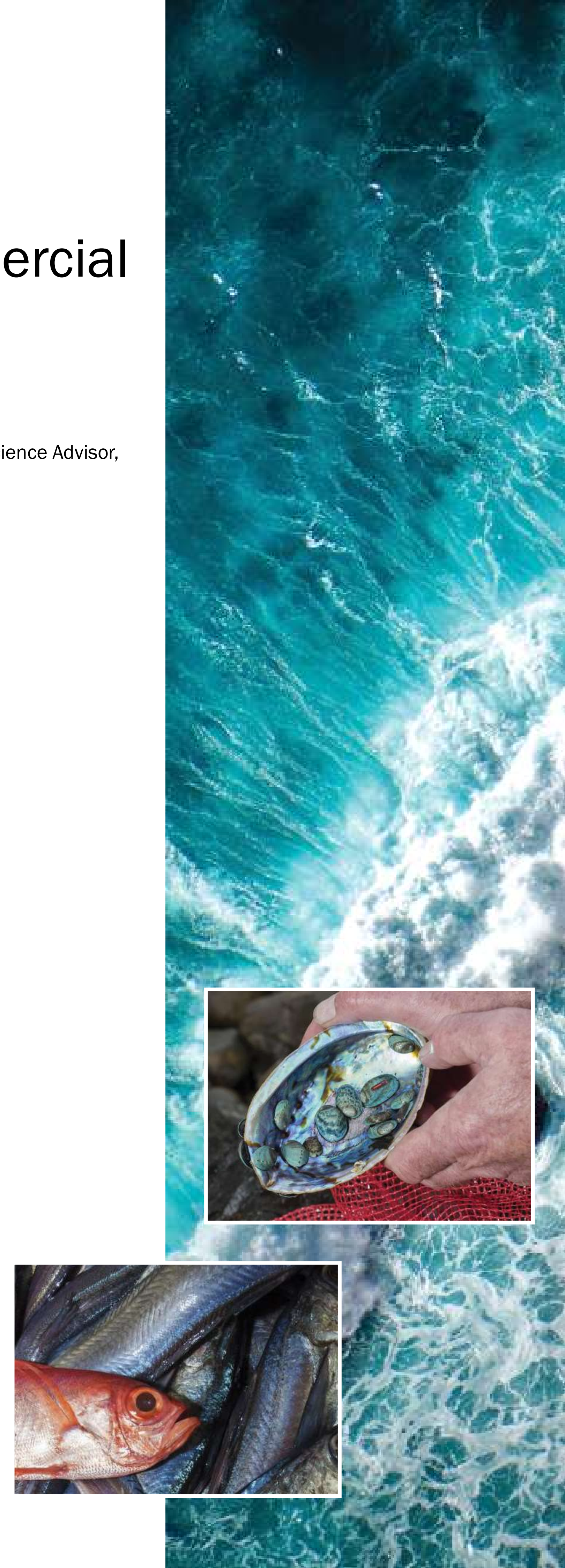
The Future of Commercial Fishing in Aotearoa New Zealand

A report from the Office of the Prime Minister's Chief Science Advisor, Kaitohutohu Mātanga Pūtaiao Matua ki te Pirimia.

Full Report



February 2021

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Back cover: *Pāua fishing vessel on Rēkohu Wharekauri the Chatham Islands.*

Ka pū te ruha, ka hao te rangatahi

FOREWORD FROM THE PMCSA

Kia ora koutou

This report was prepared at the request of the Prime Minister in late 2019 and has had a difficult gestation, having been rudely interrupted by a pandemic response which called on the time and energy of the team here in the Office, and the many participants on whom we relied for expertise and input. It has also had a difficult birth, as we strived to digest a deluge of feedback and listen to wildly different opinions on our early drafts. As such, it is worth emphasising at the outset that the views in this foreword are personal.

Beyond the foreword, the recommendations we present are those of the Office of the Prime Minister's Chief Science Advisor (OPMCSA). These have drawn heavily on the expertise of our panel and the large number of contributors and peer reviewers, but few would endorse the report in its entirety. As well as being available in this long narrative form, the report forms the basis of a web resource, which will be easier to browse, and our short report gives a more digestible summary of our findings. But first, some reflections on our foray into commercial fishing:

Scope of our report – science advice on commercial fisheries

The stakeholders we talked to during this project all shared a remarkable passion for the ocean. We thank them for their enthusiasm to share this passion with us. Many had deeply held views and it was a significant challenge to stay within our scope without straying into fraught relationships and decades-old feuds.

To be clear, the scope of this report is *to provide science advice to the Prime Minister on commercial fisheries (excluding aquaculture)*, which sounds simple. It is not. Some stakeholders were placed offside from the start simply by the scope and the framing – an indication of the poor relationships and lack of trust that characterise this sector. So at the outset, it is worth acknowledging that science advice on commercial fisheries won't solve all the many problems faced by an increasingly challenged marine environment, globally and locally.

Solving these problems will need people to work together on a system change, as partners not adversaries. Such a system change needs to address not just commercial fishing, but recreational fishing too. It needs to address not just fishing, but the many other environmental stressors on the marine environment – climate change, land-based impacts such as sedimentation, and pollution. To acknowledge these sector challenges, we have tried to place our recommendations within a broader context. We stray beyond our scope in the first three themes of our recommendations, in our general call for overarching leadership in the ocean realm. That said, the specific recommendations in this report are within the scope of commercial fisheries and, if implemented, will make a difference.

Irrespective of individual – sometimes widely divergent – views of how environmentally sustainable commercial fisheries are in 2020, nearly every stakeholder we talked to agreed we could do better in at least some areas. There are many differences that can be made in the short term to help the pendulum swing towards a greater emphasis on the environment in which we fish, and away from emphasising just the fishing itself. There are conversations around innovation in data management, technology, policy, and collaboration that can pilot good practice to catalyse change. This benefits everyone, including commercial fisheries, which have everything to gain from a healthy marine environment.

Context and framing – the QMS is in place, but we can do better for our environment

The context in which our science advice is provided is important. Since our scope was restricted to commercial fisheries, we have placed our recommendations within the framework of the Fisheries Act 1996 which provides the legislation for the Quota Management System (QMS). Those seeking to completely revolutionise the management of fisheries need not read on – a review of the QMS was outside our scope.

Over the course of this work, many stakeholders identified the parts of the Fisheries Act 1996 that are under-used. These can enable protection of special marine habitats and an ecosystem approach to fisheries management (EAFM). The most striking example is perhaps Section 9(c), which enables the protection of habitats of particular significance for fisheries management – but has never been used. These provisions can be used in the short term and enable immediate action. We challenge the Minister and the regulator to strengthen their arm and use these provisions to catalyse change.

Many argue that the protection tool that should be used is a Marine Protected Area (MPA), under the purview of the Minister of Conservation, and some that the Resource Management Act should be more often used to protect the inshore environment and marine life. These conversations often run parallel, creating indecision and hostility.

A shared understanding of our environmental bottom line and collective aspirations for our environment are needed to harmonise these conversations and bring all voices to the table. This was beyond the scope of our work, but we highlight some local examples where a collaborative approach has made progress in setting up a framework for improving environmental outcomes. The single biggest challenge to progress is the lack of trust and shared vision between stakeholders – in stark contrast to our last project (on rethinking plastics), there is little evidence of widespread social and cultural licence for change.

The need for a partnership approach with iwi to respect the Treaty and the Māori Fisheries Settlement was emphasised throughout and needs to be fully understood by scientists seeking change.

"The facts"

There is no accepted single source of truth in the fisheries sector and this report does not claim to be one. Passionate debate arises from (over-)interpretation of uncertain datasets by all sides, which supports conflicting narratives of 'what the evidence says'. We have tried to highlight where particular points of contention lie in interpreting data and were saddened by the number of incidences of 'alternate facts' that we navigated in this project.

The inherent uncertainty in fisheries management is very easily manipulated to support a particular narrative. From an agreed percentage of how many of our stocks have been assessed, to the size of the original non-fished biomass, to a percentage of this biomass that can be sustainably harvested, to whether our trawling footprint is increasing or decreasing – the very basis of our fisheries management is often fiercely contested. Where possible, we have tried to explain the alternate interpretations of uncertain information. In other places we highlight where data, the interpretation of data, or both, are contested.

Data, data, data – it is dark down there, but we must make decisions anyway

We do have a lot of data about the ocean but in many ways, we also know frighteningly little. What we do know is often uncertain, creating error bars in measurements which foster the differences in interpretations that fuel dissent. The data we do have is poorly integrated across different stakeholders. The mountain of electronic and other data collected for compliance purposes could be better mined for environmental, commercial, and social outcomes. New tools can support this if the data is shared. Aggregation of non-sensitive data from industry sources and integration with data from a wider range of scientists from different disciplines and regulators could radically change the amount of information available on which to base decisions, and the decision-making processes must be open to incorporate this data in a transparent way. Deep local knowledge and mātauranga Māori are also under-used and we could listen more to on-the-ground expertise.

In the meantime, lack of data is used by many to excuse lack of action – this must change. Data is expensive to collect and information will never be perfect. Transparency in what we don't know, our levels of uncertainty, and how we manage this, is as important as sharing what we do know.

Research, science and technology efforts could be better coordinated across the sector

The industry levy funds vital data gathering and research for significant commercial species. It does not pay for basic public good research or research that would be valuable for other fished species. This creates a resourcing shortfall, unreasonable expectations on this funding, a lack of trust and perverse incentives. There are many new high-tech tools and cool new ideas that could change the way we fish, but public good funded research is not always well connected to industry questions or environmental challenges. Fishers understand the issues better than anyone and have many great ideas – we should empower them to innovate and try them out. Many fishers would love to understand the basic biology of commercial species more fully, to inform better fisheries management decisions that take an ecosystem approach – but this research is often not prioritised.

Relationships between researchers looking at different aspects of the marine environment, housed in different institutions, mirror the poor relationships in the sector as a whole. A lot of energy is wasted trying to deconstruct an opposing narrative, which could be better spent coming to a shared understanding.

We need to ensure the regulator is nimble, trusted and well placed for success

This contested environment presents our regulator with formidable challenges. More resource is needed to enable the regulator to keep pace with the ever-changing stocks. Plans are critical for success, but an agreed fisheries management plan is the beginning of a solution, not the end. Despite big strides in the introduction of electronic monitoring and initial cameras on vessels, we found that there is sometimes a lack of confidence that plans will be implemented. Making data and information more accessible will help improve transparency of prioritisation and decision making. This will benefit everyone by allowing more independent scrutiny, which will build trust.

Slow processes and high data requirements can provide unnecessary hurdles to innovators to try new fishing practices. A higher-trust, more permissive environment to trial and optimise new equipment could enable our innovators to flourish and address the many challenges in this environment.

But above all, we need overarching leadership

Although beyond the bounds of science advice, the need for leadership across the many different strands of oceans governance was clear. Science can support the journey, but the governance of the oceans needs to provide a framework in which to do so. We were delighted to see the Oceans and Fisheries Minister and Under-Secretary appointed after the recent election.

This report – fishing today, fishing beyond 2040

Our report begins by clarifying our Terms of Reference and outlines detailed recommendations in seven themes, which represent the conversations in our panel meetings.

We then provide the challenging context in which commercial fishing takes place and lay out the many stressors which the marine environment faces, in addition to those posed by all types of fishing.

To help understand how to make progress in this complex area, we try to capture the complexities of fishing in 2020. This is the most contested section of our report in that impressions of the status quo vary a great deal.

Finally, with the context set, we outline ideas and innovations that could help us fish smarter in the future. There are no silver bullets. Not all the ideas are new, and not all the new ideas will be successful. But we think they offer hope that challenging current thinking about how, where, and when we fish can move the conversation forward to create a future that is better than the past. We end with an aspirational vision of the future to challenge old thinking and encourage new.

Ngā mihi nui

I'd like to give my heartfelt thanks to our hard-working panel for their collegial spirit and painstaking explanations of the complexities of this field to us novices in the OPMCSA. Particular thanks to my co-chair Craig Ellison for his deep knowledge, enthusiasm for science, patient expertise, and for connecting us to the sector.

To the hard-working team in the OPMCSA who did a mountain of work in a gruelling year – thank you. Celia Cunningham led the project ably supported by Rachel Chiaroni-Clarke, Ellen Rykers, George Slim, Susie Meade, Manmeet Kaur and Daksha Mistry-Surti. Thanks all for all the hard yards. Ka pai.

Thanks to the fishing industry for letting us march into your world uninvited and sharing your thinking and expertise, introducing us to your members, and hosting us on vessels, in factories and in boardrooms. The depth of knowledge and ideas to protect your environment in your midst is under appreciated and I hope that we have helped to tell some of your success stories to balance the darker ones.

Thanks to the many researchers, officials, fishers and environmentalists who supported our kaupapa from within our limited Terms of Reference and scope, even though your frustrations with these in terms of addressing the wider problems in the marine environment were palpable. Your input was incredibly valuable, and we hope that you feel heard, especially in the first three themes of our recommendations.

And a final thanks to everyone involved for their energetic engagement. Even for those who were unable to contain the occasional outbursts of anger, hostility and despair, your commitment to our marine environment was clear and has earned my respect.

He moana pukepuke e ekengia e te waka

Juliet Gerrard

Professor Dame Juliet A. Gerrard DNZM HonFRSC FRSNZ
Prime Minister's Chief Science Advisor
Kaitohutohu Mātanga Pūtaiao Matua ki te Pirimia

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PART 1: INTRODUCTION

1.1 INTRODUCTION TO THIS REPORT

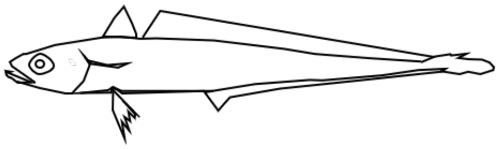
The scope of this report is to provide science advice on commercial fishing. But commercial fishing does not take place in a vacuum, so we begin by providing some context of the wider issues in the marine environment and then narrow the focus to within the confines of the Fisheries Act 1996.

Section 1.2 provides our Terms of Reference as agreed at the beginning of the project.

Southern blue whiting (*Micromesistius australis pallidus*) fishery. Image credit: Neil Bagley/NIWA.

1.2 TERMS OF REFERENCE, AGREED WITH THE PM IN EARLY 2020

Towards a vision for commercial fisheries in Aotearoa New Zealand in 2040



BACKGROUND

Aotearoa New Zealand's fisheries are a significant economic, cultural, social, and ecological natural resource. Maintenance of this resource and respect for our taonga species requires management that ensures sustainability of fisheries stocks and the wider marine ecosystem. As technology has developed and international and national attention turns towards integrated management systems that combine the best of quota management with protection of ecosystems, Aotearoa New Zealand has an opportunity to lead with innovative approaches. This project seeks to support this goal.

What do we as a country value when we look to the future in commercial fisheries? The values below are adapted from the industry and reflect the views of the project's expert panel:

- **Challenge and inspire** – use knowledge and science to challenge, inspire and guide a better future for commercial fisheries and Aotearoa New Zealand.
- **Responsibility** – to be good ancestors and ensure we maintain and enhance the resource for those generations to come.
- **Te hā o Tangaroa kia ora ai tāua –** protection of the environment (and ecosystem) so that utilisation is possible and sustainable.
- **Respect** – respect for the oceans, the people, and the products we produce and share. We reflect on what sustains us, the contributions made, and the high value of our products.
- **Retain what has worked** – build on strong foundations to enhance outcomes for commercial fishing, the community and the environment, and remain open to new ways of doing things.
- **Crown obligations** – have respect for the agreements made between the Crown and iwi in relation to fisheries and the marine environment, such as the Treaty of Waitangi and the 1992 Fisheries Settlement.

The research considers these values as we build on other work undertaken. For example, the Parliamentary Commissioner for the Environment undertook a review of our environmental reporting systems in 2019. The report commented that:

> *Current fisheries management systems… rarely take into account the effects of fishing on the wider ecosystem.*[1]

The Ministry for the Environment reported on the marine environment in 2019. Reporting showed marine catch has remained stable over the last decade and that in 2018 68% of marine catch came from stocks that were scientifically evaluated. The report also comments that:

> *Stock assessments apply to individual fish stocks so they do not account for interactions between different stocks or interactions with the broader marine environment.*[2]

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[1] https://www.pce.parliament.nz/publications/focusing-aotearoa-new-zealand-s-environmental-reporting-system
[2] https://www.mfe.govt.nz/publications/environmental-reporting/our-marine-environment-2019

In 2015 Fisheries New Zealand undertook a Fisheries Management System review, and from this review they developed a major work programme called the Fisheries Change Programme to enhance and update the fisheries system. The programme is currently underway.[3]

A report in 2017 by The Nature Conservancy found that while Aotearoa New Zealand's Quota Management System (QMS) has consistently ranked well compared to other countries against a range of global indicators, we do not routinely report on the ecosystem impacts of fishing.[4]

Around half of wild seafood caught in Aotearoa New Zealand is certified to the Marine Stewardship Council's (MSC) Fisheries Standard as well-managed and sustainable (this compares to 15% worldwide).[5] Incremental improvements are made to MSC standards and fisheries must continue to improve their practices in order to be recertified.

AIM OF PROJECT

The aim of the project is to help identify ways to reduce the gaps in data and knowledge in the fisheries sector. This is important to ensure that fishing is being undertaken sustainably and to meet Aotearoa New Zealand's commitment[6] to taking a more integrated approach to fisheries management, which includes consideration of the wider environment and its inhabitants.

This project will convene an expert panel which seeks to identify innovative technologies and methods that can be applied to fisheries to achieve these goals. It will provide recommendations on how Aotearoa New Zealand can move towards a vision for a modernised, data-driven approach to efficient and effective fishing which preserves this resource for future generations.

The aims of the panel are to:

- Reduce the gaps in data and knowledge, and improve data accessibility, in the commercial fisheries sector.
- Identify ways to help ensure that fishing is being undertaken sustainably.
- Consider the wider environment, ecosystem, and its inhabitants; and
- Help Aotearoa New Zealand commit to a more integrated approach to fisheries management.

SCOPE

The scope for the project was finalised in conjunction with the expert panel. The research will be evidence-based and seek to create a vision for commercial fisheries in Aotearoa New Zealand in 2040 supported by knowledge-driven management and an ecosystem approach.

In the context of this vision, the research will consider:

1. **Data and knowledge gaps.** Consider the effectiveness of our processes for collecting information, how fit-for-purpose the data we collect is, where our data and knowledge gaps are, what impact these have on achieving the vision, and how these can be improved.
2. **Mātauranga Māori.** Consider how to appropriately represent mātauranga Māori together with science in achieving the vision.

[3] https://www.mpi.govt.nz/protection-and-response/sustainable-fisheries/strengthening-fisheries-management/fisheries-change-programme/
[4] https://www.nature.org/media/asia-pacific/new-zealand-fisheries-quota-management.pdf
[5] https://www.msc.org/en-au/media-centre-anz/media-releases/new-zealanders-choose-sustainable-seafood-for-future-generations
[6] United Nations Convention on Biological Diversity (1992). See https://www.doc.govt.nz/globalassets/documents/about-doc/role/international/nz-6th-national-report-convention-biological-diversity.pdf

3. **Innovation.** Explore relevant new technologies, innovative research, models, and approaches, and how these can provide opportunities to fill knowledge gaps and improve fisheries management.
4. **Application**. How can we apply this research to fill knowledge gaps and step towards the vision.

OUT OF SCOPE

The research will not review or make recommendations on:

- Quota ownership and Crown obligations
- Aquaculture
- Recreational fishing including catch reporting
- Customary fishing

However, the report will explain how these factors impact and interact with the in-scope aspects of the project. Linkages and overlaps between in and out-of-scope factors may be commented on.

PROCESS

- Terms of Reference agreed with the Prime Minister.
- Wide stakeholder engagement will be included with an open reference group process.
- The membership of the panel and wider reference group will be public and processes open.
- Call for nominations of the expert panel and wider reference group will be sought from the key institutional contact lists. The panel shortlisting will actively seek to support a diverse and balanced panel. Expert panel approached and wider reference group assembled to guide the Office of the Prime Minister's Chief Science Advisor in preparing the report.
- The report will be delivered to the Prime Minister and later made public on the PMCSA website.

TIMELINE OF ACTIVITIES

- Scope drafted – early February 2020
- Call for nominations via key institutional contacts list – February 2020
- Panel establishment – March 2020
- Research and engagement – March to June 2020
- Reporting – July-August 2020

Timeline was updated to account for delays due to COVID-19.

1.3 OUR PANEL

We convened an expert panel to create a diverse and balanced group that could guide the OPMCSA and the PMCSA in preparing this report.

- **Juliet Gerrard, Co-Chair**
- **Craig Ellison, Co-Chair**, Seafood New Zealand
- Dr Chris Cornelisen, Cawthron Institute
- Livia Esterhazy, World Wildlife Fund
- Dr Rosemary Hurst, NIWA
- Dr Andrew Jeffs, University of Auckland
- Andrew (Anaru) Luke, Cawthron Institute
- Raewyn Peart, Environmental Defence Society
- Professor Michael Plank, University of Canterbury
- Dion Tuuta, formerly Te Ohu Kaimoana
- Dr Maren Wellenreuther, Plant & Food Research

We are incredibly grateful to the support and hard work that the panel has put into this research. The values below reflect the views of the project's expert panel and framed our work:

- **Retain what has worked** – build on strong foundations to enhance outcomes for commercial fishing, the community and the environment, and remain open to new ways of doing things.
- **Challenge and inspire** – use knowledge and science to challenge, inspire and guide a better future for commercial fisheries and Aotearoa New Zealand.
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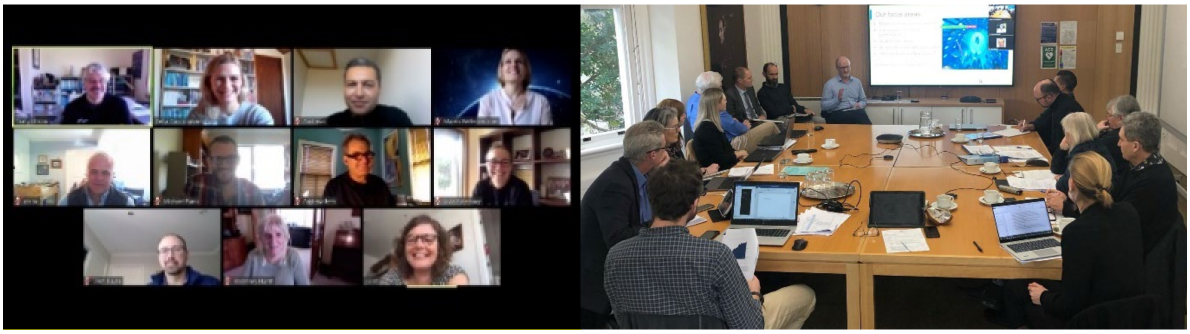
- **Crown obligations** – have respect for the agreements made between the Crown and iwi in relation to fisheries and the marine environment, such as Te Tiriti o Waitangi and the 1992 Fisheries Settlement.



1.4 ACKNOWLEDGEMENTS

We thank the many researchers, stakeholders and interested parties who agreed to be on our reference group, met with the team, provided introductions, generously contributed time, energy and suggestions to this project through conversation, consultation, peer review or high-level comments on the report. We are particularly grateful to those who hosted the team to give us the necessary insights into the setting of commercial fisheries on which we were providing advice. Though we have incorporated as much feedback as possible, we acknowledge that this is an area with highly contested views and that as a result not all suggestions could be actioned. As such, **our acknowledgement of people who helped us with this project in no way reflects endorsement of the project itself**. We have done our utmost to keep track of everyone who has contributed and they are recorded below. Please accept our sincere apologies for any inadvertent errors.

We'd also like to acknowledge those who chose not to be listed in these acknowledgements.

Ngā mihi nui ki a koutou.

Abbie Bull, Ministry for the Environment
Adam Smith, Massey University
Alec Woods, Pacific Networks
Alaric McCarthy, Cawthron Institute
Alex Rogers, Hauraki Gulf Forum
Alice Rogers, Victoria University of Wellington
Alison Collins, Ministry for the Environment
Alison Greenaway, Manaaki Whenua
Alistair Jerrett, formerly Plant & Food Research
Amanda Leathers, World Wildlife Fund
Anastasija Zaiko, Cawthron Institute
Andrew Hill, Fisheries New Zealand
Andrew Peti, New Zealand Coastal Seafoods
Andrew Talley and the team at Talley's Motueka
Angus McIntosh, University of Canterbury
Anita Lee, Marine Stewardship Council
Anna Madarasz-Smith, Hawke's Bay Regional Council
Anna Yallop, Seafood Innovations
Anne Gabriel, Marine Stewardship Council
Anthony Tuanui, cray fisher, Rēkohu Wharekauri the Chatham Islands
Aroha Spinks, World Wildlife Fund
Ashley Rowden, Victoria University of Wellington
Balam Jimenez, Victoria University of Wellington
Barry Torkington
Barry Weeber, ECO NZ
Becky Shanahan, Hawke's Bay Regional Council
Beth Fulton, CSIRO, Australia
Beth Hampton, Ministry for Primary Industries
Brendan Flack, East Otago Taiāpure Committee
Bronwen Golder, Stanford Centre for Ocean Solutions
Bubba Cook, World Wildlife Fund-NZ
Carol Scott, Southern Inshore Fisheries Management Company
Caroline Wahid, Department of Conservation
Carolyn Lundquist, University of Auckland
Carolyn Walker, Ministry for Business, Innovation and Employment
Cath Wallace, ECO NZ
Ceri Warnock, University of Otago
Charles Heaphy, Sealord
Charlotte Austin, Fisheries New Zealand
Chris Battershill, University of Waikato
Chris Hepburn, University of Otago
Chris Rodley, SnapIT
Chris Tyler, SnapIT
Christina Stringer, University of Auckland
Cliff Law, NIWA
Conrad Pilditch, University of Waikato Constance Nutsford, Ministry for the Environment
Dan Bolger, Fisheries New Zealand
Dan Hikuroa, University of Auckland
Dana Briscoe, Cawthron Institute
Danette Olsen, Ministry for Business, Innovation and Employment
Darren Guard, Guard Safety
Daryl Sykes, NZ Rock Lobster Industry Council
Dave Jose, Foodstuffs
Dave Kelbe, Xerra Earth Observation Institute
Dave Kellian, Fisher, Leigh
Dave Woods, Precision Seafood Harvesting

David Ashton, Plant & Food Research
David Howes, Fisheries New Zealand
David Jones, Sanford
David Middleton, Pisces Research
David Schiel, University of Canterbury
Deanna Clement, Cawthron Institute
Debbie Freeman, Department of Conservation
Duncan Currie, Deep Sea Conservation Coalition
Edward Abraham, Dragonfly Data Science
Elisabeth Easther
Elizabeth Macpherson, University of Canterbury
Emma Jones, NIWA
Erena Le Heron, Le Heron Leigh Consulting
Euan Harvey, Curtin University, Australia
Francisco Blaha, fisheries consultant
Freya Hjorvarsdottir, Fisheries New Zealand
Gaia Dell'Ariccia, Auckland Council
Gary Cameron, PāuaMAC4 Industry Association, Rēkohu Wharekauri the Chatham Islands
Geoff Keey, Forest and Bird
Geoffroy Lamarche, Office of the Parliamentary Commissioner for the Environment
George Clement, Deepwater Group
George Makene, Ministry for Primary Industries
Georgina Nicholson, University of Auckland
Gerry Closs, University of Otago
Glenice Paine, for Waikawa Fishing Company
Graham Rickard, NIWA
Greg Bishop, formerly Lee Fish
Helen Mussely, Plant & Food Research
Ian Angus, Department of Conservation
Ian Ruru, ESR
Ian Tuck, NIWA
Igor Debsky, Department of Conservation
Jacinta Ruru, University of Otago
James Williams, NIWA
Jason Mika, Massey University
Jason Tylianakis, University of Canterbury
Jeremy Helson, Seafood New Zealand
Joe Prebble, GNS Science
Johan Svenson, Cawthron Institute
John Roche, Ministry for Primary Industries
John Tanzer, World Wildlife Fund-Global
Jonathan Peacey, The Nature Conservancy
Josie Crawshaw, Bay of Plenty Regional Council
Julie Hall, Sustainable Seas National Science Challenge
Karl Warr, Better Fishing
Karli Thomas, Deep Sea Conservation Coalition
Katherine Short, Terra Moana
Katina Conomos, The Noises Marine Protection and Restoration Project
Ken Hughey, Department of Conservation
Kevin Hague, Forest and Bird
Kim Drummond, Te Ohu Kaimoana
Kim George, Fisheries New Zealand
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Kypros Kotzikas, United Fisheries
Lara Taylor, Manaaki Whenua
Laura Domigan, University of Auckland
Laurie Beamish, Ngāi tai ki Tāmaki
Laws Lawson, Fisheries Inshore New Zealand
Libby Liggins, Massey University
Liz Slooten, University of Otago
Louise Furey, Tāmaki Paenga Hira Auckland Museum
Lucy Jacob, World Wildlife Fund
Lucy Tukua
Mark Edwards, NZ Rock Lobster Industry Council
Mark Geytenbeek, Fisheries New Zealand
Mark Lokman, University of Otago
Mark Morrison, NIWA
Mark Sowden, Stats NZ
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Max Kennedy, Ministry for Business, Innovation and Employment
Megan Carbines, Auckland Council
Melissa Bowen, University of Auckland
Michelle Cherrington, Moana New Zealand
Michael Bunce, Environmental Protection Authority
Mike Smith, National Iwi Chairs Forum Oceans Group
Mike Taitoko, Takiwā
Moana Tamaariki-Pohe
Monique Holmes, Te Ohu Kaimoana
Murray Skeaff, University of Otago
Naomi Parker, Ministry for Primary Industries
Naomi Simmonds, Te Whare Wānanga o Awanuiārangi

Nate Smith, Gravity Fishing
Nici Gibbs, Fathom Consulting
Nick Cameron, pāua fisher, Rēkohu Wharekauri the Chatham Islands
Nick King, Cawthron Institute
Nick Shears, University of Auckland
Nicola Wheen, University of Otago
Olive Andrews, South Pacific Whale Research Consortium
Oliver Floerl, Cawthron Institute
Oliver Wade, Marlborough District Council
Pablo Higuera, University of Auckland
Pamela Mace, Fisheries New Zealand
Perya Short, Marine Stewardship Council
Peter Ritchie, Victoria University of Wellington
Peter Win, New Zealand Coastal Seafoods
Philipp Neubauer, Dragonfly Data Science
Pierre Tellier, Ministry for the Environment
Pita Turei, Taumata-a-iwi, Auckland Museum
Rebecca Mills, The Lever Room; Sustainable Seas National Science Challenge
Richard Ford, Fisheries New Zealand
Richard Le Heron, University of Auckland
Richard Newcomb, Plant & Food Research
Richard O'Driscoll, NIWA
Richard Wells, Resourcewise
Rob Major, Cawthron Institute
Rob Murdoch, NIWA
Rochelle Constantine, Te Whare Wānanga o Tāmaki Makaurau - University of Auckland
Rod Neureuter, The Noises Trust
Ross Vennell, Cawthron Institute
Sam Birch, Lee Fish
Sam Thomas, Department of Conservation
Sarah Flanagan, University of Canterbury
Sean Cooper, Department of Conservation
Serean Adams, Cawthron Institute
Shane Geange, Department of Conservation
Shaun Ogilvie, Cawthron Institute
Shelton Harley, Fisheries New Zealand
Simon Childerhouse, Cawthron Institute
Simon Thrush, University of Auckland
Simon Upton, Parliamentary Commissioner for the Environment
Stacey Faire, Bay of Plenty Regional Council
Stacey Whitiora, Plant & Food Research
Steve Urlich, Lincoln University
Steve Wing, University of Otago
Storm Stanley, Pāua Industry Council
Stuart Brodie, Ministry for the Environment
Stuart Yorston, Sealord
Sue Marshall, Plant & Food Research
Sue Neureuter, The Noises Trust
Susan Thorpe, Hokotehi Moriori Trust
Tai Ahu, Te Ohu Kaimoana
Tamar Wells, Te Ohu Kaimoana
Tane van der Boon, MAUI63
Te Aomihia Walker, Te Ohu Kaimoana
Te Atarangi Sayers, Motiti Rohe Moana Trust
Te Taiawatea Moko-Mead, Te Ohu Kaimoana
Te Tuani Paki, Ngāi Tahu
Thomas Brzostowski, The Nature Conservancy
Tim Armitage, Sanford
Tim Haggitt, University of Auckland
Tim Harwood, Cawthron Institute
Tim Higham, formerly Hauraki Gulf Forum
Tā Tipene O'Regan
Tom McClurg, Toroa Strategy
Tom Searle, Lee Fish
Tom Trnski, Tāmaki Paenga Hira Auckland Museum
Tony Craig, Terra Moana
Veena Patel, Fisheries New Zealand
Vince Galvin, Stats NZ
Vicki Watson, Aotearoa Circle
Volker Kuntzsch, formerly Sanford
Vonda Cummings, NIWA
Xavier Pochon, Cawthron Institute
Zoe Neureuter, The Noises Trust

1.5 RECOMMENDATIONS

These recommendations aim to support movement towards 100% sustainably managed oceans, reflecting our aspirations for commercial fishing in 2040. They were developed through a consensus process with our panel with open sharing of a wide range of views. Alongside the recommendations we provide considerations for supporting their implementation.

Not every panel member fully supports each individual recommendation and consideration but, taken together, the recommendations are a fair representation of the collective view of the group.

The first three themes of the recommendations acknowledge that our Terms of Reference were limited to one part of the marine environment only – commercial fisheries – but that there are issues to solve beyond our narrow scope.

These themes cover:

1. Strengthened leadership.
2. A bold Oceans Strategic Action Plan.
3. Te ao Māori | A connected worldview in 2040 and beyond.

The remaining themes focus on commercial fisheries and can be achieved within the Fisheries Act 1996 – facilitating urgent action.

These cover:

4. A refined set of regulatory tools.
5. A data platform that enables informed commercial and environmental decision making.
6. An ecosystem approach to fisheries management (EAFM) is embraced within the current regulatory framework, including the Fisheries Act 1996.
7. Research and innovation are maximised.

THEME 1: STRENGTHENED LEADERSHIP

Recommendations	Considerations
1. We welcome the appointment of an Oceans and Fisheries Minister and Under-Secretary to ensure cohesive oversight of all marine activities within Aotearoa New Zealand's territorial sea and EEZ. This will allow holistic management of the marine domain and productive, sustainable fisheries. a. The Oceans and Fisheries Minister might lead development of an Oceans Strategic Action Plan to provide ongoing strategic oversight for the marine domain (see Theme 2). b. The Oceans and Fisheries Minister might facilitate multi-party conversations to build a culture of trust and collaboration in the marine domain, taking a Treaty-based approach that is inclusive of all Māori and non-Māori (essential for Theme 2). c. As a first step, the Oceans and Fisheries Minister might prioritise immediate evidence-informed actions to protect the marine environment within the provisions of the Fisheries Act 1996 (see Themes 2 and 6).	• All actions relating to Theme 1 must reflect the special relationship between the Crown and Māori, particularly relating to Article 2 of the Treaty of Waitangi, the Māori Fisheries Settlement 1992, and section 5 of the Fisheries Act 1996. • The Oceans and Fisheries Under-Secretary can support co-partnership with iwi, respecting rights embodied in the Treaty of Waitangi, the Māori Fisheries Settlement 1992 and section 5 of the Fisheries Act 1996. • The Oceans and Fisheries Minister might work collaboratively with other key Ministers in the marine domain in developing an Oceans Strategic Action Plan to allow synthesis and prioritisation of varied responsibilities within a cohesive framework, including: o Minister of Māori Crown Relations: Te Arawhiti o Minister for Māori Development o Minister of Conservation o Minister for the Environment o Minister of Research, Science and Innovation. • The Oceans and Fisheries Minister might work collaboratively with other relevant Ministers, including: o Minister for Climate Change o Minister of Local Government o Minister for Land Information o Minister for Biosecurity o Minister of Transport o Minister of Foreign Affairs o Minister of Energy and Resources o Minister of Statistics o Minister of State for Trade and Export Growth o Minister of Treaty of Waitangi Negotiations o Minister for Food Safety.

THEME 2: A BOLD OCEANS STRATEGIC ACTION PLAN

Recommendations	Considerations

2. Develop a bold Oceans Strategic Action Plan for 2040 to protect and manage Aotearoa New Zealand's territorial sea and EEZ, with a clear integrative framework to prioritise, coordinate, implement and measure outcomes to achieve 100% sustainably managed oceans.
 	
The panel recognised that such a plan is beyond its Terms of Reference. The following recommendations pertain to the commercial fisheries aspects of such a plan and could be enacted ahead of a larger look at the oceans:
a. Through a Treaty-based and multi-stakeholder approach, develop an evidence-informed action plan that agrees upon the definition and role of an ecosystem approach to fisheries management in Aotearoa New Zealand and how it can be achieved within the context of the Quota Management System (QMS) and a changing climate (see Theme 6).
b. Provide a clear framework for annual reporting, decision making, future planning, and lead agency responsibility to coordinate all efforts in this space, including providing clarity around the roles of local and central government, Treaty partners and kaitiaki in fisheries and biodiversity management (see Theme 6).
c. Set an expectation that any fisheries-related plans, when created or revised, must specify how they will progress the objectives of the Oceans Strategic Action Plan and demonstrate progress against this in annual review reports (see Theme 6).
d. Include actions to support the move from volume to value in commercial fisheries through full product utilisation and a premium brand associated with Aotearoa New Zealand (see Theme 7).
e. Clearly prioritise actions across a multi-year programme, starting with those that can be achieved in the short term in an evidence-informed manner to protect the marine environment within the provisions of the Fisheries Act 1996 (see Theme 6).
	• Develop the shared Oceans Strategic Action Plan through a co-design process with iwi, respecting rights embodied in the Treaty of Waitangi, the Māori Fisheries Settlement 1992 and section 5 of the Fisheries Act 1996.
	• Review the detailed thinking in previous iterations of Oceans Policy development.
	• Consider implementing international targets, including those related to percentage coverage of coastal and marine protection, within Aotearoa New Zealand's context, particularly relating to Article 2 of the Treaty of Waitangi and the Māori Fisheries Settlement 1992.
	• Facilitate discussions between the regulator and other central government agencies, local government, iwi, industry, environmental organisations, and marine guardians to build a shared understanding of the most effective way to manage the marine domain through the Oceans Strategic Action Plan.
	• Informed by multi-stakeholder discussions, the Oceans Strategic Action Plan might:
	  ○ Operationalise increased application of an ecosystem approach to fisheries management (see Theme 6).
	  ○ Be based on a true co-partnership model and a dual framework of mātauranga Māori and western science (see Theme 3).
	  ○ Enable tangata whenua to exercise kaitiakitanga.
	  ○ Enable local knowledge and connections to be maximised (see Theme 5.h; Theme 7).
	  ○ Reflect the level of national consistency that is desirable, while acknowledging local context, including the willingness and capacity of stakeholders to undertake management actions.

	- Explicitly address tensions and conflicts in the objectives of stakeholders and regulators in the marine domain. - Explicitly address environmental decline to achieve ecosystem resilience in the marine domain (see Theme 3). - Address environmental impacts of fishing (see Theme 6.f,g). - Aim to reinvigorate Aotearoa New Zealand's global reputation for innovative and effective fisheries management. - Consider international exemplars of strong Indigenous leadership in fisheries management (see Theme 3). - Uphold and build on Aotearoa New Zealand's international obligations and commitments. - Consider how trade agreements might facilitate more sustainable commercial fisheries. - Improve consistency across the marine domain by: harmonising discrepant definitions; agreeing high-level principles; defining environmental outcomes and targets, with an environmental bottom line and clear aspirations. - Be implemented through use of all regulatory and non-regulatory levers necessary (see Themes 3, 4, 6). - Define the relationships between the different legislative requirements and strategic visions across Ministries, Departments and Agencies to provide clarity to stakeholders, including but not limited to the: - Fisheries Act 1996 - Marine Reserves Act 1971 - Resource Management Act 1991 - Wildlife Act 1953 - Marine Mammals Protection Act 1978 - Maritime Transport Act 1994 *Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020,* especially objective 12.

	o *Prosperity Sustainability Protection: Strategic Plan 2019*, Ministry for Primary Industries o Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012. o Animal Welfare Act 1999. • Work collaboratively with other ministries when developing the Oceans Strategic Action Plan, feeding into and responding to ongoing relevant work, for example: o The 2020 review of the Resource Management Act 1991. o The reform of marine protected area (MPA) legislation reform, including how it relates to Section 9 of the Fisheries Act 1996. o Recent case law (such as Motiti Protection Area decisions of 2019).

THEME 3: TE AO MĀORI | A CONNECTED WORLDVIEW IN 2040 AND BEYOND

Recommendations	Considerations
3. Building on the other Themes, acknowledge that successful application of an ecosystem approach to fisheries management must take a holistic, long-term approach that considers future generations. a. Explicitly address cumulative effects and the interconnected nature of ecosystems and mitigate other stressors on fisheries, beyond commercial fishing including: i. Land-based impacts, especially sediment from forestry and land-use changes ii. Climate change iii. Plastics iv. Disease and invasive species v. Recreational fishing vi. Aquaculture vii. Population pressure and growing population viii. Mining and the energy sector.	• Support the wellbeing of the people who fish to ensure a sustainable workforce. • Consider using existing concepts to embed te ao Māori within policy, including '*He Awa Whiria*', building on the work undertaken in developing *Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020* (Department of Conservation), and *Vision Mātauranga* (Ministry of Business, Innovation and Employment). • Develop principles for assessing and responding to cumulative effects in Aotearoa New Zealand, with flexibility for local application e.g. Hauraki Gulf Forum. • Analyse existing methods, tools and data to identify and assess cumulative effects. • Foster connections between high-tech tools and community knowledge. • Support regional plans combining land-based, coastal, marine and other impacts, to reflect the 'transboundary' nature of issues (see Theme 2). • Increase responsiveness within the Fisheries Act 1996 and related policies to climate change impacts on distribution and movement of species within and outside of the EEZ (see Theme 4). • Consider research and incentives into reducing the carbon footprint of the fishing fleet (see Theme 7). • Marine Protection Area strategy and planning could create a framework that gives consideration to stock resilience against the impacts of climate change and provide policy that is flexible enough to account for movement of species distribution due to climate change, where this is relevant (see Theme 2). • Undertake analyses to model the economic, socioeconomic and environmental benefits of changing

	to more sustainable plastic use in the fisheries sector. • Facilitate an active dialogue around rethinking plastics and other waste by setting targets and identifying opportunities to keep materials in circulation or shift to more sustainable alternatives with the fisheries sector. • Align with the Parliamentary Commissioner for the Environment's recommendation in *Managing our Estuaries* to manage estuaries as a single entity from the mountains to the sea.

THEME 4: A REFINED SET OF REGULATORY TOOLS

Recommendations	Considerations
4. Refine the regulatory framework for fisheries management to support more responsive and transparent decision making to improve fisheries and environmental outcomes. a. Improve the processes for input and engagement in fisheries management, particularly in regards to undertaking effective iwi and stakeholder engagement, public involvement, and adequate checks and balances. b. Improve transparency through increasing the accessibility of information used to inform decision making, including data collected by and for the regulator (see Theme 5). c. Enable the increased use of observational and localised community knowledge, mātauranga Māori and fishers' observations in regulatory decision making, ensuring there are appropriate processes to corroborate and validate data (see Theme 5). d. Develop a mechanism to ensure that all relevant research is incorporated into regulatory decision making (see Theme 5). e. Include a step within formal decision-making processes that ground truths quantitative modelling results against real-world observations as far as practicable. f. Support operationalisation of an ecosystem approach to fisheries management to improve environmental outcomes by utilising data from existing electronic collections and expanding data collection where practicable (see Themes 5, 6). g. Empower fishers to innovate to enable them to improve environmental outcomes (see Theme 7). h. Continue to update the process behind setting and updating the deemed value of species within the Quota Management System to make it more responsive to short-term changes in species abundance and distribution, to avoid either perverse incentives to discard catch or incentives to catch in spite of penalties. i. Develop a dashboard to present the Fisheries New Zealand Stock Assessment Plenary Annual Report and Aquatic Environment and Biodiversity Annual Review information to more clearly showcase new data and knowledge and important data and knowledge gaps. j. Support development of mechanisms to increase consumers' ability to access traceability information on fish and fish products.	• The regulatory framework could be aligned to ensure that it is fit-for-purpose to enact the Oceans Strategic Action Plan and to provide legislative backing to policy on managing the environmental impacts of fishing (see Theme 2). • Consider a 'traffic light' approach that could provide a transparent way to prioritise assessment of stocks (see Theme 7.a.iv). • Ensure Fisheries Assessment Working Groups have an inclusive culture and processes. • Improve transparency around the Fisheries Assessment Working Groups and what data is considered in their assessments to build confidence in independent scientific scrutiny. • Ensure there are adequate checks and balances on the decision-making process including provision for independent review. • Decision-making processes should not allow a paucity of data to prevent active management decisions to be made, and the decision-making process in these circumstances should be transparent. • Actively seek data and information as an integral part of the stock assessment process, including from fishers and non-Fisheries New Zealand funded scientists (see Theme 5). • Review labelling requirements for fish and fish products in relation to increasing transparency to inform consumer choice.

THEME 5: A DATA PLATFORM THAT ENABLES INFORMED COMMERCIAL AND ENVIRONMENTAL DECISION MAKING

Recommendations	Considerations
5. Cultivate a data platform that facilitates integration of data from a range of sources, compiles datasets in an accessible centralised platform, and turns them into information that can be readily applied in fisheries management and other areas of the marine domain, including state-of-the-art environmental reporting (see Theme 2). *Specific to commercial fisheries:* a. Work across government and with stakeholders to develop common data standards for the centralised data platform and reporting of ocean-related data and open data agreements. b. Aggregate existing datasets from within and outside government, determine data gaps, and provide detailed prioritisation of efforts to fill gaps for: i. Fish stocks (number of stocks and frequency of assessment) ii. Habitat, especially the seafloor iii. Biodiversity iv. Marine invasive species v. Protected marine species vi. Sedimentation vii. Ocean climate and acidification viii. Litter. c. Link and integrate relevant fisheries datasets to enable timelier, spatially explicit analysis of fisheries interactions with protected species. This will include linking and integrating fishers' electronic reporting with the protected species bycatch data from observers (data about seabird, marine mammal, shark, coral bycatch). d. Enable more timely monitoring and risk assessment of protected species bycatch by ensuring bycatch data flows into quantitative risk assessment models, so that managers can see bycatch hotspots and monitor impact on priority protected species in close to real time (see Theme 6). e. Engage with industry for the purposes of establishing an industry-wide agreement around sharing non-sensitive aggregated data with regulators, e.g. seafloor mapping (see Theme 6). Enable open and proactive use. f. Collaborate with and enable industry and others to fill data gaps where appropriate (see Theme 7). g. Increase opportunistic collection of data, e.g. through fishers, citizen science and ships of opportunity (see Theme 7.g). h. Include data, research and local knowledge gathered outside the formal government process in the centralised data platform, including from: i. Local and regional councils ii. Research institutes, universities, other formal institutes	• Align process with *Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020* objective 4.2 'National, agreed common data standards and open data agreements are ensuring that everyone has access to a federated repository of biodiversity information' (see Theme 5.a). • Align the data platform with the *Fisheries New Zealand Science and Information Data Transformation Strategy*. • Coordinate development of the data platform with Stats NZ *Data Investment Plan*. • Current ocean monitoring efforts in Aotearoa New Zealand could be built on to establish an ocean observing system (see Theme 6). • Identify lead ministries for maintaining and updating specific ocean-related databases at a national level, integrated within an ocean observing system (see Theme 6). • Transition towards an increased number of stocks being reviewed annually (see Theme 4 and Theme 5.b.i). • Consider privacy concerns; future-proofing for emerging technologies (see Theme 7); initial investment cost; the need for back-end data support; transition; funding models; the sensitivity of data on taonga species. • Consideration of data issues can build on work already undertaken by the regulator, e.g. the matrix developed at the Ministry for Primary Industries. • Consider how research data that is publicly funded (including that held by research institutes, universities and other formal institutes) may be better stored and accessed (see Theme 5.e).

iii. Iwi and community groups iv. Citizen science v. Video vi. Emerging technologies e.g. environmental DNA (eDNA). i. Incorporate key trends from local government reporting within annual reporting (such as the Fisheries New Zealand Stock Assessment Plenary annual report and Aquatic Environment and Biodiversity Annual Review).	

THEME 6: AN ECOSYSTEM APPROACH TO FISHERIES MANAGEMENT (EAFM) IS EMBRACED WITHIN THE CURRENT REGULATORY FRAMEWORK, INCLUDING THE FISHERIES ACT 1996

Recommendations	Considerations
6. Within the current regulatory framework, transition Aotearoa New Zealand's fisheries management system to an ecosystem approach through supporting and resourcing the expansion and uptake of wider ecosystem monitoring and driving a shift towards more ecosystem-friendly fishing methods. In the longer term, the Oceans Strategic Action Plan should facilitate and define a shared understanding of what an ecosystem approach to fisheries might encompass and what this approach aims to achieve within the context of Aotearoa New Zealand's fisheries management (see Theme 2). **In the shorter term:** a. Create a framework for prioritisation and protection of Habitats of Particular Significance for Fisheries Management (see 9(c) of Fisheries Act 1996) and review barriers to usage. Produce guidance documentation for the definition and identification of Habitats of Particular Significance for Fisheries Management (see 9(c) of Fisheries Act 1996) and required evidence base. b. Support research that advances application of an ecosystem approach to fisheries management, such as how species, including bycatch, interact to form a functional ecosystem (see Theme 7). c. Develop a set of national marine ecosystem indicators and establish long-term monitoring (including habitat, bycatch and taonga species) to better inform implementation of an ecosystem approach to fisheries management with clear goals. d. Secure funding and commitment for the long-term monitoring to be established and maintained. e. Review best practice international approaches to national marine ecosystem indicators and incorporate relevant learnings into the Aotearoa New Zealand context. f. Define and implement an effective ecosystem protection regime in fisheries management. g. Support the development of alternative fishing methods (see Theme 7). h. In partnership with iwi, industry and environmental NGOs, develop approaches and incentivise innovation to minimise or eliminate adverse effects of fishing gear (e.g. full contact bottom trawling and dredging) on benthic habitats. E.g. further restrict the areas trawled, switch to less damaging gear when available, focus on developing new technology where less damaging gear is not currently available (see Theme 7). i. Review and prioritise restoration approaches for damaged habitats (see Theme 3 and Theme 7.a.iii).	• Investigate which species are suitable as indicators for ecological monitoring, referring to work previously undertaken, e.g. in Aotearoa New Zealand deepwater fisheries (see Theme 6.c). • Align work on an ecosystem approach to fisheries management with: o *Te Mana o Te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020*, especially objective 12. o The Parliamentary Commissioner for the Environment's report focusing on Aotearoa New Zealand's Environmental Reporting system, including recommendation 1(h). • Consider the range of tools available for protecting the ecosystem, including those that focus on species, habitat, flexible spatial and temporal management, as well as consideration of the use of buffer zones around no-take protection areas. • Fund gear innovation research designed to reduce impact on the benthic habitat (see Theme 7). • Ensure just transitions in any regulatory changes to preferred fishing methods. • Review the use of full contact bottom trawling and dredging methods for fisheries and ecosystem monitoring research; explore how other research methods could be used (e.g. estimating fish biomass with eDNA surveys) and how environmental impact of monitoring can be reduced. • Consider new approaches to the use of minimum and maximum legal sizes for species where research supports that this approach is beneficial to support sustainability (see Theme 7).

THEME 7: RESEARCH AND INNOVATION ARE MAXIMISED

Recommendations	Considerations
7. Take a more holistic and strategic approach to research and innovation in the marine domain to enable innovation to thrive and support more sustainable fishing (see Theme 3). a. Undertake a comprehensive review of fisheries research funding and establish a funding and research strategic action plan, including: i. Clear prioritisation of research questions to be answered, and technology to be explored, to inform and be informed by the Oceans Strategic Action Plan (see Theme 2). ii. Clarity on the role of industry levy funding and government funding. iii. Resource and incentivise the development and use of fishing methods that are more selective and reduce adverse impacts on the marine environment, particularly on benthic habitat and marine protected species (see Theme 6.i). iv. Investment in methods that improve the efficiency of assessment of fish stocks. v. Prioritisation of real-time risk management (e.g. avoiding protected species), increasing value through innovations in processing and by-product development, and innovations that support more cost-effective data collection at a lower fisher burden. vi. Support for research to fill key data gaps, particularly the basic biology of commercial fish species. b. Review the pathway to testing new fishing methods to reduce the barriers to enable innovation in trawl technology and other fishing methods. c. Invest in and incentivise innovation in environmental protection, prioritising research that enables bottom trawls to fish lighter (see Theme 6.i). d. Develop clear pathways and remove barriers for fishers to be involved in research and innovation, including support with applying for funding. e. Fast track the special permit processes to enable innovative new methods to be trialled, with key requirements to gather data and evidence of effectiveness of new methods (see Theme 5). f. Create and support a researcher/industry collaborative platform for accelerating innovation and its implementation, as well as innovation from existing companies. g. Support citizen science projects in the marine domain and guide data collection efforts to meet the Tier 1 standard so that data can feed into government reporting and decision making (see Theme 5). h. Support development of tertiary training focused on fisheries management science.	• Consider continuing or reinstating 50% partnership funding for fisheries research and development through a fisheries-specific fund. • Consider funding support of industry transition to new technologies to encourage innovation. • Align strategic funding plan with commentary in the Parliamentary Commissioner for the Environment's *A review of the funding and prioritisation of environmental research in New Zealand.* • Continue Fisheries New Zealand review of enabling innovation in trawl technology (EITT) and the barriers to innovation and implement changes (see Theme 7.b). • Continue work on Fisheries New Zealand real-time risk management initiative with the goal of producing a fisher-friendly app (see Theme 4). • Consider mechanisms of sharing good practice while maintaining IP rights. • Support researchers to be partners in technological development not just providers. • Support climate change research that can inform fisheries management (see Theme 3). • Consider annual innovation showcase and awards to further encourage research and innovation.

1.6 AIM OF THIS REPORT

By drawing on local and international research and experience, and highlighting best practice examples, we aim to inspire innovative thinking and changes in fisheries management in 2040 and beyond.

The report aims to identify ways we can fill knowledge gaps, increase our understanding of the marine environment, and ultimately take a more holistic approach to fisheries management. The evidence base for this report includes scientific and peer-reviewed literature, government, research, and technical reports, working papers, and personal communications. The report does not attempt to cost solutions nor to prioritise them at a detailed level.

1.7 OUT OF SCOPE

As outlined in our Terms of Reference (section 1.2), the report does not review or make recommendations on the areas outlined below. However, the report signposts how these factors impact and interact with the in-scope aspects of the project. Linkages and overlaps between in- and out-of-scope factors will be highlighted. We acknowledge that we are looking at only one part of a complex system, which limits the impact of the recommendations if carried out in isolation.

We acknowledge that we are looking at only one part of a complex system, which limits the impact of the recommendations if carried out in isolation.

While there are a select number of freshwater species that are managed under the fisheries management system, we have focused on the marine environment.

QUOTA OWNERSHIP AND CROWN OBLIGATIONS

This project does not make recommendations on distribution, controls of ownership of New Zealand quota, preferential allocation rights, aggregation limits or other factors of quota ownership and Crown obligations.

AQUACULTURE

Aquaculture and wild fisheries are complementary sectors, each with different solutions for sustainable and ethical seafood production. New technologies and approaches in aquaculture, like the move towards open-ocean farming, may become more important in the future (New Zealand Government, 2019a). While these linkages are touched on, they are not a focus of the project.

RECREATIONAL FISHING INCLUDING CATCH REPORTING

Recreational fishing is a popular activity in Aotearoa New Zealand with an estimated 700,000 people going fishing in a given year. An estimated 7 million individual finfish and 3.9 million individuals of other marine species were caught by recreational fishers in 2017-2018 (Wynne-Jones *et al.*, 2019). Recreational fishing is significant economically, with one report estimating that recreational fishers spend approximately $1 billion a year (Southwick *et al.*, 2018). The New Zealand Marine Research Foundation estimates that 6% of all landed catch is taken by recreational fishers (New Zealand Marine Research Foundation, 2016). However, the recreational take is more significant for certain species, such as snapper/tāmure[7], the largest recreational fishery, with recreational fishers responsible for over 40% of total catch across Aotearoa New Zealand (OpenSeas, 2017). In some areas, the recreational catch exceeds the commercial catch – for example, in Tīkapa Moana the Hauraki

[7] *Pargus auratus.* Note the taxonomic status of this species is being debated, and it may also be referred to as *Chrysophrys auratus.*

Gulf, recreational catches of snapper, kahawai[8] and kingfish/haku[9] exceed commercial takes (Hauraki Gulf Forum, 2020).

Recreational fishing is restricted by rules (such as daily catch limits and size limits) depending on area and species (Ministry for Primary Industries, 2020b). In Aotearoa New Zealand, recreational fishing includes both amateur fishers and charter fishing vessels. While the per person catch limits apply to each passenger on a charter vessel, the number of passengers can be such that the vessel's take could exceed the catch of a smaller commercial vessel (as has been anecdotally reported). While recreational fishing is a contributor to overall catch volumes, it is not a focus of this project. We note that improving our estimates of recreational catch and incidental fishing mortality will be essential for enhancing the sustainability of our fisheries, as well as confronting the challenge of shared fisheries.

CUSTOMARY FISHING (NON-COMMERCIAL)

Customary fisheries are a right of tangata whenua. They include traditional and customary practices and customary non-commercial food gathering. Customary fishing takes place in rohe moana (defined customary fishing areas). Customary fishing rights are guaranteed under the Treaty of Waitangi – and protected by the Treaty of Waitangi (Fisheries Claims) Settlement Act 1992 and 1992 Deed of Settlement.

Customary fisheries are significant although volumes of catch are not readily available. Over 200 kaitiaki have been appointed by tangata whenua to manage customary food gathering, and there are over 40 mātaitai reserves and 10 taiāpure (where tangata whenua can undertake management of fisheries resources). As with recreational fishing, customary fishing is another fisheries activity that sits outside the QMS and commercial fisheries. While recommendations in relation to customary fishing are out of scope, customary practices and knowledge are discussed.

[8] *Arripis trutta*. The Kermadec species *Arripis xylabion* is found seasonally in Northland waters.
[9] *Seriola lalandi lalandi.*

1.8 SOME KEY TECHNICAL TERMS AND HOW WE USE THEM

A report of this breadth is necessarily cross-disciplinary, incorporating input from a wide variety of people with different expertise, who may use terms in very specific (and sometimes rather different) ways. Here we lay out definitions of some key terms and how we use them in this report. A full glossary of technical terms and abbreviations with definitions can be found in section 7.2. Approximate translations of all Māori words and phrases are provided in section 7.1.

This report is about **commercial fishing**: taking fish, aquatic life or seaweed in circumstances where a fishing permit is required as per section 89 of the Fisheries Act 1996. We use the term 'commercial fisheries' to refer to wild-caught marine life that is harvested to sell. We did not include seaweed in this report.

In this report, **sustainability** or **sustainable use** usually refers to sustainability as defined in the Fisheries Act 1996 – that is, (a) maintaining the potential of fisheries resources to meet the reasonably foreseeable needs of future generations, and (b) avoiding, remedying or mitigating any adverse effects of fishing on the aquatic environment. Sometimes, we use a narrower definition referring to the long-term maintenance of a single fish stock without considering the wider ecosystem impacts. At other times, we use a broader meaning of sustainability that encompasses ecological and social factors, including but not limited to biodiversity (genetic, species and ecosystem diversity), environmental and ecosystem impacts.

In this report, a **stock** or **fish stock** usually describes a management unit of a species as defined by Fisheries New Zealand (FNZ). A stock may be a discrete biological population, with little to no reproductive mixing with other stocks of the same species. In other cases, there may be migration or mixing between stocks.

Biodiversity refers to the variety of life. It pertains to the variety of *different* species present, the variability of ecosystems themselves, and diversity *within* species. Biodiversity is a critical part of ecosystem and planetary health but not the major focus of this report.

An **ecosystem approach to fisheries management** (EAFM) and **ecosystem-based fisheries management** (EBFM) are different terms used widely in the literature. Both involve moving beyond single-species measures to incorporate wider ecosystem effects into management. We generally use EAFM, unless referring to specific literature which uses EBFM. They differ from **ecosystem-based management** (EBM) which refers to management of the ocean more broadly – not just fisheries.

Threatened species are those assessed according to the New Zealand Threat Classification System as facing imminent extinction because of their small total population size and/or rapid rate of population decline. This includes three sub-categories: 'Nationally Critical', 'Nationally Endangered' and 'Nationally Vulnerable'. **Protected species** are defined under the Wildlife Act 1953. In the marine environment, all marine mammals, seabirds (except black-backed gulls), all sea turtles, some corals and some fish are protected species. A species may be protected but not threatened, or it may be both protected and threatened.

People from different disciplines use the term marine protected area (MPA) as an umbrella term for spatial areas in the marine environment where restrictions exist in order to conserve nature or maintain biodiversity values. There are a range of legal tools that offer differing levels of protection in the marine environment. Protected areas in the marine environment include marine reserves (as defined in the Marine Reserves Act 1971), benthic protection areas (BPAs), mātaitai and taiāpure reserves, and others. Different marine protection tools are discussed in detail in section 4.2. The term MPA is often conflated with 'marine reserve' in everyday use, but is uses a wider definition in this report.

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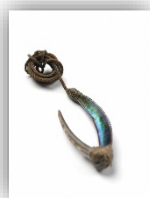

Part 2: Context

We briefly introduce the historical and current state-of-play for commercial fishing and ocean research, highlight key work that we build upon, outline motivations for improving the sustainability of the commercial fishing industry, and describe the guiding frameworks and exemplars for this project.

Part 3: Challenges for the marine environment

To provide context for the stressed environment in which fishing takes place, we describe the range of non-fishing stressors acting on the marine environment, including climate change, land-based impacts, diseases and invasive species, plastic pollution, and their cumulative effects. We then provide an evidence synthesis on how commercial fishing challenges the marine environment, focusing on the ecosystem.

Part 4: The regulatory space is complex

In this part of the report, we outline the complexity of the regulations in the marine domain and demonstrate the resulting challenges at local, national, and international levels.

Part 5: Commercial Fisheries in 2020

We provide a brief overview of the key tools used for fisheries management in Aotearoa New Zealand, synthesise the evidence on the state of our commercially fished stocks, highlighting data and information gaps as well as contested information, and describe various initiatives underway in the sector.

Part 6: A future focus: Science, technology and innovation

We take a future focus and introduce innovative ideas and scientific solutions to address sustainability issues in the commercial fishing sector, concluding with a vision for fishing in 2040 to inspire action.

PART 2: CONTEXT

Pā kahawai (trolling lure), Aotearoa New Zealand 1750-1850. Oldman Collection, gift of the New Zealand Government 1992. © Museum of New Zealand Te Papa Tongarewa.

2.1 A BRIEF HISTORY OF FISHING IN AOTEAROA NEW ZEALAND

Fishing has always been an integral part of our island nation's identity. Our fishing history dates back to when Māori arrived in their waka, equipped with advanced fishing methods and knowledge of te moana. Over centuries, Māori extended this deep knowledge to local fishing grounds and their taonga species (Wehi *et al.*, 2013; Ministry for the Environment and Stats NZ, 2019b). As kaitiaki, Māori managed Aotearoa New Zealand's fisheries under the authority of a rangatira, who was responsible for the sustainability of these resources (Bess, 2001; Matthews, 2018). The importance of kaimoana to Māori is reflected in the names of people and places, as well as in oral history and legends (Paulin, 2007).

Our fishing history dates back to when Māori arrived in their waka, equipped with advanced fishing methods and knowledge of te moana.

The arrival of Europeans added scale to fishing pursuits, along with new methods and technologies. By the early 1980s, the way we fished had transformed (McClintock *et al.*, 2000). Fishing was generally limited through licences (e.g. number of vessels), other controls such as gear restrictions, and some limits on access to particular species in particular areas (Cullen and Memon, 1990). New fisheries were developed in deeper waters, and our focus shifted to exports. Inshore fish stocks were depleted and the sustainability of fishing practices and management (or lack thereof) came to the fore.[10]

Enter Aotearoa New Zealand's QMS, introduced in 1986 for an initial 26 species. An innovative initiative at the time (Mace *et al.*, 2014), the QMS created perpetual and tradeable private rights in the commercial fish harvest (individual transferrable quota (ITQ)) and aimed to provide for utilisation of the fisheries resource while ensuring sustainability, as well as improving the economics of the industry. Under the QMS, the regulator (now Fisheries New Zealand (FNZ)) sets a total allowable catch (TAC), makes allowances for the customary and recreational sectors, and allocates a catch allowance to the commercial sector (allocated among quota owners through the mechanism of ITQ). In the years following the introduction of the QMS, some stocks increased (Hughey, 1997) although some others declined, but overall, the QMS was acknowledged to be a big step forward as stocks were generally maintained, and the system was recognised and imitated internationally (McKoy, 2006; Lock and Leslie, 2007). The introduction of the Fisheries Act in 1996 occurred as a part of wider resource management law reform and further defined the use of sustainability in fisheries management.

Meanwhile, Māori fishing rights (both commercial and customary) had been severely eroded since 1840. The Treaty of Waitangi recognises the rights of Māori to their natural and cultural resources, including fisheries. But these rights were not realised until the Māori fisheries settlement was implemented under the Māori Fisheries Act 1989 and the Treaty of Waitangi (Fisheries Claims) Settlement Act 1992. The settlement acknowledged the forced accommodation between the Treaty and the QMS by mutual consent between Māori and the Crown.

Since the settlement, the Māori seafood sector has experienced significant growth (Reid *et al.*, 2019). Iwi and Māori businesses comprise a significant proportion of the commercial fisheries and aquaculture sector, owning 27% of quota (Inns, 2013; Tuuta and Tuuta, 2018).

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[10] This brief history does not attempt to catalogue the range of management options that have been tried over the preceding decades (see for example, 'The historical development of fisheries in New Zealand with respect to sustainable development principles' (Gibbs, 2008)).

2.2 FISHING TODAY IN AOTEAROA NEW ZEALAND

Today, our marine economy is estimated to directly contribute $3.8 billion to the economy, with fisheries and aquaculture contributing around $1 billion of that figure (Ministry for the Environment and Stats NZ, 2019b). Seafood is in demand both here in Aotearoa New Zealand and overseas, and this demand is expected to grow (Thurstan and Roberts, 2014).

Unlike most food production, fisheries involve harvesting in the wild. Seafood, as with other food production, comes with an environmental cost. To grow the fishing industry within a managed quota of developed fisheries, it should be in everyone's interest to improve the quality, value and sustainability of fish caught – while still enabling an affordable domestic market. An increasingly eco-conscious global market – especially at the premium end – is yet another driver to fish sustainably.

It should be in everyone's interest to improve the quality, value and sustainability of fish caught.

Our fisheries management is led by government agency Fisheries New Zealand, part of the Ministry for Primary Industries (MPI). We continue to use the QMS within the Fisheries Act 1996 as part of a fisheries management programme that draws on an increasingly broad evidence base to inform management. A significant amount of the fisheries research and data collection undertaken is cost recovered from quota owners.

A report in 2017 by The Nature Conservancy found that Aotearoa New Zealand's QMS has consistently ranked well against a range of indicators (The Nature Conservancy, 2017). However, the report noted that we do not routinely report on the ecosystem impacts of fishing, and there are many stocks we know little about.

We continue to learn about the health of our marine environment, the ecosystems within it, and the impacts of commercial fishing. This growing body of knowledge could be a driving force for adapting the way we manage fisheries to ensure their sustainability. But in practice, capturing this information can be expensive and challenging. It is thus a body of knowledge that remains incomplete, meaning many decisions are inevitably made without a comprehensive evidence base, or decisions are not made at all. Combined with the many diverse and strongly held views, this creates an environment in which fisheries management approaches are highly contested, both globally and in Aotearoa New Zealand (Bess and Rallapudi, 2007; Pomeroy *et al.*, 2007; Winder and Rees, 2010; Peart, 2018; Said *et al.*, 2018; Grip and Blomqvist, 2020).

As well as the range of stakeholders within the commercial fishing industry, many others have an interest in the health of our shared marine environment. This includes the recreational and customary fishers, the general public, researchers, government representatives, tourism operators, those interested in mining the seabed, environmental groups, iwi, community groups and future generations (see figure 1).

Tensions between commercial and environmental priorities often surface, but new multi-stakeholder approaches show that, with a shared vision and goal, people can come together to address complex issues in our marine environment. Currently, these are relatively few and covering small areas, but they provide inspiration for a way forward.

There is a significant opportunity for innovative technology, new scientific approaches, and more extensive data collection and use, to better inform our fisheries management as we strive for more sustainable practices. This report examines these in detail.

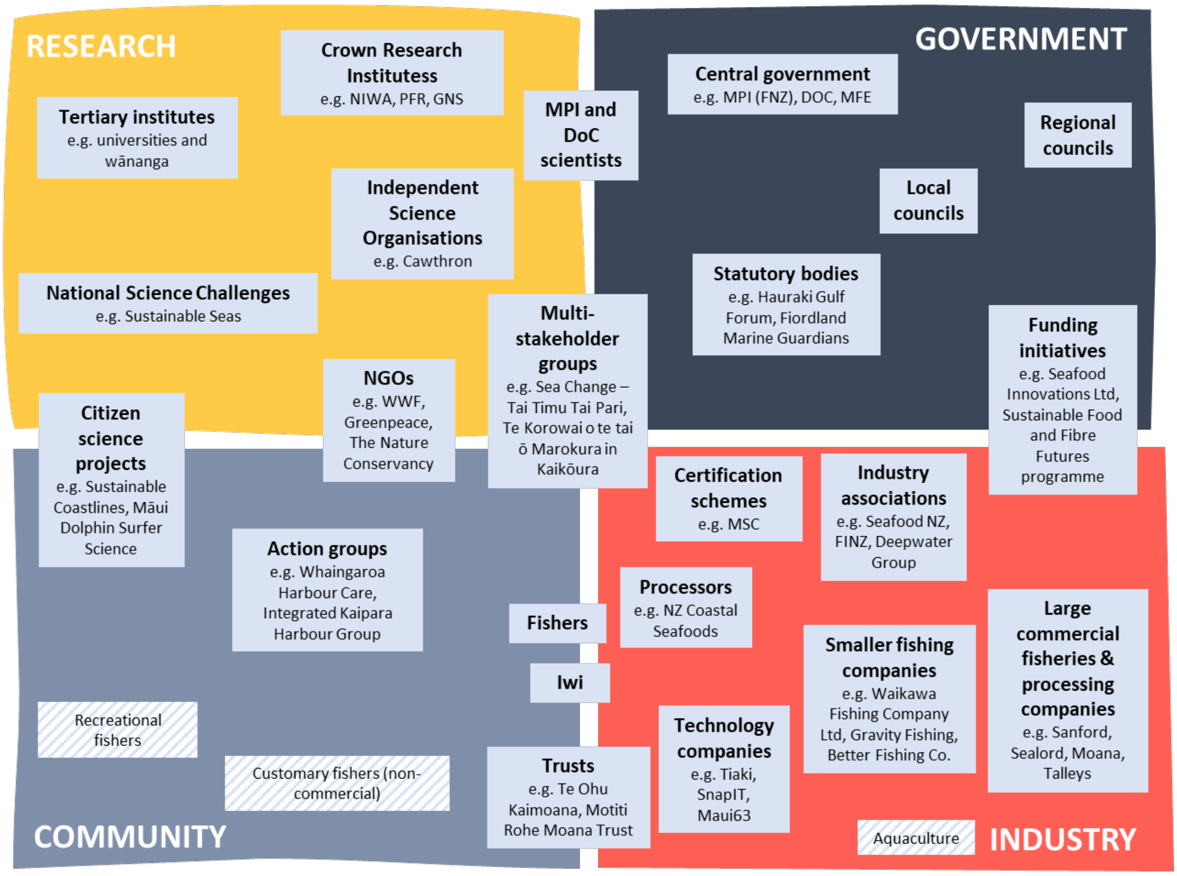

Figure 1: Some of the many stakeholders with interests in Aotearoa New Zealand fisheries.

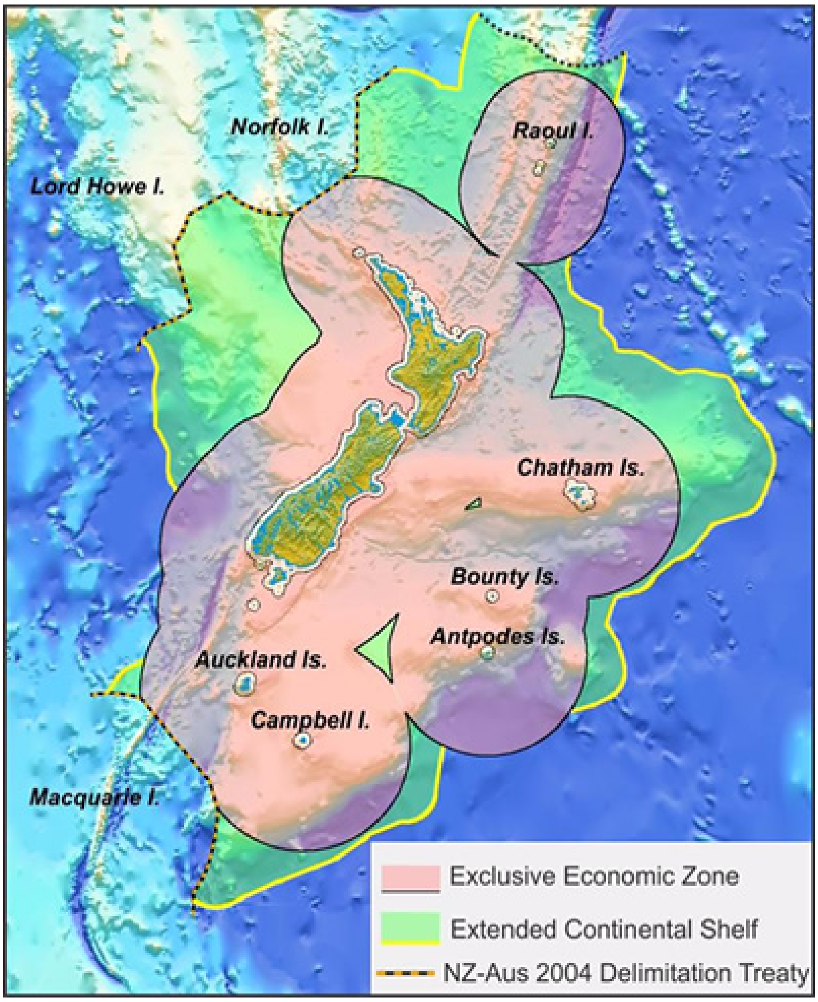

Figure 2: Map showing Aotearoa New Zealand's exclusive economic zone (EEZ). Image credit: GNS Science.

Aotearoa New Zealand's exclusive economic zone (EEZ) – one of the largest in the world, at around four million square kilometres – is generally mapped in far less detail compared to our land environment. Our EEZ is many times the size of our land mass, and its greatest depths stretch much further than our highest mountains. Marine environments are vast in scale and the remote, deep and challenging locations pose practical obstacles. Studying our oceans is expensive: research can require costly equipment used in difficult environments – like deep seafaring vessels, imaging equipment, and underwater vehicles. Processing the resulting data can also be costly and time-consuming, particularly where we continue to rely on manual processing.

Tens of millions of dollars is dedicated to ocean research efforts every year, but this barely scratches the surface. There is a diverse array of scientific researchers: from government departments, Crown Research Institutes (CRIs), tertiary and other research institutes, local and regional councils, NGOs, community groups, and those in the fishing industry. They all contribute to collecting, researching and analysing data in our marine environment and fisheries. Data collection is undertaken for many different reasons, whether these are related to environmental and sustainability outcomes or to economic and commercial ones. Our most extensive data collection efforts have a strong focus on compliance, which presents an opportunity to expand the use of this data for environmental and commercial purposes.

Tens of millions of dollars is dedicated to ocean research efforts every year, but this barely scratches the surface.

Choosing how we focus our data collection and research efforts is critically important. We need to have the right knowledge to progress towards a more sustainable fishing future and to measure whether we are moving in the right direction – while accepting that decisions need to be made in the absence of complete information.

2.4 RECENT RELEVANT GOVERNMENT REPORTS

This report arises from a need to renew our efforts to be at the forefront of sustainable fishing. We note there are others working to address the challenges faced by fisheries and the broader marine environment. These reports have highlighted our gaps in understanding around marine ecosystems and environmental monitoring.

2.4.1 OUR MARINE ENVIRONMENT 2019 FROM THE MINISTRY FOR THE ENVIRONMENT AND STATS NZ

"Stock assessments apply to individual fish stocks so they do not account for interactions between different stocks or interactions with the broader marine environment."
- *Our Marine Environment 2019*, Ministry for the Environment and Stats NZ.

Although fisheries decisions can consider direct environmental interactions, e.g. with associated or dependent species, biodiversity or habitats of particular significance to fisheries (if information is available), this is often not the case.

2.4.2 FOCUSING AOTEAROA NEW ZEALAND'S ENVIRONMENTAL REPORTING SYSTEM BY THE PARLIAMENTARY COMMISSIONER FOR THE ENVIRONMENT (PCE)

"Current fisheries management systems have a single-species focus and rarely take into account the effects of fishing on the wider ecosystem. For example, ecosystem changes due to fishing and climate change are rarely explicitly included in the single-species fisheries management carried out in New Zealand."
- *Focusing Aotearoa New Zealand's environmental reporting system*, Parliamentary Commissioner for the Environment.

While a focus on assessment of individual stocks does not necessarily mean that wider ecosystem effects are not being taken into account (e.g. through other sections of the Fisheries Act 1996), it similarly does not provide assurance that they are. There is very little explicit, relevant and useable information about ecosystem changes available to fisheries managers beyond what is monitored by fisheries stock assessments.

2.4.3 *TE MANA O TE TAIAO – AOTEAROA NEW BIODIVERSITY STRATEGY 2020* BY THE DEPARTMENT OF CONSERVATION

The Department of Conservation also recently published *Te Mana o te Taiao – Aotearoa New Biodiversity Strategy 2020*. The document provides a strategic direction for the protection, restoration and sustainable use of biodiversity, particularly Indigenous biodiversity, in Aotearoa New Zealand. The strategy and planned approach to implementation are highly relevant to management of our fisheries and marine environment.

> "Papatūānuku (Earth mother), Ranginui (sky father) and their offspring are in serious trouble, and we urgently need to do a better job of looking after them. The state of nature is a legacy that we leave for future generations."
> - Te Mana o te Taiao 2020, Department of Conservation.

2.4.4 FISHERIES CHANGE PROGRAMME BY FISHERIES NEW ZEALAND

A regulatory work programme called the Fisheries Change Programme is underway by Fisheries New Zealand to enhance and update the fisheries management system, in response to a review by Fisheries New Zealand in 2015. The successful implementation of electronic reporting across the commercial fishing sector produces far more information than its paper-based predecessor. The opportunity, or challenge, is how to make fullest use of this data in the timeliest way possible. This opportunity provides a potentially greatly expanded role for scientific input into fisheries management. Allocative choices should be specific about the basis for decision making, whether this is based on scientific evidence or on other considerations.

Our report seeks to build on this recent work and provide an evidence base to support policy objectives from the Fisheries Change Programme and other workstreams, as well as suggesting wider recommendations for consideration, prioritisation and implementation as appropriate.

2.5 WHY FISHERIES ARE IMPORTANT

Aotearoa New Zealand benefits from its commercial fishing industry for a number of reasons – it upholds Treaty obligations, contributes to the economy and provides thousands of jobs, while supplying food for people here and overseas. However, these benefits from the industry will only be maintained if our fishing practices are environmentally, economically and socially sustainable. There are many stresses on the marine environment including those from commercial fishing practices (see part 3). As examined in more detail in part 5, quota owners have a share in perpetual harvest rights for QMS stocks and have an interest in ensuring the integrity of commercial harvest rights and the management system that supports them. While quota owners are incentivised under the QMS to ensure sustainability, this does not always eventuate in practice.

There are also challenges with workforce sustainability and wellbeing, and some deepwater operators are reliant on imported workers (as are many primary industry sectors) (O'Connell, 2020). The industry faces challenges as society's expectations change with regard to how food is harvested, how animals are treated and how environmental footprints are reported, monitored, and managed[11] (Ponte, 2012; Jaffry *et al.*, 2016; Ministry for Primary Industries, 2019a; Campbell-Arvai, 2015; Kaiser, 2019; Alonso *et al.*, 2020).

There are many stresses on the marine environment including those from commercial fishing practices.

We can draw on a wide range of evidence to better understand these issues and how to address them, with a focus on applying innovative new ideas to embed sustainability in our fisheries management system and fishing practices, while upholding Māori commercial fishing rights.

These issues are discussed through the following subsections:

- Māori have an enduring right to fish
- Commercial fisheries contribute to the economy
- Fish is an important part of our diet
- The wellbeing of our fishers matters
- Society's expectations are changing
- We can build on the QMS to improve sustainability

Figure 3: Juliet met workers on the filleting line at Talley's in Motueka.

2.5.1 MĀORI HAVE AN ENDURING RIGHT TO FISH

The introduction of the QMS in 1986 with the Fisheries Amendment Act was not fully inclusive of Māori. It triggered a protracted legal process in which a forced accommodation of the QMS within the Treaty was eventually agreed by mutual consent of both partners. Thus our fisheries system has Māori Treaty rights fundamentally built into it, resting on the Treaty of Waitangi and embodied in the Fisheries Settlement 1992. Some see the inviolate position of the fisheries settlement as impeding strategic thinking for future Māori participation. Others are more open to evolving the way we fish, so long as this is done in full partnership with iwi, by mutual consent. An overview of some of this history is provided below but more detailed information can be found elsewhere (for example, (Boast, 1999; Johnson and Haworth, 2004; Toki, 2010; De Alessi, 2012; Wheen and Hayward, 2012; Bargh, 2016; Te Ohu Kaimoana, 2020a, 2020b)).

The Fisheries Settlement 1992 is seen as having restored Māori commercial fishing rights. Prior to the settlement, the rights had been widely accepted, but never defined in law. In 1987, court action and the ensuing passing of the Māori Fisheries Act 1989 provided an interim settlement whereby 10% of quota species in the QMS at the time were to be bought back by the Crown and transferred to Māori over three years. The Fisheries

[11] See Sanford sustainable development reporting case study.

Settlement 1992 subsequently provided Māori with funds to buy a 50% share of Sealord, including a large share of quota. Government also promised that 20% of any future quota would be allocated to Māori. This reconfigured the economic landscape of Aotearoa New Zealand's fishing industry. Māori established commercial enterprises, such as Aotearoa Fisheries Limited (trading as Moana New Zealand), which is the sole or joint shareholder of several Aotearoa New Zealand commercial fishing companies. A trust, Te Ohu Kaimoana, was established to advance and advocate for Māori fisheries. Te Ohu Kaimoana and various iwi charitable organisations deliver economic and social benefits to some Māori. In 2011 the Marine and Coastal Area (Takutai Moana) Act 2011 was enacted, which provides for the special status of the common marine and coastal area as an area that is incapable of ownership.

The 1992 Fisheries Settlement is seen as having restored Māori commercial fishing rights. Prior to the settlement the rights had been widely accepted, but never defined in law.

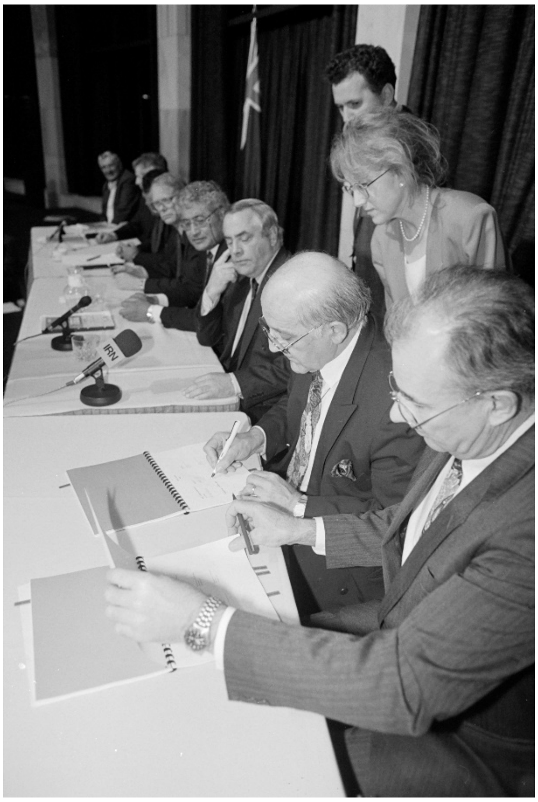

Figure 4: The signing of the Māori Fisheries Settlement 1992. From right: Sir Don McKinnon, Tā Tipene O'Regan, Sir Douglas Graham and others involved in negotiations. Image credit: Michael Smith, Dominion Post Collection, National Library of New Zealand Te Puna Mātauranga o Aotearoa, Alexander Turnbull Library, Wellington.

As part of the Settlement, Māori endorsed the QMS. The Settlement also restored customary fishing rights, ensured Māori would be appointed to statutory fishing bodies, and agreed to regulate Māori self-management of fishing for communal subsistence and cultural purposes.[12]

However, there are ongoing issues – for example, around the resolution of historic quota management issues, which are known colloquially as '28N rights'[13] (Seafood New Zealand, 2019; Te Ohu Kaimoana, 2020b). '28N rights' give holders preferential rights where there are increases in total allowable commercial catch (TACC), which can result in those without these rights (including iwi) having their share of TACC proportionately decreased (Te Ohu Kaimoana, 2019a). These unresolved issues continue to hinder current fisheries management.[14]

As per the Treaty, Māori have perpetual rights to fish and to exert rangatiratanga over their fisheries – maintaining the sustainability of fisheries and their surrounding environment. Sustainability of the fisheries resource is a pillar of these agreements and, to uphold the fundamental rights of Māori, there needs to be a sustainable resource for future generations to fish. Maintaining environmental and ecosystem health in our oceans to meet these obligations is paramount. These rights also mean that the way we achieve sustainable fisheries must uphold the terms of the Fisheries Settlement 1992, unless this is changed by mutual consent of Māori and the Crown. Commentators have highlighted the tensions inherent between kaitiakitanga principles

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[12] See Settlement History at Te Ohu Kaimoana.
[13] A now repealed section of the Fisheries Act 1983 on "Reduction of provisional maximum individual transferable quotas". It has been carried through as Section 23 "Effect of increase in total allowable commercial catch".
[14] For example, a 2020 review of sustainability measures.

and commercial rights. Dame Anne Salmond comments, “Once again, modernist ideas of ‘property’ and profit have entangled in complex ways with mana and ancestral tikanga relating to the ocean” (Salmond, 2017).

Changes made to fisheries management, including those that shift the focus further towards EAFM, should be made in partnership with Māori. Indeed, they are often in harmony with traditional approaches (see section 2.7.1: Te ao Māori). A current concern expressed by Te Ohu Kaimoana is that an increasing number of areas are being closed to commercial fishing in the government’s pursuit of a more ecosystem-based fisheries management approach (Te Ohu Kaimoana, 2020a). The importance of a partnership approach to these changes cannot be overstated if we are to facilitate the continuation and strengthening of an effective, legally sound, and authentic co-management approach to improving the sustainability and strengthening the resilience of our fisheries.

> Changes made to fisheries management, including those that shift the focus further towards an ecosystem approach to fisheries management (EAFM), should be made in partnership with Māori.

2.5.2 COMMERCIAL FISHERIES CONTRIBUTE TO THE ECONOMY

The marine economy, including commercial fisheries, is a big contributor to Aotearoa New Zealand’s economy. For the 2016-2017 year, the marine economy was estimated to contribute $3.8 billion directly to the economy, as well as an additional $3.2 billon indirectly (Ministry for the Environment and Stats NZ, 2019b). Fisheries and aquaculture are estimated to contribute almost a third of this figure. A report prepared for the industry concluded that wild-caught commercial fisheries had a direct economic contribution of $550 million in 2015 (Williams *et al.*, 2017).

Fisheries contribution to the economy is particularly significant for dispersed regional parts of Aotearoa New Zealand that may otherwise have limited economic opportunities.

> Fisheries contribution to the economy is particularly significant for dispersed regional parts of Aotearoa New Zealand.

To grow business, companies need to improve the quality and sustainability of the catch and derive higher value from fish products. There is incentive to innovate, but this is often offset by a complex regulatory environment that sometimes provides perverse incentives for unhelpful practices (see part 4). A regulatory imperative and/or direct financial gain may drive necessary changes to reduce impact.

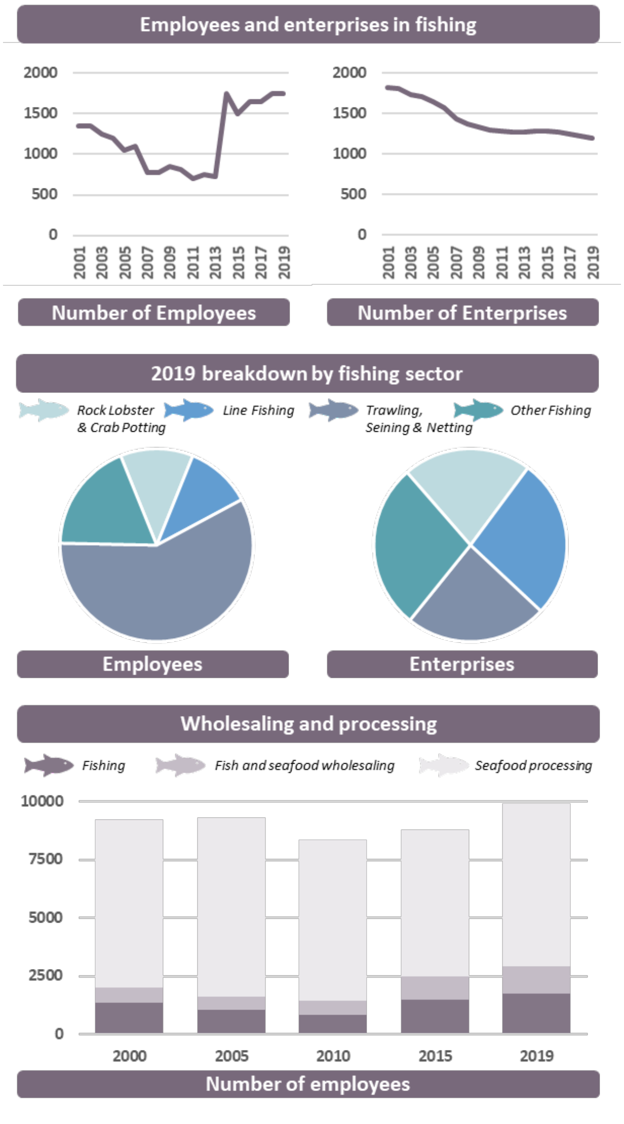

Figure 5: Counts of enterprises and employees in fishing sector (data from Stats NZ).

In 2019, the number of businesses in the fishing industry was evenly distributed between four groupings: rock lobster and crab potting; line fishing; trawling, seining and netting; and other fishing.[15] However, by employee count, trawling, seining and netting accounted for over half of employment.

The fishing sector creates more jobs in both processing and wholesaling. In 2019, seafood processing accounted for 7,000 employees, while fishing accounted for 1,750, and fish and seafood wholesaling accounted for 1,150. There are also jobs created in shipbuilding and repair services. Growing the by-product industry has the potential to further increase jobs, discussed later in section 6.7: Using the whole fish to develop high-value by-products.

The continued significant contribution to Aotearoa New Zealand's economy relies on healthy fish stocks, which themselves rely on healthy ecosystems and habitats. Ensuring that economic pressures or benefits do not outweigh environmental concerns will be crucial for a sustainable fisheries resource.

Ensuring that economic pressures or benefits do not outweigh environmental concerns will be crucial for a sustainable fisheries resource.

2.5.3 FISH IS AN IMPORTANT PART OF OUR DIET

Fish is an integral part of the diet in Aotearoa New Zealand, with 91% of New Zealanders purchasing seafood. Forty percent report buying seafood at least once a week, and most of us expect to increase our consumption in the future (Ministry for Primary Industries, 2019a). Customers from Australia and Aotearoa New Zealand report similar purchasing patterns (Ministry for Primary Industries, 2019a). In Australia, seafood consumption increased significantly during the last few decades, with one study finding a 45% increase between 1995 and 2011 (Sui *et al.*, 2016). The Australian experience reflects a worldwide pattern – the demand for seafood is increasing and projected to continue to grow (FAO, 2020b).

The demand for seafood is increasing and projected to continue to grow.

According to the Food and Agricultural Organisation (FAO), global per capita fish consumption grew from 9.0 kg (live weight equivalent) in 1961 to 20.5 kg in 2018, and is projected to reach 21.5 kg in 2030, although there is considerable regional variation (FAO, 2020b). Aotearoa New Zealand's per capita consumption is between 20-30 kg per year (FAO, 2020b). Fishing sustainably now will allow us to keep eating seafood in the future.

Figure 6: Hoki/blue grenadier (*Macruronus novaezelandiae*) fillets on sale in a supermarket. Image credit: Dave Allen/NIWA.

The demand for seafood exists because seafood is a relatively healthy source of protein. It is leaner than most red meats and generally higher in essential fatty acids (Thurstan and Roberts, 2014). National dietary guidelines consistently recommend people eat seafood for health benefits (Farmery *et al.*, 2018).

However, many families cannot afford the cost of highly nutritious foods (FAO, 2020a). This is also true for seafood, for example, an Australian study found seafood intake was lowest in socioeconomically disadvantaged communities (Farmery *et al.*, 2018). The study also found that lower price-point fish in Australia was less

[15] 'Prawn fishing' has been combined with 'other fishing' due to low numbers.

nutritious and had a worse environmental impact (Farmery *et al.*, 2018). This highlights the need to consider sustainable consumption from environmental, nutrition and socioeconomic perspectives. A comparison of the environmental impact of different forms of food production is outside the scope of this report. However, it is worth noting that aquaculture could assist in filling this role, indeed, aquaculture production now surpasses wild catch worldwide.[16] Reducing reliance on wild-caught fish may be of value, and could also allow sale of wild-caught fish as a premium product (see section 6.7: Using the whole fish to develop high-value by-products). Aquaculture is beyond the scope of this report.

Food security and nutritional issues are projected to become important issues globally with the dual impacts of a growing population and climate change (FAO, 2020a). Seafood provides essential local food, livelihoods and export earnings (Smith *et al.*, 2010). Many consider that healthy fisheries are important for food and nutrition security, particularly as the impacts of climate change become more apparent (Kemp *et al.,* 2020).

Fishing sustainably now will allow us to keep eating seafood in the future.

2.5.4 THE WELLBEING OF OUR FISHERS MATTERS

The health, safety and wellbeing of fishers and their communities is vital to the ongoing strength and productivity of the commercial fisheries industry. To date, economic and environmental sustainability have been the focus (Britton and Coulthard, 2013). Broadening this scope to factor in the social aspects of sustainability is important to maintain the wellbeing of the people and communities who make up the industry.

Figure 7: Safety sign onboard the RV *Tangaroa.*

Globally, fishers today are facing the dual pressures of limited fish and more management (Woodhead *et al.*, 2018). Aotearoa New Zealand has its own set of challenges that can place a heavy burden on fishers and their families. As part of the Fisher Wellbeing Programme established in September 2019, the Ministry for Primary Industries commissioned an initial study to understand the wellbeing needs of our local commercial fishing industry. Key needs identified include economic wellbeing, regulation that has the least impact on livelihoods, self-determination on fisheries decisions, identity and sense of belonging, physical and mental wellbeing, and social connectedness.

Pressures that fishers may face include:

- Cost of leasing annual catch entitlement (ACE).
- Cost of operating.
- Negative public perception of fishers.
- Uncertainty around the future of fisheries (catch cuts, access to ACE, further closures etc.).
- Uncertainty around access to fish (whether they will be able to lease ACE in the coming year).

These findings have been used to inform a fisher wellbeing strategy to improve wellbeing and resilience across the sector. The Fisher Wellbeing Programme has five objectives:

1. Identify key wellbeing drivers, challenges and opportunities for fishers in New Zealand.
2. Facilitate and build cross-sector commitments to fisher wellbeing.
3. Increase wellbeing support capacity of frontline Fisheries New Zealand staff.

[16] See Our World in Data

4. Increase regional wellbeing support for fishers.
5. Increase resilience of fishers, their whānau and fishing communities.

The timeframe to achieve these outputs is by June 2023, at which point governance of the support network is likely to shift from Fisheries New Zealand to the industry.

Some fishers also face barriers to entry into the industry. As with other primary industries, fisheries are managed to maximise value to Aotearoa New Zealand not local communities.[17] It is well documented that the implementation of an ITQ system reduced the number of independent small-scale fishers, which was in part by design to rationalise and increase efficiency in the industry (Stewart *et al.*, 2006). The level of quota allocated to fishers meant many had to choose between either acquiring further quota or exiting the industry (Stewart and Walshe, 2008).

Fishing is a business with high infrastructure needs. Since the late 70s the industry has been concentrated: 10% of the vessels caught more than 80% of the fish as the industry was dominated by a number of large operators (Cullen and Memon, 1990). The quota system drove further concentration and also placed quota in the hands of non-specialist investors. Roughly 15 years after the QMS was established, over 3,000 predominantly small-scale fishers had exited the industry (Stewart *et al.*, 2006), largely due to compliance costs, uncertainty about future QMS policy and the high cost of quota (Stewart and Walshe, 2008). Continued concentration is occurring in the ownership of quota for deepwater species. At the same time there has been an increase in participation by small-scale fishers in the inshore fishery, apparently driven by the introduction of the ACE (Stewart and Callagher, 2011). Currently small-scale ACE fishers make up around 80% of the inshore fleet.[18] Financially it can be difficult for independent fishers to compete against companies with vertical integration that own large amounts of quota. That said, these companies do provide an option for independent fishers to operate under an owner-operator model which provides infrastructure and a route to market that may not otherwise be accessible. There are costs and benefits associated with every model of ownership or use.

Roughly 15 years after the QMS was established, over 3,000 predominantly small-scale fishers had exited the industry, largely due to compliance costs, uncertainty about future QMS policy and the high cost of quota.

Fisheries contribute to the wellbeing of coastal communities. The introduction of the QMS shifted the fisher ecosystem towards large-scale operators, based in larger ports, resulting in a loss of local employment in fisheries (Healy, 2006). This change within the sector came with both positive and negative outcomes. The Faroe Islands provide an example of a fisheries management system that has prioritised social sustainability as highly as ecological and economic sustainability. The wellbeing of our commercial fisheries sector is an important aspect of sustainability that should be considered during fisheries management decisions.

2.5.4.1 MANAGING HEALTH AND SAFETY IS IMPORTANT IN A RISKY ENVIRONMENT

In 2017, Maritime New Zealand published survey results on health and safety in the commercial fishing sector from perspectives of both workers and employers (Maritime NZ and WorkSafe NZ, 2017). Commercial fishing is a high-risk sector, along with other sectors such as agriculture, construction, manufacturing and forestry.

There are relatively high numbers of workers who say that they behave in risky ways, particularly when it comes to working when overtired or when sick or injured.

[17] Input from Fisheries New Zealand.
[18] Input from Fisheries New Zealand.

Over the last ten years there have been 13 work-related fatalities in the fishing sector. The majority have occurred within the 'fish trawling, seining and netting' industry categorisation and almost half were classified as a drowning. This compares to 50 work-related fatalities in the forestry sector over the same time period, which has a smaller workforce than fisheries (Safetree, 2020). Worldwide, the number of work-related fatalities among fishers is likely in the thousands, but a precise estimate is difficult to pin down due to patchy data. In the UK, there were 79 work-related fatalities in the fishing industry over the ten-year period from 2008 to 2018 (Elliott and Holden, 2019).

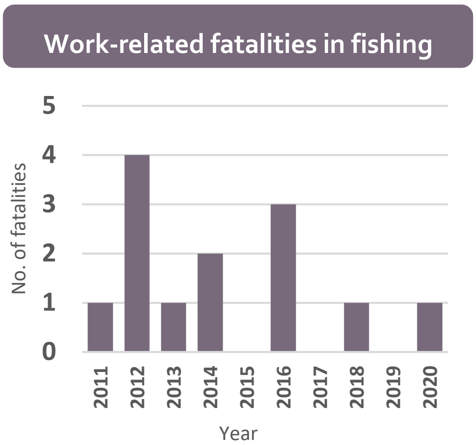

Figure 8: Work-related fatalities in fishing to from January 2011 to July 2020 (Data from WorkSafe NZ).

Health and safety is increasing as a priority for employers. More are saying that formal audits at regular intervals are part of their normal business and that everyone in the business values ongoing improvements (Maritime NZ and WorkSafe NZ, 2017). These changes will help to ensure the health and safety of the fisheries workforce.

There is also growing recognition of the mental health challenges faced by fishers globally, although this has not received as much attention as physical health (Woodhead *et al.*, 2018). A 2015 study from Australia found that Australian fishers exhibit poor mental health, including depression, anxiety and self-harm (King *et al.*, 2015). This was linked to the inherent resource dependence of fishing and uncertainty associated with top-down policy changes, issues also faced in Aotearoa New Zealand.

2.5.5 SOCIETY'S EXPECTATIONS ARE CHANGING

Consumers are increasingly paying attention to the social and environmental dimensions of the food they eat, generating many different responses, including certification programs, watch lists and local/slow food movements. Currently for Aotearoa New Zealand consumers, quality and price rank above ethical considerations and fishing method when choosing seafood (Ministry for Primary Industries, 2019a). However, an Australian study has shown that when consumers have a good understanding of sustainability in the seafood sector, this becomes the most important factor in their purchasing decision (Lawley *et al.*, 2019). This suggests that increasing dialogue around seafood sustainability may lead more people to make purchasing decisions based on the sustainability credentials of seafood.

Figure 9: Snapper at Lee Fish in Leigh, north of Auckland. Every fish shipped from here is accompanied by a code that traces back to the fisher and vessel that caught the fish.

A specific area of concern for some relates to the humane treatment of fish. Advocates for animal rights have highlighted that there is a lack of humane slaughter requirement for wild-caught fish, as reported recently in local media. Commentary on fish welfare is also increasing internationally.

Approaches that make fishing more humane and sustainable, and ways to share that information easily and transparently with customers, will help to maintain demand for wild-caught fisheries from Aotearoa New Zealand. Until these practices become widespread throughout the industry, they may offer a price premium for fishers to motivate good practice (see 6.7.7: case study: How a commitment to transparency and traceability has generated a premium product).

> Approaches that make fishing more humane and sustainable, and ways to share that information easily and transparently with customers, will help to maintain demand for wild-caught fisheries from Aotearoa New Zealand.

These changing demands provide impetus to innovate to make fishing more humane and sustainable.

2.6 WE CAN BUILD ON THE QMS TO IMPROVE SUSTAINABILITY

For over 30 years, Aotearoa New Zealand's fishing legislation has recognised that our fisheries resources are finite and has provided a framework based around the purpose of providing for the "utilisation of fisheries resources while ensuring sustainability". This is the foundation of the QMS and Aotearoa New Zealand's current legislative and management approach to fisheries.

The QMS aims to preserve fish stocks for future generations by creating a long-term stake in the fishery which could help offset short-term economic pressures that can result in severely depleted fish stock (Arnason, 2005; McKerchar *et al.*, 2015). However, there is a complex interplay between economic incentives and regulatory requirements that impact on achieving sustainable utilisation of fish stocks while also addressing broader environmental and societal goals. The consideration of ecosystem impacts is provided for under the Fisheries Act 1996 (Fathom, 2019[19], summarised in appendix 1; Macpherson *et al.*, 2020) and where considerations are given affect this allows for the management of fishing to become more rigorous and nuanced. However, implementation has been variable and we can do better.

The current fisheries management regime has mechanisms that can enable an ecosystem approach. Aotearoa New Zealand has already incorporated some aspects of ecosystem-based approaches into fisheries management alongside the QMS (Cryer *et al.*, 2016), often through the use of fisheries plans. For example, the Draft National Inshore Finfish Fisheries Plan, released for consultation in November 2019, suggests certain ecosystem approaches to fisheries management, such as integrating management of multiple stocks caught within a fishery, that could be applied in future (Fisheries New Zealand, 2019e). However, this plan is yet to be implemented.

The New Zealand Government has committed to taking an ecosystem-based approach to fisheries management that integrates sustainable harvesting with wider biodiversity considerations (Hon Min Nash, 2018; Department of Conservation, 2019b). Local research to foster ecosystem thinking in Aotearoa New Zealand's fisheries management system is underway as part of Sustainable Seas (see 5.8.1 case study: Sustainable Seas/Ko ngā moana whakauka), but more work is needed to integrate the research and policy intent with community

[19] The Fathom report (2019) is available from the Seafood New Zealand website. A summary is included as appendix 1. See also appendix 1, reproduced from Fathom (2019).

knowledge, and to translate lofty goals to day-to-day decision making in the fisheries management system and practice in our oceans.

Perhaps the fundamental challenge faced by all those focused on a sustainable fishing goal is to translate an incomplete but increasingly sophisticated understanding of the complex interactions and cumulative pressures on our ecosystems into effective and actionable policies and regulations, along with robust indicators to monitor progress. This ambitious goal is likely to take some time to achieve and demands strong leadership by the fisheries management agency, and a connected community of stakeholders with a shared vision of the future. However, it offers an opportunity to be world leaders in managing future commercial fisheries.

The fundamental challenge faced by all those focused on a sustainable fishing goal is to translate an incomplete but increasingly sophisticated understanding of the complex interactions and cumulative pressures on our ecosystems into effective and actionable policies and regulations, along with robust indicators to monitor progress. This ambitious goal is likely to take some time to achieve and demands strong leadership by the fisheries management agency, and a connected community of stakeholders with a shared vision of the future.

This report aims to address this challenge by focusing on how we can fill data gaps, translate data into knowledge, and draw on new innovations to inspire the development of a fisheries management system within the Fisheries Act 1996 that enables more sustainable commercial fishing practices.

This underpins recommendations in Themes 4-7.

2.7 GUIDING FRAMEWORKS AND EXEMPLARS

Addressing the challenge of building an environmentally, socially and economically sustainable commercial fisheries industry requires overarching frameworks to guide our thinking. This report has been guided by different frameworks, intimately connected by their holistic systems approach. Te ao Māori, the Māori worldview, has long recognised the interconnectedness of all things and the need to address complex issues in a holistic way.

Additionally, regulatory and management approaches to our marine environment – both here in Aotearoa New Zealand and overseas – increasingly aspire to an ecosystem approach. We can look to exemplars overseas for inspiration and ideas to enhance our commercial fisheries. This section includes a brief overview of international jurisdictions that, alongside Aotearoa New Zealand, are known for their best practice fisheries management.

2.7.1 TE AO MĀORI

As an island nation populated by talented seafaring tūpuna, the ocean is of special importance to Māori. This is reflected in strong Māori views on fisheries management, drawing on tikanga to fulfil the role as kaitiaki of our oceans. For example, interviews with 22 kaitiaki from 14 North Island iwi found that they share common concern about the decline in abundance and diversity of kaimoana (Dick *et al.*, 2012). This concern extends beyond ecological health, to cultural ramifications. Declining kaimoana leads to fewer opportunities for iwi, hapū and whānau to work communally, and to share stories and mātauranga across generations. The loss of signature kaimoana affects the ability of iwi to practice manaakitanga (hospitality, generosity), which in turn results in a loss of mana and identity.

The Māori Fisheries Settlement 1992 vests management of large portions of our fisheries with iwi, again reflecting the significance of kaimoana in Māoridom. As discussed in section 2.1, around 27% of fisheries quota are owned by Māori and three of the five biggest fishing companies in Aotearoa New Zealand are Māori-owned (Inns, 2013; Tuuta and Tuuta, 2018).

As an island nation populated by talented seafaring tūpuna, the ocean is of special importance to Māori.

Wisdom from te ao Māori offers a knowledge framework that is in many ways orthogonal to that of western science (Gerrard and Kukutai, 2019). Te ao Māori sits on a foundation of mātauranga Māori, which takes holistic view of the natural world, valuing deep community knowledge as well as more quantitative approaches. Mātauranga also incorporates both knowing and doing. In the marine environment, where scientific knowledge is naturally limited by the inaccessibility of elements of interest, mātauranga Māori has special value. Some important concepts within te ao Māori include:

- Tikanga – the right way of doing things; defines how mātauranga is put into practice.
- Kaitiakitanga – guardianship, or an ethic of environmental care (Jackson, 2020).
- Rangatiratanga – self autonomy and independence.
- Whanaungatanga – a sense of kinship and belonging that develops through working together.
- Manaakitanga – generosity and hospitality.

A more detailed explanation of te ao Māori and related concepts can be found in Reid *et al.* (2019).

Western science and te ao Māori offer complementary lenses with which to view the world and solve problems. Drawing on both frameworks in partnership offers a unique strength to policymakers charged with managing our marine environment.

In particular, the concept of 'ecosystem thinking' has synergies with mātauranga Māori. While much of western science has relied on reductionist thinking, ecosystem thinking requires deep knowledge of entire systems and how complex interrelationships between component parts drive the emergent properties of the whole (see section 2.7.5: Ecosystem thinking). However, conflicts between some aspects of ecosystem-based approaches and te ao Māori remain: for example, some seek to couch ecosystem services in econometric terms, whereas Māori perspectives may lend more weight to cultural and spiritual considerations (Reid *et al.*, 2019).

The concept of 'ecosystem thinking' has synergies with mātauranga Māori.

A key difference between te ao Māori and the western worldview is their respective approaches to conservation. Traditionally, western conservation can often involve preservation of the environment separate from human activities, whereas Māori view humans as an integral part of the environment, with the role of kaitiaki. In the context of fisheries, this can create divergent views about whether permanent 'no-take' protected areas are appropriate, with a Māori view more likely to manage populations with limited take (though there are of course exceptions, see section 5.7: Iwi initiatives), through a series of rāhui defined in space and time to nurture all populations. Rāhui are just one approach in the mātauranga toolbox. Other practices include rotational use of mahinga kai (food gathering areas), harvesting smaller individuals to protect breeding stock, protection of kōhanga (nursery areas) and active translocation/reseeding (Dick *et al.*, 2012). In some ways these tools foreshadowed multiple-use protection areas used widely overseas (Aburto *et al.*, 2020).

Recent research has explored the Māori perspective of fisheries management and sought to effectively integrate te ao Māori and western science for true collaboration and co-governance. The Sustainable Seas National Science Challenge has published work in this area while also embracing the partnership model in practice (Maxwell *et al.*, 2020; Jackson, 2020).

One outcome of these efforts is the *He Waka-Taurua* model, a metaphorical framework for marine co-management (Maxwell *et al.*, 2020). A waka-taurua consists of two waka temporarily lashed together to achieve a common purpose (see figure 10).

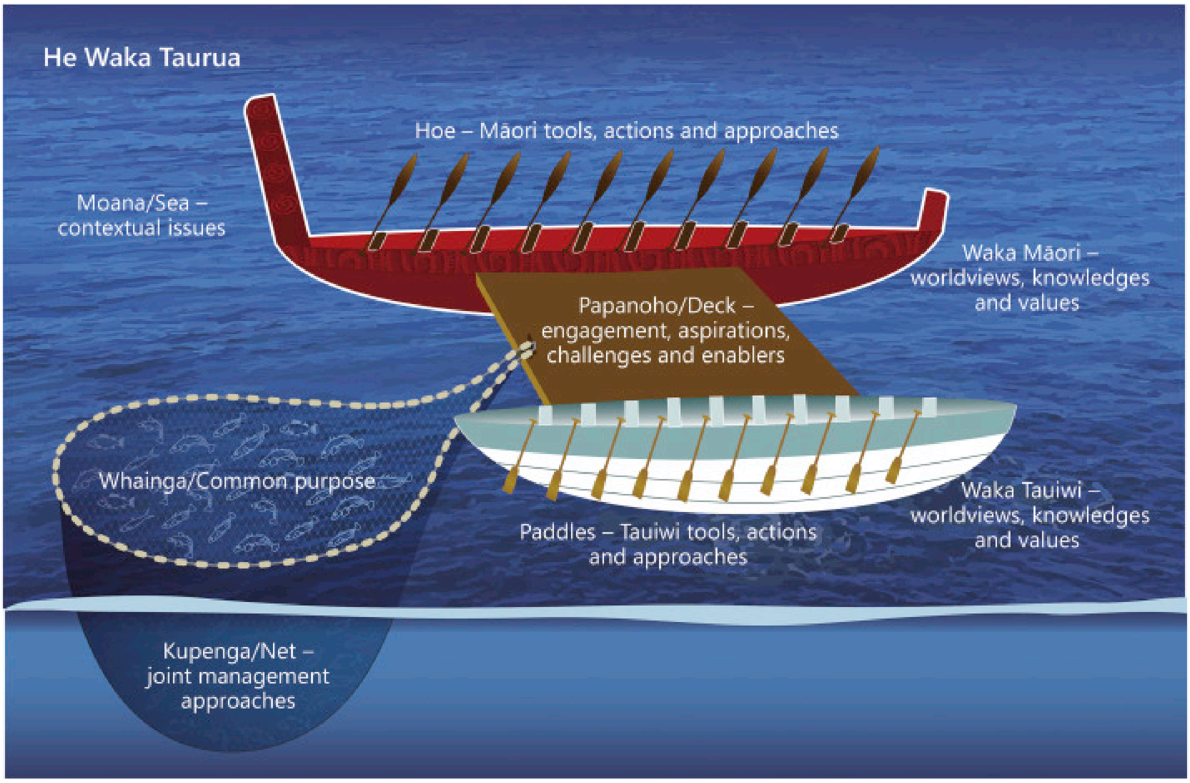

Figure 10: *He Waka-Taurua* framework for recognising multiple worldviews to achieve holistic co-governance/co-management. Image from (Maxwell *et al*., 2020).

Another useful metaphor is *'He Awa Whiria'*, which refers to the multiple, interconnecting channels in a braided river (Macfarlane and Macfarlane, 2019; Department of Conservation, 2020). In this approach, multiple worldviews and scientific disciplines interweave to support actions and interventions. It recognises separate but equally valid knowledge systems – like two sources feeding into a single braided river – that mix to generate new understanding. The '*He Awa Whiria'* approach was applied in the development of *Te Mana o Te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020* (Department of Conservation, 2020).

In the research space, the policy framework *Vision Mātauranga* aims to "unlock the potential of Māori knowledge" (Rauika Māngai, 2020; Ministry of Business Innovation and Employment, 2020). It is the guiding policy for the Ministry of Business, Innovation and Employment (MBIE) and is incorporated into the operating principles of CRIs.

There are a range of other tools and frameworks that have been developed for agribusiness that could be useful for working with te ao Māori alongside western environmental management and research (Hutchings *et al.*, 2017; Rob, Harmsworth and Awatere, 2015).

- **Mauri Compass Tool:** for understanding the mauri (essential quality and vitality of a being or entity) of a waterbody and interconnected parts of its system. It involves using standardised tests to assess 12 parameters (referred to as compass points), assigning a value for each from one to five. The assessment of tangata whenua, wairua, mahinga kai, and culture can only be assigned by tangata whenua. The others draw on western science and include habitat, biodiversity, water biology, water chemistry, freshwater eel/tuna[20] growth rates, freshwater eel species, abundance and population, and biological health.

[20] *Anguilla dieffenbachii* and *Anguilla australis.*

- **Te Mauri Model Decision Making Framework:** The 'mauri-o-meter' is a tool that assesses the impact of practices or activities on the mauri of a resource and attributes scores and weightings to each. The wellbeing factors are interconnected and include: mauri of the whānau (family, economic), community (social), hapū (cultural) and ecosystems (environment). The framework supports decision making by integrating quantitative and qualitative data and providing a sustainability assessment.
- **Cultural Health Index (CHI)** (Tipa and Teirney, 2006)**:** A Māori-led and developed tool to monitor change in a specific environment based on three components: 1) whether the site has traditional significance to tangata whenua (yes/no); 2) a qualitative assessment of the mahinga kai (natural resources) of the site; 3) a stream health index made up of qualitative ordinal rankings. The tool is adaptable for different environmental domains.
- **Te ao Māori framework for environmental reporting** (Scheele *et al.*, 2016): This scoping document includes a series of measures for environmental monitoring that align with te ao Māori values and would give full voice to the Māori worldview for reporting on environmental impacts.

Figure 11: The *'He Awa Whiria'* (braided river) metaphor provides a possible approach to interweave two worldviews. Image credit: Rakaia River, Andrew Cooper/Wikimedia (CC BY 3.0).

Successful partnerships of Indigenous and western knowledge have occurred both here in Aotearoa New Zealand and overseas. Some examples are outlined below. Effective co-governance examples have several characteristics in common: key among these is that Indigenous people and their perspectives must be included at the very beginning of a programme or initiative. There is a power imbalance between western and Indigenous worldviews, and Māori must have rangatiratanga or power within co-governance frameworks for meaningful implementation of te ao Māori principles (Tiakiwai *et al.,* 2017; Reid, *et al.,* 2019).

Aotearoa New Zealand examples:

- ***Sea Change – Tai Timu Tai Pari*** brought together stakeholders across Tīkapa Moana the Hauraki Gulf to develop a marine spatial plan, aiming to restore the mauri of the Gulf (Le Heron *et al.*, 2019). This was a complex undertaking with a wide array of iwi, enterprises and voices contributing to the development of the plan over four years and not without tensions. The Māori worldview was incorporated into the eventual spatial plan. The Government appointed a Ministerial Advisory Committee to help shape their response to the conservation and fisheries related proposals in the spatial plan, which is pending (see 3.3.5 case study: Managing land-based impacts through a multi-sector marine spatial plan).

- The community group **Kaikōura Coastal Marine Guardians (Te Korowai)** developed a management strategy for the Kaikōura marine environment in 2012 (Maxwell *et al.*, 2020). This was built around four pillars, including 'sustaining customary practices', which aimed to restore and maintain Ngātī Kurī's traditional fishing areas, tikanga and mātauranga (Te Korowai o Te Tai ō Marokua, 2012). The strategy was enacted through the Kaikōura (Te Tai ō Marokura) Marine Management Act 2014. This legislation also made the Kaikōura Marine Guardians a statutory body, appointed by Ministers to advise on issues affecting the Kaikōura marine environment, but required a specific act of Parliament (see 4.4.2 case study: Te Korowai o te tai ō Marokura in Kaikōura shows how regional responsibility can streamline fisheries management).
- **He korowai o Matainaka** – in this project, traditional ecological knowledge was merged with scientific understanding and engaged the mana whenua Kāti Hauirapa to improve management of īnaka/whitebait[21] spawning and mahika kai sites along the Waikōuaiti River in Otago (Carter, 2019). "What really counts in an ever changing world is the re-engagement between people and the environment that will reinstate mātauraka[22] Māori processes into contemporary mahika kai management relationships and practices… the knowledge will be combined with science to ensure the most beneficial adjustments are made for efficient and sustainable future environmental management."
- **The Moana Project** brings together iwi, Māori academics and other researchers, and the seafood sector to develop sensors and knowledge exchange platforms to gather oceanographic data (Kaiser *et al.*, 2019). It is envisaged that data collected will feed into models and lead to more efficient and informed forecasting and decision making (see 6.2.3 case study: The Moana Project – Arming vessels with sensors to help validate ocean models).

"What really counts in an ever changing world is the re-engagement between people and the environment that will reinstate mātauraka Māori processes into contemporary mahika kai management relationships and practices… the knowledge will be combined with science to ensure the most beneficial adjustments are made for efficient and sustainable future environmental management."

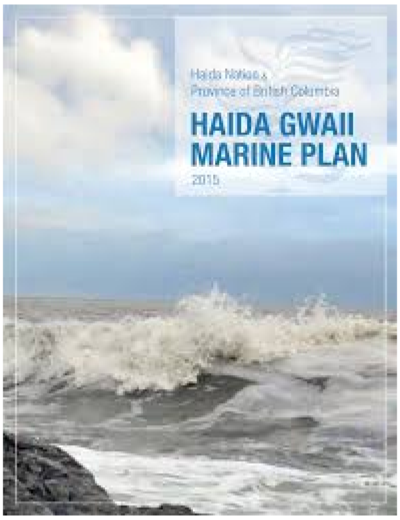

Figure 12: The Haida Gwaii Marine Plan was co-developed by the Haida Nation and the Province of British Columbia in Canada.

Indigenous knowledge features in marine management in many places around the world, for example:

- In Canada, the Haida Gwaii Marine Plan released in 2015 was co-developed by the Haida Nation and Province of British Columbia (Marine Planning Partnership Initiative, 2015). The plan is founded on Haida ethics and values, and outlines how these relate to principles of ecosystem-based management.
- The Hui Mālama o Mo'omomi people of Hawaii designed and implemented their own management plan that exerts their traditional stewardship, incorporating scientific assessments (Maxwell *et al.*, 2020).

[21] *Galaxiidae* species.
[22] Ngāi Tahu dialect for mātauranga.

- In December 2018, the North Pacific Fishery Management Council of Alaska adopted a Bering Sea Fishery Ecosystem Plan that explicitly incorporates Indigenous knowledge into decision making (North Pacific Fishery Management Council, 2019). Communities in the Bering Strait region have vast knowledge of local ecosystems passed down for millennia.

The potential of a holistic long-term approach in the marine environment is underscored in Theme 3 recommendations.

2.7.2 INTERNATIONAL BEST PRACTICE

Although reviewing international fisheries management is beyond the scope of this report, throughout our research and discussions with stakeholders, a handful of jurisdictions were repeatedly held up by multiple people alongside Aotearoa New Zealand as leading in aspects of commercial fisheries.[23] We can look to parts of these international fisheries management systems for inspiration to improve the sustainability of our fisheries, with the caveat that they are not universally accepted as gold standard by all parties.

Figure 13: Fresh catch on the dock in Seward, Alaska. Image credit: Arthur T. LaBar/Flickr (CC BY-NC 2.0).

Each region takes a unique regulatory and management approach, from which we draw specific elements for inspiration below.

ICELAND

Icelandic fisheries management has a rights-based system very similar to Aotearoa New Zealand's but with important differences. Each stock is managed through an annual TAC, with individual operators having ITQs based on their quota allocation. The government later introduced a resource rent tax which has changed over the years but requires the industry to pay fees to access fishing resources (Gunnlaugsson *et al*., 2018). Trust is built through independent fish surveys. Fisheries data is widely accessible.

In recent years, the Icelandic fishing industry has focused heavily on the use of fish by-products (Sigfusson, 2019; den Hollander and Thorsteinsson, 2020). While the volume of fish caught in Iceland has decreased over the past few decades, their export value has increased. Much of their success in this area appears to be due to an organisation called the Iceland Ocean Cluster and their 100% Fish Project (discussed in detail in section 6.7: Using the whole fish to develop high-value by-products).

[23] Input from John Tanzer WWF; Beth Fulton, CSIRO.

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ALASKA

Alaskan fisheries management differs by stock, based on a mix of federal and state policies. The North Pacific Fishery Management Council has authority to determine how the federal legislation will be implemented for Alaska's fisheries and sets an annual TAC. Management is guided at the federal level by the United States National Oceanic and Atmospheric Administration (NOAA) and national standards for fishery conservation and management. NOAA has developed an Integrated Ecosystem Assessment initiative to guide effective ecosystem-based management (see 2.7.3 case study: Integrated ecosystem assessments to inform ecosystem-based fisheries management) which Alaska is beginning to apply, starting with conceptual models (Rosellon-Druker *et al.*, 2019).

In Alaska, fishers have come together to share data in order to allow real-time identification of hotspots to avoid for bycatch. This example is discussed in section 6.5.5: Dynamic ocean management will help protect non-target species in real time.

Fishers have come together to share data in order to allow real-time identification of hotspots to avoid for bycatch.

BRITISH COLUMBIA

Fisheries management in British Columbia, Canada, is based on a mix of federal and state policies. The ITQ management approach was introduced around five years after Aotearoa New Zealand's own QMS system. These management approaches are similar.

Figure 14: Trawlers in British Columbia. Image credit: Geoff Sowrey/Flickr (CC BY-NC 2.0).

British Columbia implemented an innovative bycatch quota system for bycatch in the Trawling Groundfish Fishery (Area 2B) in 1996 (Edinger and Baek, 2015). On top of the ITQ, this fishery has also had an individual vessel bycatch quota system paired with a 100% mandatory observer programme. This allows a specified proportion of their TAC to be comprised of bycatch. Fishers made changes to their fishing operations in response, for example through reduced towing time, improved handling of discarded fish, and increased selectivity in their operations. Edinger and Baek (2015) found that the use of individual vessel bycatch quota was highly effective at mitigating bycatch in this fishery, though recommend caution and careful consideration in applying this approach to other fisheries.

This allows a specified proportion of their TAC to be comprised of bycatch.

NORWAY

A new Marine Resources Act came into force in Norway in 2009 representing a paradigm shift in fisheries management for the country by mandating the application of EAFM (Gullestad *et al.*, 2017). The industry is highly regulated with quotas and licensing requirements.

An Atlantis ecosystem model of the Norwegian and Barents Sea has been developed (see section 6.4.18: Models can support ecosystem approaches to fisheries management) (Hansen *et al.*, 2016, 2019). Although there is a long way still to go, some of the management takes into account multi-species fisheries and interactions between species. For example, management of capelin[24] takes into account the importance of capelin for Northeast Arctic cod[25] (Howell *et al.*, 2016; Nilsen *et al.*, 2020). There are multispecies considerations in setting catch levels on several of the main fisheries (cod, haddock[26], capelin) and some level of balance between fishing of high trophic level and low trophic level species (Zhou *et al.*, 2019).

Figure 15: Norwegian fishing boats. Image credit: Javier Rodríguez/Flickr (CC BY-SA 2.0).

Norway is undertaking some exciting new innovative management techniques, including the use of genetic techniques to regulate cod fisheries in real time. This is discussed in 6.4.7 case study: Real-time genetic management of a marine fishery.

A new Marine Resources Act came into force in Norway in 2009 representing a paradigm shift in fisheries management for the country by mandating the application of the EAFM.

AUSTRALIA

In Australia, there are eight different jurisdictions each with their own fisheries legislation (Farmery *et al.*, 2019). The Australian Fisheries Management Authority (AFMA) works with state/territory government agencies to meet sustainability objectives. Many fisheries in Australia are ITQ-based, mostly single-species but some multi-species fisheries (Pascoe *et al.*, 2017). Some fisheries activities are defined as 'threatening processes' under the Environment Protection and Biodiversity Conservation Act 1999 (Australian Government, 1999). These include 'incidental catch (or bycatch) of seabirds during oceanic longline fishing operations', 'incidental catch (or bycatch) of sea turtle during coastal otter-trawling operations within Australian waters north of 28 degrees south', and 'injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris'. Australia has established spatial closures for gillnet fisheries in certain areas to protect Australian sea lions[27] in their habitat and breeding colonies (Australian Fisheries Management Authority, 2015).

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[24] *Mallotus villosus.*
[25] *Gadus morhua.*
[26] *Melanogrammus aeglefinus.*
[27] *Neophoca cinerea.*

There is also a gillnet dolphin mitigation strategy aiming to empower fishers using gillnets to avoid and mitigate dolphin interactions (Australian Fisheries Management Authority, 2019).

Some fisheries activities are defined as 'threatening processes' under the Environment Protection and Biodiversity Conservation Act 1999.

FAROE ISLANDS

In the Faroe Islands, fisheries management reform that came into effect in 2018 recognises all living marine resources in the Faroese waters as the property of the Faroese people. This is in some ways the opposite of quota management where quota rights are held by individuals (although quota rights do not create a property right in fish, but only a right to harvest a proportion of the TACC). Prior to the reform, limited access and prioritising social outcomes led to stock decline (Danielsen and Agnarsson, 2018). Policy changes that seek to balance ecological, economic and social sustainability appear to be able to achieve that (Danielsen and Agnarsson, 2020). The historical and cultural context of the Faroe Islands is very different than Aotearoa New Zealand and may have limited relevance. The Faroese Ministry of Information has further information on recent and ongoing reforms in the management of their fisheries.

Fisheries management reform that came into effect in 2018 recognises all living marine resources in the Faroese waters as the property of the Faroe people.

2.7.3 CASE STUDY: INTEGRATED ECOSYSTEM ASSESSMENTS TO INFORM ECOSYSTEM-BASED FISHERIES MANAGEMENT

In the United States, NOAA has developed an integrated ecosystem assessment as an approach to ecosystem-based fisheries management (EBFM) (NOAA Fisheries, 2017). The framework organises and summarises social-ecological evidence so that it can be integrated to inform a holistic management response (Rosellon-Druker *et al.*, 2019). Each fisheries management council applies the framework differently to suit the local context and available evidence.

Each fisheries management council applies the framework differently to suit the local context and available evidence.

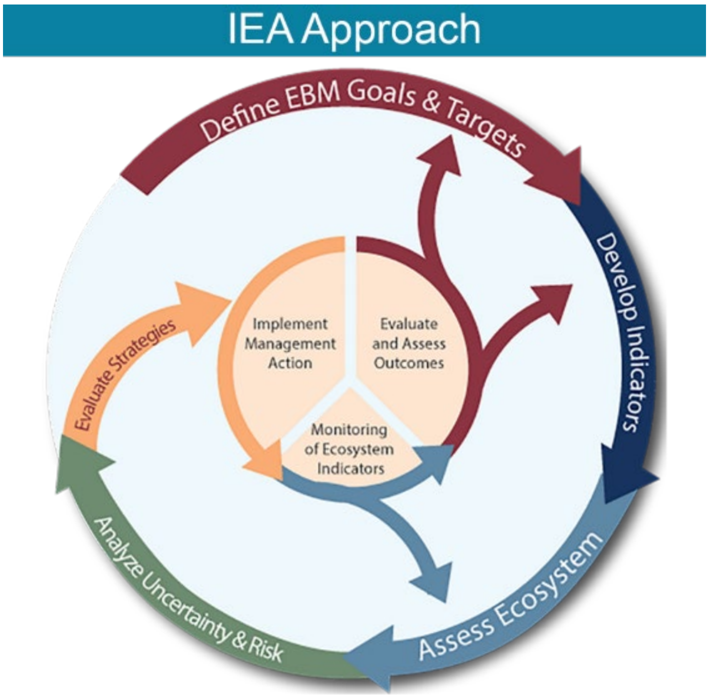

Figure 16: The integrated ecosystem approach process developed by NOAA.

There are several steps in the assessment process:

1) **Define the system and the outcomes you want to achieve.** Taking a collaborative approach, a scoping exercise is used to identify the relevant ecological, social and economic components of the ecosystem, which become part of the conceptual model to show the structure and connections within it. Evidence that feeds into the model can include scientific information, place-based knowledge and qualitative information, as shown in the models developed for two fisheries in Southeast Alaska (Rosellon-Druker *et al.*, 2019). This process also identifies knowledge gaps. Management or planning goals and objectives need to be clearly defined at this step. The model serves as the basis for future assessment against the objectives, and can be used to structure simulation modelling tools. Several regions in the US have done this first step of the integrated ecosystem assessment.

2) **Choose indicators and use these to assess the ecosystem.** The next step is to identify, select and validate indicators that capture the status and trends of the key ecosystem components defined in step 1. These are qualitative or quantitative data points that provide a measure of how the ecosystem is doing. Where indicators aren't available these need to be developed. The indicators are then used to collectively assess the status of the ecosystem and are reported in an Ecosystem Status Report for fisheries managers and stakeholders. A lack of scientifically rigorous and sensitive indicators that are logically linked to ecosystem outcomes to decision

makers may provide a roadblock. Indicators have been developed and Ecosystem Status Reports produced for several regions in the US.

A lack of scientifically rigorous and sensitive indicators that are logically linked to ecosystem outcomes to decision makers may provide a roadblock.

3) **Assess the risk to the ecosystem from different pressures.** This step involves performing an Ecosystem Risk Assessment to determine the probability that different natural and human pressures, including management actions, could cumulatively cause undesirable outcomes for the components of the ecosystem identified in the first step. NOAA has developed a framework to determine the type of assessment that should be used based on different analytical approaches and system complexity, and alternative frameworks have been developed by other groups. The results can help prioritise management action. An Ecosystem Risk Assessment has been completed for the Northeast in 2020 and is underway for the Eastern Bering Sea.

4) **Evaluate how different management strategies could impact outcomes for the ecosystem.** In the final stage, the findings from the assessment are used to evaluate the impacts of different management strategies on the objectives defined in step 1, demonstrating how each may contribute to declines or improvements in ecosystem health any trade-offs between options. Management Strategy Evaluations are a decision support tool – it does not prescribe management approaches but rather inform managers which strategies could be the most useful in achieving their objectives.

   The West Hawai'i Management Strategy Evaluation for a coral reef ecosystem shows the outcome of the full Integrated Ecosystem Assessment process and shines a light on management trade-offs while highlighting the tension between ecosystem recovery and use of ecosystem services (Weijerman *et al*., 2018).

The potential of an EAFM to fisheries management is underscored in our theme 6 recommendations.

2.7.4 BLUE ECONOMY

A term that is sometimes used to capture a holistic approach to managing human use of the oceans is 'blue economy'. This is not a framework that we have adopted in this project, but the thinking has informed our approach and views.

There is no widely accepted clear definition of the term 'blue economy'. It is sometimes used interchangeably with 'ocean economy' or 'marine economy' and some argue that this lack of agreed definition limits its utility.[28] Some definitions are in the table below.

Table 1: Definitions of the 'blue economy' from a range of sources.

Definition	Source
"The Blue Economy conceptualises oceans as 'Development Spaces' where spatial planning integrates conservation, sustainable use, oil and mineral wealth extraction, bio-prospecting, sustainable energy production and marine transport."	United Nations (United Nations, 2014).
"The 'blue economy' concept seeks to promote economic growth, social inclusion, and the preservation or improvement of livelihoods while at the same time ensuring environmental sustainability of the oceans and coastal areas."	World Bank (World Bank and United Nations Department of Economic and Social Affairs, 2017).
An economy "comprised of activities that will generate economic value and contribute positively to social, cultural and ecological wellbeing".	Sustainable Seas National Science Challenge (Yeoman *et al.*, 2019).
"A sustainable blue economy is a marine-based economy that: Provides social and economic benefits for current and future generations; Restores, protects and maintains the diversity, productivity, resilience, core functions, and intrinsic value of marine ecosystems; Is based on clean technologies, renewable energy, and circular material flows."	World Wildlife Fund (World Wildlife Fund Baltic Ecoregion Programme, 2015).
"The 'Blue Economy' is an emerging concept which encourages better stewardship of our ocean or 'blue' resources."	The Commonwealth.

The narrowest definitions tend to focus on value extracted from 'use' (e.g. through commercial fishing, aquaculture, tourism, minerals) while broader definitions encompass 'non-use' value associated with ecosystem services and biodiversity. Many descriptions also include reference to sustainability and responsible stewardship.

Stewardship of the oceans is not straightforward. Unlike the land, few parts of the ocean are permanently owned or occupied. Use of the ocean is temporary and non-exclusive, with multiple uses in the same space over time. Conceptions of the blue economy focus on holistic, ecosystem-based approach to the whole ocean, rather than individual aspects (McGinnis, 2012; Sustainable Seas National Science Challenge, 2019b).

Unlike the land, few parts of the ocean are permanently owned or occupied. Use of the ocean is temporary and non-exclusive, with multiple uses in the same space over time.

[28] Input from Industry.

Like land-based natural resource enterprises, social and cultural acceptance (or 'social licence to operate') is integral to enacting a truly transformative blue economy (Newton *et al.,* 2020). Social licence to operate has proved challenging for some marine industries in Aotearoa New Zealand, such as salmon aquaculture farms in the Marlborough Sounds (Baines and Edwards, 2018).

Activities that comprise Aotearoa New Zealand's blue economy include, but are not limited to:

- Fishing of wild fisheries (commercial, recreational and customary),
- Aquaculture,
- Ecotourism and recreation,
- Shipping/maritime transport, plus activity at ports and marinas,
- Offshore minerals, and
- Offshore energy production.

As the nature and scale of activities in Aotearoa New Zealand's maritime area shifts, we will need to make informed and integrated decisions about how, where and when those activities proceed.

As the nature and scale of activities in Aotearoa New Zealand's maritime area shifts, we will need to make informed and integrated decisions about how, where and when blue economy activities proceed.

Figure 17: Ecotourism is also part of a 'blue economy'. A Bryde's whale surfaces next to a whale watching boat in Tīkapa Moana the Hauraki Gulf. Image credit: Aucklandwhale/Wikimedia (CC BY-SA 4.0).

SUSTAINABLE SEAS NATIONAL SCIENCE CHALLENGE

In Aotearoa New Zealand, 'creating value from a blue economy' is one of the core research themes for the Sustainable Seas National Science Challenge. This theme is underpinned by four key ideas:

1. Societies will rely on the oceans for future food, energy and economic security.
2. Oceans offer economic development potential.
3. Realising this potential requires investment in science and technology.
4. We must transition to sustainable growth (Sustainable Seas National Science Challenge, 2019b).

Research emerging from this theme has mapped Aotearoa New Zealand's growing marine economy, visualised the complex interconnections and feedback loops inherent in marine enterprises, and envisaged new categories to help us rethink management of the economy (Connolly and Lewis, 2019; Envirostrat Ltd, 2019; Lewis, 2020).

An economic analysis commissioned by Sustainable Seas estimated that 'blue economy' activities contribute around 3% to our GDP and employ around 70,000 people (3.3% of total employment) (Yeoman *et al.*, 2019). The analysis showed that tourism was growing (pre-COVID-19), offshore oil and gas exploration was declining, while aquaculture was poised for growth.

As the 'blue economy' concept has originated overseas, adapting it for the Aotearoa New Zealand context requires some work. For example, an Indigenous worldview is not explicit within most blue economy frameworks, but here in Aotearoa New Zealand it makes sense to incorporate a te ao Māori lens (see section 2.7.1: Te ao Māori) (Bargh, 2014). Sustainable Seas has identified other unique Aotearoa New Zealand drivers for a blue economy, including our export market, green premiums, and capital/wellbeing approaches to central and local government (Sustainable Seas National Science Challenge, 2019b). Use of this concept more widely would require a definition of blue carbon for use in Aotearoa New Zealand.

BLUE ECONOMY COOPERATIVE RESEARCH CENTRE

An Australia-based initiative, the Blue Economy Cooperative Research Centre aims to bring together stakeholders in the seafood, aquaculture, marine renewable energy and offshore engineering sectors to address the challenges of offshore food and energy production. Several Aotearoa New Zealand-based organisations are partners of the Blue Economy Cooperative Research Centre, including New Zealand King Salmon, AUT, Plant & Food Research, Cawthron Institute and the University of Auckland.

2.7.5 ECOSYSTEM THINKING

Protecting ecosystem structure and functioning is critical to ensure a sustainable future for the fishing industry. Fisheries management in Aotearoa New Zealand generally views each species of interest in isolation, although the Fisheries Act 1996 does enable wider consideration of ecosystem impacts to be taken into account in fisheries management decisions (see section 5.9: We need a plan for our oceans). Our current system primarily relies on measuring the stock sustainability of individual commercially fished species to determine how many can be caught. This provides a critical tool in fisheries management, and a certain level of reassurance of overall ecosystem health if all the stocks remain plentiful over an extended period of time.

But there are also limitations: a catalogue of single-species measures alone does not capture the full picture (see part 5). First of all, there may be large uncertainties associated with stock assessments, especially for small fisheries where data gathering is poorly resourced or even with data the species is hard to assess. Beyond this, complex interactions are at play within an ecosystem. Long-term resilience of stocks to heavy fishing might require a more complete set of data which reflects the capacity of the marine environment to sustain the fisheries stock. Looking at a collection of single species as a measure for ecosystem health is limited. It is analogous to monitoring spending as a measure for financial health, without looking at debt. We need to measure and monitor more parts of the ecosystem and the interactions among them, across different trophic levels, to truly understand ecosystem health and mitigate the risk of ecosystem collapse. An explicit ecosystem approach builds on the best practice of experienced fishers who understand their environment after many years of observation. We found examples where this works well and include them to inspire more widespread adoption of these practices.

> We need to measure and monitor more parts of the ecosystem and the interactions among them, across different trophic levels, to truly understand ecosystem health and mitigate the risk of ecosystem collapse.

We have used ecosystem thinking as a guiding framework for this report in conjunction with a te ao Māori worldview. Through an ecosystem lens, we recognise the need to monitor the pressures we put on our marine environment while we build better understanding of the interconnections between parts of the system. We also recognise that there are social and economic dimensions to fisheries that interact with the ecosystem that need to be part of our thinking. The 4.4.1 case study: Fiordland created a novel model for managing the marine area, is seen by some as an example of where an EAFM has been successful, from both a fisheries and biodiversity perspective.

Incorporating measures of ecosystem health may lead regulators down an EAFM path. EAFM can be defined in many different ways (Pikitch *et al.*, 2004; Lidström and Johnson, 2020). Fisheries New Zealand has described it as an 'integrated approach to managing the competing values and uses of fisheries resources while maintaining the ecosystems that support them' (Fisheries New Zealand, 2019e). Challenges in implementing EAFM include having robust methods for recognising when an ecosystem is adversely impacted, understanding direct and indirect effects of fishing one species on other ecosystem components, reconciling multiple fisheries operating under different management systems, and identifying indicators that can deliver useful information for these management systems (Hilborn, 2011). There are no 'off-the-shelf' measures to reassure regulators that ecosystems are well managed, and local knowledge will be vital in translating these general principles into action.

> There are no 'off-the-shelf' measures to reassure regulators that ecosystems are well managed, and local knowledge will be vital in translating these general principles into action.

This underpins recommendations in Theme 6.

PART 3: CHALLENGES FOR THE MARINE ENVIRONMENT

Sediment near Okura. Image credit: Geoff Reid NZ.

3.1 FISHING IS ONE OF MANY STRESSORS ON OUR OCEANS

The marine environment is under enormous stress, with environmental degradation and worldwide declines in biodiversity. Some of these impacts are also seen here in Aotearoa New Zealand (Ministry for the Environment and Stats NZ, 2019b). We rely on healthy stocks of fish as a food source, which is dependent on the health of the marine environment and ecosystem. Fisheries management cannot focus solely on changes to fishing, but the poor integration of the Fisheries Act 1996 with conservation legislation makes this challenging.

Fishing is one of many stressors on fisheries stocks, marine ecosystems and the marine environment. All forms of fishing are, in turn, impacted by the other stressors on our marine environment. Aside from fishing, there is a growing body of evidence about the impact of other activities and issues on our marine environment and ecosystems, including climate change and land-based activities. Both are understood to have ongoing impacts on our fisheries and wider marine environment. Mitigation efforts and innovative ideas, if implemented in an appropriate and timely way, can help to curb these. Other stressors include diseases and invasive species and plastics in the marine environment. None of these issues occur in isolation. Their cumulative effects compound in the environment and need to be considered together in a framework, alongside fishing, to address ongoing issues. The challenges faced by commercial fisheries therefore need to be understood and addressed in the context of other environmental stressors and their cumulative effects.

The challenges faced by commercial fisheries therefore need to be understood and addressed in the context of other environmental stressors and their cumulative effects.

Growing the knowledge base around basic ecosystem functioning is important to determine the extent of different stressors on marine environments. There is a need to understand what's most important in an ecosystem, what causes the most damage and what the other stressors are, to inform management across an integrated system.

Before we delve into details about the impact of fishing on target species, non-target species, ecosystems, and the marine environment as whole (explored in sections 5.3 and 3.3 respectively), we first briefly highlight the evidence for how key stressors impact the marine environment and ecosystems, and how this creates a challenging context for commercial fisheries management. This section details the added stressors that place more pressure on our marine environment, providing context for why we must improve how and where we fish to avoid irreversible tipping points in our shared ocean. Specifically:

- Climate change is a huge threat to our oceans.
- Land-based activities impact coastal fisheries.
- Diseases and invasive species threaten the marine environment.
- Plastic pollution is building in the ocean.
- Cumulative effects mean the stresses compound.

Other stressors in the marine environment that we do not discuss here include indirect factors such as population pressure and a growing population, and other commercial marine activities such as aquaculture, mining and the energy sectors, and maritime transport.

The discussion of various stressors acting cumulatively in the marine environment underpins recommendations in Themes 1, 2, 3, 6 and 7.

3.1.1 CLIMATE CHANGE IS A HUGE THREAT TO OUR OCEANS

Climate change threatens the stability of our oceans and fishing as we know it (Ehrhart *et al.*, 2020; Bonar, 2021). Aotearoa New Zealand's marine life is adapted to a relatively stable environment, so even small changes may have a significant effect. The changing climate is already impacting both the ocean and fisheries (see appendix 2) (Lundquist *et al.*, 2011; Barange *et al.*, 2018; Davies *et al.*, 2018a; Law *et al.*, 2018; Ministry for the Environment and Stats NZ, 2019b). Climate-related challenges are emerging – for example, the movement or expansion of fish stocks into areas where there is no quota held, as the ocean warms. Responding and adapting to climate change must therefore underpin our approach to fisheries management.

For these reasons, climate change could be a catalyst for refining Aotearoa New Zealand's fisheries management into a more responsive instrument, nimble in its response to expected and unexpected changes. Fisheries New Zealand has four fisheries-related projects on climate change underway to address this.

Climate change could be a catalyst for refining Aotearoa New Zealand's fisheries management.

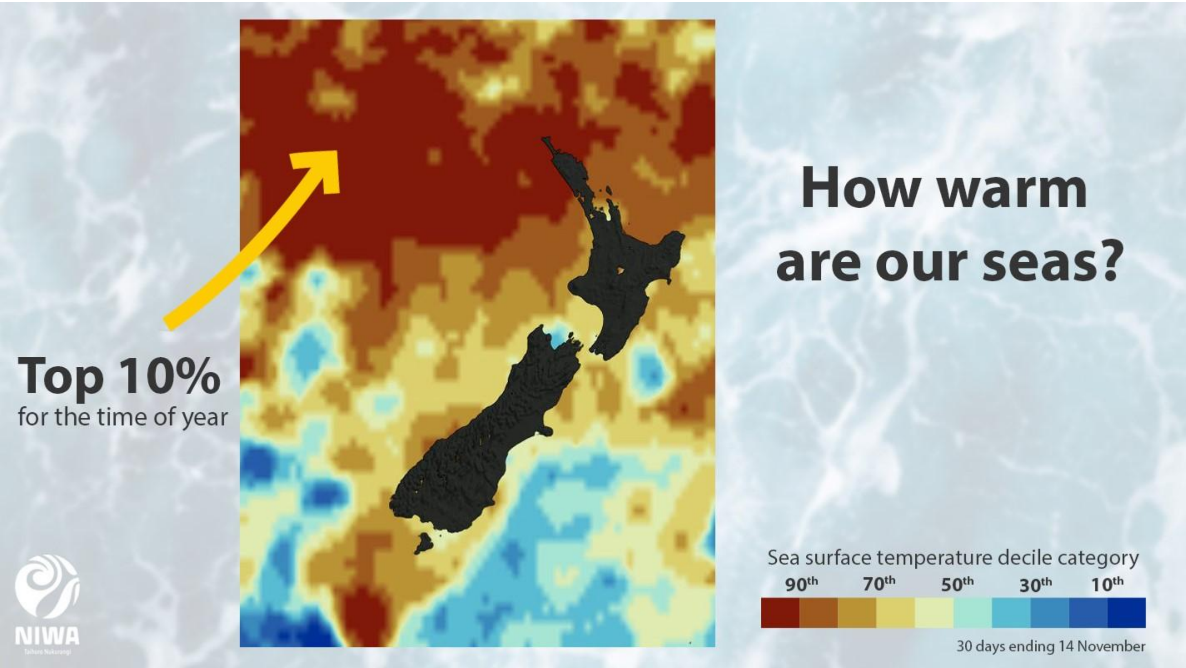

Figure 18: Climate change may be leading to more frequent marine heatwaves. This image shows a marine heatwave to the northwest of Aotearoa New Zealand in November 2020. Image credit: NIWA, with data from NOAA.

Monitoring, modelling and scenario analyses all help to shape a picture of what the future may look like in a changing climate, but all are riddled with gaps and uncertainty (Brett *et al.*, 2020). This uncertainty is due to limited data to inform models, but also because we do not understand enough about the complex and varied interactions that occur in the marine environment to know what the outcomes may be. Even with knowledge gaps, we know that:

- **Changes are already happening.** Fishers, fisheries managers and researchers are already seeing changes that may be attributable to climate change, but the lack of data and monitoring make it difficult to assess, plus causal mechanisms are not well understood. In Alaska, the Pacific cod[29] fishery has been closed for the

[29] *Gadus microcephalus.*

2020 season not because of overfishing but due to climate change impacts. In Aotearoa New Zealand, these changes are the subject of multiple studies (Pinkerton, 2018). For example, researchers believe that poor recruitment in the CRA2 rock lobster fishery[30] is partly driven by climate change (see 5.3.5: case study: Mixed messages: Are we overfishing our rock lobsters?). Links between changing weather patterns and important commercial stocks such as snapper, red cod/hoka[31] and rock lobster/crayfish/kōura[32] have been identified (Beentjes and Renwick, 2001; Dunn *et al.*, 2009; Parsons *et al.*, 2014). Declining green-lipped mussel/kuku[33] populations around the country may also be partly attributable to a changing marine environment due to climate change (overfishing and sedimentation have also been identified as key drivers) (Handley *et al.*, 2020). Iwi in Horowhenua have noticed a decline in a taonga freshwater eel species with research pointing to affects from climate change (Ministry for the Environment and Stats NZ, 2020). In Lyttelton, a loss of bull kelp/rimurapa[34] leading to a decline of mussels and degradation of the ecosystem has been observed, both attributed to climate change (Ministry for the Environment and Stats NZ, 2020).

- **Further changes are imminent.** Extensive climate-induced changes are expected in the marine environment over the next few decades (Williams *et al.*, 2017; Ministry for the Environment, 2020). Climate change will have a significant impact on oceans but the exact ecosystem-level implications – the changes in species composition, distribution, and habitat impacts – are unknown (Peart, 2018; Jarvis and Young, 2019; Ministry for the Environment and Stats NZ, 2019a). These all increase the risk of unforeseen and rapid changes to species and communities, particularly in combination with other stressors such as fishing pressure, ocean acidification, temperature shifts, and habitat changes (Pinkerton, 2010; Pinkerton, 2018). The increased carbon dioxide in our atmosphere is causing ocean acidification, which is known to cause direct and indirect harm to marine ecosystems (Doney *et al.*, 2020) – this is of particular concern (see appendix 15: Ocean acidification studies underway). The Moana Project has been set up to investigate ocean circulation, connectivity and marine heatwaves by harnessing commercial fishing vessels for data collection and providing an open-access database (see 6.2.3 case study: The Moana Project – Arming vessels with sensors to help validate ocean models). Australian researchers are undertaking research for the federal government to determine strategies for fisheries management to address climate change (Fulton *et al.*, 2018). A similar exercise may be beneficial here.
- **Mitigation and adaptation are both needed.** Climate change is a global issue. Even if we do everything we can to mitigate climate change impacts locally, actions and responses from other countries will affect the changing climate here in Aotearoa New Zealand. It is certain that our fisheries industry will need to adapt. A key point highlighted by the Aotearoa Circle's scenario planning efforts is that, whether significant warming occurs or abrupt decarbonisation takes place to dampen global heating, the fisheries industry is going to face significant changes in how and where they can operate (Ehrhart *et al.,* 2020). The ability to rely on fisheries resources as we do today is not a given, and evidence-based management will play a crucial role in future-proofing our fisheries to withstand climate change impacts (Ehrhart *et al.,* 2020).
- **Aotearoa New Zealand will not be the worst affected.** Predictions of climate change impacts on the marine environment suggest that the relative impact on our EEZ may be less than other countries, which may provide a competitive advantage – a small silver lining in a gloomy global outlook.

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[30] See Review of the CRA2 rock lobster fishery and *The 2017 stock assessment and management procedure evaluation for rock lobsters (Jasus edwardsii) in CRA 2*
[31] *Pseudophycis bachus.*
[32] *Jasus edwardsii.*
[33] *Perna canaliculus.*
[34] *Durvillaea spp.*

The ability to rely on fisheries resources as we do today is not a given, and evidence-based management will play a crucial role in future-proofing our fisheries to withstand climate change impacts.

An increasing proportion of fisheries stakeholders acknowledge that the issue of climate change should be high priority for fisheries management, especially as anecdotal evidence increasingly points to its immediate impact on our marine environment. Rather than summarise the wealth of literature relating to climate change, the marine environment and fisheries (as has been done elsewhere – see Willis *et al.*, 2007; Royal Society of New Zealand, 2016; Lake *et al.*, 2017; Barange *et al.*, 2018; Davies, *et al.*, 2018a; Pinkerton, 2018; Winder, 2018; IPCC, 2019), here we highlight what climate change means for how we manage our fisheries and the resulting guiding principles to underpin fisheries management approaches.

Staying at the leading edge of fisheries management in a changing climate will require:

- **Being responsive, adaptable and flexible.** The inherent uncertainty in the timing and extent of climate-related impacts makes it difficult to plan for, but itself dictates the need for a regulatory and management framework that allows for nimble responses to changing circumstances, recognising regional variation. This may demand a shift in thinking away from the spatial and single-species approaches because, for example, the species mix in an area may change significantly from year-to-year in response to water temperature.
- **Ongoing monitoring to inform actions.** This will require long-term data gathering to inform decisions on faster timelines (see section 6.2.1: Changing fisheries demand nimble and responsive decision making).
- **Taking a holistic approach.** Acknowledging that the stressors from climate change will be acting in concert with stressors from other activities, such as land-based impacts and fishing practices, and applying buffers to allowances to support system resilience (see section 3.1.5: Cumulative effects mean these stresses compound).
- **Mitigation efforts.** Cutting emissions in fleets, supply chains and wider organisations will be necessary and will require innovative ideas to transition to a zero-carbon way of fishing.

A number of the innovative ideas outlined later in the report can help achieve these goals (see part 6: A future focus: Science, technology and innovation).

These principles are driving factors for recommendations in Themes 1, 2, 3, 5 and 7.

3.1.2 LAND-BASED ACTIVITIES IMPACT COASTAL FISHERIES

The degradative impacts of land-based activities on the marine environment are well described. Linkages between the land and sea are of critical importance for our fisheries. Shallow coastal waters, harbours, intertidal areas and mangroves are key breeding and nursery areas for many coastal fisheries, including some important commercial fisheries, and are important for primary productivity. These areas are known to be under increasing pressure from land-based activities (Morrison *et al.*, 2014a). Although not discussed in this report, land-based impacts can be significant for freshwater fisheries, particularly through barriers such as dams, culverts and sea openings, which can be a driver for migratory species habitat loss and affects species such as freshwater eels, whitebait, and flounder.[35]

[35] *Pleuronectidae* species.

3.1.2.1 SEDIMENTATION IS AN ACCUMULATING PROBLEM IN THE MARINE ENVIRONMENT

An important land-derived issue facing our coastal waters is the run-off of sediment and nutrients. In terms of the threat to marine habitats, in one study researchers identified land-derived sedimentation as equally threatening as bottom trawling, with only ocean acidification and rising sea temperatures ranking higher (MacDiarmid *et al.*, 2012) – although relative impacts are obviously context-specific and particular to the impacted habitat.

Figure 19: Aotearoa New Zealand has some of the highest sediment run-off in the world. Image credit: Geoff Reid NZ.

Aotearoa New Zealand has some of the highest sediment run-off of any country in the world, contributing an estimated 1% of worldwide sediment input into the marine environment from our coastlines (Our Changing World, 2013). In total, Aotearoa New Zealand loses around 35 million truckloads of soil from the land into the sea each year. Once in the sea, it permanently alters the marine environment. Accelerated sedimentation affects coastal environments around the country and ongoing run-off compounds the effects of erosion that has been occurring for many years.

Aotearoa New Zealand has some of the highest sediment run-off of any country in the world, contributing an estimated 1% of worldwide sediment input into the marine environment from our coastlines.

Vegetation slows rain from hitting the ground and stabilises the soil structure with roots. Therefore, when vegetation is removed, more rain hits the land and more soil erodes into the sea. Aotearoa New Zealand has a naturally high rate of soil loss in some regions due to a combination of soil types, hilly geography, and high and intermittent rainfall, but land uses that remove established vegetation – such as agriculture, forestry and coastal land development – have accelerated this (Thrush *et al.*, 2004; Basher, 2013; NIWA, 2018). Wetland loss is another contributor to marine water quality: wetlands trap sediment and can remove nitrates from run-off, but around 90% of Aotearoa New Zealand's pre-European wetlands have been drained. There is a lack of long-term data tracking sediment accumulation but scientists have found evidence of our land-based activities changing sediment in Aotearoa New Zealand's marine environment following humans' first arrival in 1500 AD (Handley *et al.*, 2020).

When soil and sediment run-off enter the marine environment, it has an adverse effect on marine ecosystems through a number of changes that cascade and interact (Environment Foundation, 2018), including:

- **Smothering bottom-living organisms.** There is evidence that areas that used to be habitats for cockles[36] and pipis[37] decades ago are now below mud (Morrison *et al.*, 2009).
- **Changing habitats on the seafloor.** Sediment can settle on marine plants and seaweeds, smother them, and stop the population replenishing (Greiner *et al.*, 2013). This includes kelp forests (Udy *et al.*, 2019). Because plants provide habitats for other living organisms and fuel the food chain, this decreased productivity

[36] Cardiidae species.
[37] *Paphies australis.*

negatively affects the ecosystem. Some commercial fisheries have nursery grounds or habitats in areas that are highly susceptible to accelerated sedimentation, such as blue cod/rāwaru[38], which are bottom-dwelling fish predominantly found coastally near rocky reefs (Peart, 2018).

- **Reducing water clarity in coastal areas.** Sediment can block light shining through to plants, limiting their energy intake and growth, and plants can't grow as deeply because of the opacity of the water (Morrison *et al.*, 2009). Subtidal seagrass meadows, which are important nursery grounds for juveniles of some species, are now mostly restricted to offshore islands around Aotearoa New Zealand (Clark and Crossett, 2019).
- **Clogging the gills of filter feeders.** Sediment will stress filter feeders, such as bivalve shellfish like pipi and tuatua[39], by making them slower or requiring them to use more energy. If this leads to the loss of filter feeders in an area, it would have cascading effects on that ecosystem.
- **Changing fish gill structure.** There is evidence that turbidity causes changes in the gill structures of some species, such as snapper. In one experiment, juvenile snapper exposed to more turbid conditions lost weight, but their oxygen uptake was not affected (Cumming and Herbert, 2016).
- **Loss of amenity value.** Increased sedimentation in harbours has led to the loss of sandy beaches, expanding mangrove forest filling in harbours, and requirement for dredging to maintain navigable waterways.
- **Poisoning marine life where sediments carry toxins.** See section 3.1.2.2, below.

More sediment is discharged into the marine environment in heavy rain and extreme weather conditions, so climate change is likely to exacerbate these issues. Storms can also cause settled sediment to re-suspend in shallow marine waters which can aggravate the conditions.

Addressing sedimentation is difficult due to the large number of different sources that contribute, including conservation land, forestry, agriculture, earthworks and stream bank erosion (Peart, 2017). It will require removing pressures on the environment (e.g. replanting trees and changing land management practices) and active efforts to restore environments (e.g. replanting seagrass or transplanting bivalves). Alone, neither is sufficient because even if no further sediment affects an area, it still has the lasting damage from sediment to date. Restoring a habitat will have limited benefits if further sedimentation will occur in that area.

Addressing sedimentation will require removing pressures and active efforts to restore environments.

Knowledge of how to restore environments is growing, but restoration trials are generally required for the specific location. For example, some studies have determined that mussels play a critical role in filtering out sedimentation and nitrogen cycling (denitrification). Efforts to restore mussels in areas where they have declined or been lost could help to remediate the negative impacts from land activities. Community groups and researchers are working together to determine how to best restore shellfish and seagrass in a number of places around the country, including Tīkapa Moana the Hauraki Gulf[40], Te Tauihu-o-te-waka Marlborough Sounds and Te Tai Tokerau Northland (NIWA, 2017).

The *Tai Timu Tai Pari Hauraki Gulf Marine Spatial Plan* has recommended a series of active restoration efforts in the Hauraki Gulf Marine Park (see 3.3.5: case study: Managing land-based impacts through a multi-sector marine spatial plan). A review of habitat restoration methods commissioned by the Ministry for Primary Industries is underway to inform these efforts. Sedimentation is a significant focus for councils and a major

[38] *Parapercis colias*.
[39] *Paphies subtriangulata.*
[40] See also *Restoring the Hauraki Gulf with mussels*

component of the *National Policy Statement for Freshwater Management 2020*, which provides local councils with direction on how they should manage freshwater under the Resource Management Act 1991. This is an issue that will take time and national emphasis to address.

3.1.2.2 CONTAMINANT ISSUES TEND TO BE MORE LOCALISED

Land-based activities can lead to the introduction of contaminants into the marine environment, either via sediment loss (i.e. fertilisers within the sediment) or through other discharges in the environment. These issues tend to be more localised and less likely to impact the whole ecosystem, but are still important and may require localised approaches to mitigate harms. Examples of contaminants that can affect the marine environment include:

- **Pollution from vehicles.** Heavy metal contaminants, oil and microplastic pollution are deposited on roads and then wash into waterways (The Office of the Prime Minister's Chief Science Advisor, 2019). Heavier road traffic near the coast is the biggest cause, as seen in Tāmaki Makaurau Auckland where marine sediments in the upper Waitematā Harbour have high levels of lead, zinc, copper and polycyclic aromatic hydrocarbons resulting from the discharge of stormwater from roading (Auckland Council, 2013; Abrahim and Parker, 2002).
- **Discharge of waste products.** Sewage and other pollutants in urban stormwater can make their way into the marine environment, typically during heavy rain or flooding. This can upset the balance of nutrients in the marine environment, create public health risks and result in the loss of amenity values, particularly when the sewage has not had adequate treatment (Ministry for the Environment and Stats NZ, 2019b). Increases in storm frequency, which may result from climate change, will increase the number of these discharge events.
- **Use of fertilisers.** When fertiliser is used, particularly for intensive farming, it frequently leads to nutrients washing into the marine environment, which can upset the nutrient balance and lead to excess growth of some organisms, including triggering algal blooms, deoxygenation and dead zones (Moreau *et al.*, 2019).
- **Materials and paints.** Pollutants and toxic substances can enter the environment after being released from materials such as unpainted galvanised iron roofs or antifouling paints used on boats.

All of these stressors provide challenges for commercial fisheries, who may need to harvest sustainably in a contaminated (and stressed) environment.

Figure 20: Heavy metal contaminants and other pollutants can enter the marine environment after being washed from roads.

3.1.2.3 FISHERIES MANAGEMENT AND LAND-BASED REGULATIONS ARE NOT INTEGRATED

Despite a strong evidence base showing that land-based activities affect our marine environment and fisheries, there has been limited work to incorporate this knowledge into management decisions or to manage land-based activities. There are increasing localised efforts to do so, but progress is slow given the challenges of balancing impacts of the sectors using the land. This does not necessarily indicate a legislative gap, but may represent a failure in implementation.

The *New Zealand Coastal Policy Statement 2010* does provide guidance to local authorities in their day-to-day management of the coastal environment, including guidance on waters managed or held under other Acts (see Policy 5).

Land-based activities affect our marine environment and fisheries, but there has been limited work to incorporate this knowledge into management decisions.

Some research, monitoring and restoration efforts are underway in Aotearoa New Zealand relating to land-based impacts on the marine environment, such as the Whaingaroa Harbour Caregroup in Raglan whose members plant trees to improve the coastal environment. The Integrated Kaipara Harbour Group is looking at some approaches to prevent and mitigate land-based impacts, including retiring steep slopes from productive use. Other multi-stakeholder groups are taking an integrated approach for land, water and infrastructure management to protect the marine environment including the Fiordland Marine Guardians (see 4.4.1: case study: Fiordland created a novel model for managing the marine area) and Te Korowai o te tai ō Marokura in Kaikōura (see 4.4.2: case study: Te Korowai o te tai ō Marokura in Kaikōura shows how regional responsibility can streamline fisheries management).

Improving the sustainability of our fisheries requires better management of land-based activities. This currently falls outside the realm of fisheries management but highlights the need for an integrated approach to both monitoring and management. A national view of the impacts of land-based influences upon seafood production does not exist; this could be facilitated by better coordination and planning of the many disparate marine monitoring programmes operating around the country. Estuary management would also need to be incorporated into an integrated approach. This would align with the Parliamentary Commissioner for the Environment's call for an approach to managing estuaries that treats estuaries and the waterways that feed into them as a single entity from the mountains to the sea, *ki uta ki tai* (Parliamentary Commissioner for the Environment, 2020b).

This discussion underpins recommendations in Themes 1-3.

3.1.3 DISEASES AND INVASIVE SPECIES THREATEN THE MARINE ENVIRONMENT

Invasive species are widely recognised as one of the greatest threats to marine biodiversity, having already transformed many marine habitats around the world (Molnar *et al.*, 2008). The most harmful of these displace native species, change ecosystem structure and food webs, and alter fundamental processes, such as nutrient cycling and sedimentation, all of which can trigger a loss of ecosystem services (Molnar *et al.*, 2008; Walsh *et al.*, 2016). Most invasive species do not permanently establish in a new environment, but when this does happen, the consequences can be significant.

Invasive species are widely recognised as one of the greatest threats to marine biodiversity, having already transformed many marine habitats around the world.

Figure 21: A biosecurity diver checks for invasive species. Image credit: Crispin Middleton/NIWA.

Pathogens and invasive species can enter and spread through the marine environment via vessels, human-mediated transfer, aquaculture, plastic pollution and other mechanisms (Diana, 2009). Global trade and transport are the leading way that bioinvasion occurs (Seebens *et al.*, 2013) and the risk of new species being introduced into ecosystems and disrupting biodiversity is growing because of increased marine traffic (Ministry for the Environment and Stats NZ, 2019b). Some border regulations and international policies already exist to reduce the risk of introduction of non-Indigenous species from the most common entry points, including requirements to demonstrate biofouling and ballast water management (Cunningham *et al.*, 2019). Efforts to actively prevent invasive species from entering regions throughout Aotearoa New Zealand help maintain biodiversity.

Other stressors on the marine environment increase the threat of invasive species displacing native species. Floating plastic can carry invasive species across our oceans (Rech *et al.,* 2016). Organisms can 'hitch a ride' on plastic and move into otherwise inaccessible territories (Gregory, 2009). The accumulation of plastic pollution in the ocean means this risk continues to increase (see section 3.1.4: Plastic pollution is building in the ocean). Climate change (discussed in section 3.1.1) is another stressor that will amplify the impacts of invasive species by making their spread, survival and establishment easier (Ministry for the Environment, 2020). Diseases and invasive species can enter from outside our waters but can also be spread domestically around Aotearoa New Zealand.

One example is toxoplasmosis, a disease caused by a parasite[41] which can infect Hector's dolphin/tūpoupou and Māui dolphin/popoto[42] populations. The parasite is spread into the marine environment through rainwater and run-off. There is a current action plan to mitigate the population decline caused by this disease (Department of Conservation, 2019a). This is an issue where many of the management strategies needed to reduce transmission are far-removed from the marine environment (e.g. reducing feral and stray cat populations). Another example

[41] *Toxoplasma gondii.*

[42] *Cephalorhynchus hectori hectori* and *Cephalorhynchus hectori maui*. The taxonomic status of Hector's and Māui dolphins is debated.

of a harmful parasite is *Bonamia ostreae*, which can kill Bluff or dredge oysters/tio[43] (Culloty and Mulcahy, 2007; Lane *et al.,* 2016). Overseas oyster fisheries have been severely damaged by the parasite and similar impacts are possible here – the parasite was first detected in Te Tauihu-o-te-Waka the Marlborough Sounds in 2015. The Ministry of Primary Industries-led long-term management response includes a governance group comprising of many different players (Biosecurity New Zealand, Aquaculture New Zealand, Fisheries New Zealand, Environment Southland, Awarua Runaka, Southland District Council, and the Bluff wild oyster fishery).

Recognising the growing threat of diseases and invasive species to the marine environment, some regional approaches to marine management are prioritising biosecurity. For example, Te Korowai o te tai ō Marokura in Kaikōura (outlined in case study 4.4.2) are looking to the approaches used by the Northland and Southland regional councils for inspiration. The Fiordland Marine Guardians (outlined in case study 4.4.1) have taken it further by being the first area to implement a domestic pathway management plan, which sets out rules and standards that must be met by all vessels entering the region for biosecurity (Cunningham *et al.*, 2019).

Increasing pathogens and invasive species will make marine ecosystems less resilient to other stressors and the establishment of invasive species and introduction of disease could have major consequences for the commercial fishing industry. Actions to reduce the risk from invasive species and diseases will be important to maintain a sustainable commercial catch.

3.1.4 PLASTIC POLLUTION IS BUILDING IN THE OCEAN

Most plastic that enters the environment ultimately ends up in the ocean. Local charity Sea Cleaners remove approximately 160,000 litres of rubbish from Aotearoa New Zealand's marine environment every month.

Figure 22: Ghost gear and other waste made of plastic and other materials washed ashore on Te Hauturu-o-Toi Little Barrier Island. Image credit: Simon Thrush.

Of the 86 million tonnes of plastic thought to be in oceans worldwide, it is estimated that 80% came from land and the remaining 20% from activities at sea – with commercial fisheries being a large contributor (Li *et al.,* 2016). Estimates indicate that around 99.5% of the plastic in the ocean is below the surface where it damages habitats or is mistaken for food, contributing to declines in marine biodiversity (WWF, 2015; UNEP, 2016; Royal Society Te Apārangi, 2019).

Plastic is known to impact commercial fisheries stocks or the ecosystems that they rely on through physical harm (e.g. entanglement) or through other physiological impacts that occur after ingestion and Fisheries New Zealand collects some data from observers on these impacts. Species at all trophic levels can be affected, with plastic particles and the associated chemicals accumulating up the food chain. Plastic has been identified in the guts of finfish in Aotearoa New Zealand, including commercial species (Markic *et al.*, 2018). For fish sampled in Auckland

[43] *Ostrea chilensis.*

there was a 16.3% overall ingestion rate which was comparable to global ingestion rates (Markic *et al.*, 2018). Plastics have also been identified in green-lipped mussels around Aotearoa New Zealand (Webb *et al.*, 2019).

The physiological impacts of ingesting plastic are not clear-cut and further research is needed, but emerging evidence on a range of species at different trophic levels suggests it can cause physiological changes in health and reproduction. The impacts differ depending on whether macro-, micro- or nano-plastics are ingested, the plastic's associated chemicals, and the concentration at which these chemicals accumulate up the food chain (The Office of the Prime Minister's Chief Science Advisor, 2019).

Plastic in the marine environment may also help spread pathogens and invasive species, contributing to the issues discussed in section 3.1.3. A local study looking at plastic debris on 27 beaches along Te Tara-o-te-Ika a Māui the Coromandel Peninsula found that plastic poses a high biosecurity risk, with both native species and non-Indigenous marine species being brought into the environment on plastic. Rope debris from fisheries and aquaculture operations was the leading way that biosecurity pests were carried in (Campbell *et al.*, 2017).

The plastic pollution crisis has a significant negative impact on the marine environment and the organisms within it, so poses a direct risk to the sustainability of our fisheries. The cumulative effects of plastic causing physical or physiological harm to species, disruptions to ecosystems and habitats, and introducing invasive species to new environments, will have negative impacts on our commercial fish species and the ecosystems that they rely on.

The plastic pollution crisis has a significant negative impact on the marine environment and the organisms within it, so poses a direct risk to the sustainability of our fisheries.

Plastic breaks down over time into smaller pieces. The amount of plastic that can enter the food chain will therefore continue to increase as the available particles get smaller and can be ingested at lower trophic levels. The impacts of plastic pollution on fisheries is likely to get worse over time.

Currently the data we collect on plastic in the marine environment, the impacts on species and ecosystems, and the presence of plastic in marine organisms is limited and fragmented. The issue of plastics in seafood is likely to gain considerable traction in the coming years. A coordinated effort to research and monitor plastic ingestion and physiological outcomes, particularly on our commercial fisheries, is necessary.

Fisheries exports may be hindered by the contamination of seafood in the future. Microplastics are considered an emerging threat to food security (De-la-Torre, 2020). Depending on what comes to light as more research is undertaken to assess the human health impacts of ingesting plastic-contaminated seafood, there is a chance that regulatory restrictions relating to food contamination could include microplastics and nanoplastics.

Microplastics are considered an emerging threat to food security.

Importantly, even without evidence of harm or regulatory action, public perception of plastics in seafood could have a seriously negative impact on the industry. If seafood is seen as a route for microplastics and associated chemical pollutants to enter the human diet, it may deter people from eating it. Aotearoa New Zealand's commercial fisheries sector is particularly vulnerable to the economic implications associated with plastic in the marine environment because we market our seafood as pure and grown in pristine conditions.

While most of the plastic in the marine environment is outside the control of the commercial fisheries sector, a significant proportion is thought to come from commercial fishing activities. The UNEP estimates at least 640,000 tonnes of fishing gear are lost every year (Macfadyen *et al.,* 2009). Ghost gear (abandoned, lost or discarded fishing gear) is a significant issue in the marine environment, some of which is plastic. The scale of ghost gear is considerable and as a result, it is recognised as a growing threat to marine life that urgently needs to be addressed. The industry can therefore make a significant difference to reduce the negative impacts of plastics on fisheries by taking action to reduce plastic use and loss through fishing activities, building on the initial steps made such as not using fish aggregating devices (FADs) in Aotearoa New Zealand waters (with some high sea exceptions) and supporting the draft FAO's Voluntary Guidelines on Marking Fishing Gear in 2018.

The UNEP estimates at least 640,000 tonnes of fishing gear are lost every year.

These issues relating to plastic in the marine environment and possible actions for the fisheries industry to take are discussed in more detail in the *Rethinking Plastics in Aotearoa New Zealand* report released by our Office in December 2019 (The Office of the Prime Minister's Chief Science Advisor, 2019). The report highlights the need for the fisheries sector to take action on plastics. It includes recommendations to Government to:

- undertake analyses to model the economic, socioeconomic and environmental benefits of changing to more sustainable plastic use on the fisheries sector, and
- to facilitate an active dialogue around rethinking plastics, by setting targets and identifying opportunities to keep plastics in circulation or shift to more sustainable alternatives.

Some work is already underway by the Ministry for Primary Industries which may help to address the issues outlined above, starting by quantifying the issues of plastics in the marine environment via fish catches, microplastics from plankton recorder transects, and the frequency and density of marine litter on the seabed.

3.1.5 CUMULATIVE EFFECTS MEAN THESE STRESSES COMPOUND

Our marine environment and the ecosystems within it are in their current state because of many different stressors, including those already outlined, as well as fishing, as detailed in section 3.3. Looking at issues in isolation fails to appreciate that these stressors can overlap in space and time and that a single activity can generate multiple pressures.

Figure 23: In the early 1990s, the northwest Atlantic cod (*Gadus morhua*) fishery collapsed after reaching a tipping point. Image credit: Matthieu Godbout/Wikimedia (CC BY-SA 3.0).

Species' responses to different stressors can be non-linear and can cause cascading effects within an ecosystem (Hodgson *et al.,* 2019). Understanding cumulative impacts is key to predicting and preventing irreversible tipping points (Thrush *et al.*, 2020).

Fisheries collapse is one type of tipping point driven by a range of direct and indirect factors. Perhaps the most famous example is the collapse of the northwest Atlantic cod[44] fishery in the early 1990s, which led to a moratorium on fishing (Myers *et a*l., 1997). Coral transitions are another well-known tipping point, where reefs shift from hard coral cover to macroalgal cover (Lowe *et al.*, 2011). These shifts can be driven by a complex array of phenomena, including climate change, sedimentation, pollution, and overfishing. An example in Aotearoa New Zealand is the collapse of the Tasman and Golden Bay scallop/tupa[45] fishery (Peart, 2018).

[44] *Gadus morhua.*
[45] New Zealand scallop, *Pecten novaezelandiae.*

Aotearoa New Zealand's coastal and marine systems are vulnerable to rapid changes or tipping points because our disconnected frameworks currently do not take an approach focused on cumulative effects (Davies *et al.*, 2018).

Aotearoa New Zealand's coastal and marine systems are vulnerable to rapid changes or tipping points because our disconnected frameworks currently do not take an approach focused on cumulative effects.

Understanding the consequences of multiple stressors and accounting for these in fisheries management decisions is crucial to preserve our marine ecosystems for years to come. Recent case law has shown that decisions under the Resource Management Act (RMA) 1991 may impact on commercial fishing (see 4.4.3: case study: The establishment of the Motiti Protection Areas sets a new precedent for local coastal management). Cumulative effects must be considered under both the Resource Management Act 1991 and the Fisheries Act 1996 but there is significant room for improvement in how cumulative effects are assessed and accounted for in practice under both statutes. Taking a cumulative impacts approach acknowledges that commercial fishing is not the only stressor on an ecosystem, while also recognising that a more precautionary take may be necessary because of reduced resilience in that system caused by multiple stressors.

3.1.5.1 APPLYING CUMULATIVE EFFECTS ASSESSMENTS IN DECISION MAKING IS CHALLENGING

The activities that affect the marine environment are multifaceted and varied. Their consequences are too. This makes it complex to study and model the outcomes. Multiple methods to assess cumulative pressures and impacts exist, but each are limited in some way. Mapping methods can reveal what species overlap with stressors, but this relies on assumptions about impacts being direct and additive (Hodgson *et al.,* 2019). Experimental methods can delve into how different stressors interact – whether additive, indirect or cascading – but applying this to a large number at once is not feasible.

Figure 24: Effective management of fisheries and the ocean requires consideration of cumulative impacts: from the land to the sea, *ki uta ki tai*.

Advances in systems thinking, methodological improvements, increasing access to big data, and integration of assessments into legislation and regulations are making the study and application of cumulative effects modelling more feasible (Hodgson *et al.,* 2019). These assessments can be used in EAFM (see section 2.7.5: Ecosystem thinking), marine spatial planning (see 3.3.5: case study: Managing land-based impacts through a multi-sector marine spatial plan) and conservation planning. Guidance on systems thinking and place-based understanding of environmental changes could be drawn from mātauranga Māori (see section 2.7.1: Te ao Māori) (Davies, *et al.*, 2018a). Mātauranga can guide more holistic and integrated approaches for environmental decision making (Clapcott *et al.*, 2018). Concepts such as *ki uta ki tai* (from the mountains to the sea) reflect this holistic understanding of the environment and resource management.

Concepts such as *ki uta ki tai* (from the mountains to the sea) reflect this holistic understanding of the environment and resource management.

We first need to overcome some practical obstacles in order to implement cumulative effects assessments more widely (Davies *et al.*, 2020). Gaps in ecosystems and species data, or inaccessibility of data (as discussed in section 5.3: Commercial fishing has impacts on target species sustainability and section 3.3 Fishing effort has wider ecosystem impacts), will hinder applications. We will never gather all the data needed to fully understand the cumulative impacts of stressors. A more realistic objective is to have sufficient information to allow more balanced decisions under unavoidable uncertainty (Hodgson *et al.*, 2019). Use of more consistent definitions and methods will also help to standardise processes and facilitate comparisons across systems and studies. Moving away from siloed approaches to more collaborative and connected structures that take a holistic approach to management will further facilitate these efforts.

We will never gather all the data needed to fully understand the cumulative impacts of stressors. A more realistic objective is to have sufficient information to allow more balanced decisions under unavoidable uncertainty.

This underpins recommendations in Themes 2 and 3.

As a starting point, the Sustainable Seas National Science Challenge (see 5.8.1: case study: Sustainable Seas/Ko ngā moana whakauka) developed the Aotearoa Cumulative Effects framework, a decision-making tool which guides collaborative cumulative effects management through a series of questions (Davies, 2019).

Davies (2019) also identified gaps and where future efforts should be focused:

- Analysis of existing methods, tools and data to identify and assess cumulative effects,
- Developing guidelines/guidance for assessing cumulative effects in Aotearoa New Zealand,
- Conceptual models, risk assessments, and gap analyses to help identify sources of uncertainty and their importance, and
- Further testing and trialling of these principles and the Aotearoa Cumulative Effects framework in real-world case studies to adapt these tools for use across spatial and temporal scales.

Whether a particular fishery can cope with losing a proportion of its population each year depends on more than the amount taken. The fishery may be under stress from sedimentation occurring in the nursery ground and destroying the juvenile habitat, or may have to adapt to changing environmental conditions that reduce food availability. Neglecting to consider the wider pressure on the ecosystem may increase the risk of collapse because the population may be less resilient (Davies, *et al.*, 2018b; Ehrhart *et al.,* 2020). Ultimately, even though it is complex and difficult to implement cumulative impacts assessment, fisheries management cannot afford not to do this.

Whether a particular fishery can cope with losing a proportion of its population each year depends on more than the amount taken.

3.2 COMMERCIAL FISHING HAS IMPACTS ON TARGET SPECIES

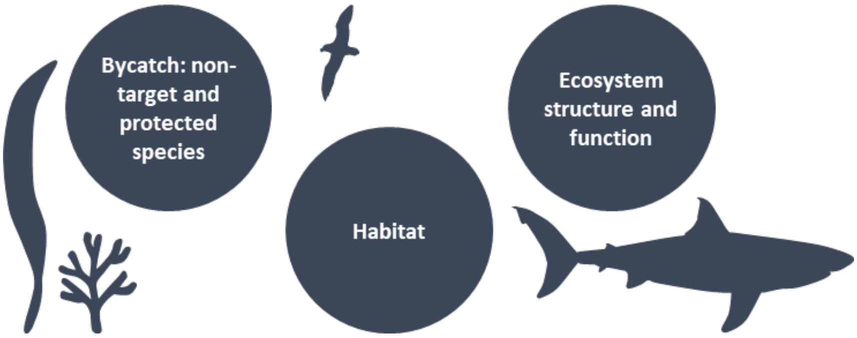
By definition, commercial fishing has a direct impact on the species that are harvested. Since harvesting of target species is discussed in depth in part 5, this obvious impact is not discussed further in this section.

Figure 25: A local fisher unloads his catch of snapper on Auckland's waterfront in the mid-1970s. Image credit: photographer unknown/NIWA.

3.3 FISHING EFFORT HAS WIDER ECOSYSTEM IMPACTS

Fishing is one of the stressors on the marine environment. The stress imposed by fishing is not uniform – the relative importance of fishing as a detrimental impact on the ecosystem depends on location, target species, size of catch and the methods used (illustrated in section 5.3). This section of the report explores what we know about the impacts of fishing on marine ecosystems, current data and reporting of this information and related measurements of performance, and opportunities for improvement in the future.

Data that helps us understand ecosystem health and the role that fishing and other impacts can cumulatively play in driving ecological change is important to manage a fishery, in addition to data on single-species and fish stocks covered in part 5. Knowledge about species and habitats is a key component of understanding these impacts, but exploration of Aotearoa New Zealand's marine environment is still at an early stage (Jarvis and Young, 2019). This section is separated into the following areas:



Much of our monitoring and data collection is focused on commercial species, which are not necessarily good proxies for ecosystem health. There are many clear and well-studied environmental impacts of fishing activities but there are also significant data and knowledge gaps. The Ministry for the Environment states that there is insufficient information about tipping points in our marine ecosystems, as well as the environmental limits around the sustainable use of marine resources (Ministry for the Environment and Stats NZ, 2019a). This is partly due to a strong focus on managing stocks and some direct environmental impacts rather than considering the broader ecosystem effects (which require more information and are harder to predict).[46]

> There are many clear and well-studied environmental impacts of fishing activities but there are also significant data and knowledge gaps.

The Ministry for the Environment reports on environmental performance, including pressures and changes. The most recent environmental reporting on the marine environment (including oceans, seas, coastlines and estuaries) was delivered in 2019 and occurs every three years (Ministry for the Environment and Stats NZ, 2016; Ministry for the Environment and Stats NZ, 2019b).

Fisheries New Zealand also reports on environmental and ecosystem factors in their Aquatic Environment and Biodiversity Annual Review (AEBAR). The AEBAR is published every year although not all sections are updated annually (they are updated as new information becomes available and are substantially overhauled when large pieces of research are completed). Research is also undertaken by the Department of Conservation, particularly through their Conservation Services Programme.

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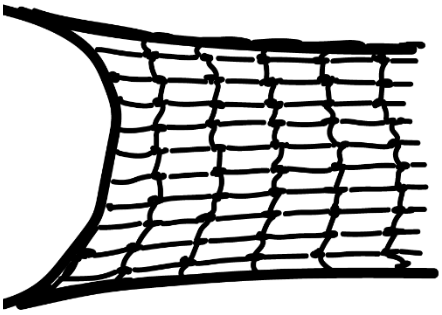
[46] See Fisheries New Zealand statement on how they manage to ensure fishing is sustainable.

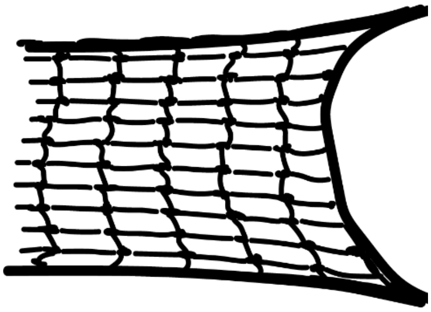
3.3.1 MOST COMMON COMMERCIAL FISHING METHODS

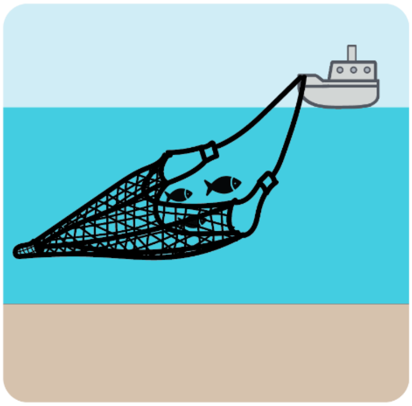
The schematic gives a high level overview of fishing methods used commercially, with some pros and cons of each method, to guide the non-expert reader.



NETS

Ability to catch many fish quickly but can bruise or damage fish





Trawling

Dragging a net through the water behind a vessel.

✓ Efficient way to catch lots of fish. Provides 84% of NZ's catch by volume

? Bycatch depends on location, depth, mesh size, exclusion devices and acoustic deterrents

Midwater

✓ Very little seabed damage

Jack mackerel

Bottom – net stays in contact with seafloor

⊗ High risk of seabed habitat damage

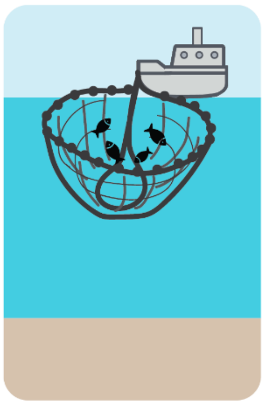
Orange roughy

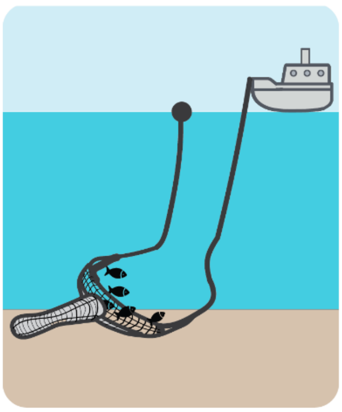
Purse seine

A net is dropped near the surface and pulled together like a drawstring.

✓ Low bycatch, unless FADs used

Skipjack tuna





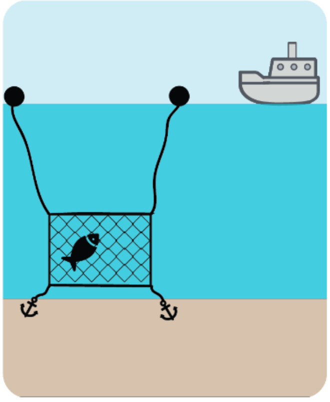
Danish seine

A conical net with two wings is dropped near or on the seafloor. The wings and ropes encircle fish and herd them into the net.

✓ Can be selective if schools of fish targeted

⊗ Risk of damage to seabed habitats

John Dory



Set gillnet

Anchoring a net halfway down or near to the seafloor. Fish swim into the net and get stuck

ⓧ High risk of bycatch depending on location, mesh size, exclusion devices and acoustic deterrents
Rig

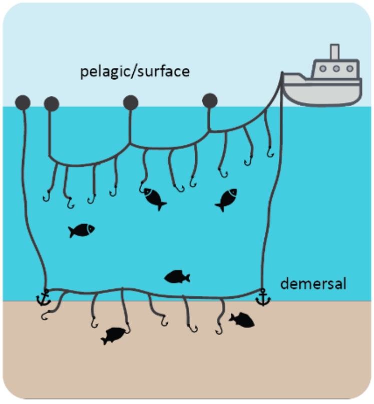
LINES

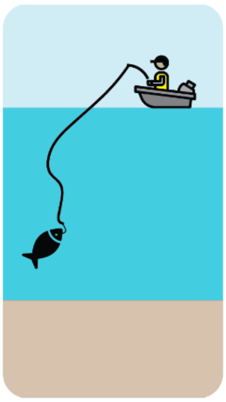
Doesn't bruise fish and causes minimal other damage but catch limited by number of hooks

Longlining

Using a very long fishing line with shorter lines and baited hooks every few feet

ⓘ Bycatch is variable depending on fishery, proximity to surface, time of day, hooks and weighting
Snapper





Handlining

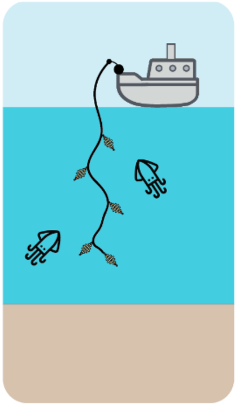
A fishing pole and line mainly used by recreational fishers.

✓ Low risk of bycatch

Trolling

Using a line or multiple lines with lures and dragging horizontally through the water to simulate prey movement

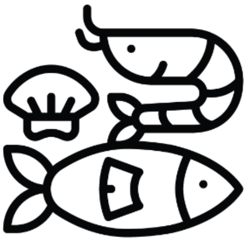
✓ Selective, low risk of bycatch
Albacore tuna



Jigging

Using a line and moving it up and down to attract target species

- Selective, low risk of bycatch
- Squid

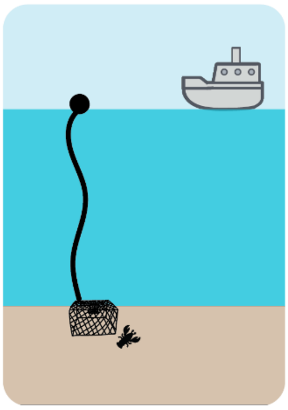


OTHER METHODS

Dredging

Vessel tows a steel net (dredge) along the seafloor and scrapes up all the shellfish living there

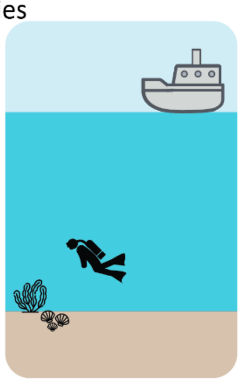
- High risk of habitat damage
- Oyster



Trapping

Potting: a pot-like trap attached to a long rope is baited, dropped in the water and retrieved later. Once entered, the target marine organism can’t escape.

- Some bycatch can escape via gaps
- Difficult to scale, only effective for some species
- Rock lobster



Diving

Hand gathering

- No bycatch
- Labour intensive
- Pāua

Icons adapted from Zlatko Najdenovski, Freepik, monkik, iconixar, mavadee and eucalypt via Flaticon.

3.3.2 BYCATCH OF NON-TARGET AND PROTECTED SPECIES

Non-target species or bycatch are those taken as catch during fishing operations where they are not the intended target of fishers. While bycatch of marine mammals, seabirds and sharks is an issue often highlighted in the media, invertebrates and non-target fish species are also caught as bycatch (including protected species). There is significant bycatch of non-target species every year – much of which is dead on recovery or killed by predators if returned to the ocean (Roux *et al.*, 2015; Griggs *et al.*, 2018; Ministry for Primary Industries, 2020a). While there can be direct mortality (e.g. death from crushing or drowning in trawls, entanglement in longlines), individuals may survive the initial capture but have variable levels of survivability on release due to injury or shock.

There is significant bycatch of non-target species every year – much of which is dead on recovery or killed by predators if returned to the ocean.

Key bycatch of commercial fishing effort includes:

- Non-target fish and invertebrates (includes some protected species),
- Sharks, rays and chimaeras (includes some protected species),
- Seabirds (protected, except black-backed gulls/karoro),[47] and
- Marine mammals (protected).

Non-target fish can include those that are desirable commercial species but are undersized (not able to be legally landed) or those for which fishers do not have ACE. Issues relating to discards of non-target fish are discussed in section 5.2.2.2: Discards.

Innovative approaches to reduce bycatch and avoid interaction with protected species are included in section 6.3: How we fish and section 6.5: Where and when we fish.

Figure 26: Mixed species bycatch from a deepwater trawl. Image credit: MPI/NIWA.

[47] *Larus dominicanus dominicanus*

3.3.2.1 DATA COLLECTION

Bycatch and discards data currently relies heavily on observer coverage and may sometimes assume there is no difference in fishing practices between observed and fishing trips (Anderson *et al.,* 2019). However, this is not the case (Bremner *et al.*, 2009; Simmons *et al.*, 2016; Hoyle *et al.*, 2017; McCormack, 2017; Winder, 2018). Observed bycatch is consistently much greater than that self-reported by fishers, which needs to be accounted for when interpreting bycatch data.

Observed bycatch is consistently much greater than that self-reported by fishers.

While protected species impacted by fisheries activities have been studied, this research and assessment is also impacted by wider issues in fisheries data collection and reporting (discussed in section 5.5.4: Data transformation strategy). Issues include electronic reporting data from observers not being directly included in the Centralised Observer Database, and errors in how data is entered and linked (Abraham and Berkenbusch, 2019). Multiple organisations could benefit from working with observer capture data, so developing collaborative working methods would be beneficial for consistency, reliability and timeliness of protected species bycatch data (Thompson *et al.*, 2017). Some government organisations do already work together through the Marine Hub (a policy development and advice group).

In general, most ecological risk assessments undertaken for Aotearoa New Zealand fisheries have been qualitative or semi-quantitative (Ford *et al.*, 2018), which points to a lack of comprehensive or in-depth data being available. Actively seeking this information should be an integral part of the stock assessment process, which currently has a single-species focus, as discussed in section 5.2.2: Setting catch limits and allocating catch allowance. The most recent assessments for marine mammals and seabirds do include quantitative risk assessments, but note areas where little quantitative information is available. For example, potentially key threats to Hector's and Māui dolphins such as climate change effects and seismic disturbance were not addressed quantitatively (Roberts *et al.*, 2019); there was little quantitative information to inform cryptic mortality for seabirds (Richard *et al.*, 2020), and Abraham *et al.* (2017) noted in the *Assessment of the risk to New Zealand marine mammals from commercial fisheries* that "for most species, the assessment relied on expert judgement to derive distributions for marine mammals. A quantitative analysis of the distribution of New Zealand marine mammals would help improve the estimation of fisheries-related fatalities."

Most ecological risk assessments in Aotearoa New Zealand have been qualitative or semi-quantitative, which points to a lack of comprehensive or in-depth data being available. Actively seeking this information should be an integral part of the stock assessment process.

Long-term datasets on bycatch species, outside of landings, is an area that could be improved for many species and locations. One-off surveys may be the only historical data in many cases. While these datasets are very valuable, access could reportedly be improved to facilitate more analysis of this data (The Sustainable Future Institute, 2011; The Nature Conservancy, 2017; Ministry for the Environment and Stats NZ, 2019b). This is discussed further below.

These considerations underpin recommendations in Themes 5 and 6.

3.3.2.2 CURRENT REPORTING AND PERFORMANCE

Issues relating to bycatch are detailed every year by Fisheries New Zealand in their AEBAR (Fisheries New Zealand, 2018a), so a comprehensive discussion of bycatch is available for analysis in those reports. Table 2 summarises information Fisheries New Zealand presents as 'Indicators and Trends' in the 2019-2020 AEBAR.

Table 2: Summary of indicators and trends from 2019-2020 AEBAR.

Indicator	Measurement	Summary extracted from Ministry for Primary Industries (2020)
Non-target fish and invertebrate catch		
Annual discards as a fraction of the catch of the target species	Mean discard fraction.	Largest mean discard fraction – scampi[48] trawl fishery, 3.8 kg of bycatch is discarded for every kg of scampi caught. Smallest discard fraction – oreo[49], jack mackerel/hautere[50], and southern blue whiting[51] fisheries (0.01 kg). Trends are provided for some individual fisheries.
Sharks, rays and chimaeras (Chondrichthyans)		
Risk assessment and threatened species classification	Qualitative risk assessment and CPUE analysis for some QMS stocks; Qualitative risk assessment and relative biomass trends for some non-QMS species.	There are 11 species of shark in the QMS. CPUE analysis have been completed for six species only. School shark/tope[52] and elephant fish/makorepe[53] are declining in some areas, but all others are stable or increasing. Trends in abundance of eight non-QMS species provided are mostly stable or increasing, except for pale ghost shark.[54] Some species are classified as threatened or endangered.
NZ seabirds		
Population size	Periodic estimate (2,000).	Not reported: multiple species (Taylor, 2000).
Population trend	Periodic estimate (2,000).	Not reported: multiple species (Taylor, 2000).
Threat status	Multiple species (NZ threat status updated 2017).	Not reported: multiple species (Robertson *et al.,* 2017). Many species are classified as threatened or endangered.
Number of interactions	Estimated captures by bird group and fishery.	In 2017-2018 an estimated 3,329 seabirds were captured.
Trends in interactions	Estimates captures by bird group.	Total captures of all seabirds show a decreasing trend between 2002-3 and 2016-17, except for white-chinned petrel.[55] Detail provided for several seabird species. A quantitative spatially explicit risk assessment (completed in 2020) ranks the risks to each seabird species or group.

[48] *Metanephrops challengeri.*
[49] Includes three species managed as one stock: black oreo (*Allocytus niger*), spiky oreo (*Neocyttus rhomboidalis*) and smooth oreo (*Pseudocyttus maculatus*).
[50] *Trachurus symmetricus.*
[51] *Micromesistius australis pallidus.*
[52] *Galeorhinus galeus.*
[53] *Callorhinchus milii.*
[54] *Hydrolagus bemisi.*
[55] *Procellaria aequinoctialis.*

Indicator	Measurement	Summary extracted from Ministry for Primary Industries (2020)
NZ sea lion/rāpoka[56]		
Population size	Periodic estimates, Department of Conservation unpublished data.	Total population size in 2016: 11,755 New Zealand sea lions including pups. Number of pups born in 2019-20: Maungahuka Auckland Islands – 1,740; Motu Ihupuku Campbell Island – 595; Rakiura Stewart Island – 48; and Otago Coast – 21.
Population trend	Time series (1990-2020) of estimated annual pup production at Maungahuka the Auckland Islands, Motu Ihupuku Campbell Island, Rakiura Stewart Island, and New Zealand South Island, variable number of data points depending on location.	Annual pup production generally increasing (NZ Mainland, Rakiura Stewart Island, Motu Ihupuku Campbell Island). Maungahuka Auckland Island previously decreasing, more stable since 2010.
Threat status	New Zealand/IUCN threat status.	Nationally Vulnerable/Endangered.
Number of captures	Observed captures in trawl fisheries from 2016-2019.	Three observed captures in trawl fisheries in 2016-17. Seven observed captures in trawl fisheries in 2017-18. Seven observed captures in trawl fisheries in 2018-19.
Trends in observed captures (both sexes)	Graph showing observed captures across all Maungahuka Auckland Islands trawl fisheries (dead or alive) by sex from 1992-2020.	Observed captures have trended down since 2000-2001 but increased slightly in 2016-2019.
Trends in estimated deaths (females only)	From Large *et al*. 2019. Graph showing annual estimate of female deaths across SQU, SCI, OTH fisheries from 1993-2017.	Estimated deaths (females only) have trended down since 1993, with an increase in the years between 2002 and 2006. Spatially explicit risk assessments identify spikes in risk to females in the bottom trawl squid fishery 1994-97 and 2005-6.
NZ fur seal/kekeno[57]		
Population	Unknown. Rough estimate from papers 20-30 years ago.	Unknown, potentially 100,000 in New Zealand EEZ.
Population trend	Commentary. Trends known for some mainland colonies but not for offshore island colonies.	Increasing at some mainland colonies. Range thought to be increasing.
Threat status	New Zealand/IUCN threat status.	Not Threatened/Least Concern.
Number of interactions	Estimated captures in 2015/2016. Observed captures in 2017/2018. Estimated annual potential fatalities (Abraham *et al*., 2017).	Trawl fisheries: 80 observed catches (2017-18), 375 estimated captures (2015-16). Surface-longline fisheries: 12 observed captures (2017-18), 24 estimate captures (2015-16). All fisheries: 949 estimated annual potential fatalities (2017).

[56] *Phocarctos hookeri.*
[57] *Arctocephalus forsteri.*

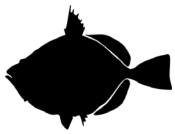
Indicator	Measurement	Summary extracted from Ministry for Primary Industries (2020)
Trends in interactions	Trawl fisheries observed captures (dead, alive, and rate per tows) and proportion of tows observed (2003-2018). Surface-longline fisheries observed captures (dead, alive, and rate per hooks) (2003-2018) and estimated captures (2003-2016).	In trawl fisheries, the rate of observed captures has decreased over time while observer coverage has increased. In surface-longline fisheries, the rate of observed captures has seemed to trend up from 2009 (rate of observer coverage not shown) and possibly dropping from 2015. Estimated captures are around four to seven times higher than observed captures.
Hector's dolphin and Māui dolphin		
Population size	Hector's dolphin: annual estimates for east coast, west coast and south coast of South Island. Māui dolphin: periodic estimates (2011, 2015).	Hector's dolphin: median estimates of 8,968 (East Coast SouthIsland.), 5,388 (West Coast South Island), 217-508 (95% c.i. South Coast South Island) & unknown (North Coast S.I). Māui dolphin: 63 (in 2015-2016), 55 (in 2010-2011).[58]
Population trend	Hector's dolphin: Unknown. Māui dolphin: Periodic estimates.	Hector's dolphin: Unknown (inconsistent evidence, uncertainty). Māui dolphin: Declining over longer period, possible stabilization in recent years.
Threat status	New Zealand/IUCN threat status.	Hector's dolphin: Nationally Vulnerable/Endangered. Māui dolphin: Nationally Critical/Critically Endangered.
Number of fisheries deaths (includes cryptic deaths)	A spatially explicit risk assessment is used to estimate the risks from different threats, including fishing (Roberts *et al.* 2019). Only fisheries observer data are used as inputs to the model.	Hector's dolphin: set nets (estimated 44), trawl (estimated 14). Māui dolphin: set nets (estimated 0.10), trawl (estimated 0.02).
Trends in interactions	Commentary.	Hector's dolphin: set net stable,[59] trawl decreasing. Māui dolphin: set net decreasing, trawl decreasing.
NZ common dolphin/aihe[60]		
Population size	No measurement.	Unknown in Aotearoa New Zealand but 4,000,000 worldwide.
Population trend	Unknown.	Unknown.
Threat status	New Zealand/IUCN threat status	Not Threatened; Data Poor, and Secure Overseas (2013). IUCN: Least Concern.
Number of interactions	Periodic estimated and observed captures	Most recent estimates in 2017 of 143 annual potential fatalities. One observed capture in trawl fishery in 2017-2018.
Trends in interactions	Graphs of observed captures (dead, alive, rate per tows) (2003-2018) and estimated captures (2003-2015)	Captures have decreased in the jack mackerel trawl fishery since 2003. Captures in trawl fisheries have fluctuated since 2003.

[58] Note these numbers are contested (Brownell Jr *et al.*, 2019).
[59] In late 2020, bans on trawling and set nets around much of the South Island and the West Coast of the North Island were extended.
[60] *Delphinus delphis.*

In general, there are many areas where data is not available and conclusions cannot be drawn regarding trends. Further discussion is provided for each of the following categories, by way of example:

- Non-target fish and invertebrates.
- Sharks, rays and chimaeras.
- Seabirds.
- Marine mammals.

NON-TARGET FISH AND INVERTEBRATES



While many non-target species sit within the QMS, they may not be assessed at all if they are considered nominal stocks (see section 5.2.2.5) or may not be scientifically evaluated if data is lacking.

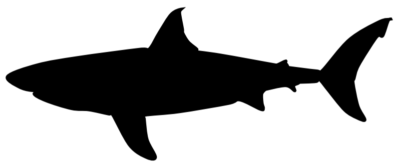
Non-target fish species are less studied in general so non-direct impacts on stocks and sustainability are also not well understood. For example, the impact of marine reserves on non-target species has not been the focus of monitoring surveys (Díaz-Guisado, 2014). While ecosystem change is a common threat to species recovery, often very little is known about the species themselves (Hare *et al.*, 2019). In Aotearoa New Zealand, deepwater surveys catch and record data on 200-300 species and inshore surveys catch and record data for 120-140 species (although not in all areas, e.g. north-east North Island). However, only data for key survey species is used routinely for stock assessment. Consequently, even where data may be available there is a lack of knowledge in this area.

Fisheries New Zealand reports in the AEBAR (2020) that there are "trends showing increased rates and levels of catch and discarding of several non-target species or species categories, especially some non-QMS fish species and invertebrates" (Ministry for Primary Industries, 2020a).

> "Trends showing increased rates and levels of catch and discarding of several non-target species or species categories, especially some non-QMS fish species and invertebrates."
> - AEBAR 2020.

Coral, most species of which are protected under the Wildlife Act 1953, occur as bycatch, particularly in deepwater bottom trawling fisheries and with dredging (Tracey *et al.*, 2020). Any protected coral accidentally brought to the surface must be immediately returned to the sea. Corals that are habitat-forming can also provide important habitat for other species and coral communities are slow to recover from fishing impact (discussed further in section 3.3.3: Habitat).

SHARKS, RAYS AND CHIMAERAS



While some shark species are target stocks for commercial fisheries, others are non-target or protected but may be incidentally caught in fishing gear given the significant overlap of sharks and fishing effort (Francis, 2017a, 2017b; Queiroz *et al.*, 2019).

Sharks are a significant player in marine ecosystems as an apex predator and control populations of other species. Their niche is similar to tuna, so they can often be caught in commercial (and recreational) fisheries targeting tuna stocks. However, there is reportedly very little knowledge on sharks in Aotearoa New Zealand (Finucci *et al.*, 2019b; Pinte *et al.*, 2020). Choosing the most appropriate management approach for conservation of sharks is heavily dependent on our knowledge, much of which comes from commercial fisheries reporting (MacNeil *et al.*, 2020).

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There is a *National Plan of Action for the Conservation and Management of Sharks* (Ministry for Primary Industries, 2013b), which focuses on conserving and managing sharks taken in Aotearoa New Zealand fisheries. This plan differs from others in that some shark species are commercially-targeted (e.g. rig/spotted dogfish[61], school shark and elephant fish). There are also regular risk assessments of commercial fishing to New Zealand chondrichthyans (which includes sharks and other cartilaginous fishes like rays) (Ford *et al.*, 2018). While the risk assessment states that "available information did not suggest that commercial fishing is currently causing, or in the near future could cause, serious unsustainable impacts", it also states that there was low confidence in many of the risk scores. The risk assessment was qualitative, though it notes that the increasing amount of data means quantitative techniques could be applied to some shark species in the medium term to improve assessment of fisheries risk to those species. The assessment also identifies short-term opportunities that can be taken for some species including:

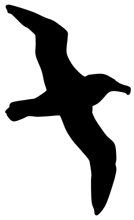
- Reviewing data that has already been collected from trawl surveys (such as catch rates and biological information).
- Analysing overlap between fisheries activity and shark distribution range at a finer scale.
- Undertaking biological studies to improve estimates of population parameters.
- Developing indicators of abundance for species where this is currently lacking.
- Increasing taxonomic or observer education on identifying sharks.

These are opportunities that could be applied to many species to make better use of available information and to strengthen data collection methods. There is reportedly an improved risk assessment process being planned under the next shark *National Plan of Action*, as the plan is currently being advised and updated.[62]

Other gaps are in understanding of post-release mortality of some shark species (Francis, 2017a). While targeted research on some shark species is likely to be difficult and expensive, (Francis, 2017b) recommends increasing biological data take from bycatch and tagging of sharks to increase information on movements and stock range. Research that has already been undertaken includes tagging of great white sharks/mangō-taniwha[63] using a range of techniques since 2005 (Hillary *et al.*, 2018). This has helped us build our understanding of large-scale migration patterns and sets a foundation for more targeted research, such as identifying hotspots of abundance (Francis, 2017a). An environmental DNA study was undertaken in California to inform fisheries management of great white sharks in real time; similar approaches could provide opportunities for conservation efforts in Aotearoa New Zealand (see 6.4.17: case study: Managing great white shark conservation through eDNA).

[61] *Mustelus lenticulatus.*
[62] Input from Fisheries New Zealand.
[63] *Carcharodon carcharias.*

SEABIRDS



There is a *National Plan of Action* to reduce the incidental catch of seabirds in New Zealand fisheries (Ministry for Primary Industries, 2013a), which has been updated in 2020 (Fisheries New Zealand and Department of Conservation, 2019, 2020). The vision for the plan is to work towards zero fishing-related seabird mortalities and has eleven measurable objectives to work towards achieving the plan's goals. The ministries describe understanding how seabirds and fisheries interact, and what impact this has on seabird population trends, as an ongoing challenge (Fisheries New Zealand and Department of Conservation, 2020). There has also been a substantial update to seabird chapters in the AEBAR 2019-2020.

Fisheries New Zealand and the Department of Conservation expect the use of digital monitoring, geospatial position reporting and electronic reporting on all commercial vessels, as well as cameras on vessels to greatly improve information on seabird capture in fisheries. In section 6.4.1, we discuss how digital monitoring is expected to substantively change how fisheries are monitored in Aotearoa New Zealand and how it will improve information on seabird capture events across a broad range of fisheries.

The latest risk assessment of commercial fishing to Aotearoa New Zealand seabirds was published in 2020 (Richard *et al.*, 2020). The risk assessment is based on the spatial overlap between seabird and fishing effort distributions, and the probability of incidental capture or death, and uses observer records on incidental captures on-board commercial fishing vessels. The risk assessment reported that black petrel/tāiko[64] were at "very high risk" from commercial fisheries (see 6.3.8: case study: A collaborative effort to protect vulnerable seabirds), and five species were at "high risk" from commercial fisheries (Salvin's albatross/toroa[65], Westland petrel/taiko[66], flesh-footed shearwater/toanui[67], southern Buller's albatross/toroa[68] and Gibson's/Antipodean albatross[69]).

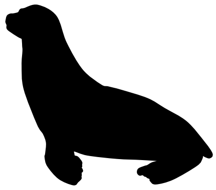
Observer coverage at the level undertaken in Aotearoa New Zealand is unlikely to detect captures of very rare species, cannot effectively quantify seabird capture, and is not particularly representative (e.g. seasonality, vessel characteristics, location) (Debski *et al.,* 2016). For example, less than 2% of trawl tows were observed in inshore fisheries in 2009-2010 (Ramm, 2012; Ministry for Primary Industries, 2020a).

Observer coverage at the level undertaken in Aotearoa New Zealand is unlikely to detect captures of very rare species, cannot effectively quantify seabird capture, and is not particularly representative.

Non-governmental organisations have advocated for a zero-bycatch goal, with gear innovations to reduce seabird capture a key component of achieving this[70]. Efforts to design and deploy such gear are discussed in section 6.3: How we fish and section 6.5: Where and when we fish.

[64] *Procellaria parkinsoni.*
[65] *Thalassarche salvini.*
[66] *Procellaria westlandica.*
[67] *Puffinus carneipes.*
[68] *Thalassarche bulleri.*
[69] *Diomedea antipodensis.*
[70] See reporting by Forest and Bird and WWF.

MARINE MAMMALS



Marine mammals are much more studied than many other non-target species – particularly our threatened Aotearoa New Zealand species (Baker *et al.*, 2019). The latest assessment of risk from commercial fisheries to all marine mammals was undertaken in 2017 (Abraham *et al.*, 2017), there has also been more recent risk assessments for Hector's and Māui dolphins (Roberts *et al.*, 2019) and New Zealand sea lion (Roberts and Doonan, 2016).

There is a New Zealand sea lion Threat Management Plan, and a Hector's and Māui dolphins Threat Management Plan has been in place since 2008 and in 2020 a new plan was proposed and implemented (Department of Conservation and Fisheries New Zealand, 2019). Mitigating interactions with commercial fisheries is a key aspect of the sea lion plan alongside the need for a more holistic approach to manage other threats to sea lions. For the dolphin plan, the objectives include that dolphin deaths from fisheries threats do not exceed population sustainability thresholds, cause localised depletion; or create substantial barriers to dispersal or connectivity between subpopulations.

Though there is a lot of research on these species, there are still research objectives to improve information on fisheries impacts and make data more easily accessible (Ministry for Primary Industries and Department of Conservation, 2017; Department of Conservation and Fisheries New Zealand, 2019).

Protected species bycatch in commercial fisheries has trended down over time, though continued measurement effort is needed to verify these trends (Department of Conservation, 2019b). It is hard to distinguish between reduction in catch being due to the reduction of populations or due to changes in technology and practices in fisheries, so this is a contested area.

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3.3.3 HABITAT

3.3.3.1 FISHING IMPACTS ON HABITAT

Fishing can cause both direct and indirect impacts to marine habitat. One of the most obvious impacts is when benthic trawling is undertaken. In this fishing method, nets are weighted so they drag along the seafloor and this causes damage to the marine environment. In the 2019-2020 fishing year, 46% of our catch volume was caught through bottom trawling.[71] Biogenic habitat (composed of living groups such as corals) are often significant habitats for fish and invertebrate species, particularly in juvenile life stages (Tracey and Hjorvarsdottir, 2019). Even decades after bottom trawling has been halted, there can be little to no recovery in a benthic community (Baco *et al.*, 2019; Clark *et al.*, 2019).

In the 2019-2020 fishing year, 46% of our catch volume was caught through bottom trawling.

[71] Information from Fisheries New Zealand. This includes 'bottom trawl', 'precision bottom trawl' and 'bottom pair trawl' categories.

The impacts of bottom trawling are highly context dependent, and depend on variables such as location, substrate, presence of vulnerable biota, scale, frequency, duration, intensity, and how it is deployed (Tracey and Hjorvarsdottir, 2019; Hughes *et al.*, 2014) (section 3.3.1 details currently used fishing methods and section 6.3 covers gear innovations in progress).

Even decades after bottom trawling has been halted, there can be little to no recovery in a benthic community.

Benthic trawling is used for a wide variety of fisheries both in the deepwater and inshore fisheries. Bottom trawling allows large quantities of fish that live on or near the seabed to be caught in one trawl. However, bottom trawling can also damage fragile sea life such as corals and sponges that provide habitat for fish species, some of which are protected (see section 3.3.2.2: Current reporting and performance). Seamounts and other underwater hills or knolls are often a haven for these fragile habitats and can be targeted by fishing as they are highly productive areas and are home to many commercial fish species. Fishers do not target hard surfaces for bottom trawling to avoid losing gear and catch (Eayrs *et al.*, 2020). Dredging similarly damages benthic habitat and is generally used in harvesting shellfish like scallops and Bluff oysters (Southern Scallop Working Group and Fisheries New Zealand, 2020; Ministry of Fisheries, 2009). Certain areas of habitat are of particular importance to specific fisheries, while others may be of importance to non-target species and support ecosystem health.

There are also impacts related to the sediment that is released from gear contacting the seabed. For example, these plumes can smother corals and plug polyps, affecting their ability to feed (Tracey and Hjorvarsdottir, 2019).

While direct impacts can be more easily studied and understood, there are more complex and significant knowledge gaps. There is a lack of understanding of resilience and recovery dynamics of deep-sea and coastal habitats impacted by benthic trawling (Clark *et al.*, 2019). Little is known about how the functioning of our ecosystems (and the benefits we gain from them) is impacted by changes to seabed habitats, including productivity on continental shelves and benthic habitats of significance (Jarvis and Young, 2019; Ministry for the Environment and Stats NZ, 2019a). These issues are discussed further in section 3.3.7.2: Food webs.

There are many examples of the impacts of bottom-disturbing fishing methods on the habitat of a target stock. The Challenger Scallop fishery (SCA7) is one such stock – located in Tasman and Golden Bays. In the late 1950s, commercial dredging for scallops began and peaked at 10,000 tonnes in 1975 (Williams *et al.*, 2014). The fishery then rapidly declined and closed for two years in the 1980s. Despite a short-lived recovery in the 1990s (though reaching only half of the volumes harvested in the 70s), the fishery has never recovered, even with enhancement activities being undertaken (such as reseeding populations with scallop spat). Other factors, such as sediment flows into the bays (and consequent suspended sediment), may also be contributing to the lack of substantial recovery over time, despite intense management and fishery enhancement efforts (Shotton *et al.*, 2008). As referenced in section 5.3.3.1: Managing stocks with incomplete data, in 2020 a Southern Scallop Strategy was implemented for SCA7, which acknowledged there has been little evidence to suggest the resource is recovering and that a fresh approach is needed.

Figure 27: New Zealand scallop. Image credit: jacqui-nz/iNaturalist NZ (CC BY-NC 4.0).

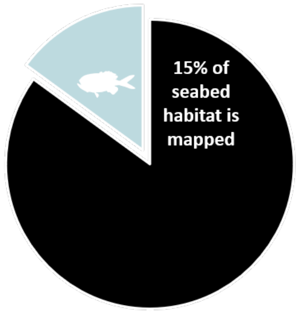
Because of the known impacts, bottom trawling and dredging are banned in some ecologically important areas of Aotearoa New Zealand's seas.

This discussion underpins our recommendations in Theme 6.

3.3.4 DATA COLLECTION, REPORTING AND PERFORMANCE

When it comes to the seafloor, around 15% of Aotearoa New Zealand's marine environment has been swath-mapped to a level that lets us define the seabed habitat, in a publicly accessible format (MacDiarmid *et al.*, 2013a), though efforts are underway to map more of the ocean as part of an ambitious international project to map the entire ocean floor by 2030.

Swath-mapping is a type of acoustic scanning that helps to define seabed habitats on a large scale. Beams of soundwaves are reflected off the seafloor and the strength of the echoes indicate the hardness and texture of the habitat. In order to observe patterns – whether there are improvements or declines – we require adequate detail, comprehensive and consistent data and time series (MacDiarmid *et al.*, 2013b; Jackson and Lundquist, 2016).



This leaves 85% of Aotearoa New Zealand's seabed habitat largely unmapped. Where we do have knowledge about the characteristics and extent of habitats that are of significance to species and to fisheries it can then allow us to manage these habitats appropriately (Peart, 2018; Ministry for the Environment and Stats NZ, 2019b). We have opportunities to increase our knowledge in this area to improve our understanding of where further management responses might usefully apply. The Ocean Survey 20/20 programme aimed to provide better knowledge of our ocean territory (coordinated by Land Information New New Zealand (LINZ)). The first survey in this programme was undertaken between 2008 and 2010 of the Peiwhairangi Bay of Islands coast. However, the programme was discontinued, as the *National Marine Research Strategy for the Natural Resources Sector* was developed (Land Information New Zealand, 2014)

Industry also collects data about the seafloor, although this is not publicly available. There is an untapped data resource here that could be aggregated (once data has been desensitised) to get a better picture of our benthic habitats and geography.

This underpins recommendations in Theme 5.

Industry also collects data about the seafloor, although this is not publicly available. There is an untapped data resource here that could be aggregated (once data has been desensitised) to get a better picture of our benthic habitats and geography.

In 2007, around one third of Aotearoa New Zealand's deep sea benthic areas became protected from bottom trawling in an agreement between industry and government (Helson *et al.*, 2010). These BPAs provide protection for some ecologically important habitats that are within trawling depth. The degree of protection afforded by these BPAs is fiercely contested. Industry argue that when the BPAs were first established they endeavoured for them to be representative of Marine Environment Classifications, geologic regions, depth ranges, and underwater topographical features (Helson *et al.*, 2010). Others contest this, arguing that much of the protected area may have little benthic habitat of importance to commercial fisheries and may not be suitable for benthic trawling regardless of the protections provided – for example, areas may be too deep to bottom trawl (Geange *et al.*, 2017; Rieser *et al.*, 2013; Mossop, 2020; Eddy, 2013). Work on marine environment classification is ongoing and best available information continues to evolve.

The degree of protection provided by these BPAs is fiercely contested.

The total annual area of the seafloor that is bottom-trawled is not increasing and has remained under 100,000 km^2 per year over the last decade (see figure 28). However, each year new areas are trawled (schematic figure 29a and appendix 3).

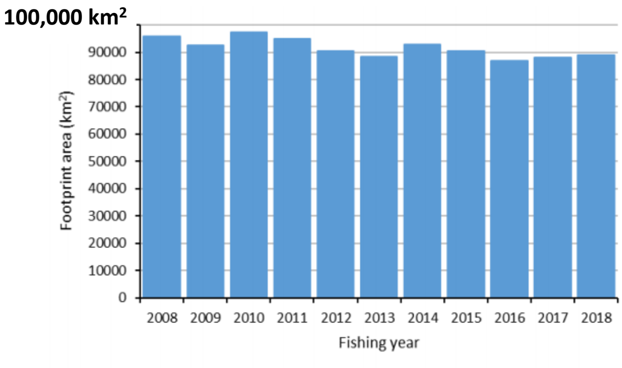


Figure 28: Figure taken from AEBAR 2020, see Figure 11.13 Annual footprint (km²) for bottom-contacting trawling for inshore and deepwater fish stocks, from TCERs, TCEPRs, and ERS, for the 2007-08 (2008) to 2017-18 (2018) fishing years. (From Baird and Mules (2021, in review)).

Over the last 20 years, the annual expansion of the cumulative trawl footprint in the deepwater fisheries has slowed, from around 1,000 km^2 in 2002 to under 100 km^2 in 2019. However, the overall 'cumulative trawl footprint' in deepwater fisheries (the total area of our seafloor that has ever been trawled) is still increasing (schematic figure 29b). This is a concern given the long time for recovery of some fragile seafloor habitats (see section 3.3.3). Understanding the extent and patterns of contact with newly trawled compared to previously trawled areas, the habitats and species impacted, and the recovery time for the area trawled, are important factors in understanding the nature of benthic damage from trawling activities in our waters.

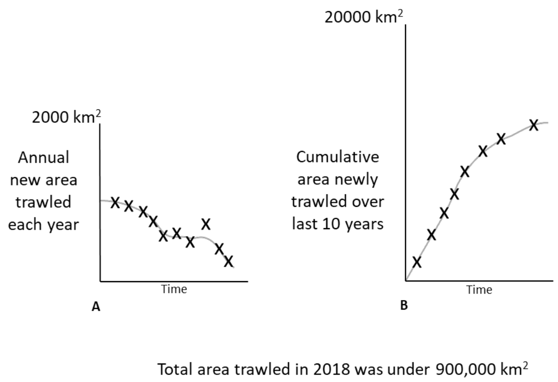


Figure 29: Schematic to demonstrate how a trend in decreasing amount of newly trawled areas (a) still increases the cumulative trawl footprint (b). (Schematic used as the data is disputed but the principle is not).

Figure 29 is drawn as a schematic to illustrate the principle and approximate scale, which are not contested. The precise figures for the annual increase in the cumulative trawl footprint are hard to measure and the most recent data for both deepwater fisheries and inshore fisheries held by Fisheries New Zealand is appended (estimates from Baird and Mules (2021, preliminary data, publication pending)) are included in appendix 3. Note that elements of the data remain a matter of dispute, for example from WWF.

The way that areas that are 'newly trawled' are estimated can differ depending on the starting point of the data (e.g. how far back records go) and the level of information available (e.g. how precise location data is).[72] The resulting estimates can vary depending on how the analysis is undertaken. Where large areas have clearly been newly explored, these are generally highlighted in Fisheries New Zealand research and reporting (see for example, Black and Tilney (2017)). In recent years, this has been mainly in the north and central areas of the Challenger Plateau. The use of electronic positioning reporting data in 2018 and 2019 has allowed for more precision in locating the start and end positions of tows, which has consequently affected standard reporting

[72] For example, resolution of reporting can mean that new transects may be artificially aggregated and must be accounted for in analysis. Input from FNZ.

measures used by Fisheries New Zealand.[73] Further linking of observer data with electronic positioning reporting data will advance understanding of the habitats and species that are being impacted in the newly trawled regions.

There is a lack of agreement in the approach to assess impacts. Internationally, indicators for assessing impacts of trawling and dredging have been proposed by many but have not been evaluated or agreed upon (Hiddink *et al.*, 2020). This is reflected in Aotearoa New Zealand where the approach to assessment[74] is not accepted by all stakeholders and opinions on the value of the assessments differ. Aotearoa New Zealand's assessment processes lag behind best practice and we are limited by our lack of data (Ford *et al.*, 2016).

Aotearoa New Zealand's assessment processes lag behind best practice and we are limited by our lack of data.

Habitat information is provided by Fisheries New Zealand in the AEBAR (Fisheries New Zealand, 2018a). Habitats of particular significance for fisheries management (HPSFM) are included in Section 9(c) Environmental Principles of the Fisheries Act 1996, but have not been used to protect habitats. While there have been no HPSFM formally identified (see section 4.2.1.3: Actioning the use of habitats of particular significance for fisheries management and table 3), other legislative tools have been used (discussed further in section 4.2: Managing impacts through protection tools) and area-based management tools that have been implemented under the Fisheries Act 1996. Further information is included in appendix 4: Land-based effects data.

Table 4 highlights environmental areas of concern and summarises the Ministry for the Environment's marine environmental reporting in these areas. This is not a comprehensive summary of all environmental information available – it is to show what information is analysed and presented within the current environmental reporting framework. All summaries are based on a compilation of available data and literature review.

A review of Aotearoa New Zealand's key biogenic habitats in 2019 presented available information on 15 key biogenic habitats in our waters (Anderson *et al.*, 2019). The review identified significant and extensive data gaps on where these habitats occur in Aotearoa New Zealand as well as the absence of baseline and temporal monitoring surveys for most biogenic habitats. The focus on biogenic habitat also excludes much of the seabed habitat (noting this habitat is not typically defined as sensitive) (MacDiarmid *et al.*, 2013a). Note that if the indicator is stable then it does not necessarily mean it is at a healthy level.

The review identified significant and extensive data gaps on where these habitats occur in Aotearoa New Zealand as well as the absence of baseline and temporal monitoring surveys for most biogenic habitats.

[73] For example, number of contacted cells, aggregate area, and footprint are affected. The effect of this is greater for inshore fish stocks than for deepwater data. Input from FNZ.

[74] The current approach uses the overlap of trawl footprint with Marine Environment Classification, Benthic Optimised MEC, and depth classes.

Table 3: Measurements and assessments of habitats taken from the 2019-2020 AEBAR.

Indicator	Measurement	Summary extracted from Ministry for Primary Industries (2020)
Benthic impacts		
Annual number of tows	Annual reporting	2017-18: 65,133 trawl tows, 50,288 shellfish dredge tows.
Trend in number of tows	Total reported trawls by fishing year (1990-2018) by reporting mechanism. Number of dredge tows by fishing year (1990-2018) by fishery (SCA, OYS).	Number of trawls and dredge tows have decreased over the last 30 years, more significantly for dredge tows.
Cumulative overlap of trawl footprint with BOMEC[75] habitat classes for 2007-08 to 2017-18	BOMEC class, total area, area open to bottom fishing, deepwater footprint area, inshore footprint area (total over ten year period).	Total area trawled between 2007 and 2017 is 2.7 million km^2. The footprint area (as % of total marine area) is around 7% for deepwater and 6% for inshore.
Habitats of particular significance for fisheries management		
No 'Habitats of Particular Significance for Fisheries Management Habitat' (HPSFM)	N/A	N/A (see section 4.2.1.3)

Table 4: Summary of the environmental reporting on habitat from Our Marine Environment 2019.

Indicator	2018/2019 Summary
Habitat	
Seagrass meadows	Decreased but predicted stable or increase (good to moderate confidence in data).
Mangrove forests	Increased and predicted to increase (good confidence in data).
Kelp forests	Remained stable and predicted to remain stable although vulnerable (good confidence in data).
Bryozoan thickets	Decreased and predicted to continue to decrease (moderate to low confidence in data).
Stony coral	Stable or decreased and predicted to remain stable or decrease (good to moderate confidence in data).
Beds of large shellfish	Decreased and predicted to continue to decrease (good to moderate confidence in data).
Calcerous tubeworm mounds	Stable and predicted to remain stable or decrease (good confidence in data).

In 2014, Morrison *et al.* undertook a study of areas of particular significance for finfish fisheries management in Aotearoa New Zealand (Morrison, *et al.*, 2014b). The review finds that despite decades of fisheries research, knowledge of habitats of significance is low due to our modest understanding of fish species' life histories, habitat usage and spatial structuring. Filling these information gaps is framed in the review as an issue that is not fixable in the short-to-medium term and that applying limited resources for increased science understanding and management is "only in part a science question: social and political pressures will also strongly drive such decisions." The 'habitat' section of AEBAR was not updated in the 2019-20 edition.

Despite decades of fisheries research, knowledge of habitats of significance is low due to our modest understanding of fish species life histories, habitat usage and spatial structuring.

There are maps that show approximate and broadly classified habitats. However, when this is compared to more detailed surveys of a particular area it becomes apparent how imprecise these classifications are (Department of Conservation and Ministry of Fisheries, 2011).

[75] Benthic-optimised marine environment classification.

There is a national marine coastal habitat geographic information system (GIS) layer that gives a high-level view, but does not incorporate detailed local information (such as that held by regional councils). NIWA has recently undertaken research for the Department of Conservation (with the Ministry for Primary Industries and the Ministry for the Environment) that outlines some of the issues with current Aotearoa New Zealand habitat mapping schemes. As recently as 2020, Waikato Regional Council commented that the data management for habitat information was unhelpful as data sources were held by many different organisations; data was stored in many different formats; and metadata was often lost, making the data much less useful.

As recently as 2020, Waikato Regional Council commented that the data management for habitat information was unhelpful as data sources were held by many different organisations; data was stored in many different formats; and metadata was often lost, making the data much less useful.

The council states that a "concerted effort is needed (across Aotearoa New Zealand) to catalogue what exists and to collate and store this data appropriately" (Waikato Regional Council, 2020). This is not a new issue as it is known that much detailed information from regional surveys is not recorded in the national habitat map (Department of Conservation and Ministry of Fisheries, 2011). This detailed information is much more useful when planning for marine protection, particularly when habitat mapping is combined with other information like video surveys (see section 6.4.14: Underwater and surface cameras give a wider and sharper view of the ocean) or benthic sampling.

Aotearoa New Zealand has several marine environment classification systems with iterations over time:

- Marine Environment Classification (MEC) – 20 class levels. This is used for both pelagic and benthic elements of marine ecosystems.
- Benthic Optimised Marine Environment Classification (BOMEC) – 15 class levels to show differences in benthic community composition (up to 2,000 m depth). Developed in 2012 for Aotearoa New Zealand waters (Leathwick *et al.*, 2012).
- National Coastal Marine Habitat Classification (2011)/New Zealand Marine Habitat Classification Scheme (2013).
- Various classifications for demersal fish (Leathwick *et al.,* 2006; Stephenson *et al.*, 2018; Stephenson, Leathwick, *et al.*, 2020).
- Newly developed national seafloor classification by the Department of Conservation.

While BOMEC and MEC can be broadly consistent at a large scale (e.g. over hundreds of kilometres), they are not reliable at a finer scale (Bowden *et al.*, 2011). This is an area where consistency across the marine domain through harmonisation of classification and agreement on high-level principles and definitions would be beneficial.

This discussion underpins recommendations in Themes 2 and 6.

A 2019 review undertaken by NIWA for the Ministry for the Environment found there are extensive and significant data gaps on where biogenic habitats occur (Anderson *et al.*, 2019). While there are national databases for two types of biogenic habitat (seagrass and mangroves), there are another 13 habitats for which this national inventory is missing (Anderson *et al.*, 2019). These are kelp forests, algal meadows, rhodolith beds, bryozoan thickets, sponge gardens, shellfish beds, non-calcareous tubeworm fields, calcareous tubeworm mounds, deep-sea chemoautotrophic tubeworm patches, stony-coral thickets, bush coral fields, sea pen fields and xenophyophore beds. Value could be gained by compiling existing data into a national dataset.

Figure 30: Rhodolith beds at the Te Miko Reef, Peiwhairangi Bay of Islands. Image credit: Roberta D'Archino.

Value could be gained by compiling existing data into a national dataset.

Councils may undertake mapping for a variety of purposes, including navigation safety purposes (updating charts), as well as protecting marine biodiversity. Geospatial position reporting (GPR) data identifies where fishing has occurred and whether vessels have gone to new areas, but it is not linked to observer data. If linked data such as benthic bycatch, this could show which areas are more sensitive and vulnerable to practices like trawling, noting that the degree to which this tool can identify sensitive habitat is only as good as the data.

Figure 31: Diver in a *Macrocystis* kelp forest, Otago. Image credit: Chris Hepburn.

There are extensive and significant data gaps on where biogenic habitats occur. While there are national databases for seagrass and mangroves, there are another 13 habitats for which a national inventory is missing.

This discussion underpins recommendations in Themes 6 and 7.

Seabed that has been mapped at a finer detail (in the last decade) includes:

- Peiwhairangi Bay of Islands (East Northland)
- Raukawa Moana Cook Strait and Te Ara-a-Kiwa Foveaux Strait (LINZ shipping lane surveys)
- 6,000 hectares of seabed habitat northeast of Rangitoto ki te Tonga D'Urville Island (NIWA for Marlborough District Council)
- 43,000 hectares of seabed habitat in Tōtara-nui Queen Charlotte Sound, involving two vessels and 280 days on the water (NIWA and Discovery Marine Ltd for Marlborough District Council) (Neil *et al.*, 2018).

3.3.5 CASE STUDY: MANAGING LAND-BASED IMPACTS THROUGH A MULTI-SECTOR MARINE SPATIAL PLAN

Tīkapa Moana the Hauraki Gulf is a national taonga that surrounds Aotearoa New Zealand's most populous region. It has been under stress for many decades. The stressors on the marine environment of Tīkapa Moana the Hauraki Gulf are multifaceted, cumulative and increasing. To date, traditional management approaches have failed to reduce the ongoing ecological degradation.

> Traditional management approaches have failed to reduce the ongoing ecological degradation.

Recognising this, the Hauraki Gulf Forum was established in 2013 through the Hauraki Gulf Marine Park Act 2000 as an independent group with representatives of all agencies involved in managing the Gulf to work collaboratively to find a solution to improve and protect the Gulf and better manage its resources (Peart, 2017). A steering group that included representatives from mana whenua, Auckland Council, Waikato Regional Council, the Department of Conservation, the Ministry for Primary Industries and the Hauraki Gulf Forum guided the process known as *Sea Change – Tai Timu Tai Pari*. A stakeholder working group developed an agreed plan of action, although the process was not without tensions.

The project culminated with the publication of a Hauraki Gulf marine spatial plan – Aotearoa New Zealand's first marine spatial plan (*Sea Change – Tai Timu Tai Pari*, 2016). The plan outlines a range of proposals to respond to the environmental decline in the gulf (as highlighted in 3.3.6: case study: The Noises vs Cape Rodney-Okakari Point Marine Reserve). It was developed as an integrated package to be implemented as a whole.

Excessive sediment run-off from the land was identified a main stressor on Tīkapa Moana the Hauraki Gulf, along with fishing, causing degraded marine habitats in estuaries, harbours and the inner gulf. The consensus was that it would take a range of actions that could act in concert to reduce soil erosion, minimise sediment entering waterways and stabilise sediment once it has reached the marine environment to reduce the negative impacts and restore the health of the Gulf.

The specific recommendations were to:

1. **Develop catchment management plans** so that there is guidance on what to do for each unique catchment.
2. **Establish catchment sediment load limits** to make sure there are achievable targets that will lead to improvement over time and to facilitate compliance monitoring.
3. **Increase sediment traps in contributing freshwater waterways** by reinstating natural or engineered wetland systems to reduce the impacts of any loss of sediment that does occur.
4. **Manage waterways** to reduce the amount of sediment and contamination making it in by changing land use, planting trees around waterways and developing infrastructure.

5. **Ensure good sediment management practice** by establishing best practice expectations, sharing that information widely and removing roadblocks so that people can take action.
6. **Review forestry impacts on sedimentation**, collaborating with the sector so that improved practices can be adopted sector-wide.
7. **Protect highly erodible soils** through planting or avoiding development to keep the soil in areas where it is likely to run off.
8. **Address sediment in the coastal marine area** by coming up with innovative and novel ways to reduce sediment so that habitats can be re-established.

Figure 32: The Tīkapa Moana Hauraki Gulf as seen from space. Image credit: MODIS Land Rapid Response Team/NASA Visible Earth.

The strength of this approach is that it recognises the multifaceted causes of accelerated sedimentation and the need for a range of solutions – both active and passive.

The plan also outlined specific actions related to fish stocks. Some selected actions are listed here:

1. Transition away from using commercial fishing methods that impact benthic habitat in the Gulf.
2. Undertake fish stock reviews: identify priority species and develop a schedule.
3. Initiate an urgent review of rock lobster stocks.
4. Implement a package of management measures aimed at reducing the density of kina/sea urchins[76] and restoring healthy kelp forests.
5. Implement measures aimed at restoring abundant hāpuku/hapuka/groper[77] stocks.
6. Undertake an urgent review of purse seining.
7. Improve fisheries information and compliance through reporting and observer coverage.

Implementing recommendations within the plan has taken time, highlighting that the disconnect between recognising environmental problems and the systematic implementation of solutions to these problems is a major hurdle. Concerns have been raised about the lack of action,[78] and activities relating to the plan are progressing. Waikato Regional Council and Auckland Council responded to the plan and have implemented workplans following its release. The Government appointed a Ministerial Advisory Committee to help shape their response to the conservation and fisheries related proposals in the Spatial Plan.

The disconnect between recognising environmental problems and the systematic implementation of solutions to these problems is a major hurdle.

Initiatives that align with the plan have also gained traction, with the Department of Conservation and Fisheries New Zealand partnering with The Nature Conservancy to fund a shellfish bed and mussel reef restoration project in the Gulf.

[76] *Evechinus chloroticus.*
[77] *Polyprion oxygeneios* and *Polyprion spp.*
[78] See NZ Herald reporting here and here.

3.3.6 CASE STUDY: THE NOISES VS CAPE RODNEY-OKAKARI POINT MARINE RESERVE

Ōtata is the largest island in the Noises group, a chain of islands, outcrops and rocky reefs in the middle of Tīkapa Moana the Hauraki Gulf. Known as Ngā Poitu o Taramainuku to Māori, the islands and their surrounding waters have provided kaimoana for hundreds of years, with archaeological evidence of occupation prior to the eruption of Rangitoto. Several iwi have claims and interests in the islands and the ocean in this area.

Figure 33: Ōtata Island, one of the islands in The Noises group, located in the Hauraki Gulf.

The islands provide a good example of decades-long ecological change in an environmental subjected to multiple stressors. The rocky shelves off Ōtata Island's east coast have seen the retreat of biodiverse kelp forests and the influx of kina barrens.

The Noises have been privately owned by one family, the Neureuters, since 1933. In 1995, the family formed the Noises Trust and gifted the islands to the Trust, aiming to establish long-term protection for this slice of natural heritage. The Neureuters have partnered with Tāmaki Paenga Hira Auckland Museum and the University of Auckland to advance marine protection around the Noises. Their approach engages mana whenua and has an explicit dual focus on science and mātauranga Māori.

The unique geography of the islands, combined with their position at the boundary of the inner and outer Gulf where tidal currents mix and flow, supports a diverse range of habitats, including:

- Macroalgae forests,
- Rhodolith beds,
- Shellfish beds, and
- Sponges.

The islands themselves are pest-free and are home to a thriving population of raukawa geckos[79], translocated giant wētā/wētāpunga,[80] and flax snails/pupurangi.[81] They are important breeding sites for several seabird species, including little penguins/kororā,[82] white-faced storm petrels/takahikare[83] and grey-faced petrels/ōi.[84] But seabirds are dependent on the surrounding moana too, and conservation beneath the waves hasn't kept pace with terrestrial efforts.

[79] *Woodworthia maculata.*
[80] *Deinacrida heteracantha.*
[81] *Placostylus spp.*
[82] *Eudyptula minor.*
[83] *Pelagodroma marina.*
[84] *Pterodroma macroptera.*

One seabird species, the spotted shag/kawau tikitiki,[85] has already abandoned its rocky outposts. Underwater, the scallop beds have been dredged extensively by recreational fishers and the once numerous baitfish have disappeared from the main beach at Ōtata, according to observations by the Neureuter family across several generations.

The causes underlying these changes are complex (see section 3.1.5: Cumulative effects mean these stresses compound), but two key factors are:

Figure 34: Kāruhiruhi/pied shags (*Phalacrocorax varius*) nest in pōhutukawa trees on Ōtata Island.

- **Fishing pressures –** 0.3% of the Hauraki Gulf is protected in no-take MPAs (see section 4.2: Managing impacts through protection tools). Both commercial and recreational fishing are permitted across different areas within the gulf, with restrictions on fishing methods varying across time of the year.[86] According to the *State of our Gulf 2020* report, the recreational takes of snapper, kahawai and kingfish are larger than the commercial takes for those species within the Marine Park (Hauraki Gulf Forum, 2020). The decline in species such as snapper and near-total loss of rock lobsters has been associated with a proliferation of kina and decline of kelp forests. Processes that regulate the distribution of echinoderms are poorly understood (Glockner-Fagetti and Phillips, 2020) so the causal connection is contested.
- **Reduction in water quality** – Coastal and agricultural developments on the land surrounding the Gulf have led to increasing sedimentation, turbidity and nitrogen loads in the Gulf. Other stressors include plastic pollution (Hauraki Gulf Forum, 2020).

CAPE RODNEY-OKAKARI POINT MARINE RESERVE

Fifty kilometres up the coast, we can see a marine environment protected from some stressors. Aotearoa New Zealand's oldest marine reserve was gazetted here in 1975, protecting a 5.5 km^2 patch sometimes known as Goat Island or Leigh Marine Reserve. Here, thick kelp forests shelter an array of reef species such as rock lobsters, snapper and parore/black bream.[87]

Before establishment of the marine reserve, the seafloor was carpeted with rock flat barrens inhabited predominantly by kina. Over-harvesting of predator species such as rock lobster and snapper had resulted in an imbalanced ecosystem. The establishment of the University of Auckland's Leigh Marine Laboratory in 1962 provided the impetus for an adjacent marine reserve. "They are the controls for the uncontrolled experiment

[85] *Stictocarbo punctatus.*
[86] Commercial fishing is only allowed in the inner gulf between 1 April and 30 September. See 4F of the Fisheries (Auckland and Kermadec Areas Commercial Fishing) Regulations 1986.
[87] *Girella tricuspidata*.

that is happening due to fishing and other humans activities," wrote Bill Ballantine, the Laboratory's first scientist (Ballantine, 2014).

In the 45 years since, the numbers of snapper and rock lobster have increased. A trophic cascade has ensued with the kina barrens being replaced by regenerating brown algae and diverse seaweed assemblages. Subsequent surveys have found that species diversity and abundance have increased markedly inside the reserve. Rock lobster abundance and size is greater inside the reserve when compared to unprotected sites, but numbers have declined since the mid-90s – likely due to a range of factors, including consistent fishing at the boundaries of the reserve (eCoast Marine Consulting and Research, 2014). Although not the primary goal of the reserve, it has also had a positive outcomes for fishers, boosting snapper numbers in the surrounding waters (Le Port *et al.*, 2017).

Figure 35: Snapper and kelp forest at Cape Rodney-Okakari Point Marine Reserve.

Initially, it was envisaged that the marine reserve would serve a primarily scientific purpose in line with the legislation. While it has been invaluable for science conducted at the Leigh Marine Laboratory, it has also become a place for public education, outreach and tourism. An estimated 300,000 people visit the marine reserve every year to snorkel, dive, kayak or ride the glass-bottom boat – experiencing the fish-filled waters and learning about our moana.

Figure 36: Goat Island at Cape Rodney-Okakari Point Marine Reserve.

Could the Noises' marine environment recover like Goat Island? It's likely that stopping fishing would not remediate all the ecological changes witnessed over the past few decades. But the experiences from Cape Rodney-Okakari Point Marine Reserve demonstrate that removing this pressure can go a long way to preserving and restoring marine biodiversity. Ideas for protection of the Noises have been floated: the *Sea Change – Tai Timu Tai Pari Hauraki Gulf Marine Spatial Plan* proposed a no-take MPA around the Noises, surrounded by a larger Ahu Moana Mana Whenua/community co-management area that applies dynamic management principles.

3.3.7 ECOSYSTEM STRUCTURE AND FUNCTION

Our marine ecosystem is comprised of the fish we target (section 5.3), other living animals (section 3.3.2), and both living and non-living habitat (section 3.3.3) (Lundquist *et al.*, 2015). Ecosystems are complex and can be difficult to understand yet maintaining good function in ecosystems is central for the continual provision of ecosystem services. These include, for example (Barbier, 2017):

- Goods such as fish harvests, wild plants and animals, raw materials, genetic materials and water.
- Services such as recreation, tourism, transportation, pollution control, nutrient cycling, water filtration, storm and shoreline protection, and carbon sequestration.
- Cultural benefits such as preservation for future generations and for its cultural significance.

Aside from stock depletion and habitat impacts, overfishing can result in significant changes to community structures (Grassle, 2013). There is a need for ways to measure the broad ecosystem level effects of fishing activities as a whole in order to sustainably manage fisheries.

There is a need for ways to measure the broad ecosystem level effects of fishing activities as a whole in order to sustainably manage fisheries.

In order to implement ecosystem-based approaches to fisheries management, we need to understand how ecosystems operate and be able to identify indicators to protect their function as part of fisheries management. Currently, we tend to wait for adverse impacts to materialise before implementing management responses and often struggle to respond. Ideally, we would pre-empt negative impacts via a thorough understanding of how ecosystems function.

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Figure 37: *Macrocystis* kelp forest, Kau Bay, Wellington. Image credit: Nicole Miller.

3.3.7.1 BIODIVERSITY IN OUR MARINE ENVIRONMENT

Research suggests that ecosystems with greater biodiversity may be more resilient to ecosystem changes (Hughes *et al.*, 2005; Isbell *et al.*, 2015; Rastelli *et al.*, 2020; Attenborough, 2020).

There are still many knowledge gaps around the impact of fishing on biodiversity, particularly coastal marine biodiversity (Thrush *et al.*, 2016). Diverse habitat is needed to support diverse species (Thrush *et al.*, 2006), but fishing activities like trawling and dredging can cause habitat homogenisation (where habitats become more similar or uniform, see section 3.3.3). Often impacts are not understood until a tipping point has already been reached from which the ecosystem cannot recover.

> Diverse habitat is needed to support diverse species, but fishing activities like trawling and dredging can cause habitat homogenisation (where habitats become more similar or uniform).

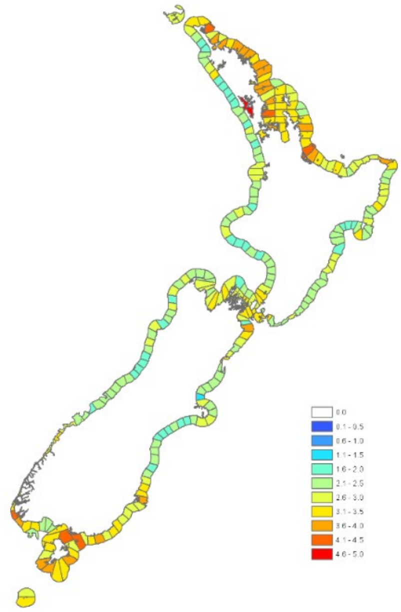


Figure 38: Spatial distribution of organismal and habitat biodiversity in our 12-nautical mile territorial seas from (Gordon *et al.*, 2010).

There are examples of habitat losses in Tīkapa Moana the Hauraki Gulf, Te Tauihu-o-te-Waka Marlborough Sounds, Tikapa Moana-o-Hauraki Firth of Thames and Te Tai-o-Aorere Tasman Bay (The Nature Conservancy, 2017) – all are habitats that are thought to be associated with high biodiversity given their role as nursery ground for marine fishes.

The knowledge we do have around impacts on biodiversity has reportedly not been fully incorporated into our fisheries management, though it has important impacts on both environmental and fisheries outcomes (Thrush *et al.*, 2016).[88]

> The knowledge we do have around impacts on biodiversity has reportedly not been fully incorporated into our fisheries management, though it has important impacts on both environmental and fisheries outcomes.

Aotearoa New Zealand has over 15,000 known marine species and there are likely many marine species that have yet to be identified (Costello *et al.*, 2012; Ministry for the Environment and Stats NZ, 2019b). Species can be identified using many different methods, from targeted studies, trawls, community science and more (Gordon and Ballantine, 2013; Liggins *et al.*, 2020). A new species of fish discovered in Aotearoa New Zealand intertidal and shallow coastal water in 2018 (a type of clingfish) was identified by examination of museum specimens. Many more species are waiting to be discovered. The New Zealand Government acknowledges that our current biodiversity system fails to tackle issues at the scale needed to address the ongoing and cumulative loss of Indigenous biodiversity (New Zealand Government, 2019c).

[88] Biodiversity mapping from (Beaumont *et al.*, 2008; Gordon *et al.*, 2010).

The New Zealand Government acknowledges that our current biodiversity system fails to tackle issues at the scale needed to address the ongoing and cumulative loss of Indigenous biodiversity.

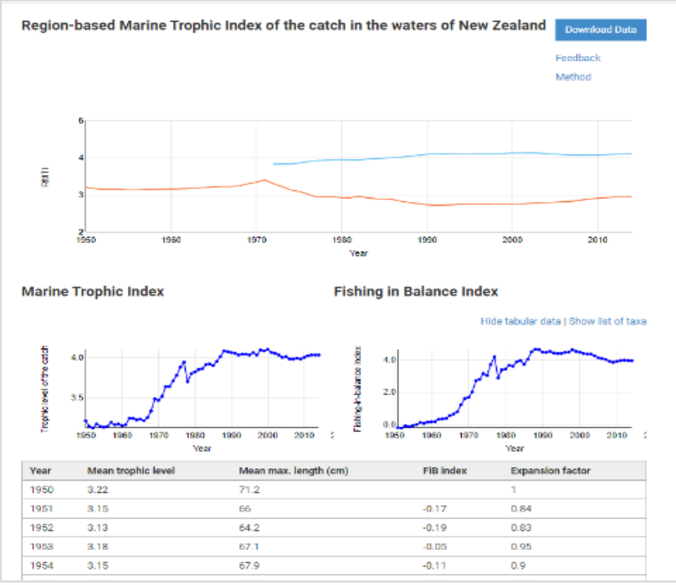
While it is challenging to consider or protect species we don't know about, even the species we know of are poorly understood. Maintaining biodiversity should be a priority for fisheries management in Aotearoa New Zealand to ensure ecosystems are resilient to stressors, including fishing.

Maintaining biodiversity should be a priority for fisheries management in Aotearoa New Zealand to ensure ecosystems are resilient to stressors, including fishing.

This discussion underpins recommendation in Themes 2, 3, 5, 6 and 7.

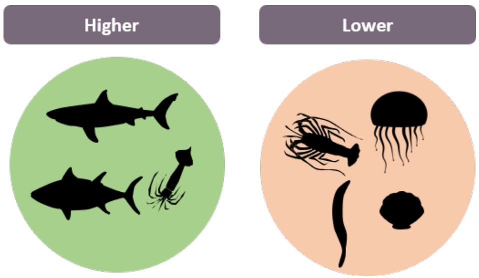
3.3.7.2 FOOD WEBS

A food web describes what eats what and aids understanding of how a change to an ecosystem will impact on different species. In the marine environment this is often determined as much by body size as it is by species. Generally speaking, the base of marine food webs are the phytoplankton and algae, while at the very top are high level predators like sharks, whales and dolphins. Juvenile top predators can also act as prey for smaller species. The position of a species in the food level is referred to as its trophic level (i.e. how far up the food chain the species are).



Year	Mean trophic level	Mean max. length (cm)	FIB index	Expansion factor
1950	3.22	71.2		1
1951	3.15	66	-0.17	0.84
1952	3.13	64.2	-0.19	0.83
1953	3.18	67.1	-0.05	0.95
1954	3.15	67.9	-0.11	0.9

Figure 39: Marine Trophic Index data for New Zealand available from Sea Around Us.



Defining marine food webs can be incredibly difficult and complex due to the sheer size of the ocean and the thousands of different interactions occurring (Albouy *et al.*, 2019). The complexity of food webs means that diverse ecosystems can be supported, but it also means that removing even a single species can have significant impacts, such as trophic cascades (see 3.3.6: case study: The Noises vs Cape Rodney-Okakari Point Marine Reserve). When we look to restoring areas, we need greater understanding of the ecosystem. For example, will reducing catch levels for rock lobster improve the situation (and at what level of reduction and on what timeframe can restoration be achieved)? Understanding food webs is important as trophic transfers often act as the foundation for ecosystem models, such as structural food web models (see section 6.4.18: Models can support ecosystem approaches to fisheries management).

Defining marine food webs can be incredibly difficult and complex due to the sheer size of the ocean and the thousands of different interactions occurring.

Often marine trophic index, a measure of the mean trophic level of fish caught, is used as an ecosystem indicator. The measure can be derived from catch data alone (Pauly and Zeller, 2018). Although few studies have analysed historical datasets on Aotearoa New Zealand's catch and quota trades (The Nature Conservancy, 2017), a recent study used long-term datasets to analyse the shifting trophic structure of marine fisheries (Durante *et al.*, 2020). The study also made use of marine trophic index, which is available from Sea Around Us.

The mean trophic level of catch in Aotearoa New Zealand has fluctuated over time as the nature of our fisheries changed (Durante *et al.*, 2020). For example, as inshore fisheries effort increased in the 50s this likely led to a reduction in the abundance of higher-level predators in the inshore fisheries and consequently to a lower mean trophic level. As fisheries expanded due to changes in vessel types, subsidies, and technologies, mean trophic level rose. For example, expansion into new offshore fishing areas can increase the marine trophic index (higher-level predators being caught) and mask fishing impacts in closer inshore fisheries. So while mean trophic levels can indicate changes in ecosystems and species abundance, its usefulness is constrained by the way it can be significantly impacted by economic, management, fishing technology and targeting patterns, as well as its reliance on the accuracy of the catch data it is based on (Pauly *et al.*, 2005; Branch *et al.*, 2010). As marine trophic index does not measure the relative contributions of particular species, the depletion of one species could be masked by larger catch from other species. Nor does the index take into account the size distribution of the catch within species, so cannot consider the change in sizes of fish that can occur when there is overfishing of larger size classes.

Overall marine trophic index is a fairly rudimentary instrument for measuring ecosystem level effects. However, it does indicate cause for concern in Aotearoa New Zealand marine ecosystems. Further research into food webs and marine trophic index would benefit fisheries management by providing a greater understanding of the ecosystem impacts of targeting certain species.

> Marine tropic index is a fairly rudimentary instrument for measuring ecosystem level effects. However, it does indicate cause for concern in Aotearoa New Zealand marine ecosystems.

3.3.7.3 ECOLOGICAL MONITORING

Globally there is a move to an EAFM and this requires conservation of ecosystem structure and function (Schmeller *et al.*, 2017; Townsend *et al.*, 2019). This in turn means we have a greater need for long-term environmental and fisheries data. Ecosystem structure and function is complex and there is scientific disagreement over which indicator can best measure the overall state of an ecosystem. Understanding our data needs and agreeing on indicators is a prerequisite to long-term monitoring and reporting of environmental indicators. This will facilitate an enduring commitment to data collection and monitoring and requires a coordinated approach and priority setting with the ecosystem at the centre of decision making. Research that considers ecological significance, not only direct commercial significance, at both a national and local level is necessary. Our systems have opportunities to improve their targeting towards developing and maintaining long-term datasets (Parliamentary Commissioner for the Environment, 2019).

Ecosystem structure and function is complex and there is scientific disagreement over which indicator can best measure the overall state of an ecosystem. Understanding our data needs and agreeing on indicators is a prerequisite to long-term monitoring and reporting of environmental indicators.

Data needs for fisheries managers will vary from other sectors (both environmental and industry-related) but many indicators will have universal value. Ecological indicators for the Aotearoa New Zealand ocean have previously been discussed in many papers and reports, for example, Pinkerton (2010), Thrush *et al.* (2011), Coll *et al.* (2016) and the Ministry for the Environment and Stats NZ (2016).[89] Research into indicators undertaken in Aotearoa New Zealand that could be built on includes:

Deepwater fisheries. A report in 2014 reviewed fisheries and environmental indicators as methods for monitoring and analysing environmental and ecosystem changes (Tuck *et al.*, 2014). The report provides an assessment of the indicators that would be most useful in measuring the performance of deepwater fisheries within an environmental context. Usefulness is measured against factors such as relevance, credibility, and cost-effectiveness. The assessment also states whether data is currently available or whether new research or data would be needed for each indicator. Indicators are suggested in the following areas:

1. Climate,
2. Oceanographic,
3. Primary productivity,
4. Food web,
5. Fisheries and fisheries management,
6. The fish community,
7. Benthic communities and habitats (seafloor integrity),
8. Top predators, threatened and endangered species.

Coastal ecosystem monitoring. A NIWA report for the Department of Conservation lays out a strategy for a cost-effective monitoring programme for coastal marine habitats (Thrush *et al.*, 2011).

National Marine Environment Monitoring Programme. Work was undertaken by the Ministry for Primary Industries in 2014 on developing a National Marine Environment Monitoring Programme for Aotearoa New Zealand (Hewitt, 2014). The report identified important data gaps for monitoring such as water chemistry, water column biology, habitats, and nearshore and deep-sea biological communities. The Ministry for Primary Industries commissioned NIWA to build an online meta-database

Tier 1 national reporting statistics. The Ministry for Primary Industries has undertaken work on 1) ocean indicators for the Atmospheric and Ocean Climate Change Tier 1 Statistic (Pinkerton *et al.*, 2015) and 2) development of a Tier 1 statistic for Aotearoa New Zealand's marine biodiversity (Lundquist *et al.*, 2015). Both pieces of work report on relevant indicators for ecological monitoring.

There has also been recent funding of over $13 million for a research programme focusing on Rangitāhua the Kermadec Islands, and their biodiversity and ecosystem.

The need for a monitoring programme is incredibly important and should align with *Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020* objectives. The objectives of the monitoring programme

[89] Marine trophic index was previously trialled in the Chatham Rise (Pinkerton, 2011; Tuck *et al.*, 2014; Pinkerton *et al.*, 2015; Pinkerton *et al.*, 2017).

should be clearly defined for fisheries as well as wider outcomes. This may, for fisheries science, present a need to consider the weighting of direct commercial significance of research against ecological significance, at both a national and local level.

Without long-term data, there is no way to measure our performance against our sustainability objectives (Vale, 2013). How this data integrates with our QMS focus on single-species stock management will be explored in part 5. Yet past attempts show that initiatives in this area struggle to progress from research to implementation.

This may, for fisheries science, present a need to consider the weighting of direct commercial significance of research against ecological significance, at both a national and local level. Without long-term data, there is no way to measure our performance against our sustainability objectives.

LENFEST OCEAN PROGRAM

Moving EBFM from a concept to an operational approach presents challenges. Work by Lenfest Ocean Program[90] and the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) has highlighted ways to address challenges in how to:

- Recognise when an ecosystem is (or is at serious risk of being) compromised.
- Implement EBFM in a way that suits different ecosystems and different fisheries (especially when they have different management systems).
- Identify which indicators can provide the most useful information for fisheries management systems.

The work, led by Dr Beth Fulton and Dr Keith Sainsbury, aims to develop practical indicators for ecosystem structure and function, as well as guidelines on how to apply these indicators in different ecosystems and management contexts (Fulton, 2018). The process this work will take includes:

- **Developing potential ecosystem indicators.** Identifying and consolidating potential indicators based on existing work, as well as potentially developing new indicators.
- **Working with managers and policymakers.** Identifying which indicators are most promising, could be readily applied in a fishery, and what challenges would need to be overcome to operationalise the indicators within existing fisheries management systems.
- **Testing robustness of indicators and assessments.** Testing the performance of the most promising indicators across different ecosystems and fisheries management systems.
- **Applying indicators in case studies.** Testing the utility and robustness of the indicators using data from case studies:
  - Bering Sea, Alaska, US.
  - Humboldt Current system, Chile.
  - Marine waters off south-west India.
  - Marine waters off south-east Australia.

There is significant potential to improve fisheries management through ecological indicators that can feed into ecosystem models (see section 6.4.18: Models can support ecosystem approaches to fisheries management).

This discussion underpins recommendations in Themes 4-7.

[90] The Lenfest Ocean Program is a grantmaking program that funds scientific research on policy-relevant topics concerning the world's oceans and communicates the results of the supported research to decision makers and other interested audiences.

3.4 DATA AND KNOWLEDGE GAPS

The challenges that the marine environment faces are significant and complex. There are multiple stressors on marine ecosystems and while commercial fishing is only one of these, it is a significant stressor. The impacts of commercial fishing go beyond the target species of the fishing operation to the wider ecosystem – the habitats and other living organisms that make up the ecosystem, influencing ecosystem structure and function. As a result, fisheries management necessarily needs to look beyond single stocks to measure and monitor the impacts of fishing on the wider ecosystem to inform future management decisions. Despite the evidence clearly demonstrating these impacts, there remain significant gaps in the data and knowledge relating to how fishing impacts the marine environment and how resilient the system is to fishing practices, which currently limits the use of EAFM in Aotearoa New Zealand. A summary of the knowledge gaps and issues that currently limit our understanding are highlighted in table 5 and covered further in part 5.

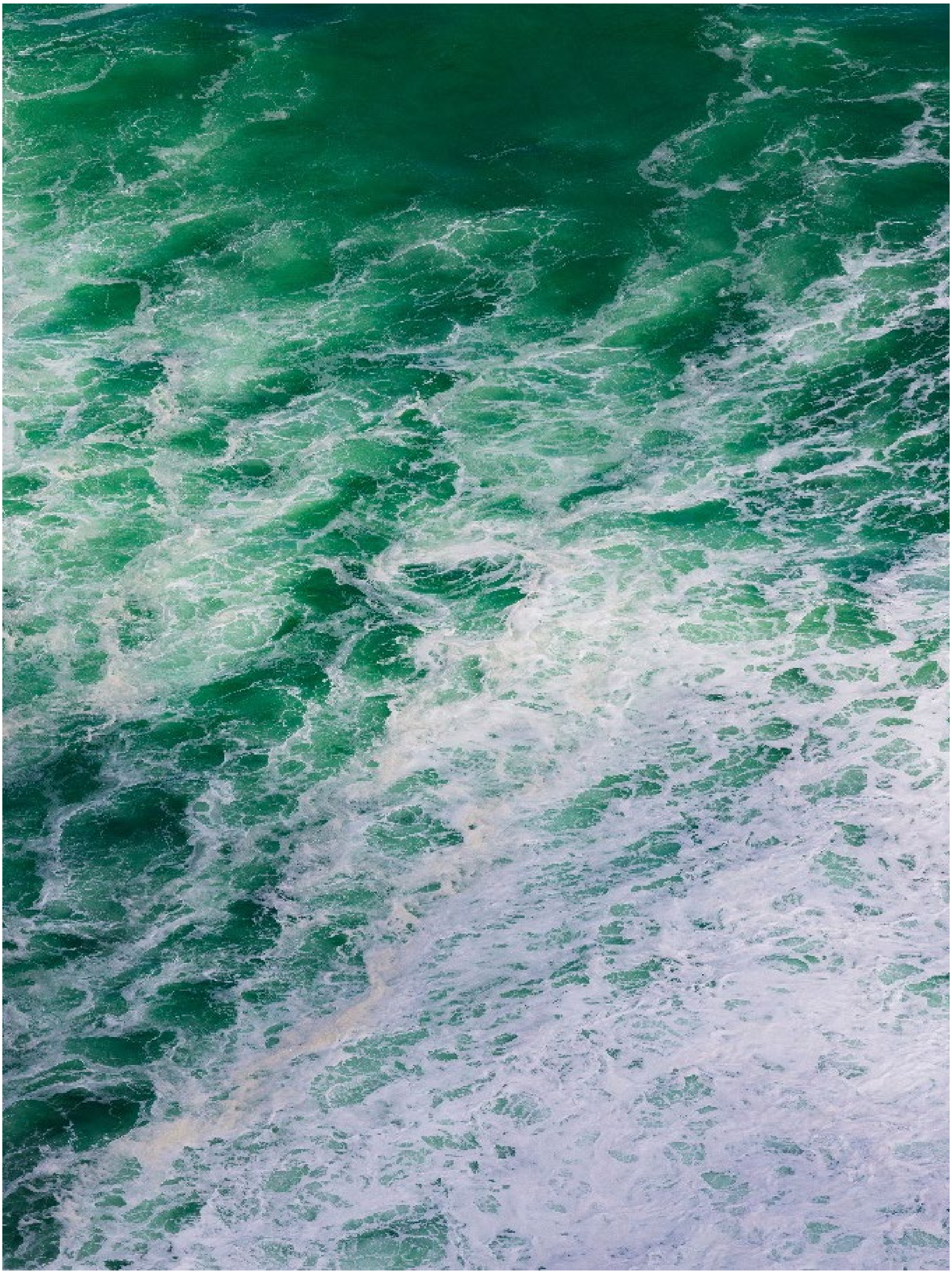
Table 5: A summary of the limitations and gaps in data and knowledge for the commercial fishing industry.

Issue	Explanation and examples	Examples of current initiatives
Lack of knowledge about impact of related issues on fisheries	**Climate change** Growing understanding of climate change impacts on marine environment and fisheries but recognition that changes are inherently unpredictable (Peart, 2018; Ministry for the Environment and Stats NZ, 2019b). **Plastics** Knowledge gaps about the impacts of microplastics in the food chain and how plastic pollution impacts ecosystems.	Research in this area, see *Impacts of Climate Change on New Zealand Fisheries and Aquaculture* (Pinkerton, 2018). Sustainable Seas has a research programme looking at human activities and environmental change effects on ecosystems. MPI projects to quantify plastic in catches, microplastics from plankton surveys, and density of marine litter on seabed.
Interface between different sectors	**Land-based impacts, including sedimentation** Sedimentation impacts from forestry or farming impact coastal fisheries (Peart, 2018) and requires both passive and active restoration efforts but challenges arise from the lack of integration of fisheries management and land-based regulations. **Cumulative effects** Significant knowledge gaps about how the range of stressors act together and how these should be accounted for in fisheries management.	Recent publication by the PCE on estuaries has relevant recommendations (Parliamentary Commissioner for the Environment, 2020b). Recommendations from *Sea Change – Tai Timu Tai Pari Hauraki Gulf Marine Spatial Plan* for active restoration efforts. Sustainable Seas development of the Aotearoa Cumulative Effects framework.
Lack of knowledge about fished/target species	Covered in section 5.3: Commercial fishing has impacts on target species sustainability	
Lack of knowledge about species and habitat	Data on fish stocks is important to manage a fishery, but so too is data that help us understand ecosystem health and the role of fisheries and other issues (cumulatively) driving environmental change. Exploration of our marine environment is still at an early stage (MacDiarmid *et al.*, 2013a).	*Fisheries Aquaculture and Innovation Plan*. Current research in this area: EBM research, Sustainable Seas Relevant Seafood Innovation Limited projects underway: Knowledge Gaps –

Issue	Explanation and examples	Examples of current initiatives
	We don't have a very good handle on how our marine environment has changed or where its headed, or even what was there to begin with and what is there now in terms of species and habitats (15% of our seabed is swath-mapped and available in a publicly accessible format). Information on characteristics and extent of marine habitats is lacking (Ministry for the Environment and Stats NZ, 2019b), including what the habitats of significance to fisheries are and where are they (Peart, 2018). There are knowledge gaps in what species exist and where and it is likely many marine species have yet to be identified.	Literature Review and hoki/blue grenadier[91] stock structure study.
Lack of knowledge about non-target species	Data and knowledge gaps relating to non-target species sustainability (Peart, 2018) and bycatch (Hare *et al.*, 2019) and limited observer coverage, particularly for inshore fisheries. Limited data results in most ecological risk assessments being qualitative or semi-qualitative. Anecdotal or observational evidence of declines e.g. seabirds. Long-term datasets on bycatch species, outside of landings, could be improved for many species and locations.	A range of research on mammal, bird and shark bycatch.
Lack of knowledge about environmental impacts of fishing	There are data and knowledge gaps around the environmental impacts of fishing activities. Data can be hard to gather and interpret. For example, little known about impact of trawling and dredging on productivity on continental shelves and benthic habitats of significance (Jarvis and Young, 2019) and resilience and recovery dynamics (Clark *et al.*, 2019). Disagreement on value of current approaches to assessing impacts (Ford *et al.*, 2016). Lacking agreed and defined ecological indicators. Other knowledge gaps relate to coastal marine biodiversity, coastal marine ecosystems, current environmental impacts, cumulative impacts of fishing on marine ecosystem, with little data on pre-QMS environmental impacts and limited information on current environmental impacts (The Nature Conservancy, 2017).	Legal requirement to manage impacts (Fisheries Act 1996 8(2a)). Current research, e.g. dredging effect on marine mammals (Cawthron), but process, cumulative effects and ecosystems impacts more difficult to study.

[91] *Macruronus novaezelandiae.*

PART 4: THE REGULATORY SPACE IS COMPLEX



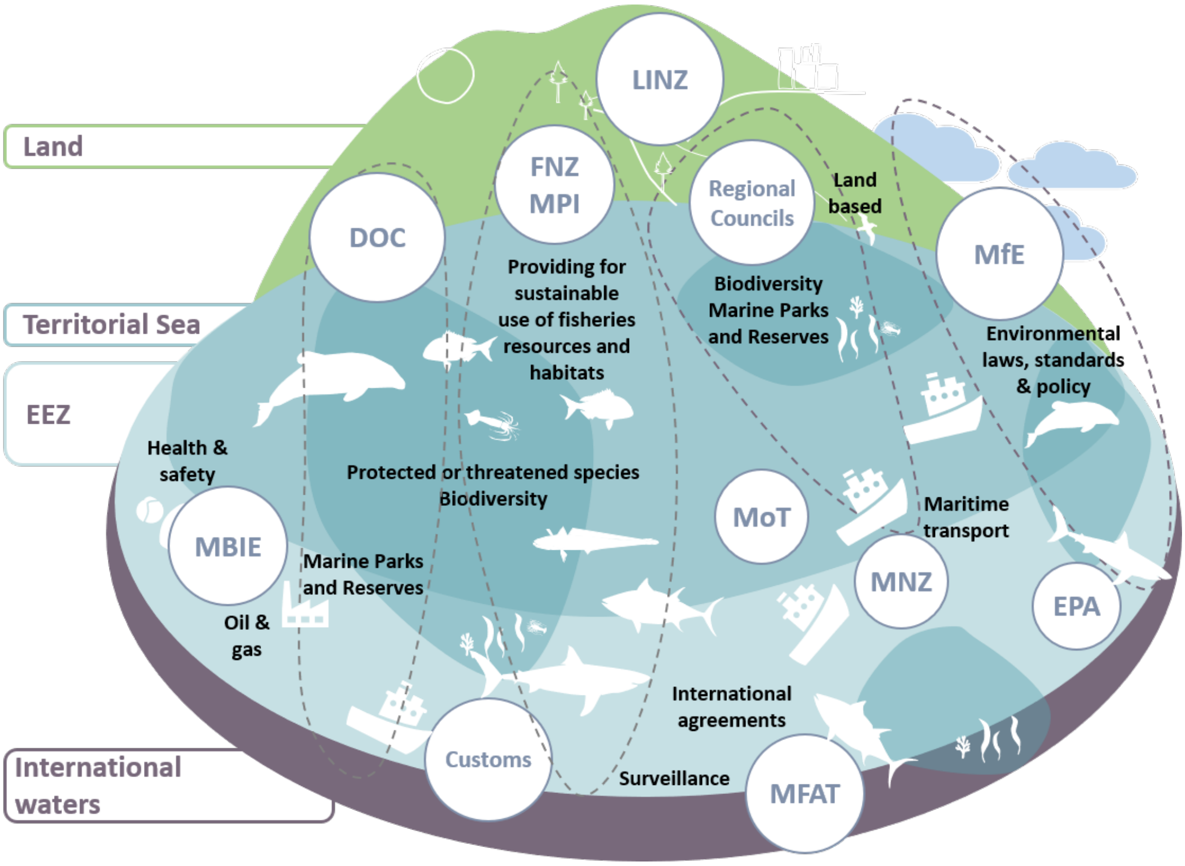


Figure 40: Major marine actors in the Aotearoa New Zealand marine regulatory space in 2020.

The marine regulatory space is complex and we do not provide a comprehensive description of the regime in this report, rather a high-level summary to provide context (for key relevant pieces of legislation see appendix 5). Direct fisheries management is the responsibility of Fisheries New Zealand, and the wider context of fisheries sustainability is a significant part of their work, in collaboration with the Department of Conservation and the Ministry for the Environment. Regional councils also have the ability to strongly influence the marine environment both through control of land-based activities and by management of the marine space itself (within the territorial sea, 0-12 nautical miles offshore) (this is discussed in section 4.4: Regions have varying approaches to management within the territorial sea).

There are many other additional regulators of activities in the marine environment covering issues like health and safety, oil and gas licensing, marine transport and discussion and participation in international agreements around ocean governance and fisheries management (see appendix 6 for a table of key regulators in the Aotearoa New Zealand marine fisheries space).

A large number of regulators in an area creates issues of regulatory overlap particularly where there may be conflicting statutory obligations, as well as having the potential to create gaps where there is no regulatory lead (i.e. none of the multiple regulators view the issue as their statutory responsibility). There is a need for overarching principles and environmental outcomes, bottom lines and aspirational targets.

A large number of regulators in an area creates issues of regulatory overlap particularly where there may be conflicting statutory obligations, as well as having the potential to create gaps where there is no regulatory lead.

Figure 41 illustrates some of the areas where there is overlap and the potential for gaps between four of the key regulators. There are significant overlaps in the regulation in areas of conservation – protected or threatened species, biodiversity, and marine parks and reserves. This can create tensions, for example where legal definitions do not align, as is the case with the term 'biodiversity'. To illustrate:

- **Fisheries New Zealand**, through the Fisheries Act 1996, has the dual objectives of ensuring sustainability, while providing for utilisation (see appendix 7). This must be done within the context of environmental principles regarding the impacts of fishing on the marine environment and information principles regarding best available information and uncertainty.
- **The Department of Conservation** is the key regulator for species protection and biodiversity in the marine environment, which includes marine reserves and parks, mammal sanctuaries, protection of protected or threatened species, and protection of biodiversity, and developing the *New Zealand Coastal Policy Statement*. This role is undertaken through a number of legislative instruments (see appendix 6).
- **Regional councils**, through the RMA 1991, can enact protections for the purposes of maintaining Indigenous biodiversity (within the territorial sea).

This is one of the key areas of regulatory complexity and is explored further through an analysis of managing impacts through protection areas (section 4.2: Managing impacts through protection tools) and in case studies on regional management (section 4.4: Regions have varying approaches to management within the territorial sea). There is a lack of connection in the way that land-based impacts are regulated and how fish stocks are managed, though there is a strong link between land-based issues and outcomes in the marine domain (see section 3.1.2: Land-based activities impact coastal fisheries).

There are also differences in how monitoring and reporting is undertaken by the different regulators and the purposes of this reporting. This creates potential for missed opportunities and lost efficiencies in how data is collected and analysed. These issues are discussed throughout this report.

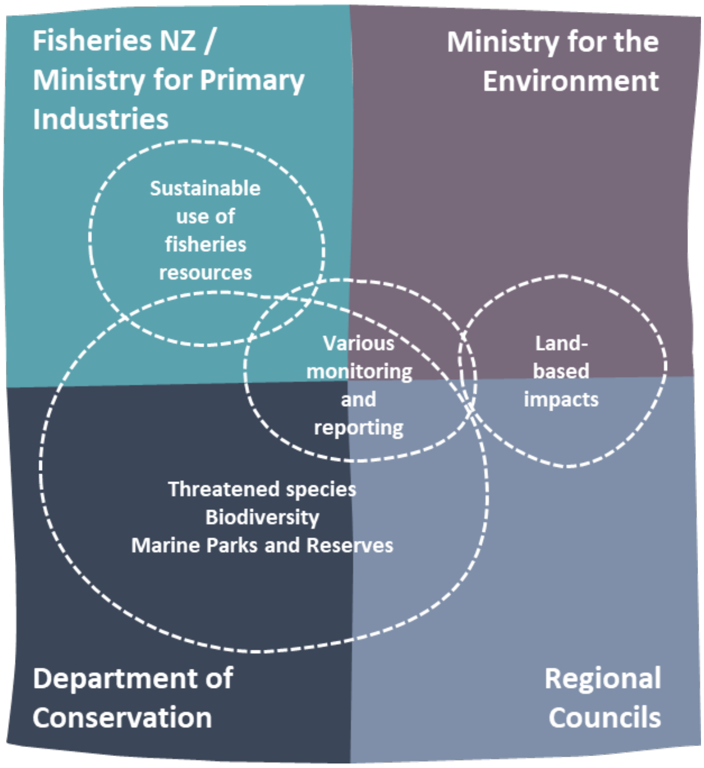


Figure 41: Four of the key regulators in the marine fisheries space and some of their overlapping roles in the marine environment.

There is a lack of connection in the way that land-based impacts are regulated and how fish stocks are managed, though there is a strong link between land-based issues and outcomes in the marine domain… this creates potential for missed opportunities and lost efficiencies in how data is collected and analysed.

Coordination of the regulatory framework forms the basis of recommendations in Themes 1, 2 and 3.

4.2 MANAGING IMPACTS THROUGH PROTECTION TOOLS

Although the scope of this report is restricted to commercial fisheries, in this section we briefly address the range of protections that can be applied to marine areas as these form an important part of the context in which these fisheries are situated. One of the most well-known tools is the MPA, where fishing is significantly restricted, or not allowed, which serves to protect representative areas that are unique or rare, or serve an important function for supporting marine life. There are many other types of tools, for example Māori have traditionally and recently used rāhui – temporary protections in space and time (see section 2.7.1: Te ao Māori) (Wheen and Ruru, 2011; Kahui and Richards, 2014; Reid and Rout, 2020). Different tools often have differing purposes and objectives and sit within a complex regulatory landscape (see table 6).

For fisheries management, the specific regulatory lever for habitat protection is through Section 9(c) of the Fisheries Act 1996. This states that, in relation to the utilisation of fisheries resources or ensuring sustainability decision makers shall take into account the environmental principle that habitat of particular significance for fisheries management (HPSFM) should be protected. However, no HPSFM have yet been defined by the regulator. There is work underway by the government, relating to MPA legislation and policy, led by the Department of Conservation and Fisheries New Zealand. This requires a close collaborative approach of Fisheries New Zealand and the Department of Conservation, reflecting the special relationship between the Crown and Māori, along with consultation with many other stakeholders.

For fisheries management, the specific regulatory lever for habitat protection is through Section 9(c) of the Fisheries Act 1996. This states that, in relation to the utilisation of fisheries resources or ensuring sustainability decision makers shall take into account the environmental principle that habitat of particular significance for fisheries management (HPSFM) should be protected. However, no HPSFM have yet been defined by the regulator.

Table 6: Examples of use of regulatory tools and processes used to enable marine protection.

Protection or management tool	Regulatory tool and process	Type of protection
Marine reserves	Enacted through the Marine Reserves Act 1971.	Highly protected areas (generally no-take) with a purpose of preserving them in their natural state as the habitat of marine life for scientific study. A broad range of activities and their effects can be managed, controlled or excluded.
Taiāpure	Enacted through Part 9 of the Fisheries Act 1996.	Estuarine or coastal areas only. Fishing allowed unless its management committee (nominated by local Māori community) recommends changes to the fishing rules and they are approved by the Minister of Fisheries. Recommendations can relate to: species fished; fishing seasons; sizes and amounts of fish; fishing areas; fishing methods.
Mātaitai Reserves	Enacted through Section 186 of the Fisheries Act 1996.	Developed and managed by tangata whenua. Prohibits commercial fishing but allows customary fishing and recreational fishing without needing a permit.
Marine mammal sanctuaries	Enacted through Section 22 of the Marine Mammals Protection Act 1978.	Activities known to harm particular marine mammal species can be restricted and strictly controlled by the Minister of Conservation within a marine mammal sanctuary.

Protection or management tool	Regulatory tool and process	Type of protection
Seamount closures	Commercial Fishing Regulations (enacted through the Fisheries Act 1996).	Prohibition on all trawling (including midwater).
Temporary closures	Section 186(a), 186(b) of the Fisheries Act 1996.	Closure of fishing area or restriction on fishing methods (186A) or closure of fisheries (186B) for up to two years. Designed for customary use, must be supported by tangata whenua.
Multiple protection methods	Through enactment of custom act (see appendix 8: Specific marine management acts).	Integrated approach to managing marine areas at a local level. (e.g. see 3.3.5: case study: Managing land-based impacts through a multi-sector marine spatial plan and 4.4.2: case study: Te Korowai o te tai ō Marokura in Kaikōura shows how regional responsibility can streamline fisheries management.
Protection Areas	Enacted through Section 30 of the Resource Management Act 1991.	Regional councils may establish and implement maintaining Indigenous biological diversity. (e.g. see 4.4.3: case study: The establishment of the Motiti Protection Areas sets a new precedent for local coastal management).
Habitats of Particular Significance for Fisheries Management (HPSFM)	Section 9(c) of the Fisheries Act 1996.	HPSFM have not yet been defined by the regulator.
Large number of gear and method specific closures	Various fisheries regulations that exist in regulation.	E.g. numerous trawl, set net, and dredging closures. Seasonal closures to protect various nursery and spawning grounds.
BPAs	Enacted with the Fisheries (Benthic Protection Areas) Regulations 2007 under the Fisheries Act 1996.	Dredging and trawling within 100 m of the seafloor is prohibited. Agreed and established in 2007, no changes to protection since establishment.
Cable protection zones	Submarine Cables and Pipelines Protection Act 1996.	As all fishing and anchoring activities (with one minor exception) are illegal within protected areas they offer some marine protection (e.g. in Raukawa Moana Cook Strait and Tīkapa Moana Hauraki Gulf).

While marine reserves and protection areas can be designated through our Marine Reserves Act 1971 (see for example, Cape Rodney-Okakari Point (Goat Island) Marine Reserve in case study 3.3.6), the use of this legislation has not been the regulatory tool of choice in a number of instances throughout Aotearoa New Zealand (Banks and Skilleter, 2010). In 2016 the latest new proposal for MPA legislation was released that, if enacted, would repeal the Marine Reserves Act 1971 (Wheen, 2016). The Act as it currently stands has been described as inflexible, with the stated purpose of marine reserves being for scientific study (for example, by presuming that a MPA will be no-take) and has a more specific focus on habitat protection (Allan, 2017; Peart *et al.,* 2019).

The *New Zealand Coastal Policy Statement* provides direction for how regional councils manage the coastal environment (how to apply the purpose and principles of the RMA), including council functions to maintain and protect Indigenous biodiversity and associated habitats and ecosystems and identified areas of outstanding natural character and features (Peart *et al.*, 2019). While providing higher-level direction to councils, the *New Zealand Coastal Policy Statement* has been criticised as not fully capturing the "temporally dynamic, spatially heterogeneous, and physically and socially complex region which characterises the interface between terrestrial, marine and lacustrine processes." (Scott, 2016).

Ideally, marine spatial planning would sit with and align to a higher strategic policy or framework for the ocean, drawing on both mātauranga Māori and western science. Parts of marine spatial planning are currently undertaken jointly by the Department of Conservation and the Ministry for Primary Industries. The 2005 *MPA Policy* guides the current approach to establishing MPAs in New Zealand (Department of Conservation and Ministry of Fisheries, 2005). Also see mention of the *New Zealand Coastal Policy Statement*, in relation to the functions of regional councils in the coastal space (see section 4.4: Regions have varying approaches to management within the territorial sea).

Ideally, marine spatial planning would sit with and align to a higher strategic policy or framework for the ocean.

Specific approaches to managing the impact of fishing activities on habitat are discussed in:

- Section 4.2.1.1: Protection strategy and the global move towards higher marine protection goals.
- Section 4.2.1.3: Actioning the use of habitats of particular significance for fisheries management.
- Section 6.3: How we fish, where gear innovation and changes to practices to manage impact on the environment are discussed.

Of course, any discussion around protection of marine habitat cannot only take scientific considerations into account. As Ian Mathieson, New Zealand Fishing Industry Guild executive secretary stated in an *RNZ* interview, "you do very much need to understand how it's impacting local communities and that's both from a recreational fishing, a customary Māori perspective and a commercial sector."

4.2.1.1 PROTECTION STRATEGY AND THE GLOBAL MOVE TOWARDS HIGHER MARINE PROTECTION GOALS

The concept of 30% marine protection[92] being a stated goal has emerged prominently in recent years (O'Leary *et al.*, 2016; Roberts *et al.*, 2019; Adams *et al.*, 2020; Attenborough, 2020), aimed primarily at biodiversity conservation. Aotearoa New Zealand has also been identified as one of a number of countries that has the ability to have a much greater impact on global conservation because of the significant size of our EEZ (Zhao *et al.*, 2020).[93] Our country has opportunities to contribute to biodiversity conservation at a significant scale (see section 4.3: Aotearoa has international obligations in the marine space). In 2016, the International Union for Conservation of Nature (IUCN) World Conservation Congress passed a resolution on increasing marine protected area coverage for effective marine biodiversity conservation:

> Encourages IUCN State and Government Agency Members to designate and implement at least 30% of each marine habitat in a network of highly protected MPAs and other effective area-based conservation measures, with the ultimate aim of creating a fully sustainable ocean, at least 30% of which has no

[92] Note: this does not only refer to 'Marine Protected Areas' as defined in Aotearoa New Zealand legislation.

[93] The research paper prioritises areas for protection based on biodiversity measures and overlays the area that is within a country's EEZ. Highest on the list is Canada, followed by Australia, the United States, Greenland, Indonesia, Russia and New Zealand.

extractive activities, ***subject to the rights of Indigenous peoples and local communities*** [emphasis ours].

The concept of a specific percentage of marine protection as a goal has already existed within the Convention on Biological Diversity's Strategic Plan under Aichi Biodiversity Target 11:

> By 2020 […] 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

Reporting from the convention working group on post-2020 targets has raised the possibility that this goal will increase to 30% when agreed in May 2021. Aotearoa New Zealand is a party to these targets (see section 4.3: Aotearoa has international obligations in the marine space).

Aotearoa New Zealand is still considering how our marine protection measures align with marine protection targets and the sustainable development goals (SDG), including SDG 14, as exact numbers depend on the criteria used to define MPAs (Grorud-Colvert *et al.*, 2019; Department of Conservation, 2019b). While over 30% of our marine environment is currently under some form of protection,[94] these are not all to a high level of protection (see 3.3.6: case study: The Noises vs Cape Rodney-Okakari Point Marine Reserve). For example, only 0.4% of the marine and coastal area is 100% protected as no-take reserves (Department of Conservation, 2019b).

Existing MPAs have been described as inefficient in protecting a representative range of biodiversity (Geange *et al.*, 2017) and the level of protection afforded by BPAs, and how they are reported, is contested. Some challenge benthic protection because it is protection on a horizontal rather than vertical basis, i.e. they only offer protection from fishing impacts to the seafloor and not the three-dimensional environment as a whole (O'Leary and Roberts, 2018). While no-take is often seen internationally as the gold standard for meeting biodiversity objectives (Sala and Giakoumi, 2018), these are not the only objectives in managing our oceans.

Distribution of marine reserve coverage is uneven. For instance, 96.5% of Aotearoa New Zealand's marine reserves are located around offshore islands in the far north (Rangitāhua Kermadec Islands) or south (subantarctic Islands) (Department of Conservation, 2019b). Additionally, the 10% target that was established in 2005 is now considered to be inadequate to meet conservation and biodiversity goals (Rockström *et al.*, 2009; Rovellini and Shaffer, 2020).

Globally, research into the effectiveness of no-take MPAs in achieving different goals has increased. In terms of restoring biodiversity and enhancing ecosystem resilience, they have been shown to be effective. A meta-analysis showed biomass of fish in marine reserves to be 670% greater than adjacent unprotected areas, and 343% greater than partially protected MPAs (Sala and Giakoumi, 2018).

Studies also show that benefits extend beyond the borders of MPAs. These benefits are further reaching than the biodiversity goals, potentially providing benefits for commercial fisheries as well, even though this is not the goal of MPAs:

- Although thought to generally occur at a small scale (for example, less than one kilometre from a reserve), adult spill over from marine reserves is common (Buxton *et al.*, 2014; Kelly *et al.*, 2002; Shears and Thomas, 2014b; Le Port *et al.*, 2017).

[94] i.e. benthic protection.

- Unprotected populations and fisheries are bolstered by larval export from protected locations (Krueck *et al.*, 2017).

A study published in 2017 looked at how snapper larvae in the Cape Rodney-Okakari Point Marine Reserve impacted fish populations beyond the bounds of the no-take MPA, using a combination of genetic parentage and relatedness analysis (Le Port *et al.*, 2017). The study found that adult snapper within the MPA were responsible for around 10% of the 'newly settled juveniles' in surrounding areas (around 400 km^2). This demonstrates that protection of adult fish within an MPA can increase recruitment outside of MPAs at a scale that is relevant to fisheries management.

Figure 42: John dory at the Poor Knights Marine Reserve. Image credit: Crispin Middleton/NIWA.

Similar results have been found internationally, for example a 1,000 km^2 study area on the Great Barrier Reef found that reserves that accounted for only 28% of the local reef area produced about half of all juvenile recruitment within 30 km (Harrison *et al.*, 2012).

The establishment and expansion of no-take marine reserves is contentious in Aotearoa New Zealand, in part due to its potential interaction with rights ratified by the Treaty of Waitangi (Donnelly, 2017). There are also tensions between iwi commercial fishery rights and mana whenua's role as kaitiaki. This was evident in the introduction of the Kermadec Sanctuary Bill. Other examples of iwi-led protection are highlighted in section 5.7: Iwi initiatives. The fishing industry also questions the ability of MPAs to achieve biodiversity protection objectives, and is critical of the significant costs they can impose on local fishers and impacts on fisheries sustainability through displacement of catch.[95] The industry is not aware of any situation in Aotearoa New Zealand where commercial fishing has benefited from the establishment of an MPA. Fisheries scientist Ray Hilborn also writes that he believes the use of tools such as catch and fishing gear limitations are more effective than no-take marine reserves in protecting marine biodiversity (Hilborn, 2020). He describes spillover effects as being generally local rather than regional in scale, thus site-specific benefits may be small at the scale of the QMA. Additionally, if the overall QMA continues to be fished at the same level, fishing effort is displaced (and potentially intensified).

For a target for proportion of no-take MPAs to be environmentally beneficial, it is important to ensure a rigorous process when designing and implementing MPAs, as areas most easily protected are not necessarily those most worth protecting (Devillers *et al.*, 2020), either for conservation purposes or for fisheries management purposes. There is a risk that when such goals are established, achieving an expansion of protected areas could lead to complacency over measurement of environmental indicators that predict and monitor outcomes. In Aotearoa

[95] Input from Industry.

New Zealand’s Goverment reporting under the CBD, it is stated that “our current coastal marine protection network does not yet protect a fully representative range of habitats…” (Department of Conservation, 2019b). Thus targets may technically be met but the meaning of success is limited (Campbell and Gray, 2019). There is also conflict between the longer-term benefits for fisheries and the short-term costs, which need to be given serious consideration.

Figure 43: Snapper inside Cape Rodney-Okakari Point Marine Reserve. Image credit: Shaun Lee/iNaturalist (CC BY 4.0).

Weigel *et al.* (2014) provide key factors in how the divide between fisheries sustainability and biodiversity conservation goals can be met in creating MPAs (see figure 44). Ecological success of no-take MPAs is very much predicated on how planning is undertaken and what is considered, for example:

- Larval retention and dispersal (Planes *et al.*, 2009; Krueck *et al.*, 2017).
- Robust monitoring programmes (Rilov *et al.*, 2020).
- Climate consideration (Bates *et al.*, 2019).
- Representation of habitat types, HPSFM, and unique biodiversity (Munguia-Vega *et al.*, 2018).
- Connectivity and spacing (Munguia-Vega *et al.*, 2018).
- Location in relation to fishing areas (Munguia-Vega *et al.*, 2018).
- Adaptability (Rilov *et al.*, 2020).

4.2.1.2 REVIEW OF MPA LEGISLATION AND POLICY AFFORDS OPPORTUNITIES

The 2005 MPA legislation and policy is currently under review and has stated objectives for planning to be science-based, and for there to be a consistent approach to classifying habitats and ecosystems with an inventory of MPAs. This was to allow gaps in the network of protection to be identified and allow for prioritisation of protection. The stated goal of the policy was to:

> "Protect marine biodiversity by establishing a network of MPAs that is comprehensive and representative of New Zealand's marine habitats and ecosystems."

From a national perspective, the objective is narrow. However, the planning forums established when implementing marine protection do take into account many of those affected, including tangata whenua, commercial fishers, recreational users, conservation, tourism, aquaculture, scientists and extractive companies.

In acknowledging the value of MPAs, we can also recognise that increased knowledge about species and habitats could allow more targeted use of this tool and allow us to understand the protective value of an MPA to different species and habitats (Jackson and Lundquist, 2016; Jarvis and Young, 2019). Species characteristics, such as lifespan, reproductive strategies and migration patterns will have a great impact on this protective value.

Changes to the design, size and application of marine reserves could increase positive outcomes and decrease restrictions, if there was a greater knowledge base to draw from. MPAs arguably also have value in informing fisheries management, by acting as reference points and allowing for detailed studies (for example, growth parameters of particular species, or ecosystem dynamics) (Willis, 2013). Technological innovations may also change the way in which protection is applied. An example of where technology has enabled dynamic species protection instead of a static protection area is illustrated in section 6.6.1: New technology can make it easier to monitor the marine environment. The wider and integral importance of dynamic, adaptive and responsive fisheries management must be emphasised in forming the foundation from which the use of protection tools may be incorporated within fisheries management objectives. There are more sophisticated approaches than static spatial tools that are now available (which are discussed throughout part 6). A clear regulatory framework and monitoring will be fundamental to guiding application of new technology in marine protection.

A clear regulatory framework and monitoring would be fundamental to guide application of new technology in marine protection.

Bridging the divide between fisheries sustainability & biodiversity conservation goals in MPAs

Creating spaces and processes for engagement

Incorporating fisheries in MPA design and MPAs into fisheries management

Engaging fishers in management

Recognizing rights and tenure

Coordinating between agencies and clarifying roles

Combining no-take-areas with other fisheries management actions

Addressing the balance of costs and benefits to fishers

Making a long-term commitment

Creating a collaborative network of stakeholders

Taking multiple pressures into account

Managing adaptively

Recognizing and addressing trade-offs

Matching good governance with effective management and enforcement

From Weigel et al. 2014

Figure 44: Ways to bridge the divide between different goals for MPAs taken from Weigel *et al.* (2014).

4.2.1.3 ACTIONING THE USE OF HABITATS OF PARTICULAR SIGNIFICANCE FOR FISHERIES MANAGEMENT

While much attention is focused on MPAs, less profile is given to specific provisions in the Fisheries Act 1996 for habitat protection.

Under Section 9(c) of the Fisheries Act 1996 the use of fisheries resources requires that, in relation to the utilisation of fisheries resources or ensuring sustainability, decision makers shall take into account the environmental principle that habitat of particular significance for fisheries management (HPSFM) should be protected. This supports the sustainability of fisheries, the environment, and our ecosystems as a whole.

According to Fisheries New Zealand, there have been no HPSFM defined or applied in the approximately 25 years the Fisheries Act 1996 has been in place. Work on preparing a guidance document for implementing Section 9(c) is described as ongoing in the AEBAR (Ministry for Primary Industries, 2020a) but is reportedly only at an early stage.[96]

> There have been no habitats of particular significance for fisheries management defined or applied in the approximately 25 years the Fisheries Act 1996 has been in place.

Defining areas has been purportedly difficult due to the specificity of significance of habitats to individual species and life stages. The resulting situation is that the regulator specifies that most habitat is significant to at least one species, yet none are quantified. There is no prioritisation framework or formal quantification of the importance of different habitats. While there are definite data and knowledge gaps acting as barriers to identification and prioritisation, there is also a substantial body of research on areas of importance (e.g. juvenile nurseries). Work has been undertaken previously, on habitats and areas of particular significance for inshore fisheries (Hurst *et al.*, 2000; Morrison *et al.*, 2014b) and overseas there are references such as the NOAA *Essential Fish Habitat* regulatory guidelines in the US on which to build.

There are restrictions on fishing that could contribute protection to (but are not a defined as) an HPSFM (see table 6). Yet without definition or quantification, the level or type of protection provided is unknown, as is the additional level of protection that might be valuable. An overall strategy, which incorporates HPSFM, could provide needed structure, prioritisation, monitoring frameworks, and measurable outcomes for assessing success.

Other MPAs or fishing-restricted areas can be pointed to in lieu of progress in HPSFM but it is worth understanding the stated purpose of establishing outcomes. HPSFM relate to their significance for fisheries management. This differs from marine reserves, which are set up to preserve, for the scientific study of marine life, “underwater scenery, natural features, or marine life, of such distinctive quality, or so typical, or beautiful, or unique, that their continued preservation is in the national interest.”[97] Mātaitai reserves recognise and provide for the special relationship between tangata whenua and their traditional fishing grounds and non-commercial customary fishing. There are many other types of protected areas, all with specific purposes (see table 6).

[96] Input from Fisheries New Zealand.
[97] Marine Reserves Act 1971

HPSFM relate to their significance for fisheries management. This differs from marine reserves, which are set up to preserve "underwater scenery, natural features, or marine life, of such distinctive quality, or so typical, or beautiful, or unique, that their continued preservation is in the national interest."

The need for and protection of HPSFM continues to be identified as important, e.g. see the management objectives of fisheries plans:

- *National Fisheries Plan for Deepwater and Middle-depth Fisheries*: Ensure that maintenance of biological diversity of the aquatic environment and protection of habitats of particular significance for fisheries management are explicitly considered in management.
- *National Fisheries Plan for Highly Migratory Species (HMS)*: Identify and, where appropriate, protect habitats of particular significance to HMS, especially within New Zealand fisheries waters.
- *National Inshore Finfish Fisheries Plan*: Develop a definition, policy and management framework to protect habitats of particular significance for inshore fisheries management.
- *National Plan of Action for Sharks*: Focus on HPSFM (e.g. pupping and nursery grounds) and need for research to be continued, consolidated, and expanded. This would allow identification of threats to these HPSFM and could guide management measures.

As our spatial information improves and there is finer-scale reporting of fishing locations and vessel tracking data – as is being presented in Fisheries New Zealand's electronic monitoring (EM) and compliance system (see section 5.5.1: Electronic catch and position reporting is live) – there are greater opportunities to monitor and manage interaction with HPSFM. Though these first must be defined, identified and synthesised within a more integrated approach.

Once HPSFM are formally identified and recorded, there can potentially be better understanding of impact and much more consistent management approaches. For example, quantification of benthic impacts on HPSFM, or as a first stage, mapping of recurrent or new fishing events with areas of HPSFM. However, a lack of quantification should not prevent protective action to be taken as there will always be an absence of perfect information.

There are also benefits of a more formal approach in terms of transparency, public trust, and industry confidence.

In many cases the fishing industry may want to advocate for protection of an HPSFM as, depending on the species, this could have a substantial impact on both short- and long-term outputs and sustainability. For example, declaring a HPSFM may help create a formal dialogue and expedite action from regional councils to mitigate land-based impacts on coastal habitats. National guidelines to formally identify these sites, with scientific input, would support establishment of protection. The way that legislation is currently administered does not support these efforts.

There are also benefits of a more formal approach in terms of transparency, public trust, and industry confidence… National guidelines to formally identify these sites, with scientific input, would support establishment of protection.

This analysis informs our recommendations in Theme 6.

Some sectors of the commercial fishing industry are demonstrably committed to identifying and protecting HPSFM – for example, the pāua[98] industry recognises that there are crucial habitats for pāua that cause potential lifecycle bottlenecks. Their focus is on juvenile habitat because good cryptic habitat with coralline algae for juveniles in the intertidal zone, adjacent to good reef and boulder habitat for adults further out, is vital for abundant and healthy pāua populations (see 5.3.7: case study: Pāua fisheries and industry-led management).

Some fisheries are demonstrably committed to identifying HPSFM.

Fisheries New Zealand identifies international examples of formalised habitat classifications that could help to define HPSFM:

- The *Essential Fish Habitat* framework being advanced in North America (Benaka 1999; Diaz *et al.* 2004, Valavanis *et al.* 2008).
- The developing NOAA *Coastal and Marine Ecological Classification Standard* for North America (Keefer *et al.* 2008; Marine and Coastal Spatial Data Subcommittee and Federal Geographic Data Committee, 2012).
- *European Marine Life Information Network* framework, which has developed habitat classification and sensitivity definitions and rankings (Hiscock and Tyler-Walters, 2006).

Overall, the range of legislation that can be applied to marine protection and the overlapping and sometimes divergent drivers of using these tools highlights the challenges in fisheries management. This illustrates the need for guiding principles and agreed goals.

This discussion underpins recommendations in Themes 2, 4 and 6.

Figure 45: Juvenile pāua. Image credit: Dave Allan/NIWA.

[98] Pāua refers to three species of edible sea snail: the black-foot pāua (*Haliotis iris*), the yellow-foot pāua (*Haliotis australis*) and the white-foot pāua (*Haliotis virginea*). Only the black-foot pāua is harvested in significant quantities commercially.

4.3 AOTEAROA HAS INTERNATIONAL OBLIGATIONS IN THE MARINE SPACE

There are many international obligations that Aotearoa New Zealand is party to that influence how we manage our fisheries. A table of international agreements is provided in appendix 9.

The obligations relate both to the marine environment within our EEZ, and to aspects of international fisheries (outside of our EEZ and highly migratory species within our EEZ).

Figure 46: Blue shark/tahapounamu (*Prionace glauca*). Image credit: Erik Schlogl/iNaturalist (CC BY-NC 4.0).

Key agreements related to sustainable fisheries include:

- **The United Nations Convention on the Law of the Sea (UNCLOS).** UNCLOS is a comprehensive regime of law and order in the world's oceans and seas establishing rules governing all uses of the oceans and their resources.
- **The United Nations Fish Stocks Agreement (UNFSA).** UNFSA sets out principles for the conservation and management of straddling fish stocks and highly migratory fish stocks and establishes that such management must be based on the precautionary approach and the best available scientific information.
- **Convention on Biological Diversity (CBD).** CBD has three main objectives: the conservation of biological diversity; the sustainable use of the components of biological diversity; and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. It includes goals relevant to fisheries management.
- **Sustainable Development Goals.** The United Nations signed up to 17 SDGs that bring together three dimensions of sustainable development (economic, social, and environmental). SDG 14 is to "Conserve and sustainably use the oceans, seas and marine resources for sustainable development."

Aotearoa New Zealand is a member of several Regional Fisheries Management Organisations (RFMO),[99] which relate to access to fisheries and also fisheries conservation and management measures. Agreed measures are generally passed into New Zealand law. Some examples of RFMOs include the South Pacific RFMO and Western and Central Pacific Fisheries Commission (WCPFC). The WCPFC seeks to address problems, including the management of high seas fisheries from unregulated fishing, insufficiently selective gear, unreliable databases, and insufficient multilateral cooperation with respect to conservation and management of highly migratory fish stocks. Aotearoa New Zealand implements the objectives of the conservation and management measures, for example, by limiting catch for key highly migratory shark species (Francis and Maolagáin, 2016). Aotearoa New Zealand must monitor and provide data to the WCPFC.

The CBD is one of a number of other international agreements that, while not directly related to fisheries management, impact on how we manage our oceans. It requires that parties should establish a system of

[99] See appendix 9 for details on these RFMOs.

protected areas or areas where special measures need to be taken to conserve biological diversity. Every four years the Department of Conservation, in consultation with other agencies, reports on the actions we have taken and progress to achieve targets (e.g. against the Aichi Biodiversity Targets, appendix 9). These agreements add an international layer to the regulatory challenges relating to marine protection discussed above in section 4.1: The complex domestic regulatory system can create gaps and overlaps. A full review of all these requirements is beyond the scope of this report.

4.4 REGIONS HAVE VARYING APPROACHES TO MANAGEMENT WITHIN THE TERRITORIAL SEA

Local marine environments are often managed in a specific way, drawing on local knowledge to manage context-specific issues. Several different approaches to managing the marine area are underway throughout Aotearoa New Zealand, with each having unique processes and outcomes. There is no one-size-fits-all approach but we highlight a few case studies of unique solutions to our complex regulatory landscape.

We found examples of long stakeholder negotiation processes resulting in a bottom-up design of how the area should be managed, as shown in Atawhenua Fiordland and Kaikōura (Urlich *et al.*, 2019). Consensus-building is a particular strength of the approach. Although they cover very localised areas, the examples highlight that progress can be made through inclusive stakeholder engagement. We have not attempted to present a comprehensive discussion of the effectiveness of different local approaches, which is beyond our Terms of Reference.

Figure 47: Kaikōura: where the mountains meet the sea. Image credit: Joerg Mueller/Wikimedia (CC BY-SA 3.0).

LOCAL CASE STUDIES

In each case we discuss local solutions rather than the role of central government:

- **Fiordland created a novel model for managing the marine area.** This case study explores the different roles of regulators in regulating, administering, monitoring and planning at a local level.
- **Te Korowai o te tai ō Marokura in Kaikōura shows how regional responsibility can streamline fisheries management**. This case study explores some examples of how having this regional body has enabled more responsive fisheries management decision making.
- **The establishment of the Motiti protection areas sets a new precedent for local coastal management.** This case study explores the extent of regional council powers in regulating the marine space when it may impact on commercial fisheries management.

- **The Hawke's Bay Marine and Coastal Group took a collaborative approach to prioritise research needs for the region.** This case study explores the research roadmap developed by a multi-stakeholder group brought together by the Hawke's Bay Regional Council.

The *Sea Change – Tai Timu Tai Pari* process undertaken by a multi-stakeholder group (including central government) in the Hauraki Gulf to develop a marine spatial plan is another example of a regional-specific approach to managing the marine environment (see 3.3.5: case study: Managing land-based impacts through a multi-sector marine spatial plan).

The *New Zealand Coastal Policy Statement* (see section 4.2: Managing impacts through protection tools) provides important guidance for local-level management.

Local-level approaches may not always be appropriate for all species, areas or management issues. For example, some threats (such as some marine invasive species) have an origin point outside of the region, or fish species may have a large biological range. Geographically isolated areas, with fewer stakeholders, may have more success at establishing local management initiatives.

There should also be regard to the mismatch in management scales between regional councils (limited to territorial sea within their region) and the QMAs (which may cross many regions and cover both the territorial sea and EEZ). This reflects the challenges of managing a complex multi-scale biological system. Anecdotal accounts from locals and fishers (relevant on a local scale) may not always be relevant to quota decisions that are made at a larger scale.

While the scope of this report is on commercial fishing, these case studies illustrate that resolving long-standing issues in the marine environment will require an overarching strategic approach to managing the oceans (Macpherson *et al.*, 2020).

While the scope of this report is on commercial fishing, these case studies illustrate that to resolve longstanding issues in the marine environment will require an over-arching strategic approach to managing the oceans.

This discussion underpins recommendations in Theme 2.

4.4.1 CASE STUDY: FIORDLAND CREATED A NOVEL MODEL FOR MANAGING THE MARINE AREA

Atawhenua Fiordland makes up part of Te Wahipounamu – a World Heritage site incorporating four of our national parks. Ten marine reserves border the national park including over 10,000 hectares of inner fiord marine habitat with species like lampshells[100] and black corals.[101] Commercial species like rock lobster and pāua are abundant.

A range of stakeholders were involved in a forum-style planning process for the local marine environment. This forum-style planning process was completed and implemented outside of the *New Zealand Marine Protected Areas Policy and Implementation Plan* (Davies *et al.*, 2018b). The resulting collaborative grouping – the Fiordland Marine Guardians – represents commercial and recreational fishers, tourism interests, recreational users, marine science and conservation, and the local community. The resulting regulation, the Fiordland (Te Moana o Atawhenua) Marine Management Act 2005, provides a novel management model.

Figure 48: Top – Buller's albatross in Fiordland. Image credit: Stephen Murphy/Flickr (CC BY-NC-ND 2.0). Bottom – Milford Sound Underwater Observatory. Image credit: Kara Brugman/Flickr (CC BY-NC-ND 2.0).

The provisions of the Act enable the Fiordland Marine Guardians to:

- Obtain, share and monitor information on the state of the area.
- Assist the management agencies to prepare and disseminate information.
- Monitor the state of the marine environment and biological diversity in the area.
- Plan for the enforcement of and compliance with the management of the area.

The Fiordland (Te Moana o Atawhenua) Marine Area includes: two pre-existing marine reserves; eight new marine reserves; and twenty-three 'china shops' – small areas of protection used for multiple reasons, such as to protect areas of special significance or particularly fragile habitats from fishing impacts. The reserves are subject to the conditions in the Fiordland (Te Moana o Atawhenua) Marine Management Act 2005 and the provisions of the Marine Reserves Act 1971. There are also specific rules around commercial, recreational and customary fishing in the Fiordland Marine Management Area.

[100] *Brachiopoda*.
[101] *Antipatharia*.

Reviews of the biological responses to changes implemented following the Act found that there was evidence of improvements, including increases in the populations of rock lobsters and blue cod, and increased diversity of reef fishes (Jack and Wing, 2013; Wing and Jack, 2014a). However, there remained an under-representation of productive kelp forest habitats in the marine reserve network and spatial closures were less effective because of converted habitat near freshwater inputs, though it was noted that these challenges provided an opportunity for targeted improvements (Jack and Wing, 2013; Wing and Jack, 2014b).

Key strengths of this approach include:

- **Consensus built**. A collaborative group allows consensus to be built between parties with competing interests (such as between commercial and recreational fishers). In Atawhenua Fiordland, a 'gifts and gains' approach was used, where stakeholders had to be prepared to individually relinquish benefits in order to collectively achieve success in sustainable management of the environment and its fisheries (Mulcahy *et al.*, 2012; Bromell, 2017).
- **Customised protections**. Specific measures and approaches can be formulated and negotiated using this approach. For example, Atawhenua Fiordland has many 'china shops', and the 'Doubtful Sound dolphin protection zones', strips at the edge fiord (thought to be critical habitat) intended to reduce encounters between vessels and dolphins (Bennington, 2019).
- **Local support and knowledge**. There can be greater use of local knowledge and organised commitment to reaching goals. For example, in the eradication of *Undaria* seaweed.

A 'gifts and gains' approach was used, where stakeholders had to be prepared to individually relinquish benefits in order to collectively achieve success in sustainable management of the environment and its fisheries.

The key weaknesses include:

- **Lengthy process.** The original stakeholder group (the Guardians of Fiordland's Fisheries) first formed in 1995 (Cunningham *et al.*, 2019) and the Act was passed ten years later.
- **Possibility of particular interests dominating.** Local organisations have the potential to favour particular interests over others (Scott, 2016). For example, this might lead to an imbalance in how interests are weighed between conservation compared to use-right (whether for fishing or for other marine-based activities).

4.4.2 CASE STUDY: TE KOROWAI O TE TAI Ō MAROKURA IN KAIKŌURA SHOWS HOW REGIONAL RESPONSIBILITY CAN STREAMLINE FISHERIES MANAGEMENT

Recognising the need for integrated land, water and infrastructure management to protect their local marine environment, Te Korowai o te tai ō Marokura in Kaikōura developed the Kaikōura Marine Strategy in 2012 which led to the Kaikōura (Te Tai o Marokura) Marine Management Act 2014. The Act established a group of Marine Guardians who advise Ministers, modelled off the Atawhenua Fiordland approach (see 4.4.1: case study: Fiordland created a novel model for managing the marine area). The statutory Guardians and Te Korowai are closely linked, with almost all members overlapping. Members represented iwi, central and local government agencies, environmental interests, tourism interests, and commercial and recreational fishing interests.

Figure 49: Top – Fishing boats off Kaikōura coast. Image credit: Nick Brunsdon/Flickr (CC BY-NC-ND 2.0). Bottom – Rock lobster, Kaikōura. Image credit: Kelvin Perrie/iNaturalist (CC BY 4.0).

In 2016, the Kaikōura region suffered a significant earthquake. In response, the Minister of Fisheries, in consultation with the local Kaikōura community, immediately closed several local fisheries. A rapid response was required to protect affected pāua, seaweed and other shellfish populations while the area recovered.

Since a diverse range of local stakeholders were already connected and had built consensus on their shared goals for Kaikōura's marine environment, the previously established local group allowed the local pāua industry to more easily draw on the collective views of the community to inform the efforts to manage and reopen the fisheries, arguably with greater agility than the regulator.[102] The shared goals of Te Korowai, underpinned by specific localised legislation, helped fisheries management approach these challenges in a nimble way.

> A diverse range of local stakeholders were already connected and had built consensus on their shared goals for Kaikōura's marine environment.

Some examples of how having this regional body has streamlined processes in fisheries management include:

- **Providing consolidated feedback into the regulatory amendment process.** In the pre-consultation phase of a regulatory amendment process to reopen fisheries, Te Korowai engages with the community and

[102] Input from Industry.

provides feedback on the views to the Kaikōura Marine Guardians, who then advise Ministers on their recommendations. Te Korowai's views also feed into the proposal to amend the regulation and are considered during the later public consultation.

- **Feeding directly into the earthquake response effort.** A representative from the Guardians was part of the Earthquake Restoration Liaison Group for informing the design, management and monitoring for the reconstruction of infrastructure along the coast. Their role was to provide advice and expertise into the rebuild process from the experience within Te Korowai and the Guardians.
- **Being across rapid research and data to inform decisions.** The Ministry for Primary Industries funded $3.5 million of community-led research projects to generate data to inform decisions in response to the earthquake, some of which related to fisheries management. The Marine Guardians have stayed across this evidence and support it feeding into regulatory processes through their advisory process.
- **Proposing localised solutions to fisheries management problems.** Through community discussions and collaboration, the group collated local knowledge about the unique bathymetry and ecology of Kaikōura and the impact to the Kaikōura community to inform a Kaikōura-specific option for the Hector's and Māui Dolphin Threat Management Plan, which was submitted to Fisheries New Zealand and informed the final advice to the Minister of Fisheries.

The emergency setting highlighted the utility of a regional group in informing agile fisheries management by the local community and industry. An established strategy and trusted relationships meant that consensus could be built quickly to inform decision making. As the demand for more responsive fisheries management increases (see section 6.2.1: Changing fisheries demand nimble and responsive decision making), regional responsibility similar to that held by Te Korowai and the Kaikōura Marine Guardians may provide a key tool to facilitate the shift to quick, responsive management underpinned by strong local knowledge.

4.4.3 CASE STUDY: THE ESTABLISHMENT OF THE MOTITI PROTECTION AREAS SETS A NEW PRECEDENT FOR LOCAL COASTAL MANAGEMENT

An exclusion zone put in place by Bay of Plenty Regional Council following an oil spill eventually paved the way for a landmark court ruling. This confirmed that regional councils have jurisdiction to control the taking of fish, provided this is not for a Fisheries Act 1996 purpose but for the purpose of maintaining Indigenous biodiversity or other resource management values.

In 2011, the MV *Rena* struck Ōtāiti (Astrolabe Reef) and spilt an estimated 350 tonnes of heavy fuel oil (Schiel *et al.*, 2016). It was Aotearoa New Zealand's worst oil spill by volume and many fish and more than 1,000 seabirds were directly impacted by the spill.

Figure 50: A gem doris/nudibranch (*Dendrodoris krusensternii*) observed in the Motiti Natural Environment Management Area in 2020. Image credit: Lukas Phan-huy/iNaturalist (CC BY-NC 4.0).

Following the spill, an exclusion zone was set up around the vessel so that salvaging operations could take place. The exclusion zone was established on the basis of navigational safety under the Maritime Transport Act 1994 and the Bay of Plenty Regional Council's navigation safety bylaw.[103]

The reefs near Motiti Island in the Bay of Plenty support significant marine biodiversity, landscape and cultural values. The Bay of Plenty has decades of monitoring data for coastal and estuarine ecosystems, which provided a scientific baseline against which to measure the impacts of the MV *Rena*. In this case, the combination of the coastline type, duration of spill, rapid response, and many other factors, meant that the Te Moana-a-Toitehuatahi Bay of Plenty coastal ecosystem showed significant resilience (Battershill *et al.*, 2016).

The absence of fishing in the exclusion zone allowed much of the marine life to increase and demonstrated the significant natural biodiversity of this area (RMLA, 2018). Motiti Island is unique in having a resident population of predominantly tangata whenua. They have had a long intergenerational aspiration for the reservation of the rohe moana to preserve their wāhi taonga, wāhi tapu and other cultural and environmental significance preserved as a taonga moana for their hapū and the shared benefit for the wider community. In this endeavour, the Motiti Rohe Moana Trust was established (prior to the MV *Rena* grounding) to allow representation on behalf of tangata whenua of Te Moutere o Motiti in legal proceedings, primarily on behalf of Ngā Hapū o te Moutere o Motiti. However, it is important to note that there are diverse tangata whenua views and not all residents of Motiti feel they are represented by the Trust.

While the grounding was not the genesis of legal efforts, it provided a dataset that supported what tangata whenua had known for many generations – that there had been significant degradation of their rohe.

As described by the Chairman for the Motiti Rohe Moana Trust and kaumātua of Te Moutere o Motiti, Umuhuri Matehaere, "Nature began to restore itself. Potential for good came from the bad."[104] The Trust considered that the reef continued to need "time to heal and rest so that it can re-emerge to its full health."[105] However, the

[103] Bay of Plenty Regional Council (2016).
[104] Umuhuri Matehaere, kaumātua of Te Moutere o Motiti, Chairman for the Motiti Rohe Moana Trust (Umuhuri Matehaere, 2017).
[105] See Umuhuri Matehaere, 2017.

exclusion of fishing was on the basis of navigational safety and once this risk was minimised and the exclusion zone was removed, fishing activities would recommence as they previously had.

"Nature began to restore itself. Potential for good came from the bad."

The Trust made an application under the Fisheries Act 1996[106] for a temporary closure of the fishing area, which was not successful for a number of stated reasons, including the lack of wide consultation with tangata whenua. Legal action continued over several years, starting with an appeal to the *Regional Coastal Environment Plan* followed by the Environment Court, High Court and Court of Appeal. Levers for protection under the RMA 1991 regarding the functions of regional councils were explored.[107]

The court case highlighted conflict between the RMA 1991 and the Fisheries Act 1996 in how the marine environment is regulated. The purpose of the Fisheries Act 1996 is to provide for the utilisation of fisheries resources while ensuring sustainability. While the need to ensure sustainability has led to the introduction of measures regarding bycatch, benthic impacts, changes to biodiversity and protection of habitats, the implementation of available sustainability tools has been variable (Fathom, 2019).

The court case highlighted conflict between the Resource Management Act 1991 and the Fisheries Act 1996 in how the marine environment is regulated.

The RMA relates to the use of land, air and water and its purpose is to promote the sustainable management of natural and physical resources. This includes the responsibility of councils to undertake coastal planning and to maintain biodiversity within the territorial sea (up to 12 nautical miles offshore) through a *Regional Coastal Environment Plan*.

The Environment Court needed to consider whether regional councils could manage the effects of fishing to maintain biodiversity under the powers of the RMA, without managing the fisheries resources themselves, which are under the remit of the Fisheries Act 1996 (Urlich, 2020).

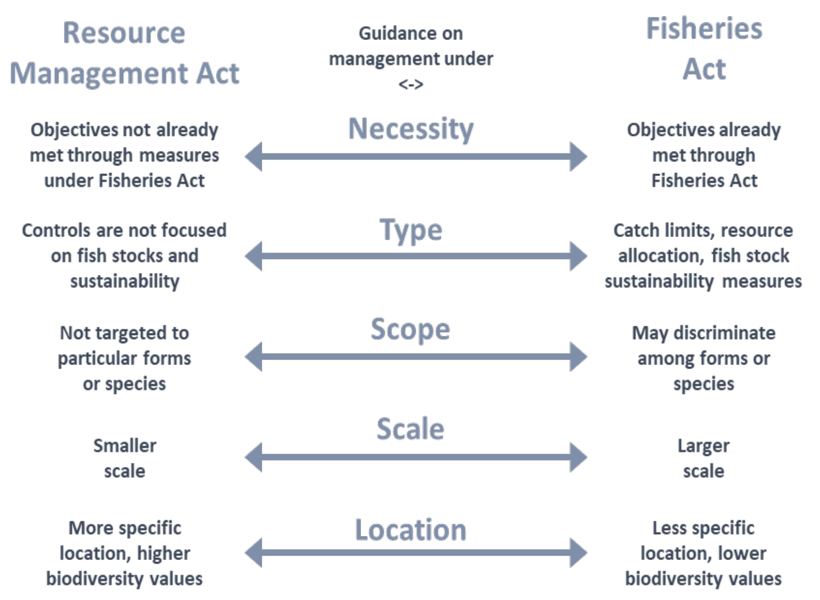


Figure 51: Five indicia identified by the Attorney General for how a council may decide to implement a control that impacts on fisheries management from (Court of Appeal, 2019).

The Environment Court has in this case directed the regional council in the primary role of governance for biodiversity. The Environment Court ruled that Bay of Plenty Regional Council could provide protections, as long

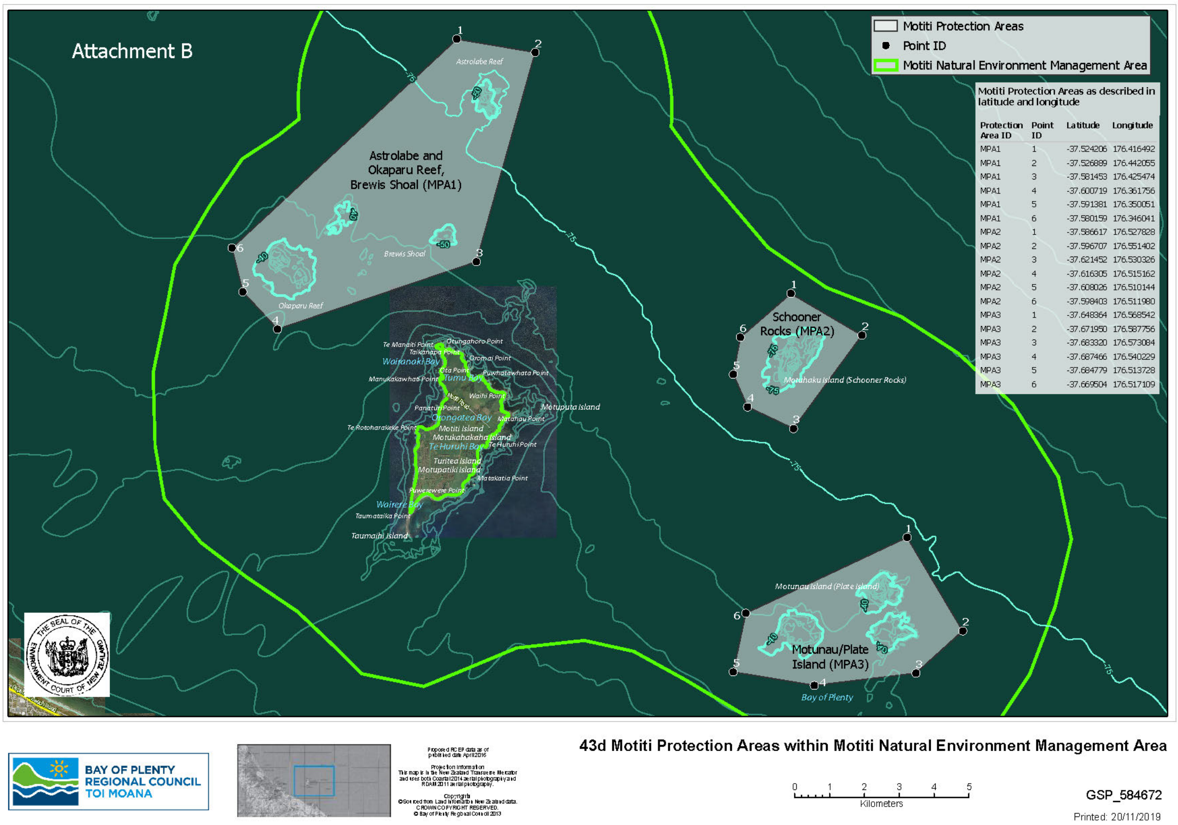
[106] Fisheries Act 1996. 186A Temporary closure of fishing area or restriction on fishing methods.
[107] Resource Management Act 1991. 30 Functions of regional councils under this Act.

the main purpose was in line with those set out under the RMA, having particular regard to the intrinsic values of ecosystems and the relationship of Māori with ancestral waters and taonga (Peart *et al.*, 2019).

> The Environment Court has in this case directed the regional council in the primary role of governance for biodiversity.

What this decision allows in practice is more complicated, but the Court of Appeal[108] outlined five indicators to provide guidance when considering whether a control could be implemented under the RMA[109] in a way that does not act for fisheries management purposes[110] (see figure 51).

The final decision directs Bay of Plenty Regional Council to implement new rules within its *Regional Coastal Environment Plan* to protect three reef systems near Motiti and complete scientific monitoring, in collaboration with tangata whenua and multiple agencies, to inform future integrated marine management solutions for the wider Motiti Natural Environment Management Area (Environment Court, 2020). The new rules will protect several areas from all fishing (whether commercial, customary, or recreational) (see figure 52).



Protection Area ID	Point ID	Latitude	Longitude
MPA1	1	-37.524206	176.416492
MPA1	2	-37.526889	176.442055
MPA1	3	-37.581453	176.425474
MPA1	4	-37.600719	176.361756
MPA1	5	-37.591381	176.350051
MPA1	6	-37.580159	176.346041
MPA2	1	-37.586617	176.527828
MPA2	2	-37.596707	176.551402
MPA2	3	-37.621452	176.530326
MPA2	4	-37.616305	176.515162
MPA2	5	-37.608026	176.510144
MPA2	6	-37.598403	176.511980
MPA3	1	-37.648364	176.568542
MPA3	2	-37.671950	176.587756
MPA3	3	-37.683320	176.573084
MPA3	4	-37.687466	176.540229
MPA3	5	-37.684779	176.513728
MPA3	6	-37.669504	176.517109

Figure 52: Motiti Protection Areas within Motiti Natural Environment Management Area (Bay of Plenty Regional Council).

The precedence of this decision, which was not universally applauded,[111] means the relationship between the councils, the Ministry of Primary Industries, and the Department of Conservation is entering a new phase. The decision emphasises the importance of co-management that is appropriate to the scale of the issue and provides

[108] See Court of Appeal (2019).
[109] Resource Management Act 1991. Section 30(1)(d)(i), (ii) or (vii).
[110] Resource Management Act 1991. Section 30(2) A regional council and the Minister of Conservation must not perform the functions specified in subsection (1)(d)(i), (ii), and (vii) to control the taking, allocation or enhancement of fisheries resources for the purpose of managing fishing or fisheries resources controlled under the Fisheries Act 1996.
[111] Feedback from various stakeholders.

a way for Fisheries New Zealand, Department of Conservation, regional councils and iwi to work more closely together (Urlich, 2020).

The decision emphasises the importance of co-management that is appropriate to the scale of the issue.

The Court direction to work with tangata whenua and multiple agencies on future marine management solutions presents several opportunities to create a new way of solving problems, using the existing agency tools, applying mātauranga Māori, building capacity of rangatahi in marine science, and exploring contemporary adaptive marine management tools.

In this case, the Regional Council was directed to establish the protection areas and did not itself advocate for the protection. The Council reportedly had some concerns around establishment of the protection areas, as part of an appeal process to the *Regional Coastal Environment Plan*, as well as having the mechanisms to manage enforcing rules. However, the decision provides greater clarity going forward and the council now has the role of communicating these changes to the wider public. Part of this will be sharing the biodiversity values with communities. The Council will be focusing on working with tangata whenua, the Ministry of Primary Industries, the Department of Conservation and key sector leaders, from the fishing communities, to ensure a collaborative process is established. This is important given that some tangata whenua have stated they do not feel their views were represented in the process or decision.[112]

As the protection areas are governed by rules that sit within a *Regional Coastal Environment Plan*, they are in place for the life of the plan, which is 10 years. The plan review process will be the mechanism to ensure that the public will have their opportunity to understand the monitoring results of the protection areas and also provide submissions on any future controls in the wider area.

The Motiti decision is an example of hapū using innovative legal means to protect their moana. It may provide councils with a greater certainty in their functions in protecting biodiversity and other resource management issues. Yet it is clear there is ongoing tension in this area. Some argue that the decision actually increases uncertainty and creates confusion in the statutory regime.[113] There is similar confusion potentially created in relation to Māori customary fisheries, and the potential risk of an inconsistent approach between regional councils and therefore uncertainty for local fishers.[114] In contrast, hapū of the Motiti Islands feel the cases reflect issues much wider than those related to fisheries, with how we relate to our environment and the governance of our community to interact in a culturally and environmentally safe manner, and that the Fisheries Act 1996 is not functioning appropriately if it is not considering and responding to the regional context provided in informed regional coastal plans.

There are several issues that councils may face that require consideration to ensure protections put in place are effective. For example:

- **Enforcement**. Councils may lack the capacity to effectively enforce protection areas. This means that many protections area would require strong community support and would rely heavily on self-policing.
- **Data requirements.** Effectively designing and monitoring protection areas relies on having ready access to data at an appropriate level of granularity to be able to make informed decisions. Councils may have

[112] Input from TA Sayers, who whakapapas to the Motiti Islands: An additional concern is that the purpose of this collaboration seems related only to fisheries and not to the cultural, natural, and RMA landscape.
[113] Input from Industry.
[114] Input from Te Ohu Kaimoana: Te Ohu Kaimoana state the Court of Appeal did not deal with any implications on Māori customary (either commercial or non-commercial) fishing interests. Specifically, it did not make a determination on whether a regional council could prevent customary fishing (commercial or non-commercial) for an RMA purpose.

access to detailed biodiversity data, at least where appropriate surveying has been carried out. This may or may not be representative of the coastal areas of interest. Fisheries electronic monitoring information is comprehensive, covering all commercial fishing, but may not be readily accessed by councils, particularly in a form that can be easily integrated with other datasets.

- **Funding.** Many councils may struggle to fund further work in marine protection, particularly where there is not a strong revenue stream (such as from ports) to support this coastal work.

The Motiti decision is an example of hapū using innovative legal means to protect their moana. It may provide councils with a greater certainty in their functions in protecting biodiversity and other resource management issues. Yet it is clear there is ongoing tension in this area.

4.4.4 CASE STUDY: THE HAWKE'S BAY MARINE AND COASTAL GROUP TOOK A COLLABORATIVE APPROACH TO PRIORITISE RESEARCH NEEDS FOR THE REGION

When various community groups came to the Hawke's Bay Regional Council with concerns about the depletion of fish stocks in the local area, it sparked the genesis of a collaborative approach to restore abundance to local waters. Advocacy groups, local iwi and hapū, government agencies and recreational and commercial fisheries started talking about concerns and aspirations for the Hawke's Bay marine area.

The challenge that the council faced was that the issues contributing to the decline fell across and between various pieces of legislation – different groups hold the responsibility to manage various issues. Under the RMA 1991, the council is responsible for land-based effects like sedimentation – a serious issue for the area given the significant large-scale clearance of native vegetation for sheep and beef farming. The council is also responsible for a range of coastal habitats, but had limited data and knowledge on these, relying on ad hoc studies over the years along with more recent state of the environment monitoring (Haggitt and Wade, 2016). The health of these habitats have significance for fisheries – however, Fisheries New Zealand is responsible for managing TAC under the Fisheries Act 1996, relying on separate information and datasets to make these decisions. Anecdotal accounts from locals and fishers who had witnessed changes over the years painted a picture of rapid degradation to various habitats and coastal species, but this was not necessarily feeding into annual catch entitlements (ACE).

Figure 53: Australasian gannet/tākapu (*Morus serrator*) at Cape Kidnappers in Hawke's Bay. Image credit: Ben Ackerley/iNaturalist (CC BY-NC 4.0).

Anecdotal accounts from locals and fishers who had witnessed changes over the years painted a picture of rapid degradation to various habitats and coastal species, but this was not necessarily feeding into annual catch entitlements.

A multi-stakeholder collaborative group was formed – known as the Hawke's Bay Marine and Coastal Group – to address the interconnected issues and cumulative impacts collectively. The group included representatives from council, iwi, the Ministry for Primary Industries, the Department of Conservation, community groups, and recreational and commercial fishing groups.

The newly established collaborative group commissioned a marine information review to map the knowledge and the knowledge gaps relating to the local marine environment, and draw on the expertise and experiences of a range of stakeholders, including people who had been fishing in the region for many decades (Haggitt and Wade, 2016). Financial contributions from all players helped cement the commitment from all groups to act on these issues.

Building on the marine information review, the group developed the *Marine and Coastal Group Research Roadmap*, launched in June 2018. The roadmap identified a common goal of "achieving a healthy and functioning marine ecosystem in Hawke's Bay that supports an abundant and sustainable fishery" (Hawke's Bay Marine and Coastal Group, 2018). The strategy focused on filling knowledge gaps to support integrated management of the marine and coastal environment, drawing on the best available knowledge systems, including a te ao Māori perspective, across three core research areas:

- Ecosystems and habitats,
- Terrestrial and coastal linkages, and
- Fisheries.

The shared goals and trusted relationships that grew from the process of collectively developing the roadmap proved to be a critical prerequisite to the group's next achievement – getting funding to start implementing the roadmap. Working with the Sustainable Seas National Science Challenge (see 5.8.1: case study: Sustainable Seas/Ko ngā moana whakauka), the Hawke's Bay Marine and Coastal Group has now completed the first stage of a three-stage research project:

- Stage 1: A systems mapping exercise of environmental stressors and feedback loops, incorporating social drivers (Connolly *et al.*, 2020).
- Stage 2: Modelling different scenarios to see what impacts these would have on the health of the marine ecosystem.
- Stage 3: Providing the scientific information required to underpin and inform management and policy decisions.

Any suggested actions would need to be taken back to the individual governing agencies to make decisions. Each agency's involvement in the process should have helped to facilitate the priority evidence being gathered to inform their decision making with regard to the local marine environment.

The success of the approach taken by the Hawke's Bay Marine and Coastal Group demonstrates the strength of tackling complex issues in our marine setting in a holistic, integrated and collaborative way. Other regions throughout Aotearoa New Zealand could look to this model for inspiration, and continue to learn from the successes and challenges faced in the coming years as the group works to guide management and policy decisions from their findings. Local area management has proved most successful in isolated areas with fewer misaligned interests, but nevertheless there are lessons to be learned that could be adapted to other regions.

The success of the approach taken by the Hawke's Bay Marine and Coastal Group demonstrates the strength of tackling complex issues in our marine setting in a holistic, integrated and collaborative way.

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PART 5: COMMERICAL FISHERIES IN 2020

Image credit: Peter Marriott/NIWA (CC BY-NC-ND 4.0).

5.1 STRUCTURE OF PART 5

Part 5 provides context on how our fisheries are regulated and managed, and looks at the state of our fisheries in 2020. It includes a summary of how we're monitoring and reporting on our performance, how we are currently performing, the research that we're currently undertaking, and the limitations of our current data and knowledge. It provides an overview only and does not set out to provide a comprehensive description. This provides further context for the research and innovation aimed to improve the sustainability of our commercial fisheries covered in part 6. The information is focused on how science can support changes, acknowledging that science alone is not a solution to all of the issues in the marine domain, and that the science is often contested. A recurring theme is the challenge of managing a complex biological system at multiple scales within our current complex regulatory system.

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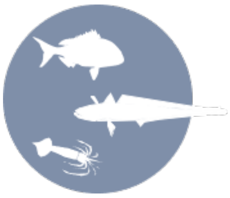
Part 5 is split into the following areas of focus:

Fisheries management involves the use of many different tools

This covers key parts of our fisheries management system, including: setting catch limits and allocating catch allowance; fisheries plans; targeted management of stocks; national plans of actions; and threat management plans.



Commercial fishing has impacts on target species sustainability

Commercial fishing targets many different stocks each year in the inshore and deepwater fisheries. Information is provided on the direct impacts of fishing activities to commercial fish species and how Aotearoa New Zealand is performing, to complement the discussion of the impacts to the wider ecosystem in part 3.

Research and regulatory initiatives are underway but poorly integrated

There are many regulatory, industry and other initiatives underway in our fisheries sector. Fisheries-related research programmes are described and discussion provided on how fisheries research is funded.

A recurring theme is the challenge of managing a complex biological system at multiple scales within our current complex regulatory system.

5.2 FISHERIES MANAGEMENT INVOLVES THE USE OF MANY DIFFERENT TOOLS

Having illustrated the complexities of the regulatory system for the marine environment in part 4, we now narrow our focus to the specifics of managing commercial fisheries themselves. Fisheries New Zealand is the key regulator tasked with guiding the sustainable use of fisheries resources to the greatest overall benefit to New Zealanders. They do so under the Fisheries Act 1996. This focus includes the sustainability of Aotearoa New Zealand's wild fish stocks, marine biodiversity, and the wider aquatic environment. This report focuses solely on commercial fishing of wild fish stocks, with aquaculture, customary and recreational fishing outside of scope (see Terms of Reference in section 1.2).

A central and significant part of fisheries management is the QMS, but this is only one element of the overall approach that Aotearoa New Zealand takes to managing fisheries. The key parts of this system are outlined in this section, including:

- **Environmental principles:** These are present within the Fisheries Act 1996 and could be more widely implemented (see also appendix 1: EAFM and the relevant Fisheries Act 1996 provisions, from Fathom (2019)).
- **Setting catch limits and allocating catch allowance:** The QMS allocates shares in each fish stock as quota. Quota generates an entitlement to catch a proportion of the TACC each year (ACE) within the relevant QMA. The Minister for Oceans and Fisheries sets the TAC, guided by the *Harvest Strategy Standard*.
- **Integrated fisheries plans:** Fisheries New Zealand produces integrated fisheries plans focusing on each of three fisheries: inshore finfish fisheries (under development); deepwater and middle-depth fisheries; and highly migratory species fisheries. Implementation of these plans is through Annual Operation Plans and Annual Review Reports (the management actions that will be implemented each year and assessment of the performance against objectives). Not all plans have been finalised or operationalised consistently.
- **Targeted management of fisheries through action plans or strategies:** Fisheries New Zealand works in collaboration with others to develop management plans to provide targeted support to fisheries that are not meeting sustainability expectations and need closer management or to outline management frameworks for protected species impacted by fisheries.
- **Managing impacts on marine species through management plans:** Fisheries New Zealand works in collaboration with others to develop management plans or strategies to provide targeted support to provide protection for species impacted by fishing.

Each of these aspects of fisheries management are described in further detail in this section, including commentary on where information is contested.

There are ongoing tensions between the management of fisheries and supporting ecosystem resilience. The connection between the numerous documents in terms of an overarching strategy or coherent governance structure is poorly understood. This makes it difficult to identify gaps in management and opportunities for reducing management overlap, and doesn't support a high level of public confidence in management of our fisheries and ocean ecosystem, an environment where data and its interpretation are highly contentious.

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5.2.1 ENVIRONMENTAL PRINCIPLES

The Fisheries Act 1996 requires that people undertaking fishing activities or making decisions covered by the Act "take into account" three environmental principles. These are:

a) Associated or dependent species should be maintained above a level that ensures their long-term viability.
b) Biological diversity of the aquatic environment should be maintained.
c) Habitats of particular significance for fisheries management should be protected.

These principles are consistent with an EAFM, drawn from UNCLOS and the UN CBD. While in the RMA decision makers must "recognise and provide for" matters of national importance,[115] the Fisheries Act 1996 is not as rigorous. In 1996 on their commentary on the then Fisheries Bill, the Primary Production Committee wrote that the "recognise and provide for" phrasing would place "too strong an obligation on persons exercising functions under the Act", opting instead for the more discretionary phrasing "take into account" (Primary Production Committee, 1996).

As discussed in part 4, Fisheries New Zealand has the dual duty of ensuring sustainability and providing for utilisation in the context of these principles. While Fisheries New Zealand does not explicitly mention these principles on their website, the Ministry for Primary Industries states that they "want to ensure our seas are healthy and there are enough fish for future generations" alongside information on MPAs, other measures to protect marine life, and how fish are counted. The extent to which these principles are "taken into account" is contested. For example, HPSFM have not been used to protect habitats (as discussed in section 4.2: Managing impacts through protection tools). Fishing impacts on associated or dependent species (as well as the wider ecosystem and biodiversity) are discussed in part 3.

5.2.2 SETTING CATCH LIMITS AND ALLOCATING CATCH ALLOWANCE

The QMS was introduced in Aotearoa New Zealand in 1986. Under the QMS, fish stocks are generally divided into species and geographic area. The system is used to limit the amount of commercial catch and allocate commercial harvest rights. It has a primary focus on single stocks. The adequacy of this approach has been challenged (see for example, The Nature Conservancy (2017); LegaSea and New Zealand Sport Fishing (2020)), however the QMS itself is outside the scope of our report.

Within the QMS, a decision is made as to the proportion of fish that can be sustainably harvested. This TAC[116] is apportioned between recreational, customary and commercial fishers and the proportion of total catch allocated to each group differs by species and area. For example, in an area with high population density such as Tīkapa Moana the Hauraki Gulf, the recreational allowance for snapper is a significant proportion (estimated at 40% in 2020). In many other fisheries, the majority of the TAC is provided for commercial interests. We do not explore this further, but focus on the commercial catch.

On introduction of the QMS, ITQs were allocated to different parties based in part on historic catch levels. The holders of ITQs have a right to fish a share of the total allowable *commercial* catch (TACC) of a particular species that can be caught in a particular area each year, or may sell their ACE to fishers.

Each year, the TACC is proportioned to quota holders who have a right to harvest a proportion of the total TACC. This is illustrated in figure 54.

[115] Resource Management Act 1991, section 6.
[116] TAC also explicitly allows for other sources of fishing-related mortality (such as mortality related to burst nets).

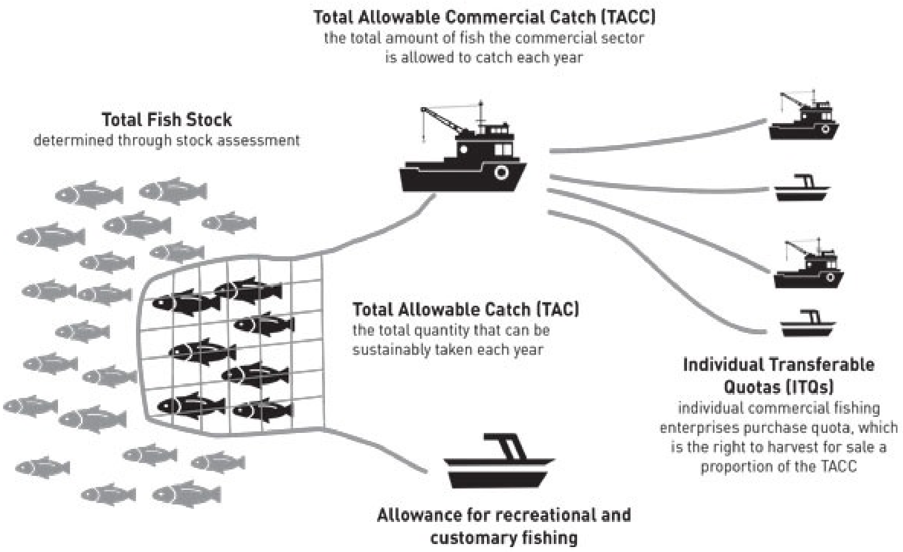

Figure 54: Summary of catch allocation. Image credit: Fisheries New Zealand.

Almost all commercially fished stocks are already in the QMS. In 2019, there were 388 in total.[117] Additional stocks can be added to the QMS via Section 18 of the Fisheries Act 1996, guided by the *Introduction Process Standard*. The Fisheries Act 1996 requires stocks to be introduced to the QMS if the existing management is not ensuring sustainability or providing for utilisation, unless another sustainability measure would better provide for the stock.[118]

THE HARVEST STRATEGY STANDARD

The *Harvest Strategy Standard* dates from 2008 and applies to all fish under the QMS and guides the way that fish stocks are managed (illustrated in figure 55) (Ministry of Fisheries, 2008). It is how the statutory requirements for stock sustainability, provided in Section 13 of the Fisheries Act 1996, are implemented in practice (but does not itself have statutory recognition). The *Harvest Strategy Standard* states that stock targets and limits should be set more conservatively for stocks where information is sparse or uncertainty is higher.

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The standard, developed in 2008, is intended to provide a consistent and transparent framework for decision makers. Not all stocks have had a target set.

Not all stocks have had a target set.

Three key aspects of the standard are below and are all contested. More information on how these limits are set is included in the rest of this section.

- A specified target abundance about which a fishery or stock should fluctuate.
- A soft abundance limit that triggers a requirement for a formal, time-constrained rebuilding plan.
- A hard abundance limit below which fisheries should be considered for closure.

[117] This excludes nominal stocks.
[118] Section 11 “Sustainability Measures” of the Fisheries Act 1996.

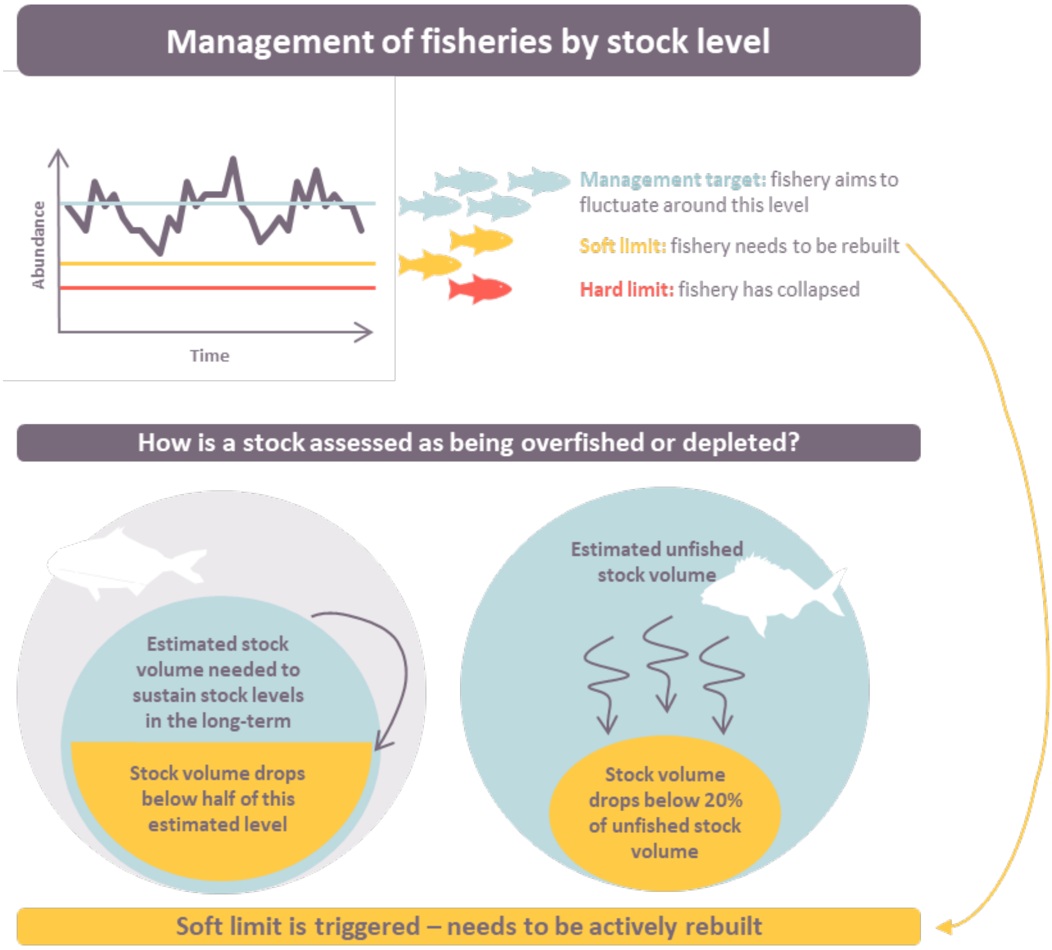

Figure 55: Summary of how fish stocks are managed based on the *Harvest Strategy Standard*. Note these are the default proportions and may vary by stock.

The key aspects of the standard are all contested.

STOCK ASSESSMENTS ARE BOTH CHALLENGING AND CHALLENGED

Fisheries New Zealand calculates how much of a particular stock can be caught each year through a stock assessment process. The aim is for stocks to be managed to a target level – a level where a fish stock can fluctuate around a balance between use and sustainability.[119] This assessment is simple in theory but relies on science that is inexact and uncertain.

This assessment is simple in theory but relies on science that is inexact and uncertain.

In particular, the following key inputs are all uncertain:

- How many individual fish there are currently in each stock (see section 5.2.2.1: Performance of stocks).
- How many fish there would be if none had been harvested (see section 5.2.2.3: Original biomass).
- The portion of the current stock that can be sustainably harvested (see section 5.2.2.4: Maximum sustainable yield).

[119] See MPI website.

- The degree of damage removal of these species does to wider ecosystem (section 3.3: Fishing effort has wider ecosystem impacts).

All of these factors are hard to measure and understand, which underpins both how challenging the fisheries management field is, and how much it is challenged.

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The assessment process factors in data such as self-reported catch and bycatch from commercial fishers, observer data, fisheries-independent research data (such as data from research vessels), and CPUE (section 5.2.2.6: The relationship between catch per unit effort and abundance), which is integrated via stock assessment models where these are available.[120] The stock assessment process is not uniform across each stock – the availability of data is highly variable and the approaches used also differ. There are numerous stocks that are not assessed due to a paucity of data (discussed further in section 5.2.2.1: Performance of stocks).

The stock assessment process is not uniform across each stock – the availability of data is highly variable and the approaches used also differ. There are numerous stocks that are not assessed due to a paucity of data.

Even for stocks with adequate data, there are inherent uncertainties relating to the use of models in a variable biological environment. All stock assessment analyses in Aotearoa New Zealand are peer-reviewed by Fisheries New Zealand using fisheries assessment working groups that include a range of science and industry experts as well as Fisheries New Zealand managers and other stakeholders. Working groups are technically open to anyone who agrees to the terms of the reference.[121] However, the often limited data and lack of trust in the decision-making process can create tension around stock assessments. This is reflected in criticism of the process that we heard from a variety of sources.

There have been times when industry has adopted more conservative catch limits than what they have been afforded because the data is lacking or not providing a reliable assessment of the stock status, or because they want a quicker rebuild to higher catch rates. In these cases a portion of the annual allowed catch is shelved. Conversely, there have also been instances where industry have mounted successful legal challenges in response to decrease in catch limits (e.g. orange roughy[122] in northern New Zealand).

Throughout these processes, the focus is primarily on the sustainability of individual stocks. Section 9 of the Fisheries Act 1996 also requires environmental principles to be taken into account (see section 5.2.1: Environmental principles), although the extent to which this occurs in practice is variable (see sections 4.2.1.3: Actioning the use of habitats of particular significance for fisheries management, and section 5.9: We need a plan for our oceans).

When a stock hits the soft limit, it is considered to be depleted or overfished and needs to be actively rebuilt, generally by reducing TAC of the stock. The timing of the rebuild can be a matter of contention.

Despite Fisheries New Zealand aiming to keep stocks at a target level, it is not universally achieved for measured fish stocks, and not all fish stocks are routinely measured (see figure 56).

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[120] This also includes consideration of levels of illegal/unreported fishing.

[121] See Terms of Reference for Fisheries Assessment Working Groups (FAWGs) in 2020 and Membership and Protocols for all Science Working Groups in 2020.

[122] *Hoplostethus atlanticus*.

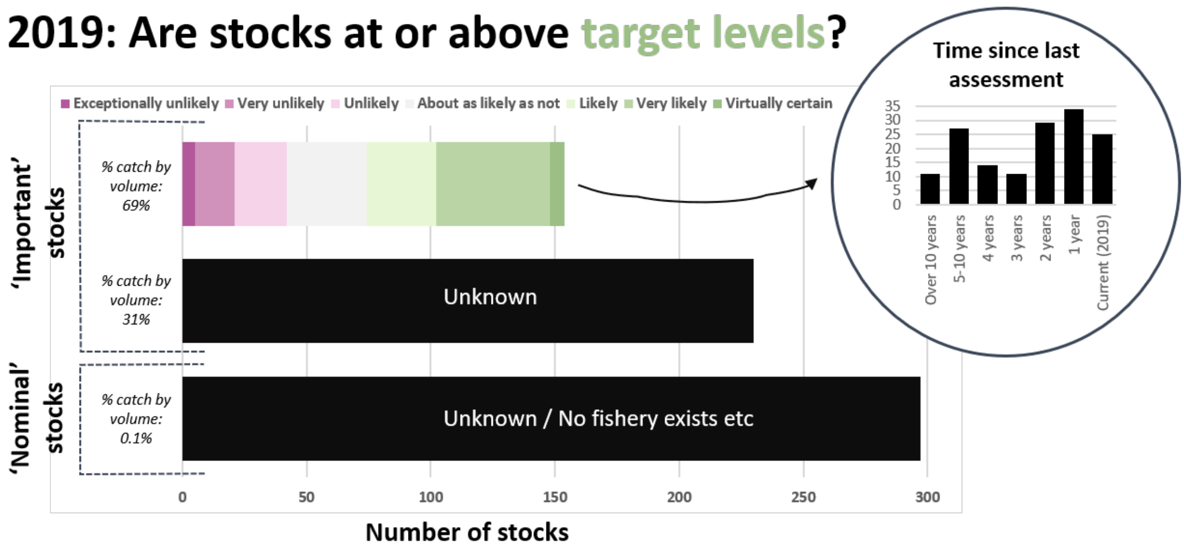

Figure 56: The status of fish stocks relative to the target level as reported by Fisheries New Zealand in 2020.

5.2.2.1 PERFORMANCE OF STOCKS

The key assessment of stock sustainability is undertaken by Fisheries New Zealand annually and published on their website. There are many differing reports of how many stocks are actually assessed (Ministry for the Environment and Stats NZ, 2019b). Note that nominal stocks are discussed in section 5.2.2.5.

Figure 56 shows the assessment of stocks by Fisheries New Zealand against the 'target level' or 'management target' criteria. The figure shows that around half of the QMS stocks were likely, very likely or virtually certain to be at or above target levels.[123] A significant proportion were about as likely as not to be at or above target levels, while the minority were likely to be below.

While in 2019 there were 160 stocks that were scientifically evaluated, there were also 228 stocks (and almost 300 nominal stocks)[124] that were not assessed (Fisheries New Zealand, 2019h). When stocks are not assessed, it is not possible to comment on their sustainability under our fisheries management regime. Of the stocks that are assessed, the time since last assessment also varies widely. While many have been completed in the last few years, others have not been assessed in over ten years.

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Figure 57 provides a comparison of stock sustainability by number of stocks, catch volume and catch value. This indicates that the stocks assessed are those with higher catch volumes and/or higher catch value. Further discussion is provided on stock performance in section 5.3.3.

[123] When considering only scientifically assessed stocks this equates to around 82%.
[124] Nominal stocks are stocks that represent less than one percent of catch.

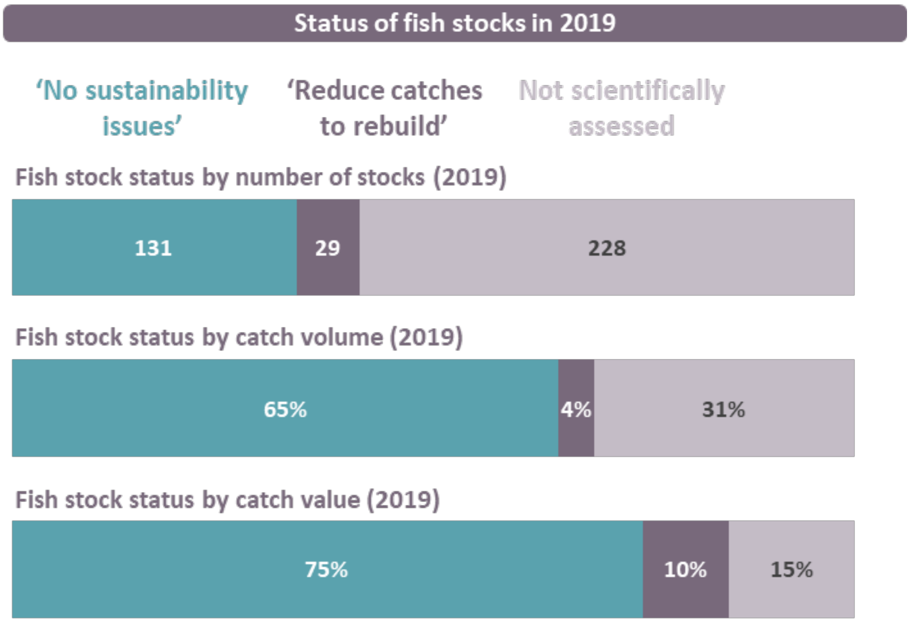

Figure 57: Fish stock status in 2019. Data from Fisheries New Zealand.

5.2.2.2 DISCARDS

Discards in fisheries refers to any fish that are landed but subsequently returned to the ocean. Discarding can refer to both legal and illegal actions, as there are rules that commercial fishers must follow around discarding, including the reporting of discarded catch. Generally, fish that are managed under the QMS must not be discarded.

Figure 58: An example of fish washed ashore that may have been illegally discarded.

Generally, fish that are managed under the QMS must not be discarded.

Commercial fishers who catch more fish than their ACE may be charged the 'deemed value' of the extra catch (if they cannot buy more ACE to cover it). The deemed value is calculated using a rate set by Fisheries New Zealand for each fish stock in the QMS and the deemed value is higher than the cost of buying ACE, to discourage intentionally fishing outside catch entitlements (Te Ohu Kaimoana, 2020b).

Some fish must be discarded – for example, when they don't meet minimum legal size limits (as for recreational fisheries). However, there are also circumstances where discarding may be illegal – e.g. of small fish (above the legal minimum size) or of catch where quota levels have been exceeded (Telesetsky, 2016). Where deemed values are high, this can create an incentive to discard catch to avoid these fees and is reportedly common in some fisheries (Mace *et al.*, 2014).

Where deemed values are high, this can create an incentive to discard catch to avoid these fees and is reportedly common in some fisheries.

Fish that are discarded may be dead already or may not survive after being released, so the resource is not being utilised. Fishing more selectively to avoid the need for discards and reducing mortality of fish upon landing (so that they can be returned unharmed) are challenges that research and innovation efforts need to address (see section 6.3: How we fish).

There is limited trusted data and information on discards, particularly in inshore fisheries where observer coverage is low, meaning there is little available quantitative information on the level of discards occurring (Mace *et al*., 2014). Discards are monitored by observers on deepwater fisheries and estimates are made of total discards (Anderson *et al.*, 2019). Discards estimates often rely on assuming similarity between observed and unobserved behaviour when it comes to discarding and recording (Anderson *et al.*, 2019). Anecdotally, there are reports that illegal discards are increasing due in part to market demands and the availability of ACE (Mace *et al.*, 2014).

Discards pose an ongoing challenge for regulators, although policy changes are currently underway (see section 5.5.3: Policy changes are underway) there is likely further work needed to reduce perverse incentives to discard illegally, as is happening overseas.

Although policy changes are currently underway, there is likely further work needed to reduce perverse incentives to discard illegally.

5.2.2.3 ORIGINAL BIOMASS

As presented in figure 55, many of the calculations of abundance and the soft and hard limits are in relation to the original biomass of a stock. This is the expected biomass in the absence of fishing. This makes the calculation of original biomass incredibly important because it is against this calculation that sustainability is measured.

Of course, in most cases the original biomass is not something that has been quantitatively observed. For some species there may be catch records that stretch far enough back in time (particularly when good records are kept from the beginning of extraction in that fishery), while for other species or stocks there is limited or no data. Fishing had already impacted on fish stocks when the QMS was introduced in 1986 (which was part of the reason for introduction), yet much of this fishing effort was unquantified (Durante *et al.* 2020) (see figure 59).

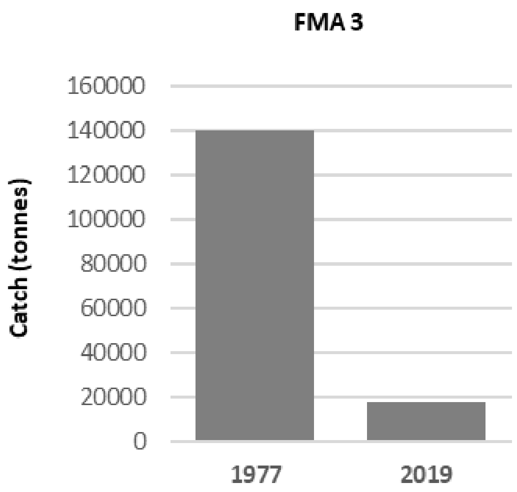

Figure 59: Estimated total catch (all species) along the east coast of the South Island (FMA3) in 1977, compared to catch levels in 2019. As reported in Durante *et al.*, (2020).

Fishing had already impacted on fish stocks when the QMS was introduced in 1986, yet much of this fishing effort was unquantified.

Calculation of the original biomass is uncertain. A variety of models can be used, depending on the available data. In many cases this modelling is complex with methodologies that are not easy to follow for non-fisheries experts. Uncertainty lies in the underlying data, in the complexity, and in the modelling approaches available. The resulting error bars in the model estimates of stock status therefore present a management challenge. This can lead to dissent (see the example discussed in case study 5.3.5: case study: Mixed messages: Are we overfishing our rock lobsters?).

Different models with different methods and different assumptions may produce significantly different estimates of biomass. For example, the range of model estimates may suggest the stock might be between 10% and 40% of original biomass. This can cause friction between stakeholders as where the stock sit within this range could trigger different management actions, from immediate closure (if at 10%) to no action (if at 40%).

Figure 60: Trevally/araara (*Pseudocaranx georgianus*) work-up. Image credit: Zinzi/iNaturalist (CC BY-NC 4.0).

5.2.2.4 MAXIMUM SUSTAINABLE YIELD

The Fisheries Act 1996 requires that the TAC is set at a level that maintains the stock at or above a level that can produce maximum sustainable yield (MSY) or proxies thereof. MSY is defined as the greatest yield that can be achieved over time while maintaining the stock's productive capacity, having regard to the population dynamics of the stock and any environmental factors that influence the stock (figure 61). The use of MSY is based on Fisheries New Zealand's interpretation of international best practice in the context of Aotearoa New Zealand. An alternative measure used by some other jurisdictions, including Australia, is maximum economic yield.

MSY is defined as the greatest yield that can be achieved over time while maintaining the stock's productive capacity.

TACs have generally been set to achieve single-species MSY-related objectives, though there has been a move to considering these targets within the wider ecosystem context, including bycatch, discards, habitat and protected species (Mace *et al*., 2014). There are criticisms of how it is currently applied, particularly given it is a theoretical construct (Peart, 2018). MSY is related to several parameters, all of which are contested, specifically original biomass (see section 5.2.2.3), current biomass (see section 5.2.2.6: The relationship between catch per unit effort and abundance), and how soft and hard limits are calculated (see section 5.2.2). The inexact and uncertain nature of these inputs therefore limits the certainty relating to MSY.

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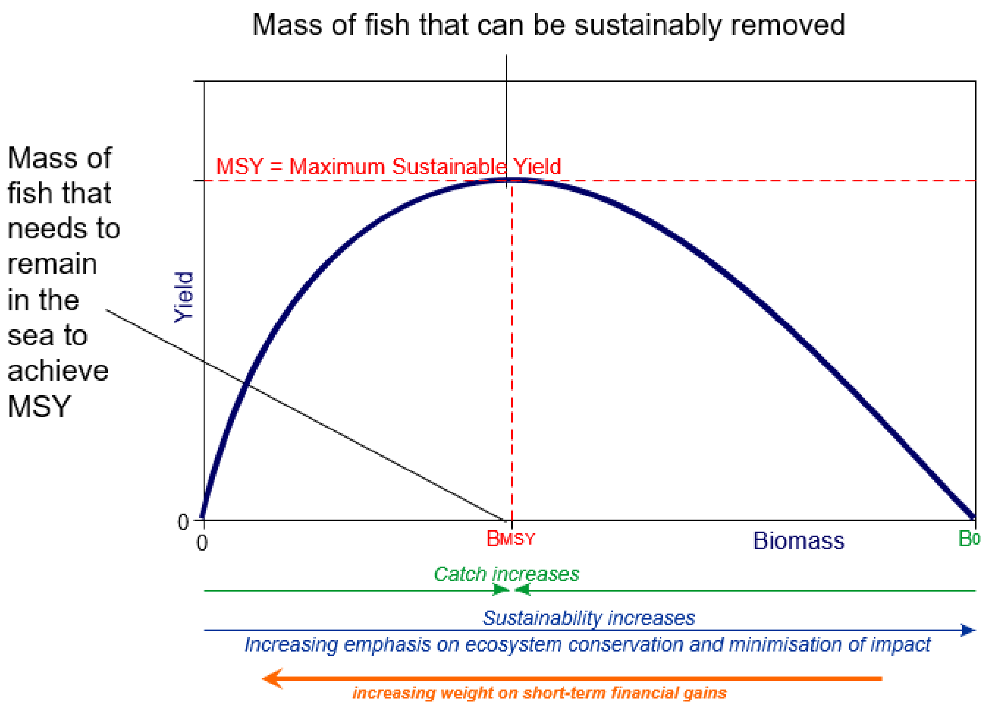

Figure 61: Calculation of maximum sustainable yield from Fisheries New Zealand. B_{MSY} is the biomass that supports maximum sustainable yield, B_0 is the original unfished biomass. **These numbers are uncertain and contested**.

5.2.2.5 NOMINAL STOCKS

Nominal stocks are an obscure part of the fisheries system to many stakeholders. It can be difficult to ascertain the importance of these stocks as, while the general reasons for excluding stocks is provided, it is not provided on a stock-by-stock basis publicly.

There is no stock status data provided for nominal stocks. In the system they represent stocks with:

- Zero TACs or TACCs.
- Small or zero annual catches (generally less than 10-20 tonnes) where there is:
  - No commercial or recreational development potential.
  - No current demonstration of customary or ecological importance.
- An 'administrative presence' only, e.g. to account for fish that stray into an area in which they are generally absent.

As our oceans warm, there could potentially be many changes to stocks that were once only an 'administrative presence'. Fish may eventually move en masse into a QMA in which they were previously rare (see section 3.1.1: Climate change is a huge threat to our oceans). Fisheries New Zealand expect to respond during periodic reviews of the classification of stocks as 'nominal' that occur every few years. There might be a need for more frequent action as oceans warm.

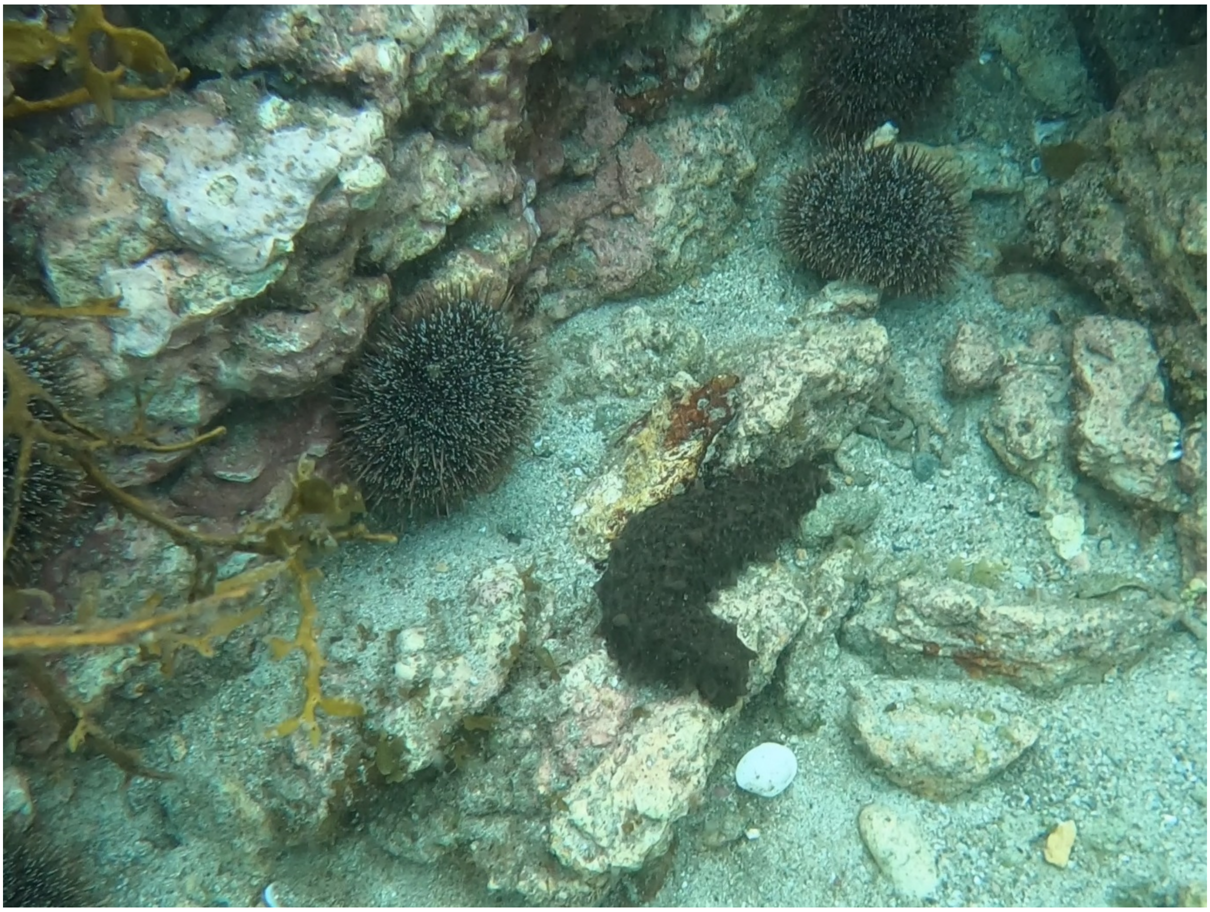

Figure 62: Kina and Australasian brown sea cucumber (*Australostichopus mollis*).

This process is less formal than some others undertaken by Fisheries New Zealand but has been described by their fisheries scientists as following a general process, shown below. In collaboration between science and management teams within Fisheries New Zealand, there are a series of rules consulted for continuing to deem a stock as nominal. Every few years the nominal stocks are judged against these rules. These rules are necessarily somewhat subjective and flexible, generally:

- For most moderate-to-high-volume inshore stocks, current and historical catches have rarely if ever exceeded about 10 tonnes in any given year (TACCs or TACs may exceed this amount, but catches are what count the most).
- For low-volume deepwater stocks, current and historical catches have rarely if ever exceeded about 10 tonnes in any given year (TACCs or TACs may exceed this amount, but catches are what count the most).
- For most moderate-to-high-volume deepwater stocks (which tend to be caught in much larger quantities than most inshore stocks), current and historical catches have rarely if ever exceeded about 20 tonnes in any given year (TACCs or TACs may exceed this amount, but catches are what count the most).
- For some high-value, low-volume inshore stocks (e.g. kina, sea cucumber, where a low volume could nevertheless be quite valuable), a lower cut-off might be more reasonable (for example, 2-5 tonnes).

- For some species with zero or very low catches, it may nevertheless have been demonstrated at some point in time that an appreciable abundance of a given species exists, e.g. several surf clam[125] stocks.
- For some species with very low commercial catches, there may nevertheless be moderate-to-high value to recreational fishers, e.g. yellow-eyed mullet/kātaha[126] in areas 1 and 9, or they may be locally important to iwi or others.

Stocks that have been included in stock status tables never become 'nominal', regardless of whether commercial catch decreases or stock range changes.

If this process was reported on more publicly then this increased transparency may allow greater comfort to stakeholders. Providing an opportunity to input concerns relating to nominal stocks may be beneficial.

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5.2.2.6 THE RELATIONSHIP BETWEEN CATCH PER UNIT EFFORT AND ABUNDANCE

It is extremely difficult to gain accurate measurements of the total number of fish in each stock. This means that proxy measurements must be used, and these are often contested. CPUE is an index of abundance sometimes used in Aotearoa New Zealand's fish stock assessments that inform setting of TAC. At a basic level, it is the amount of catch taken by a given amount of fishing effort.

It is extremely difficult to gain accurate measurements of the total number of fish in each stock. This means that proxy measurements must be used, and these are often contested.

The unit of measurement of CPUE depends on the fishery, for example it can be measured in kg-per-day, kg-per-tow, or other measures.

Conceptually when abundance of a stock increases, the effort required to catch a standard amount of fish should be lower, and vice versa.

However, measuring effort (and thus relative abundance) is not straightforward and so the CPUE may not reliably reflect abundance. For example, if increased fisher experience or improved fishing gear technology (both of which are difficult to measure) makes it easier to catch fish, this will impact the calculation of CPUE. To use a CPUE index to monitor trends in a fish stock, the assumption needs to be made that CPUE is correlated with stock abundance, yet this is not necessarily the case (Dunn *et al.*, 2000). CPUE has been described is a commonly used metric across the fishing industry. The reason it is commonly used is because the

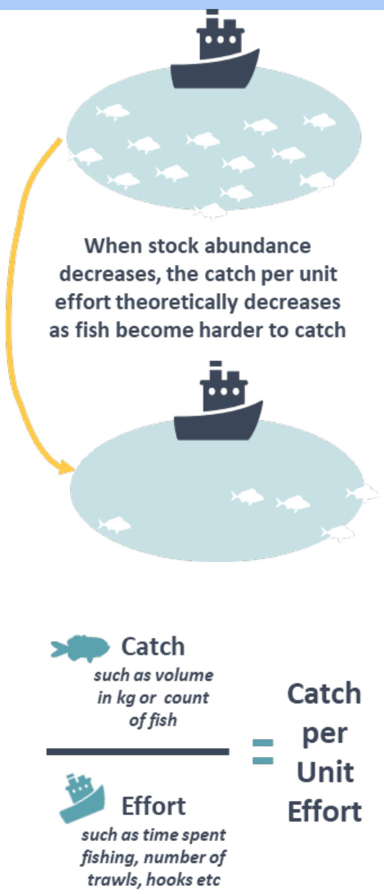

Figure 63: Simplified version of how CPUE is calculated.

[125] Surf clam is a generic term referring to seven species: deepwater tuatua (*Paphies donacina*), fine dosinia (*Dosinia subrosea*), frilled venus shell/puukauri (*Bassina yatei*), large trough shell (*Mactra murchisoni*), ringed dosinia/tuangi-haruru (*Dosinia anus*), triangle shell (*Spisula aequilatera*), trough shell (*Mactra discors*).
[126] *Aldrichetta forsteri.*

data on which it is based is cost-effective to collect and is often used for other purposes as well, and CPUE is relatively easy to calculate and interpret. Limitations are well recognised by Aotearoa New Zealand fisheries scientists and working groups.

Measuring effort is not straightforward and so the CPUE may not reliably reflect abundance.

Once the measurement of effort has been defined, the relationship between CPUE and abundance can be calculated quite simply (as a simple ratio of catch to effort) or through a much more complex standardisation process. These more complex processes are used throughout Aotearoa New Zealand's stock assessments and vary from stock to stock. A very simplified representation of this relationship is shown in figure 64.

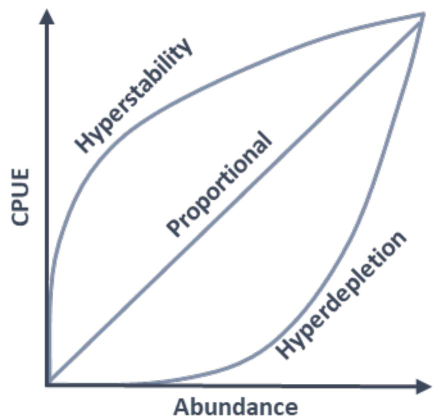

Figure 64: Types of possible relationship between CPUE and abundance. The assumption that CPUE is proportional to abundance is not always correct. Adapted from Hilborn and Walters (1992).

The assumption that CPUE is proportional to abundance is not always correct. Hyperstability is a potential issue with CPUE, where CPUE remains constant despite abundance decreasing (Harley *et al.*, 2001). It is an often cited concern by those opposed to aspects of commercial fishing.[127] This might reflect a situation where a new technology has made it easier to catch the fish (e.g. a change in netting material or design (Eigaard *et al.*, 2014) or where fish aggregate for spawning or feeding). Conversely, hyperdepletion describes a situation where abundance increases yet CPUE remains constant (e.g. all of the fish may not be available to capture (Roa-Ureta, 2012)). The relationship between CPUE and abundance is difficult to validate because of the difficulty of collecting consistent catch and effort data over a long enough time period to compare CPUE. In Aotearoa New Zealand, we have been able to compare CPUE with time series of research trawl survey results in some areas, with mixed results (see 5.3.6: case study: Chatham Rise is a unique fishery with consistent, long-term data).

The relationship between CPUE and abundance is difficult to validate because of the difficulty of collecting consistent catch and effort data over a long enough time period to compare CPUE.

Some fishers have challenged whether CPUE accurately incorporates fishing effort as they perceive it does not take into account the changes in their equipment use, the areas covered or how they target fish (Peart, 2018). CPUE aims to be applicable across a fleet and therefore will not always reflect a fisher's individual experience well.

There appears to be consensus that in many situations CPUE data may not accurately represent stock abundance, but if appropriately measured it can be a useful input into understanding abundance trends in a given fishery in the absence of alternative measures (Abraham and Neubauer, 2015). One role of the fisheries assessment working groups is to guide the CPUE analyses, assess how reliable CPUE data is when deciding how to incorporate it into full stock assessment models, and determine whether they credibly reflect stock

[127] Input from Industry.

abundance. It is therefore crucial that these working groups operate in a way that builds trust in the independent scientific assessment process.

There appears to be consensus that in many situations CPUE data may not accurately represent stock abundance, but if appropriately measured it can be a useful input into understanding abundance trends in a given fishery in the absence of alternative measures… It is therefore crucial that these working groups operate in a way that builds trust in the independent scientific assessment process.

The credibility of CPUE indices varies greatly between stocks. In 2019, a Fisheries New Zealand report on the West Coast South Island (HAK7) fishery for hake/kehe[128] concluded that CPUE indices conflicted greatly with research trawl surveys and were not a reliable index of fish abundance. In this example the CPUE data was not used in the stock assessment given the level of uncertainty in its reliability (Finucci, 2019). Trawl survey for this stock was also treated with low confidence (as trawl survey in this case was also quite unreliable).

Figure 65: Snapper, Northland. Image credit: Icolmer/iNaturalist (CC BY-NC 4.0).

The credibility of CPUE indices varies greatly between stocks.

In comparison, other fisheries such as snapper in SNA8, found that CPUE modelling was robust enough to account for changes in trawl gear and for changes in fisher behaviour (Langley, 2017). In this case, given the importance of the fishery, further independent trawls were contracted to help ensure the data used to assess the stock was as robust as possible.[129]

Some examples of factors that impact on the calculation of CPUE include:

- **Catch equipment used.** E.g. cod-end size and length, door spread and length of sweeping gear. This is explored in depth in 5.3.7: case study: Pāua fisheries and industry-led management.
- **Experience and skill.** E.g. an experienced skipper may be able to more easily locate and catch fish than a newer skipper (Eigaard *et al.*, 2014).
- **Practices used.** E.g. vessel speed: a net that is trawled more slowly will typically catch fewer snapper (Dunn, 2006; Langley, 2017) (5.3.5: case study: Mixed messages: Are we overfishing our rock lobsters?).
- **Locations fished.** E.g. seamounts and spawning aggregations can have dense aggregations of orange roughy (Kahui and Armstrong, 2012).
- **Water temperature.** E.g. warmer surface waters may lead to deep-diving species like bigeye tuna[130] avoiding gear (Pinkerton, 2018), or species moving elsewhere.

[128] *Merluccius australis*.
[129] Input from Fisheries New Zealand.
[130] *Thunnus obesus*.

- **Changes in weather.** E.g. an increase in storms and waves (and consequently water turbidity) can reduce hook and line catch rates (Townhill *et al.*, 2019).
- **Market.** E.g. the desire to avoid paying deemed values may lead to avoidance of some species (e.g. snapper) to minimise high deemed value payments (Schofield *et al.*, 2018).
- **Behaviour of the target species.** E.g. moulting and reproductive behaviour of scampi varies between the sexes and seasonally, impacting catch rates (Tuck, 2020); aggressive species can be easier to trap as they tend to guard bait, increasing catch rates (Finucci *et al.*, 2019a).
- **Interrelated fisheries.** E.g. fishers may change their fishing location to a less optimal area if a protected species would otherwise be present where the fish were greatly abundant. In practice this would decrease CPUE and indicate a lower abundance of fish, instead of reflecting fishers' behaviour in avoiding areas of greatest abundance (Te Ohu Kaimoana, 2019b).

Improvement in data collected on fishing gear and fishers experience could include information on areas such as:

- Door spread,
- Ground gear rope length,
- Sweep and bridle lengths,
- Cod-end mesh size and orientation,
- Number of years a skipper has been involved in the fishery.

Experts in fisheries science consider many of these factors when calculating standardised CPUE; for example, changes in areas fished, gear use, tow speed and other species caught can all easily be taken into account. Skipper experience, fishing gear and operational factors not recorded in logbooks can often be accounted for by including a vessel effect in the model. Experts can then assess the reliability of CPUE and other data to incorporate into full stock assessments.

Figure 66: New Zealand Scampi. Image credit: krl krl/Flickr (CC BY-NC-ND 2.0).

A suggestion from Te Ohu Kaimoana has been that some issues with CPUE could be reduced if the setting of catch limits included a consultation process where 'on-the-water' operational information was considered that otherwise are not considered or communicated in model outputs (Te Ohu Kaimoana, 2019b). Te Ohu Kaimoana has also suggested that in interrelated fisheries, portfolios of stocks could be built and evaluated simultaneously to improve groundtruth assessments based on CPUE (Te Ohu Kaimoana, 2019b) building on current analyses in inshore finfish stocks.

Seafood New Zealand has commented that although the use of CPUE has shortcomings, alternatives such as the use of fishery independent surveys also have many issues and uncertainties and are often prohibitively expensive in comparison.

5.2.3 FISHERIES PLANS

Fisheries plans are a tool used to bridge the different pieces of legislation, policies, strategies, and regulating authorities to guide action at a more refined scale and measure progress (see figure 67). They are provided for under Section 11(a) of the Fisheries Act 1996 and can enable stakeholder-led management (where a plan is approved by the Minister of Fisheries). Fisheries plans provide overarching frameworks (over a five-year timeline), from which (non-statutory) Annual Operational Plans are developed and Annual Review Reports produced.

Implementation of these plans is in two repeated stages – the first is detailing management actions for the year, including the required services that must be delivered by the ministry, and the second involves assessing and reporting on performance of the fisheries against what was planned. The plans are intended to be informed by the:

- *Harvest Strategy Standard* and *QMS Introduction Process Standard* (see section 5.2.2: Setting catch limits and allocating catch allowance),
- International Fisheries Strategy,
- Treaty Strategy,
- National plans of action and threat management plans (see section 3.3.2: Bycatch of non-target and protected species), and
- Iwi Fisheries Forum Plans.

Implementation and consistent review and update of these plans is variable and is discussed further in this section.

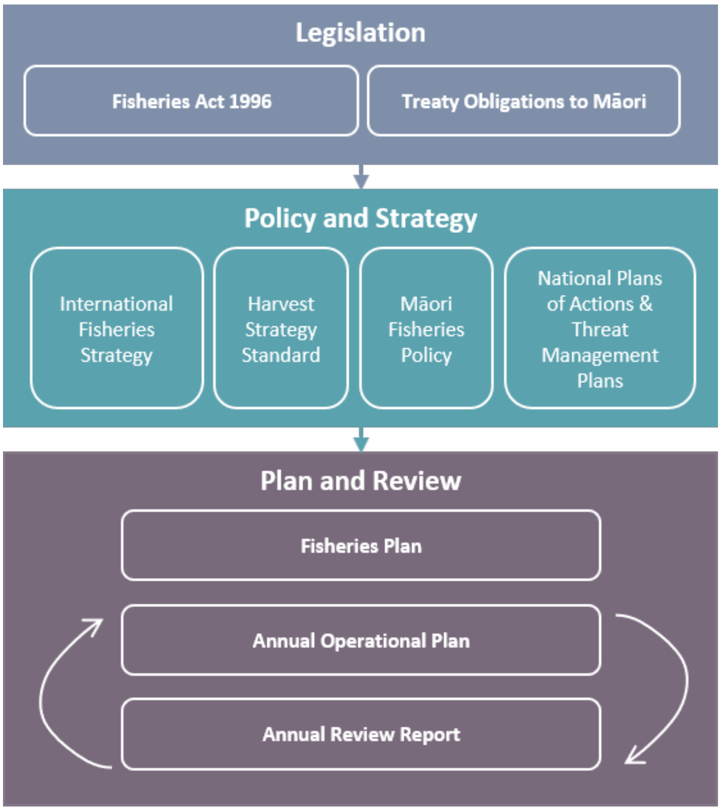

Figure 67: How fisheries plans fit into the wider context - (adapted from Fisheries New Zealand, 2019).

Implementation and consistent review and update of these plans is variable and is discussed further in this section.

Fisheries New Zealand has several key fisheries plans, which include:

- Inshore finfish fisheries (draft only),
- Deepwater and middle-depth fisheries, and
- Highly migratory species fisheries.

NATIONAL FISHERIES PLAN FOR INSHORE FINFISH FISHERIES IS STILL UNDER DEVELOPMENT

In 2020, Fisheries New Zealand consulted on a *Draft National Inshore Finfish Fisheries Plan* (Fisheries New Zealand, 2019e) for the fisheries extending out to 12 nautical miles (the territorial sea).

A draft plan was previously developed in 2011, but never finalised (Ministry for Primary Industries, 2011). The 2011 plan was reported by Fisheries New Zealand as having been trialled over a period of years and feedback sought. It does not appear that Annual Operational Plans and Reviews have been consistently produced in the years between 2012 and 2020.

The draft plan for consultation in 2020 identifies focus areas and high-level management objectives, and is supported by other plans and strategies, providing the overarching framework for the management of the fisheries for the next five years. Many of the approaches outlined in the plan have the aim of progressing Aotearoa New Zealand towards an EAFM. Particularly:

- Integrated management of multiple individual stocks in the fishery.
- Increased opportunities for engagement and active participation in management of fisheries for iwi and Māori.
- Improving environmental performance, particularly protecting habitats of significance from impacts of fishing and land-based effects.

It is important that an inshore plan is actually implemented.

NATIONAL FISHERIES PLAN FOR DEEPWATER AND MIDDLE-DEPTH FISHERIES

In 2019, Fisheries New Zealand finalised a *National Fisheries Plan for Deepwater and Middle-depth Fisheries* (Fisheries New Zealand, 2019d). Deepwater and middle-depth fisheries occur in water depths between 200 and 1,500 m and are located between the 12 nautical mile limit out to the edge of our EEZ.

The plan provides strategic direction for managing deepwater fisheries and an integrated and transparent way of defining management objectives. Management of deepwater fisheries is by collaborative agreement between Fisheries New Zealand and industry representative body Deepwater Group. Fisheries New Zealand retains all statutory responsibilities. Management objectives outlined in the plan are provided in appendix 10.

Annual Operation Plans have been produced for deepwater fisheries in 2012/13 and the years from 2015 through 2019.

NATIONAL FISHERIES PLAN FOR HIGHLY MIGRATORY SPECIES FISHERIES

In 2019, Fisheries New Zealand finalised a *National Fisheries Plan for Highly Migratory Species*. The plan establishes objectives for managing highly migratory species (fish that swim large distances), mainly impacting fisheries with the EEZ (12-200 nautical miles). There are additional obligations than those of inshore, deepwater and middle-depth fisheries, due to Aotearoa New Zealand's participation in international agreements (see appendix 10).

Key species covered in this plan include large pelagic species (like southern bluefin[131] and bigeye tuna and swordfish/paea[132]) caught in surface longline (as well as non-target species such as moonfish/opah[133] and pelagic sharks), caught by purse seine, and albacore/longfin tuna[134] (mostly caught by trolling).

[131] *Thunnus maccoyii.*
[132] *Xiphias gladius.*
[133] *Lampridae species*.
[134] *Thunnus alalunga.*

5.2.4 TARGETED MANAGEMENT PLANS EXIST BUT ARE IMPLEMENTED WITH VARYING DEGREES OF SUCCESS

Table 7: Management plans listed on Fisheries New Zealand's website in 2020.

Plan	Summary
Snapper 1 management plan	There is a Snapper (SNA1) Management Plan as there is a need to increase the biomass of the snapper population in order to meet the needs of future generations and protect the environment that snapper productivity relies on (SNA1 Strategy Group, 2016). The plan sets out a range of measures to: reduce waste and improve productivity; improve monitoring and management of the SNA1 fishery; improve reporting and understanding of snapper habitat and environment; and implement and monitor the plan.
National blue cod strategy	There is a national blue cod strategy as management issues for the species have developed in several areas around the South Island, with different regions identifying different management approaches. Issues to be addressed by the strategy include illegal take, TAC, commercial pot mesh size, released fish mortality, localised depletion, timing of fishing season, and habitat loss (Fisheries New Zealand, 2018b).
Rock lobster (CRA2)	There is a multi-staged rebuild plan in place to improve the abundance of rock lobsters in the CRA2 fishery due to the low abundance of the stock. A scientific assessment in 2017 found the number of rock lobsters in the fishery had dropped to levels where management action is required to ensure it rebuilds. TAC for the fishery was significantly reduced in 2018, this was followed by a halving of the bag limit from six to three, and the introduction of telson/tail clipping to reduce illegal catch. This fishery is further discussed in 5.3.5: case study: Mixed messages: Are we overfishing our rock lobsters?
Southern scallop fishery (SCA7) strategy	A southern scallop fishery strategy has recently been finalised. In the meantime, the SCA7 fishery remains closed (Southern Scallop Working Group and Fisheries New Zealand, 2019; Southern Scallop Working Group and Fisheries New Zealand, 2020). The stock has struggled to recover to a healthy and sustainable biomass level. The priority of the SCA7 strategy is to ensure that any future scallop fishing in Te Tauihu-o-te-waka the Marlborough Sounds is sustainable and allows the fishery to rebuild to healthy levels. This will involve understanding non-fishing impacts on scallops as well as improving scallop habitat quality and quantity in Te Tauihu-o-te-waka the Marlborough Sounds. This fishery is discussed further in section 3.3.3.1: Fishing impacts on habitat, and section 5.3.3.1: Managing stocks with incomplete data.
East coast tarakihi[135] fishery rebuild	There is a rebuild plan for the east coast tarakihi fishery. This is comprised of ministerial decisions to reduce catch limits by 30% and a range of other measures within an industry-led plan. This industry-led voluntary plan focuses on improving fishing methods and undertaking research to better understand the east coast tarakihi fishery including: improving verification of commercial fishing data, closures to known nursery grounds, agreement to leave fishing grounds when large numbers of juvenile tarakihi are encountered, testing new gears to reduce the catch of juvenile tarakihi; gathering better data on the sizes of tarakihi caught in the commercial fishery, and evaluation of management strategies to determine how each of these various initiatives can contribute to rapid rebuilding of this stock.

Management plans for protected or threatened species were outlined in section 3.3.2: Bycatch of non-target and protected species.

[135] *Nemadactylus macropterus.*

5.3 COMMERCIAL FISHING HAS IMPACTS ON TARGET SPECIES SUSTAINABILITY

Aotearoa New Zealand's total annual commercial marine catch peaked in the late 90s at around 650,000 tonnes and since then has remained at around 450,000 tonnes per year (Ministry for the Environment and Stats NZ, 2019b).

This section explores:

- Known impacts of fishing on the sustainability of target stocks.
- Data collection on target stocks and accessibility of this information.
- Reporting and performance of stocks in 2020.

Commercial fishers use a number of different fishing methods including trawling, seining, netting, dredging, longlining, hand lining, jigging, trapping, potting, diving, and hand gathering. The impacts of different fishing methods on the marine environment were illustrated in section 3.3.1: Most common commercial fishing methods. Here we focus only on the impacts on target species.

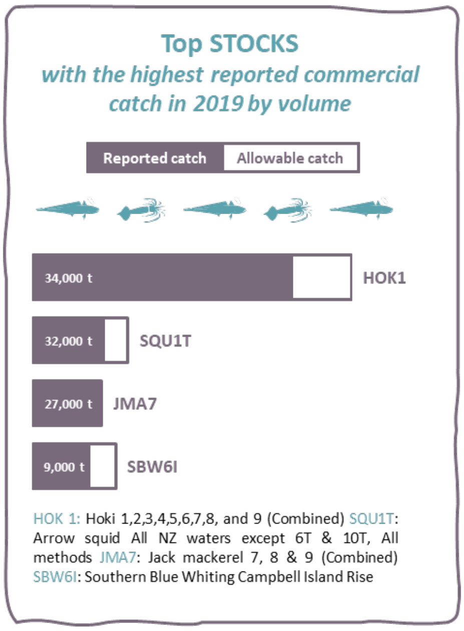

Figure 68: Catch volume – stocks (data from Fisheries New Zealand).

Figure 68 shows the fish stocks with the highest reported commercial catch in 2019 by volume. The HOK1 stock, which covers all of Aotearoa New Zealand (except for Rangitāhua the Kermadec Islands), was the highest catch by volume and is the top commercial fish for deepwater fishing. These top stocks by volume are all from deepwater fisheries.

By species, the highest reported volume of commercial catch in 2019 is similarly dominated by deepwater species, though some species also have a significant inshore component such as jack mackerel (see figure 69). Other key inshore species by volume include snapper, tarakihi, red gurnard/kumu[136] and trevally/araara[137] (Williams *et al.*, 2017).

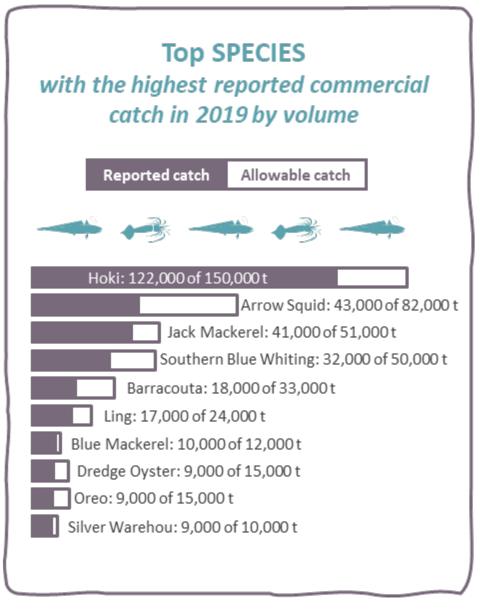

Figure 69: Catch volume – species (data from Fisheries New Zealand).

By value, rather than volume, other stocks rank more highly, such as rock lobster.

Business and Economic Research Ltd (BERL) reports that 54 key species account for 93% of the total commercial fishing catch (between 2010 and 2015) (Williams *et al.*, 2017). This means that around half of the 98 species included under the QMS account for 93% of catch volume. The 98 species included in the QMS are divided into 642[138] separate fish stocks for management purposes.

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[136] *Chelidonichthys kumu.*
[137] *Pseudocaranx dentex.*
[138] Note that some of the stocks are further divided into substocks.

5.3.1 KNOWN IMPACTS OF FISHING ON THE SUSTAINABILITY OF TARGET STOCKS

Maximising benefits from commercial fishing means ensuring that negative impacts are managed to allow safe and sustainable use of the resource, without overfishing.

Worldwide, perspectives on the state of biomass of popularly consumed fish species are opposing, with some estimating biomass to be in decline while others debate this (Hilborn *et al.*, 2019).[139] Overfishing (whether commercial, customary or recreational) – removing too many individuals from a stock – can lead to decline or even collapse (either of an individual stock or the wider ecosystem). A fish stock is generally described as collapsed when it is at a very low abundance, often theoretically defined as 10% of the unfished stock, including by Fisheries New Zealand (their 'hard limit') (Hilborn, 2012). These definitions are contested (see section 5.2: Fisheries management involves the use of many different tools).

How well a particular fishery can cope with losing a proportion of its population each year depends on the amount taken, but is also subject to wider cumulative effects (as described in section 3.1: Fishing is one of many stressors on our oceans).

Figure 70: Recent harvest.

Both large, predatory fish and small, forage fish may be vulnerable to collapse, although the former tend to exhibit long, slow declines while the latter tend to exhibit cyclical periods of growth and collapse that can span orders of magnitude in size (Pinsky *et al.*, 2011). Many sharks and rays are vulnerable because they mature later, have a long gestation period, and have fewer offspring (Bradley and Gaines, 2014). Larger fish are also more likely to be migratory, meaning they may seasonally inhabit fisheries within many different nations and, as a result, efforts to manage fishing need greater coordination to be effective (see section 5.2.3: Fisheries plans). Small pelagics can also inhabit fisheries within many different nations given their size and can number in the tens or hundreds of billions and they therefore cover very large areas.

In 2020, Fisheries New Zealand reported on 160 stocks, of which nine were reported as 'collapsed' (see table 9). There are few well-documented cases of marine species becoming extinct from being overfished (Froese and Kesner-Reyes, 2002; McCauley *et al.*, 2015; Le Pape *et al.*, 2017). Generally, fish would cease to be harvested at commercial scale before this point as it would no longer be economically viable. This risk is potentially realisable in fisheries where catch method lacks species specificity (Hauge *et al.*, 2007; Hilborn, 2012; Lake *et al.*, 2017).

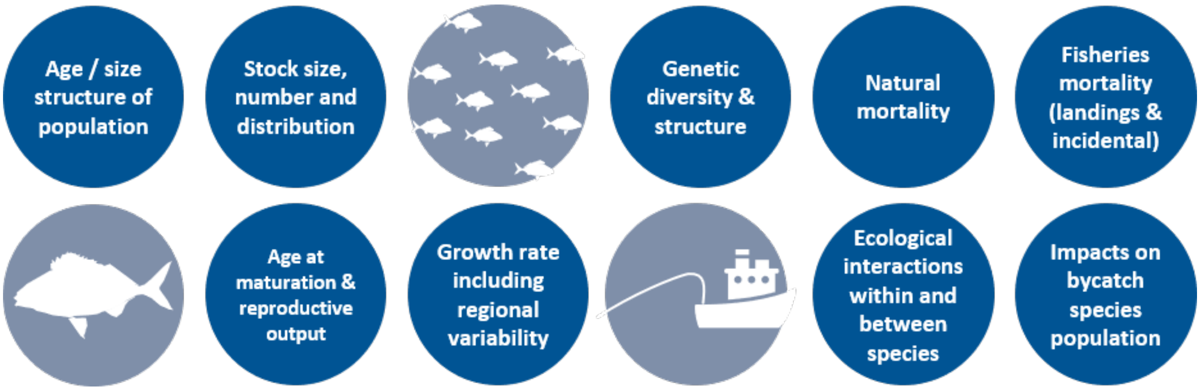
What is more common is 'ecological extinction', where a species is at such low abundance that it is no longer interacting significantly with other species in an ecosystem (Jackson *et al.*, 2001). This term has been used in some areas of Aotearoa New Zealand to describe rock lobster populations (MacDiarmid *et al.,* 2013c). So while complete extinction of a fish species we catch is perhaps unlikely, there can be considerable alterations to marine ecosystems. Impacts of fishing on marine ecosystems are discussed in section 3.3.

[139] See reporting here compared to here. See also (Palomares *et al.*, 2020), although there is contention around the methods used, see earlier debate in a Nature article 'Fisheries: does catch reflect abundance?' (Pauly *et al.*, 2013).

5.3.2 DATA COLLECTION ON TARGET STOCKS AND ACCESSIBILITY OF THIS INFORMATION

A significant proportion of data collection and research that Fisheries New Zealand and the commercial fishing industry undertake, funded through levies, is focused on fished and targeted commercial species and stocks. This is because the data is needed to undertake stock assessments under the Fisheries Act 1996. This data is very challenging and very expensive to obtain and we have incomplete and uncertain information. Cost recovery (e.g. for data needs) and funding for research needs are discussed further in section 5.8: Research programmes, funding and prioritisation.

Important information required to fully understand stocks includes:



An overview of the data collected by Fisheries New Zealand is given in table 8.

Table 8: Data collection for fisheries stock assessments.[140]

Fish stocks: stock structure	
Research	Includes biological studies on distribution, spawning areas, movements (including fish tagging), genetic and morphological differences for some stocks.
Significance	Important for assessing and managing stocks at appropriate spatial scales.
Current collection and initiatives	Much of our knowledge of fish stock structure was determined pre-QMS introduction through biological studies, patterns in commercial fisheries, and fish tagging to determine movements. Allocation of stocks to administrative QMAs in 1986 under the QMS was based on knowledge of stocks at the time for some species, or, in the case of many inshore species, limited to individual Fishery Management Areas (FMAs) that served to limit potential over-exploitation in any one area. Improvements in knowledge about stock structure over time have been dealt with in various ways under the Fisheries Act 1996, including subdividing quota area catches (usually by industry agreement, e.g. hoki, orange roughy, pāua), or amalgamating areas to be assessed if appropriate (e.g. school shark, tarakihi). Catch and effort splitting is also undertaken by industry. Stock structure issues continue to be challenging for many of our fish stocks and more focused research is required to address this. Lack of knowledge on stock structure can lead to considerable uncertainty in stock assessment and management. Current initiatives include biological studies, analysis of trends in survey and commercial fishing data, tagging (currently limited to a few species).
Fish stocks: stock size	
Research	Monitoring and estimating the size of fish stocks (the 'biomass' of a fish stock).
Significance	Estimates of the size of fish stocks are a key component of assessing whether a stock is being fished at a sustainable level.

[140] Input from NIWA.

Current collection and initiatives	Time series of research trawl and/or acoustic surveys spanning nearly 30 years in the inshore (east and west coast of the South Island, snapper fisheries of the west and east coasts of the North Island) and deepwater fisheries for hoki, hake, ling/hoka[141], southern blue whiting, orange roughy (Chatham Rise, subantarctic, west coast of the South Island). Time series of commercial catch and effort data spanning 30 years in inshore (event-based since 2007) and deepwater (event-based since 1989). Observer sampling of deepwater fisheries target and bycatch since 1986. Catch sampling in fish processing plants for inshore (snapper, tarakihi, trevally, blue cod, albacore, jack mackerel, rock lobster) and deepwater (hoki) species, to collect fish length data and otoliths for ageing.
Fish stocks: stock productivity	
Research	Age, growth and reproductive capacity of species we fish.
Significance	Allows for determination of patterns and variability in age and growth, longevity and recruitment of species we fish (the productivity of a stock informs our approach to balanced management).
Current collection and initiatives	For some key commercial species, comprehensive biological data is collected through research surveys and studies, commercial catch sampling by observers and in fish processing plants collect fish size and otoliths for ageing. There are also industry logbook programmes (e.g. rock lobster) where measurements are recorded. For other commercial species, little to no data is collected, which means that variability in reproduction, growth patterns and recruitment (i.e. productivity) are poorly understood for most species.
Fish stocks: fishing mortality	
Research	Mortality information for species we fish based on catch data.
Significance	Accurate catch data are important to determine fishing mortality in stock assessment models.
Current collection and initiatives	Long-term fisheries-related datasets are primarily in the form of fish landings, which provide a valuable resource (Ministry for the Environment and Stats NZ, 2019b). Fish landings data includes commercial catch, effort and location data spanning 30 years in inshore (event-based since 2007) and in deepwater (event-based since 1989). There are also over 30 years of Fisheries New Zealand observer data verifying commercial catches in deepwater fisheries, for a subset of the fleet.

As summarised in table 8, there is biological data collected on some key commercial species through a number of different methods, although the focus of this research is on the more economically valuable species. Data collection on key deepwater species is carried out annually, while data collection by observers allows for data collection through key fishing seasons.

Much of the data relied on (i.e. landings, bycatch) is self-reported and may not be seen as independent. Misreporting can be incentivised in some instances under the QMS and there are examples of misreporting occurring, see for example Simmons *et al.* (2015), Telesetsky (2016), Fisheries New Zealand (2018b), and Hersoug (2018).[142] There are other initiatives underway through Fisheries New Zealand's Fisheries Change Programme that hope to address this issue. For example, introducing mandatory electronic catch and position reporting to improve collection and reliability of fisheries information, incentivise better fishing practices, improve monitoring and verification capabilities and use on-board cameras. It is also important to point out that self-reported data is currently verifiable to an extent – reporting requirements provide a documentation trail of the catch and production flow process, which requires reporting at multiples stages, usually by multiple parties. These reporting requirements reduce opportunities for potential misreporting (because discrepancies could be detected), particularly where multiple companies are involved in the supply chain.

[141] *Genypterus blacodes.*

[142] For example, incentives to misreport where ACE is difficult to acquire, fishing in one area but reporting in an area where quota or ACE is located, misreporting of species identity to avoid counting against particular quota or ACE. Note that the reference Simmons *et al*. (2015) is contested.

There are a number of new scientific methods or innovative applications of existing methods that could be applied to deepen our understanding of fish stocks in Aotearoa New Zealand – these are discussed in part 6. Research trawl surveys, although often targeted, can collect a vast amount of data that could be analysed and used more widely than for specific stock assessments.

DATA AND FISH STOCK BOUNDARIES

Stock structure understanding is vital for assessing the sustainability of a fishery. How stocks are defined and managed by the regulator may not always reflect natural fish stock delineation (e.g. where they are separated by temperature changes or geographical features), especially with stock movement due to climate change (see section 3.1.1: Climate change is a huge threat to our oceans).

Stock structure understanding is vital for assessing the sustainability of a fishery. How stocks are defined and managed by the regulator may not always reflect natural fish stock delineation.

In Aotearoa New Zealand, fish stocks are allocated spatially to QMAs under the QMS and may not necessarily align with the natural boundaries of fish populations. Stock structure management continues to present a challenge and more focused research to better determine stock relationships is required for many species.

While some stock challenges are recognised and allowed for under the management system (e.g. the school shark, which is considered to be one stock but management by smaller FMAs limits potential overfishing in any one area), some issues cause significant assessment uncertainty.

For example, although the QMS has one defined hoki stock covering most of Aotearoa New Zealand's waters (HOK1), it is managed as two sub-stocks – eastern and western. There have been concerns from commercial fishers that the annual stock assessment was not consistent with the performance of the fishery, i.e. that fish catch rates are declining in the western area despite high stock estimates (Dunn and Langley, 2018; Fisheries New Zealand, 2019f).

Research on the eastern and western hoki stocks found that they are both located in multiple areas throughout the year (including both stocks in the same area at the same time). However, there is no tagging data available to estimate movement rates (Punt, 2019) and this means the modelled assumption for hoki are very uncertain (McKenzie, 2018). The lack of tagging data for hoki is because tagging requires fish to be brought to the surface, but hoki have very low survivability on being brought to the surface, making tagging not viable. While stock structure understanding is needed for assessing the sustainability of a fishery, decisions need to be made ahead of full understanding.

Fisheries New Zealand has a range of research underway to further inform the 2020 hoki stock assessment (Fisheries New Zealand, 2019f). The case study on how genetics was used to delineate Atlantic Cod stocks (see 6.4.7: case study: Real-time genetic management of a marine fishery) provides an international example of innovative techniques that can be used to manage mixed stocks similar to hoki.

5.3.3 REPORTING AND PERFORMANCE OF STOCKS IN 2020

Research related to fisheries is summarised annually by Fisheries New Zealand, principally in their *Fisheries Assessment Plenary* reports, which include the information held and used in stock assessments (Fisheries New Zealand, 2019b, 2019c, 2019a, 2020d; Roberts *et al.*, 2020). Fisheries research is also reported in the AEBAR (Fisheries New Zealand, 2018a; Ministry for Primary Industries, 2020a).

Reporting on performance of stocks is heavily informed by catch data and the accuracy of this data varies between different fisheries. For example, there is generally much higher observer coverage in deepwater compared to inshore fisheries. Fisheries with higher observer coverage are reasonably expected to have less non-compliance regarding reporting (Scott, 2019).

5.3.3.1 MANAGING STOCKS WITH INCOMPLETE DATA

As outlined in section 5.2.2.1: Performance of stocks, in 2019 the majority of assessed stocks were reported as 'sustainable' by the regulator (though the limits are contested – see section 5.2: Fisheries management involves the use of many different tools). Fisheries New Zealand reports that examples where stocks have been rebuilt under the QMS include PAU5B, CRA8, and various SNA and ORH stocks. This provides a solid base from which fisheries sustainability can be improved.

This section focuses on stocks that have not been assessed as 'sustainable' or have not been assessed at all. Where stocks have not had biomass projections (as is the case for many), it means that management measures are based on the assumption that past performance will be repeated in the future but the rate of change to marine ecosystems is such that this can no longer be assumed.[143]

COLLAPSED STOCKS

In 2020, nine stocks were reported as 'collapsed'. Information on these stocks is provided in table 9. Collapsed stocks are defined by the regulator as those that are below the hard limit (see the discussion in section 5.2.2 on stock assessments as both challenging and challenged) and which may need to be closed to rebuild at the fastest possible rate.

Several of these stocks are discussed further – see ORH7B in 5.3.4: case study: Orange roughy stock health, SCA7 in section 3.3.3.1: Fishing impacts on habitat, and the targeted management plans in table 7. The black cardinalfish/akiwa[144] species is also discussed further in table 9 and the discussion that follows. The reasons a stock came to be 'collapsed' and the resulting mitigative responses put in place are both highly contentious.

The reasons a stock came to be 'collapsed' and the resulting mitigative responses put in place are both highly contentious.

[143] Input from MfE.
[144] *Epigonus telescopus.*

Table 9: Stocks that were reported by Fisheries New Zealand as 'collapsed' in 2020.

Species	Plenary stock	Information
Black cardinalfish	CDL2, CDL3, CDL4	Black cardinalfish is a deepwater species that is slow-growing and long-lived (Tracey *et al.*, 2017). CDL2, 3, and 4 cover the eastern side of the South Island and much of the North Island, including Rēkohu Wharekauri the Chatham Islands. Quota was introduced for these stocks in the late 90s (Fisheries New Zealand, 2014). The TACC for CDL3 has remained the same since introduction, while the TACC for CDL4 increased in the mid-2000s and has remained constant since then. In CDL2 (which has the greatest levels of catch), TACC was lowered from around 2,200 tonnes to 1,600 tonnes in 2009, 1,000 tonnes in 2010, and down to 440 tonnes in 2011 (where it has remained for the last decade). Reported catch has been consistently lower than the TACC. These black cardinalfish stocks were last assessed in 2014 and the role of this species in the ecosystem is not well understood, nor are the effects of removing current levels of catch (Fisheries New Zealand, 2014). There is little relevant information on this species available.
Orange roughy	ORH7B West Coast South Island	Orange roughy is a deepwater species that is slow to mature and long-lived. The ORH7B orange roughy stock, centered near the Cook Canyon, is located off the west coast of the South Island. It has been effectively closed from 1 Oct 2007, when the TACC was reduced to 1 tonne (Fisheries New Zealand, 2020c). Reported catch began to wane in the early-mid 90s, failing to match the TACC of 1,708 tonnes. The TACC was reduced in 1995 to 430 tonnes, and reduced again in 2001 to 110 tonnes. By the late 90s, the stock was believed to be well below B_{MSY} (see figure 61). The stock was last assessed in 2004 (17% B_{MSY}).[145] An updated assessment was attempted in 2007, but the assessment model predicted a rebuilding of the stock since 2000 and was thus a poor fit for the CPUE data. The catch rate had remained consistently low despite a substantial reduction in take (Fisheries New Zealand, 2009a).
Pipi	PPI1A - Mair Bank, Whangārei harbour	Pipi are a shellfish endemic to Aotearoa New Zealand, inhabiting flat sandy beaches and estuaries. They are an important species for Māori, as well as commercial and recreational fishers. Pipi are harvested by hand. The PPI1A stock, located in Whangārei Harbour, was added to the QMS in 2004. Area closure of the Mair Bank for both commercial and recreational harvest was implemented in 2014 after the population plummeted. A survey estimated that the total pipi biomass in 2014 was 73.5 tonnes, down from 4,450 tonnes in 2010 and 10,542 tonnes in 2005 (Pawley, 2014). MPI considered that harvesting was not the main driver of this drastic decline, and the reason remains unknown (Ministry for Primary Industries, 2014). However they deemed that the fishery could not support the added pressure of fishing, and there were concerns that the bank, which protects the entrance of the harbour, could become destabilised with a reduced pipi population. Commercial harvesting ceased two years prior to the closure of the fishery, as the low abundance of pipi meant that the operation was not economically viable.
Scallop	SCA7 Golden Bay, SCA7 Tasman Bay	Scallops are an endemic shellfish found in sand, silt and mud around the coasts of Aotearoa New Zealand. The SCA7 scallop fishery is located across the top of the South Island in the Whakatū/Te Tauihu-o-te-waka Nelson/Marlborough region. Managing this fishery has proved challenging as stocks of scallops are naturally variable. After catch peaked in 1975, the fishery rapidly declined and was closed in 1981 and 1982 (Fisheries New Zealand, 2009b). When the fishery reopened in 1983, only 48 licences were issued to vessels with an annual catch limit. A 'scallop enhancement' programme allowed rotational fishing (fishing down followed by reseeding). The SCA7 was added to the QMS in 1992. Since 2002, there has been a substantial decline in scallop biomass and abundance in Whakatū/Nelson and Te Tai-o-Aorere Tasman Bay, as determined by annual surveys. Te Tai-o-Aorere Tasman Bay was closed to commercial harvesting in 2006. SCA7 was closed to commercial fishing in 2012 and was closed to all fishing in 2017 after a 2017 survey revealed the biomass had declined to around 100 tonnes (from 2,000 tonnes in 2002) (Ministry for Primary Industries, 2017b). A biomass survey occurred in 2020 to assess recovery.

[145] Input from FNZ: While the last assessment reported was in 2004, an assessment was attempted in 2020 based on an acoustic survey. A subsequent acoustic survey has also been undertaken. Both surveys found very few fish and the assessment gave unsatisfactory results but they did indicate that either the surveys didn't manage to locate the fish or that the stocks has not recovered.

Species	Plenary stock	Information
Southern bluefin tuna	STN1 / Southern Hemisphere Stock	Southern bluefin tuna are found in southern hemisphere waters, including off southern/eastern Aotearoa New Zealand. Management of this fishery is shared between different member countries of the Commission for Conservation of Southern Bluefin Tuna (CCSBT). Individuals caught within the Aotearoa New Zealand EEZ are part of a single quota, STN1, introduced to the QMS in 2004. The last stock assessment of STN1 was undertaken in 2017.[146] It found that the stock is in a very low state, estimated to be around 9% of the initial spawning stock biomass (or 38% of the spawning stock biomass capable of producing MSY) (MRAG Asia Pacific, 2017). Members of the CCBST have agreed to management procedures that are designed to rebuild the stock to a reference point of 20% of the original spawning stock biomass by 2035. In 2019, recreational catch of southern bluefin tuna was reduced to one fish per person. Australian researchers performed genetic studies to understand southern bluefin tuna population dynamics to better inform international management (see 6.4.9: case study: Genetic tagging to understand bluefin tuna population dynamics).
Pacific bluefin tuna[147]	TOR1	The Pacific bluefin tuna is a tuna species predominantly found in the northern Pacific, but is migratory and visits the South Pacific (northern Aotearoa New Zealand). It is considered to consist of only one stock worldwide, managed through the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC). The species is considered threatened, a status driven by overfishing (Fisheries New Zealand, 2020a). In the Aotearoa New Zealand EEZ, the Pacific bluefin tuna is managed under the TOR1 quota, introduced to the QMS in 2004 (Fisheries New Zealand, 2015). Catches from within the Aotearoa New Zealand EEZ are small compared to others across the Pacific, and the highly variable nature of the population within Aotearoa New Zealand waters means an Aotearoa New Zealand-specific stock assessment is not possible. The last stock assessment at the International Scientific Committee Plenary Meeting in July 2018 found that spawning stock biomass was increasing very slowly. There were several conservation and measurement measures adopted at a WCPFC meeting in December 2019 (Western and Central Pacific Fisheries Commission, 2019).

Figure 71: The pipi PPI1A stock is one of nine stocks assessed as 'collapsed'. Image credit: Sarah Hailes/NIWA.

[146] It will be removed from the list of "below the hard limit" stocks at the next update in early 2021.
[147] *Thunnus orientalis.*

STOCKS THAT ARE EXPERIENCING OVERFISHING

The table below shows stocks that the regulator has assessed as experiencing overfishing. This means that the level of fishing currently being undertaken is likely to be unsustainable for the stock. Thus there are generally management actions in place or being put in place to reduce fishing pressure (see 5.3.5: case study: Mixed messages: Are we overfishing our rock lobsters?).

Table 10: Stocks that were reported by Fisheries New Zealand as experiencing overfishing as at December 2019.

	Species and plenary stock	Information on last assessment and management measures
Virtually certain to be experiencing overfishing	**Tarakihi** TAR1E, TAR2 and TAR7 (east CS), TAR3	Last assessed in 2018. The stocks are very likely to be below the soft limit. TAC reduced in 2018 and again in 2019.
	Rock lobster CRA2 Bay of Plenty	Last assessed in 2017. Likely to be below the soft limit. Significant TACC and recreational allowance reductions in 2018. Further recreational measures currently being considered.
Very likely to be experiencing overfishing	**Pacific bluefin tuna** TOR1	Last assessed in 2018. Very likely to be below the soft limit and very likely below hard limit. WCPFC conservation and management measure adopted (CMM2019-02).
	Pāua PAU7	Last assessed in 2015. About as likely as not to be below the soft limit. TACC reduced by 50% in 2016.
Likely to be experiencing overfishing	**Flatfish**[148] FLA3 (ESO)	Last assessed in 2015. About as likely as not to be below the soft limit. Annual in-season review.
	Hake HAK7 (WCSI)	Last assessed in 2019. About as likely as not to be below the soft limit. TACC reduced by 55% in 2019.
	Snapper SNA1 - East Northland SNA1 - Hauraki Gulf/BoP	Last assessed in 2013. The stocks are about as likely as not to be below the soft limit. For SNA1 East Northland, monitoring and management measures implemented in 2013; recreational bag limit reduced and minimum legal size increased.
	Flatfish FLA3 (LSO)	Last assessed in 2015. Unlikely to be below the soft limit. Annual in-season review.
	Oreos OEO 1/OEO3A Southland Smooth Oreo	Last assessed in 2007. Unlikely to be below the soft limit. TAC and TACC for OEO1 reduced in 2007.
	School shark SCH3S/5	Last assessed in 2018 – no assessment information available but unlikely to be below the soft limit.
	John dory JDO1 (BP)	Last assessed in 2018. Very unlikely to be below the soft limit. TACC reduced in 2018.
	Rock lobster CRA4 Hawke's Bay-Wairarapa	Last assessed in 2019. Exceptionally unlikely to be below the soft limit. TAC reduced in 2017.
	Blue cod BCO7	Last assessed in 2018. The stock is unlikely to be at or above target levels, but the likelihood of being below soft or hard limits is unknown. New recreational rules and seasonal commercial closure introduced 2015; new National Blue Cod Strategy being implemented; TAC may be considered for review in 2020.
	Kingfish KIN1 EN & HG inshore	Last assessed in 2016. The stock is unlikely to be at or above target levels, but the likelihood of being below soft or hard limits is unknown. Under consideration for the 2020 sustainability round.
About as likely as not to be experiencing overfishing	**Orange roughy** (ORH2A, ORH2B, ORH3A), **striped marlin**/takatetonga[149] (STM1), **blue cod** (BCO3, BCO4), **elephant fish** (ELE3, ELE5, ELE7), **John dory**/kuparu[150] (JDO1), **stargazer**[151] (STA5, STA7), **flatfish** (FLA3), **pāua** (PAU5D), **red gurnard** (GUR2, GUR3), **rig** (SPO3), **rock lobster** (CRA1, CRA3), **school shark** (SCH1W, SCH7, SCH8, SCHN/1E), **red cod** (RCO2).	

[148] *Pleuronectiformes* species.
[149] *Tetrapturus audax.*
[150] *Zeus faber.*
[151] *Kathetostoma spp.*

STOCKS THAT HAVE NOT BEEN ASSESSED

There are many stocks that are not scientifically assessed at all (see figures 56 and 57). Aside from nominal stocks described in section 5.2.2.5, around one third of the commercial catch volume is made up of stocks that have never been assessed. While larger stocks like hoki dominate the catch volume, many species (particularly inshore species) may not be assessed due to a smaller commercial catch volume or value despite playing key ecological roles.

Two examples are provided below of species where not all stocks have been scientifically assessed by the regulator.

Figure 72: Black cardinalfish. Image taken by Pheobe Forrester. Uploaded with permission by Mark McGrouther to iNaturalist (CC BY-NC 4.0).

Black cardinalfish

As outlined in table 9 several of the black cardinalfish stocks are overfished (CDL2, 3, 4). Despite the overfished status of CDL2, 3, and 4, there have never been stock assessments undertaken of the other black cardinalfish stocks and there is little information currently available on the species.

Catches for these stocks have not always been insubstantial, for example 2,000 tonnes of CDL1 was caught in 1996-97 (figure 73). This is equivalent to the amount of fish caught in some of the top thirty stocks by catch volume today.

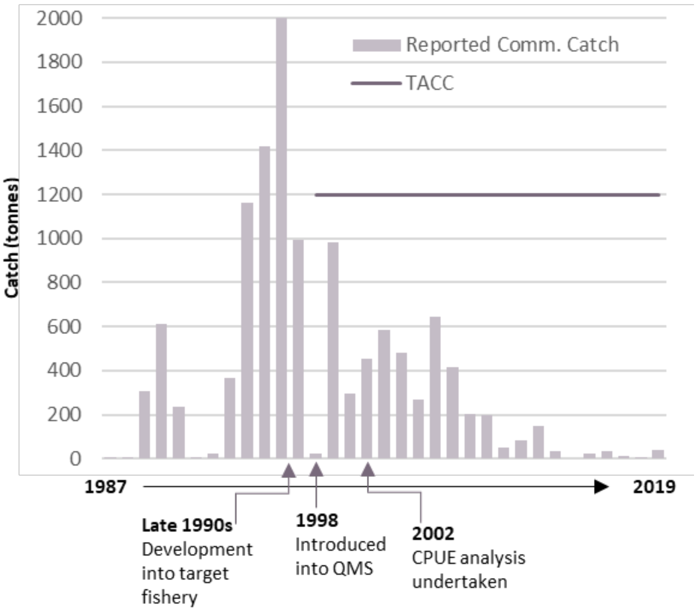


Figure 73: Reported commercial catch and TACC allowable commercial catch for CDL1 (Black Cardinalfish Auckland (East)) from 1983 to 2019. Data from Fisheries New Zealand.

While a CPUE assessment of CDL1 was undertaken in 2002, it found that there was limited application of these models for monitoring the abundance of black cardinalfish. The report suggested the fishery should be monitored carefully (Phillips, 2002). In 2009 the potential risk in this stock was flagged again by Dunn (2009), who suggested future research should investigate CDL1 and that black cardinalfish are likely to be a high-risk species in most areas.

In the intervening 10-20 years, the reported commercial catch in CDL1 has continued to drop steeply (see figure 73), yet further research efforts have not resulted in assessment of this stock (MacGibbon, 2016). Catch is not necessarily related to biomass (for example, a particular stock may no longer be targeted for commercial reasons), though when considered in light of other information (such as a decreasing catch rate/tow or data from trawl surveys) it is consistent with a decreasing biomass (Wallace and Weeber, 2005). Where further information is not available on a stock to either validate or refute assumptions relating to biomass, it leaves high uncertainty around the size of the stock and the level of impact that commercial fisheries may or may not be having. It is clear that the TACC has had no active management role for this stock, as commercial catch has never come close to reaching TACC and has not reached even 15% of this limit in the last decade.

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Hāpuku

The hāpuku stock in the northeast of Aotearoa New Zealand has never been assessed. The quota was introduced in the 1980s.

Hāpuku is packaged with bass (another groper species) under the HPB quota, which in 2019 had around 1,300 tonnes of reported commercial catch. The TACC of around 2,200 tonnes has never been caught. Fishers do not generally report these species separately so there is little data available on the catch of hāpuku (Ministry of Fisheries, 2002), yet fishers report that it is getting harder to catch and the juveniles have been called "the stuff of myths and legends" by divers. The species are (or were) an important top predator in coastal ecosystems.

Figure 74: A rare sighting of a juvenile hāpuku in 2018. Image credit: divetutukaka/iNaturalist, filmed by Danielle Watson (CC BY-NC 4.0).

There are many other fish stocks that are in the same situation of under-management, though the proportion of stocks at risk cannot be easily discerned.

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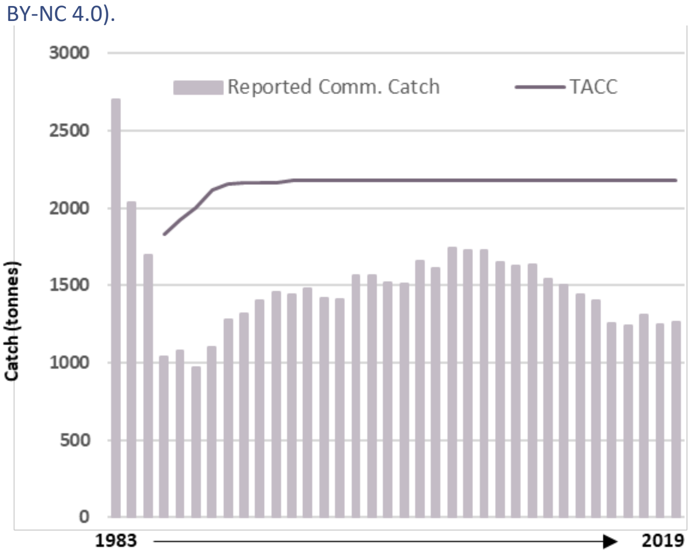

Figure 75: Reported commercial catch and TACC HPB from 1983 to 2019. Data from Fisheries New Zealand.

Black cardinalfish and hāpuku provide examples of where the volume of stock caught has consistently been well below TACC (see figures 73 and 75) and where a lack of information or assessment means that the performance (or lack thereof) of a stock has not been formally qualified or quantified.

They indicate that there may be more stocks below soft or hard limits (where a stock is considered to have collapsed) than what can be reported on based on current stock assessments. The scale of this potential issue is not readily identified as the majority[152] of stocks have not been scientifically assessed.

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[152] The majority by number of stocks.

5.3.4 CASE STUDY: ORANGE ROUGHY STOCK HEALTH

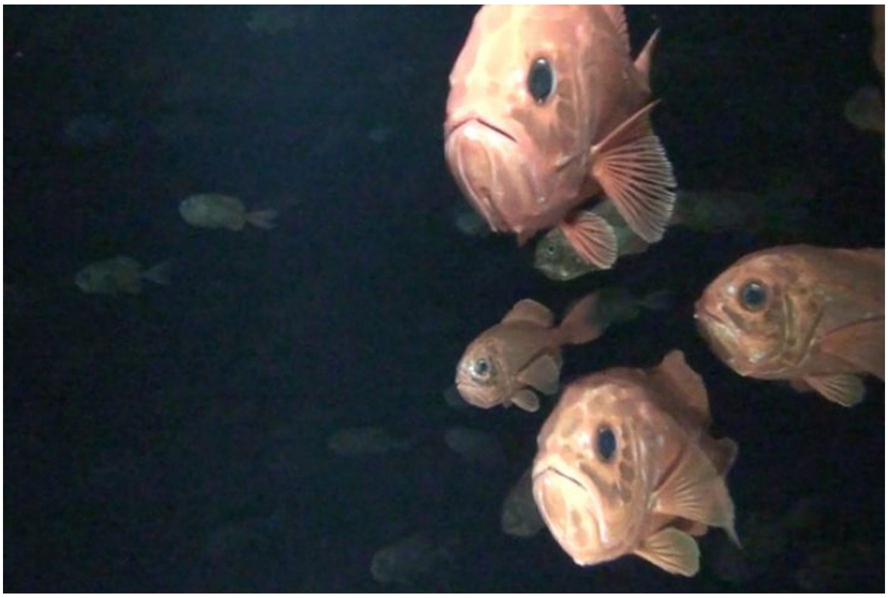

Figure 76: Orange roughy swimming above a seamount called 'The Morgue' on the Chatham Rise, captured by NIWA scientists using underwater cameras. Image credit: NIWA.

Orange roughy is a red-orange fish in the slimehead family. It inhabits deep water from 500 to 1,500 m in parts of the Atlantic and Pacific Oceans. Aotearoa New Zealand is the world's dominant harvester of orange roughy, with most of the catch exported to the United States and China. Other jurisdictions with orange roughy fisheries include Australia, the northeast Atlantic, Namibia, the Faroe Islands and Chile.

Orange roughy has a range of characteristics that make it vulnerable to overfishing. It is a slow-growing fish with a long lifespan that can exceed 150 years (Andrews *et al.*, 2009; Tingley and Dunn, 2018). Females have low fecundity, producing comparatively fewer eggs than other fish species (Clark *et al.*, 1994), and they are late to mature, with breeding beginning at about 30 years (Tingley and Dunn, 2018). They do not breed every year.

The orange roughy has a range of characteristics that make it vulnerable to overfishing.

Orange roughy are slow-moving and form large, predictable aggregations, which makes them easy to capture. They tend to aggregate around underwater topographical features (UTFs), which include seamounts, knolls, ridges and canyons. These are home to diverse benthic flora and fauna, which is damaged by the trawl gear used to harvest orange roughy (see section 3.3.3: Habitat). Although genetic studies suggest that there is just one worldwide population of orange roughy (Varela *et al.*, 2012, 2013), it is possible to deplete the local population at a specific UTF. Individuals migrate between specific feeding and spawning sites.

In Aotearoa New Zealand, commercial fishing of orange roughy began in 1979 (Francis and Clark, 2005). At the time, their low productivity and long lifespan were not known, with estimates suggesting a maximum age of about 30 years. Early stock assessments, based on trawl survey biomass estimates, greatly overestimated the unfished biomass B_0 (a generally contested number for many species (see section 5.2.2.3: Original biomass). The species' inherent susceptibility to overfishing, combined with inadequate data and knowledge, led to a period of unsustainable overfishing.

Between 1983 and 1990, around 50,000 tonnes were harvested each year – but reported catch was likely underestimated (by as much as 50%) due to catch being lost at sea and to discrepancies in converting fillet weight to whole fish (Tingley and Dunn, 2018). Reported catch peaked in 1989 at 57,000 tonnes (Francis and Clark, 2005). By 1994, the harvest had dropped to less than 20,000 tonnes. By the end of the 1990s, three of

Aotearoa New Zealand's eight orange roughy fisheries had collapsed and were closed. TAC was reduced substantially for the fisheries that remained open.

Since the late 80s, evidence for the long lifespan of orange roughy had emerged and mounted. Fish age can be determined via a range of methods, including counting circuli on scales, counting growth rings in otoliths (ear bones), radiometric dating of otoliths, and lead-radium dating. By 1988, trawl surveys undertaken showed the species was long-lived and slow growing with low productivity (Mace *et al.*, 1990). A subsequent review in 1999 also concluded that orange roughy are indeed long-lived and slow growing (Tracey and Horn, 1999). Since then, one individual sampled 1,500 km east of Wellington was estimated to be 230-245 years old. Further documentation of the early history of the science and management of the Chatham Rise orange roughy fishery can be found in Sissenwine and Mace (2007).

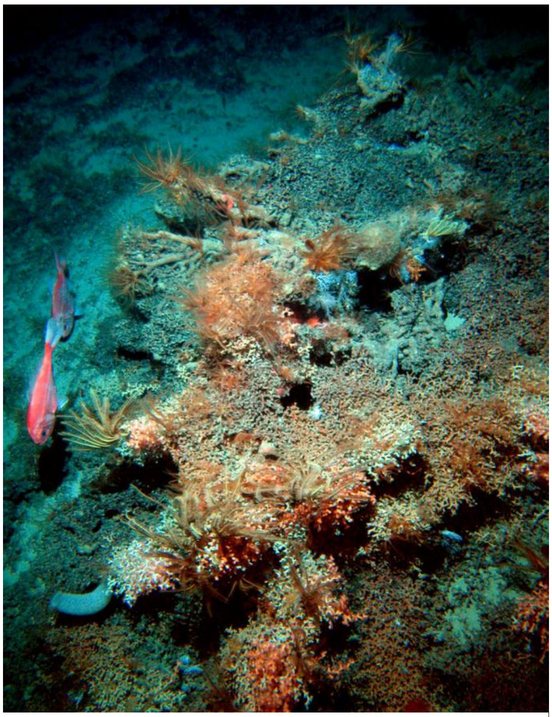

Figure 77: Two orange roughy swim through the diverse habitat on Ghoul Hill, 1,000 m deep. Image credit: NIWA.

In the last two decades, innovative technologies and better research methods have improved the management and sustainability of the orange roughy fisheries (alongside the significant reduction in catch). The stock is divided into eight QMAs, with monitoring every four years. Stock assessments incorporate several data sources, including fisheries data, life-history characteristics, and tagging data. Acoustic and video surveys and better ageing techniques enable more accurate estimates of population size and demographics. In turn, this informs management decisions to support the recovery of orange roughy stocks.

Now, some orange roughy stocks have rebuilt. In 2020, the TAC was just under 11,000 tonnes, and a commercial catch of 8,627 tonnes was reported across the eight QMAs (Fisheries New Zealand, 2020c). Most assessed stocks sit around the management target level – between 30-50% of B_0 – which aims to balance sustainability and use. In 2016, three orange roughy fisheries in Aotearoa New Zealand achieved sustainability certification from the MSC (see 6.7.6: case study: The Marine Stewardship Council).

However, there are currently two stocks of orange roughy that are assessed by Fisheries New Zealand as experiencing overfishing (Fisheries New Zealand, 2019i). A TACC reduction was implemented in 2014 for the fishery on the mid-east coast of the North and South Islands. The other overfished stock, on the west coast of the South Island (ORH7B), has effectively been closed, with a TACC of one tonne. These reductions in TACC aim to allow the stocks to rebuild. The orange roughy story is a cautionary tale that highlights the need to use the best possible data to inform stock assessment, the importance of reassessing assumptions as new information is presented, and the need to build uncertainty into our management decisions.

The orange roughy story is a cautionary tale that highlights the need to use the best possible data to inform stock assessment, the importance of reassessing assumptions as new information is presented, and the need to build uncertainty into our management decisions.

5.3.5 CASE STUDY: MIXED MESSAGES: ARE WE OVERFISHING OUR ROCK LOBSTERS?

Cray, crayfish, rock lobster, kōura: this prized crustacean goes by many names. *Jasus edwardsii* is a rock lobster species inhabiting shallow reefs around Aotearoa New Zealand's coasts as well as southern Australia. It is reported to be a relatively slow-growing and long-lived species (National Rock Lobster Management Group, 2018), though some suggest that the science in Aotearoa New Zealand is not fully settled.[153] It is one of our most lucrative fisheries, with exports worth around $300 million in 2019 (Seafood New Zealand, 2020). It is highly valued by Māori and recreational fishers. Rock lobsters are captured live in baited pots, or by divers, and the peak season is between June and November.

In Aotearoa New Zealand, the rock lobster fishery was first introduced into the QMS in 1990 and is divided into ten management stocks (see figure 78, although CRA 10 is nominal and is not commercially fished). Although most of the plenary stocks are classified as sustainable and none of these stocks are categorised as 'collapsed' by Fisheries New Zealand, CRA2, covering Te Moana-a-Toitehuatahi the Bay of Plenty north to Tīkapa Moana the Hauraki Gulf, is 'virtually certain' to be experiencing overfishing (table 11) and CRA4 in the Te Matau-a-Māui Hawke's Bay/Wairarapa region is 'likely' to be experiencing overfishing.

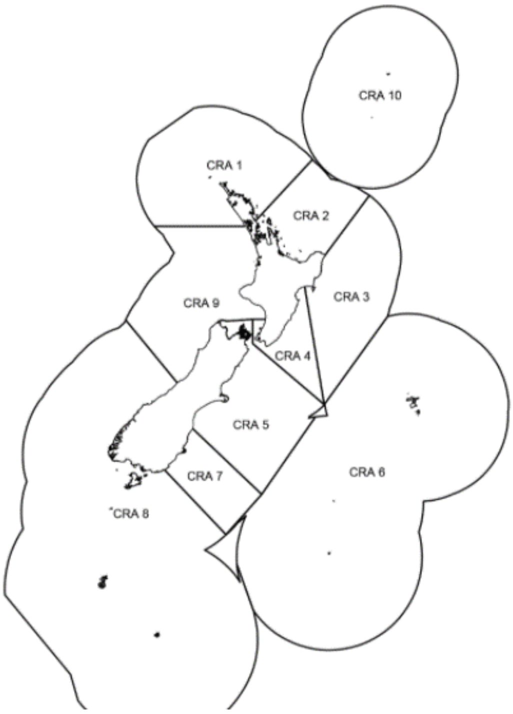

Figure 78: Map showing the different management stocks for rock lobster.

Homing in on the CRA2 stock, we can see an example of divergence between the industry, regulator and independent researchers in estimation of stock performance. The stock was last assessed by Fisheries New Zealand in 2017 – brought forward a year earlier than scheduled as iwi, recreational fishers, and commercial fishers all expressed concern about the stock. The stock assessment used the 'lobster stock dynamics' model and was overseen by the Rock Lobster Fishery Assessment Working Group. The assessment determined that CRA2 was 'likely' below the soft limit (20% of unfished spawning stock biomass), but 'very unlikely' to be below the hard limit (10% of unfished spawning stock biomass) (Webber *et al.*, 2018).

Homing in on the CRA2 stock, we can see an example of divergence between the industry, regulator and independent researchers in estimation of stock performance.

[153] Input from New Zealand Rock Lobster Industry Council Ltd.

Table 11: Status of Rock Lobster fishery by management stock as reported by Fisheries New Zealand.

Plenary stock	At or above target levels?	Overfishing?	Below the hard limit?	Below the soft limit?	Last assessment date	Corrective management action
CRA1 Northland	Unlikely	About as likely as not	Very unlikely	Very unlikely	2019	TAC reduction currently being considered.
CRA2 Bay of Plenty	Exceptionally unlikely	Virtually certain	Very unlikely	Likely	2017	Significant TACC and recreational allowance reductions in 2018. Further recreational measures currently being considered.
CRA3 Gisborne	About as likely as not	About as likely as not	Exceptionally unlikely	Exceptionally unlikely	2019	-
CRA4 Hawke's Bay-Wairarapa	About as likely as not	Likely	Exceptionally unlikely	Exceptionally unlikely	2019	TAC reduced in 2017.
CRA5 Marlborough-Canterbury	Virtually certain	Very unlikely	Exceptionally unlikely	Exceptionally unlikely	2019	-
CRA6 Chatham Islands	Unlikely	Unknown	Very unlikely	Unlikely	2018	-
CRA7 Otago	Very likely	Very unlikely	Unlikely	Unlikely	2019	-
CRA8 Southern	Virtually certain	Very unlikely	Exceptionally unlikely	Exceptionally unlikely	2019	-
CRA9 Westland-Taranaki	Unknown	Unknown	Unknown	Unknown	2015	-
PHC1	Unknown	Unknown	Unknown	Unknown	-	- [154]

As a result of the assessment, new catch limits were set from 1 April 2018: a TACC of 80 tonnes, and a recreational allowance of 34 tonnes. From 1 July 2020, the recreational daily bag limit was dropped from six lobsters to three. These measures are part of a multi-stage plan attempting to rebuild the stock. Fisheries New Zealand has proposed that a review of the CRA2 TAC, allowances, TACC, and other management controls will be undertaken at the time of the next CRA2 stock assessment, which is scheduled for 2021 (National Rock Lobster Management Group, 2019).

Others describe the CRA2 stock decline in more definitive terms: that the rock lobster is 'functionally extinct' within Tīkapa Moana the Hauraki Gulf (Hauraki Gulf Forum, 2020). The New Zealand Marine Sciences Society submitted fishery-independent analysis to the CRA2 consultation undertaken by Fisheries New Zealand in 2018 on recreational catch, outlining results from monitoring research of rock lobster abundance inside and outside

[154] Input from the New Zealand Rock Lobster Industry Council: In 2020, industry funded a characterisation and the first stock assessment for packhorse rock lobster (PHC 1) though this does not year appear to be publically available. Industry reports that the assessment suggests that following a period in the 60s and 70s when the stock was overfished, the stock has rebuilt strongly to nearly unfished levels and consideration is currently being given to catch limit increases.

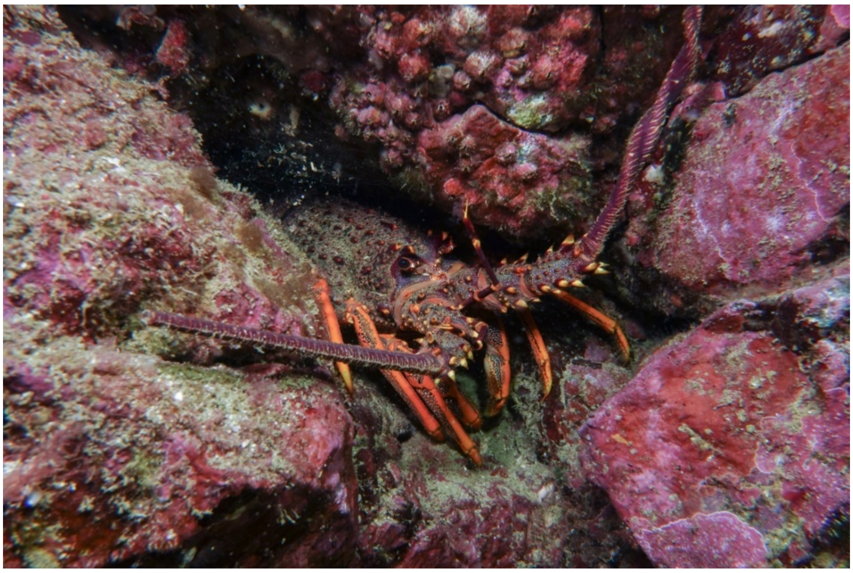

Figure 79: Rock lobster (*Jasus edwardsii*). Image credit: lcolmer/iNaturalist (CC BY-NC 4.0).

marine reserves within CRA2, using the reserves as 'unfished' reference points of what natural biomass looks like (though some state that marine reserves are not representative of habitat in the wider QMS). At Leigh and Tāwharanui north of Tāmaki Makaurau Auckland in Tīkapa Moana the Hauraki Gulf, biomass of legal-sized lobsters outside local marine reserves was 2-3% of that inside the reserves (LaScala-Gruenewald *et al.*, in press). At Hahei off the Coromandel, legal-sized lobster biomass was around 7% of the biomass in the local marine reserve. These small protected areas were cited as likely to underestimate natural 'unfished' abundance (see section 5.2.2.3: Original biomass), because the rock lobster populations inside the reserves have been steadily declining for the past 10 years, consistent with intense fishing pressure on the edges. These numbers suggest that the CRA2 stock, at least in Tīkapa Moana the Hauraki Gulf and Te Tara-o-te-Ika a Māui Coromandel parts of CRA2, may be well below the hard limit that would force a fishery closure. Part of the discrepancy is due to contested views of the biomass that is being described and how it has been calculated. For commercial fisheries where there is a significant recreational catch, stock assessments can be more uncertain due to the very limited information about the size of recreational catches.

Part of the discrepancy is due to contested views of the biomass that is being described and how it has been calculated. For commercial fisheries where there is a significant recreational catch, stock assessments can be more uncertain due to the very limited information about the size of recreational catches.

Rock lobsters play an important role in rocky reef ecosystems: they are predators of other invertebrates such as kina. When rock lobsters are removed from the ecosystem, this can result in a trophic cascade (Shears and Babcock, 2003a).[155] Kina numbers boom, and kina eat swathes of seaweed and other macroalgae. Diverse seaweed assemblages are a major primary productivity source and provide habitat for other marine organisms, so their removal has flow-on effects for a range of other species. This trophic cascade is discussed in 'The Noises vs Cape Rodney-Okakari Point Marine Reserve' (see case study 3.3.6).

Modelling of invertebrate fishing impacts (specifically for the south coast of Wellington, in CRA4) revealed that the ecosystem effects of harvesting lobster were greater than harvesting pāua or kina (Eddy *et al.*, 2015). The analysis found that current rates of rock lobster exploitation exceed rates needed for MSY (see section 5.2.2.4:

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[155] Input from NZ Rock Lobster Industry Council Ltd: Not all habitats are susceptible to kina barren in the absence of rock lobster. The trophic cascade hypothesis is disputed by the National Rock Lobster Management Group, which has provided advice to the Minister stating, "This hypothesis is controversial and the literature equivocal...sea urchins populations are affected by factors other than predation, such as diseases and temperature".

Maximum sustainable yield) (Eddy *et al.*, 2015). Reducing exploitation would increase target captures, raise CPUE, and reduce ecosystem impacts.

Another rock lobster stock of interest is CRA8, which extends around the southern and western coasts of the South Island and includes the subantarctic islands. Over the 1990s, the industry operating in the CRA8 area began to recognise that the fishery was in trouble. Fishers who had joined forces as the Southern Rock Lobster Research and Development Committee earlier in the 90s became the CRA8 Management Committee in 1996, and advocated for a management strategy to reverse the decline. This is considered a success story, with biomass increasing since around 2000 and now holding steady at more than 40% of the unfished level. This example shows that with good management, stocks can be improved, and the management strategy used in funding setting of annual catch limits could potentially be usefully deployed in other fisheries. However, wider questions remain around the functioning of these ecosystems and long-term impacts.

The New Zealand Rock Lobster Industry have pointed out that since these assessments management action was taken on 1 April 2020 to reduce catch in CRA1 and CRA2 is rebuilding. The next assessment will ascertain the impact of these actions.

Figure 80: Rock lobster larva. Image credit: Jo Virens/iNaturalist (CC BY-NC 4.0).

5.3.6 CASE STUDY: CHATHAM RISE IS A UNIQUE FISHERY WITH CONSISTENT, LONG-TERM DATA

The Chatham Rise is a special fishery because its topography and associated currents make it very productive. As such, it has been the subject of detailed study and provides an exemplar of how data can enrich models and enable long term ecological monitoring – and how resource intensive this data gathering can be.

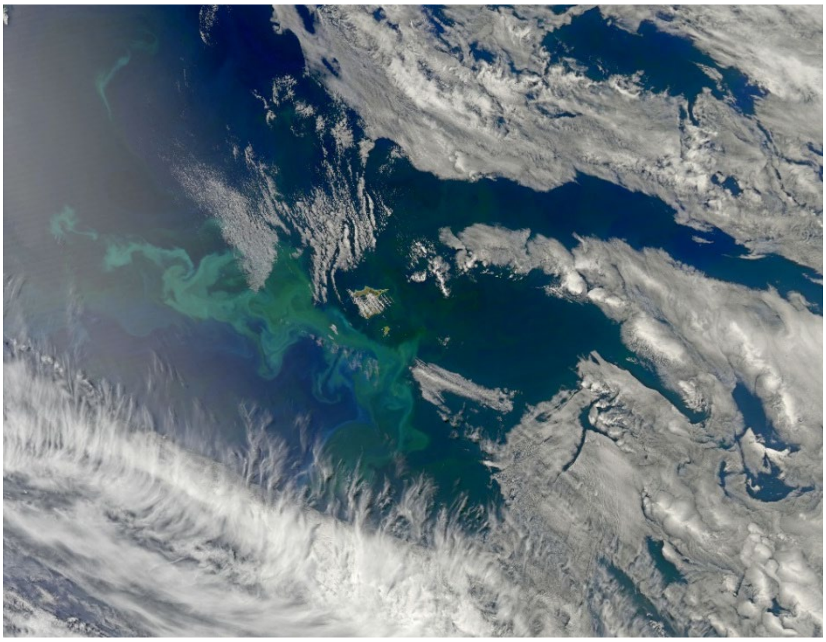

Figure 81: Phytoplankton bloom on the Chatham Rise. Image credit: Norman Kuring, Ocean Color Team/NASA Goddard Space Flight Center.

Fisheries New Zealand contract a survey by NIWA, which has been done annually since January 1992 with RV *Tangaroa*, and biennially since 2014. The total of 26 surveys have collected data on over 300 species per survey; biomass is well monitored for about 50 species and size frequency data are collected on about 45 species each survey. Consequently, we have more fisheries data available for the Chatham Rise than almost anywhere else in Aotearoa New Zealand. The Fishecoviz portal summarises (30+) key species' biomass and will summarise size frequency data as well to generate ecological indicators for monitoring (see section 6.2.2.2: An improved data system can help us move from data to information).

The rich dataset is used to develop the Atlantis model with a growing number of parameters, in addition to trawl surveys (acoustic surveys, diet studies, benthic and habitat studies, growth and age studies, oceanographic models, nutrient climatological data, commercial fishery catch and effort, and stock assessment models). The Atlantis model is further discussed in section 6.4.18: Models can support ecosystem approaches to fisheries management.

The model has been well described in the literature (see: McGregor *et al.*, 2019a; McGregor *et al.*, 2019b; McGregor *et al.*, 2020; McGregor, 2020).

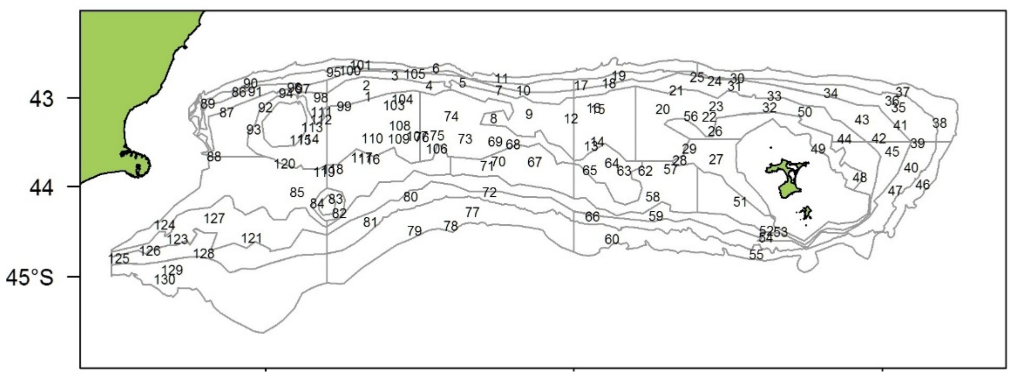

Figure 82: Chatham Rise survey area showing strata used for trawl surveys.

5.3.7 CASE STUDY: PĀUA FISHERIES AND INDUSTRY-LED MANAGEMENT

Pāua refers to three species of edible sea snail: the black-foot pāua (*Haliotis iris*), the yellow-foot pāua (*Haliotis australis*) and the white-foot pāua (*Haliotis virginea*). All three are endemic to the waters around Aotearoa New Zealand and have important cultural value to tangata whenua. Black-foot and yellow-foot pāua are harvested both commercially and recreationally, with yellow-foot only caught in small numbers. White-foot pāua is generally too small and rare to be easily collected.

Pāua inhabit shallow rocky reefs around Aotearoa New Zealand and have very localised larval settlement. Offspring are more likely to settle within the immediate vicinity, often inshore from their parent animals. Genetic studies have revealed that there are some distinct populations of black-foot pāua, separated by distance or dictated by strong currents (Will *et al.*, 2015). For example, the North Island, South Island and Chathams populations are thought to be genetically distinct populations.

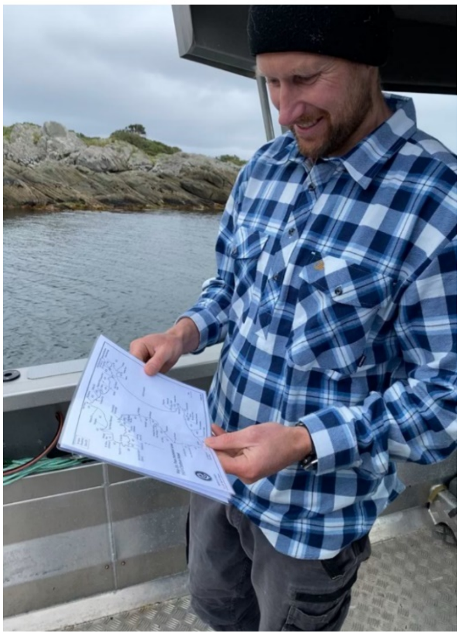

Figure 83: Top – Pāua harvested near Kaingaroa on Chatham Island. Bottom – Pāua fisherman Nick Cameron explains the fine-scale management areas within PAU4.

The pāua fishery is divided into ten QMAs although most commercial catch comes from only seven of these areas, with a combined TACC of 919 tonnes. Reported catch has been less than TACC for the past five years. The difference is reportedly accounted for by voluntary catch reductions by quota owners for a variety of management reasons.[156] In 2019, pāua exports were worth $50 million, including shell, by-product and nutraceutical sales. There is also a small but important domestic market for pāua, principally into Tāmaki Makaurau Auckland and Tāhuna Queenstown tourist restaurants.

The Pāua Industry Council is the peak industry body for pāua fishers and quota share owners. The Council is managed by a board of directors which includes the chair of each of the regional commercial stakeholder groups, PāuaMACs. All are funded by a compulsory levy on quota shares enabled by the Commodity Levy Act. The PāuaMACs tend to concentrate on regional matters while the Council provides support and deals with national level matters. Each PāuaMAC is responsible for drafting a pāua fisheries plan for its own QMA.

PĀUA IN RĒKOHU WHAREKAURI THE CHATHAM ISLANDS

The entire Chathams pāua fishery falls within PAU4 as described in the Fisheries Act 1996. PAU4 contributes more than a quarter to the national 720 tonnes of wild pāua that is commercially harvested.

[156] Input from Pāua Industry Council.

Unlike the rest of Aotearoa New Zealand, pāua can be collected using underwater breathing apparatus (UBA) in Rēkohu Wharekauri the Chatham Islands, on the premise that it may reduce the risk of shark attack on divers (Hills, 2015). The surfacing and descent of divers is thought to increase the risk of shark attack (Ministry for Primary Industries, 2013c). Since implementation of UBA at the Rēkohu Wharekauri the Chatham Islands there have been a number of great white shark incidents involving pāua divers, but none have resulted in injury. Prior to UBA several divers had been seriously injured by great white sharks.[157] Electronic reporting (ER) of the fishing method alongside the catch enabled this to be factored into CPUE, a good illustration of how technology changes must be factored into the CPUE calculation (see section 5.2.2.6: The relationship between catch per unit effort and abundance).

Figure 84: Pāua are measured and meet a minimum size specific to the area in line with the PAU4 management plan.

In 2010, fishers were concerned about localised depletion of pāua. Even though quantitative information was limited, quota owners collectively agreed to voluntarily shelve part of their ACE, thus lowering commercial harvest (Chatham Island PAU4 Fisheries Plan, 2019).

Fishers were concerned about localised depletion of pāua and quota owners came together to voluntarily shelve part of their annual catch entitlement.

In Rēkohu Wharekauri the Chatham Islands the management organisation is known as PāuaMAC4. Reflecting an appropriate scale in which this resource needs to be managed within its ecosystem, there are 57 statistical sub-areas that have been adopted within the fisheries plan. These statistical areas were identified and developed in the mid-90s by the then Ministry of Fisheries to improve catch reporting. They have since been superseded by ER and GPR and are no longer used by the Ministry. As noted, industry continue to use them as a local management tool.

Figure 85: Tom McClurg talks about the history of Chathams' fisheries.

Species like pāua are well-suited to fine-scale management because:

- They are sedentary species that naturally tend to aggregate and are more prone to be impacted by localised fishing efforts.
- Pāua fisheries are made up of large numbers of sub-populations, with characteristics and population dynamics varying at reef or bay scale. Length at maturity and growth rates can vary greatly at scales of a few hundred metres.

[157] Input from Pāua Industry Council.

- Stock information can easily be captured by industry data recording systems in real time, which allows management responses within the fishing season.

The PAU4 plan operates within the requirements of the Fisheries Act 1996 (i.e. the plan is consistent with legal requirements) and TACC settings, but also requires more stringent and detailed actions from fishers.

The plan is consistent with legal requirements and TACC settings, but also requires more stringent and detailed actions from fishers.

Key steps that are undertaken through the management plan include:

- Using the shelving of ACE to reduce fishing effort (to less than the TACC) which acts to accelerate stock rebuild when required or to raise pāua population levels to above the current Fisheries New Zealand 40% B_0 population target level.
- Controlling fishing activity (catch levels) at the statistical area level, enabling catch spreading to avoid localised depletion, and changes to minimum harvest size to above the legal requirement of 125 mm which ensures that pāua can spawn for more seasons before being available for harvest than would be the case at the current minimum legal size.

Fishers are keen to see statutory support for their more stringent management plan, which can currently only be implemented on a voluntary basis. Currently fishers that do not follow management plans are not breaking the law but rather breaking contractual requirements. The consequences of this include, for example, that they may no longer be able to lease quota from a given owner, may not be able to use certain processing facilities, or may face social consequences (which are particularly relevant in small communities like Rēkohu Wharekauri the Chatham Islands).

Aside from the PAU4 plan voluntary size limits, there are other incentives to target larger pāua. Overseas markets will often pay a premium price for larger pāua. Locally, this positively impacts population size as fewer individual pāua need to be harvested to reach the TACC. So fewer pāua are taken from the population to catch the TACC. At a 10 mm harvest size increase, estimates are that 15% fewer individuals are taken.

However, targeting fewer, larger pāua may lead to unintended management signals. The longer time spent harvesting a smaller catch, is recorded as a decrease in CPUE and be interpreted as a drop in abundance when stock assessment models are run – even if the population size may in fact be growing, as observed by local divers (see section 5.2.2.6: The relationship between catch per unit effort and abundance). This is concerning to fishers as positive changes in the industry reflecting EAFM could potentially lead to undesirable regulatory outcomes such as TACC reduction. There is potential for similar impacts to occur in other fisheries. More responsive fisheries management that allows for local knowledge input into the decision-making process could help to prevent these undesirable outcomes (discussed in section 6.2.1: Changing fisheries demand nimble and responsive decision making).

CONSIDERATION OF AN EAFM

The Pāua Industry Council is, across its regions, reviewing how they can apply an ecosystem approach to pāua management more widely (McCowan, 2019). Pāua harvesting has minimal direct impacts to habitat (e.g. use of blunt knife-like tools to prise pāua off reefs, light anchoring systems), has no bycatch, and no interactions with protected species such as seabirds or dolphins. Pāua are also not thought to have a structurally important role in ecosystems. Pāua mainly feed on drift algae and small amounts of attached seaweed, for example *Macrocystis pyrifera*, while their key predator (starfish) is a generalist and scavenger so the removal of one prey species (pāua) is unlikely to have a large impact (McCowan, 2019). There may be competition between pāua and kina as they are both reef grazers, and there is evidence that removing pāua contributes to the establishment of kina barrens (Wing *et al.,* 2015). Concerns largely centre around cumulative impacts as a whole.

Initiatives suggested in the review on how to incorporate ecosystem approaches (McCowan, 2019) include:

- Updating diver codes of conduct through annual operating plans to suggest ways to minimise ecosystem impacts, for example avoiding anchoring near recognised recruitment habitats.
- Continuing to spread catch to minimise risk of ecosystem impacts caused by local depletion of pāua (and reduce cumulative effects) and to maintain pāua populations at a relatively high level of abundance, using the Fisheries New Zealand default of 40% B_0 as a minimum target.
- Coordinating with research institutions to monitor sea temperature and ocean acidification, as well as habitat and ecosystem monitoring.
- Monitoring the abundance of pāua at different life stages, e.g. possibility of monitoring pāua recruitment using pāua 'motels'.
- Incorporating projected environmental changes into long-term management strategies and initiatives, e.g. kelp restoration, translocation to areas of cooler currents.
- Reviewing spreading of catch in the event of marine heatwaves if there is mortality.
- Developing best practices to reduce sedimentation in near-shore ecosystems.

The PAU4 plan sets out specific management objectives, which then enable easier identification of the most important science and research needed to inform more effective management. HPSFM (which are discussed in section 4.2.1.3) have been identified as a priority by the industry council for identification. The Pāua Industry Council has been tasked with work, which is now underway, to define, identify and map habitats of particular significance to pāua in all QMAs. This body of work, which is expected to be completed in 2021, can be used to inform further operationalising of an EAFM for pāua fisheries.

The PAU4 plan sets out specific management objectives, which then enable easier identification of the most important science and research needed to inform more effective management. HPSFM have been identified as a priority by the industry council for identification.

For example, once identified the industry will be able to advocate for protection of these habitats against sedimentation, dredging and debris through engagement with local council. Regional councils are obliged to take into account an existing Fisheries Plan approved under Section 11(a) of the Fisheries Act 1996 when developing their Coastal and Regional Plans. Currently (as discussed in section 3.1.2.3: Fisheries management and land-based regulations are not integrated) there is poor implementation of statutory requirements to integrate integration of management from the land to the sea.

Some of the Pāua Industry Council's current management approaches are consistent with an ecosystem approach, though they are not necessarily labelled as such. The Fisheries Act 1996 provides a platform this approach to occur, building on a platform of single-stock assessment.[158]

Some of the Pāua Industry Council's current management approaches are consistent with an ecosystem approach, though they are not necessarily labelled as such.

While this is a niche industry, it provides a good example of applying principles of community led management and a move towards an EAFM.

[158] Input from Pāua Industry Council.

5.4 RESEARCH AND REGULATORY INITIATIVES ARE UNDERWAY BUT POORLY INTEGRATED

There are many stakeholders in the marine environment who take a range of actions or undertake research to improve the health of our marine environment and the sustainability of our fisheries. These diverse groups include commercial fishers, quota owners, industry organisations, the regulator, iwi and hapū, NGOs and researchers. Each group has specific, and often conflicting, priorities which they centre their initiatives around. However, there are some shared drivers for the various efforts, including:

- Filling data and knowledge gaps, capitalising on opportunities to collect better data, and improving trust in data through improved verification and validation.
- Understanding the impacts of fishing on target species, non-target species and the broader ecosystem so that efforts can be focused on reducing harm.
- Using what we already know about the negative impacts of fishing, e.g. on habitat destruction, to improve practices.

Here we focus on current initiatives underway by various groups and how these might be better coordinated to support a more cohesive and integrated approach to fisheries management. We highlight the recent or upcoming regulatory changes by Fisheries New Zealand, various initiatives that have been taken by industry, examples of initiatives in the marine space that iwi have taken which impact fisheries management, and outline the funding and research settings relating to fisheries and the marine environment. More detailed analyses of specific research projects and innovation solutions are covered in part 6.

Figure 86: Juliet learns about research that is undertaken on the NIWA vessel RV *Tangaroa*.

5.5 REGULATOR INITIATIVES AND DATA TRANSFORMATION

In 2015 Fisheries New Zealand undertook a Fisheries Management System review, and from this review they developed a major work programme to enhance and update the fisheries system. This programme, called the Fisheries Change Programme, is currently underway.

The Fisheries Change Programme aims to:

- Strengthen and make more modern the way we manage our fisheries.
- Ensure the sustainability of Aotearoa New Zealand's fisheries.

The programme has three parts:

- **Electronic catch and position reporting**. Introducing mandatory electronic catch and position reporting to improve the collection and reliability of fisheries information.

- **On-board cameras**. Improving monitoring and verification capabilities, including the use of on-board cameras, to better observe fishing practice.
- **Fishing rules**. Changing fishing rules and policies to make them simpler, fairer and more responsive, while also incentivising better fishing practices.

These are at different stages of implementation and may evolve as the Ministry's consultation progresses. The Fisheries Change Programme is a key piece of work towards integrating biodiversity into Aotearoa New Zealand's fisheries management system and meeting our objectives under the CBD (Hon Min Nash, 2018; Department of Conservation, 2019b).

The process of making these changes also highlights the difficulties in reaching consensus decisions in a shared space where the scientific evidence available is limited or has higher uncertainty, particularly given the many different and competing interested in the marine space. For example, conservation of taonga species as a key objective may support a more precautionary approach, while enabling sustainable single species stock use has a different balance of considerations.

The process of making these changes also highlights the difficulties in reaching consensus decisions in a shared space where the scientific evidence available is limited or has higher uncertainty.

Other work that is being undertaken that is of importance to fisheries management, includes:

- MPA reform - the Government has signalled an intent to reform MPA legislation (Ministry for the Environment, Department of Conservation, Ministry for Primary Industries).
- *Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020* (Department of Conservation).

These initiatives are resource constrained and need to be integrated within other efforts across government in the marine environment.

5.5.1 ELECTRONIC CATCH AND POSITION REPORTING IS LIVE

Since 2019, all commercial fishers have been required to report catch electronically. There are some exemptions from ER, but cost is not a reason for exemption. There are now more than 1,000 vessels tracked in Aotearoa New Zealand through the electronic catch and position reporting system, which allows Fisheries New Zealand staff to track vessels in real time. In

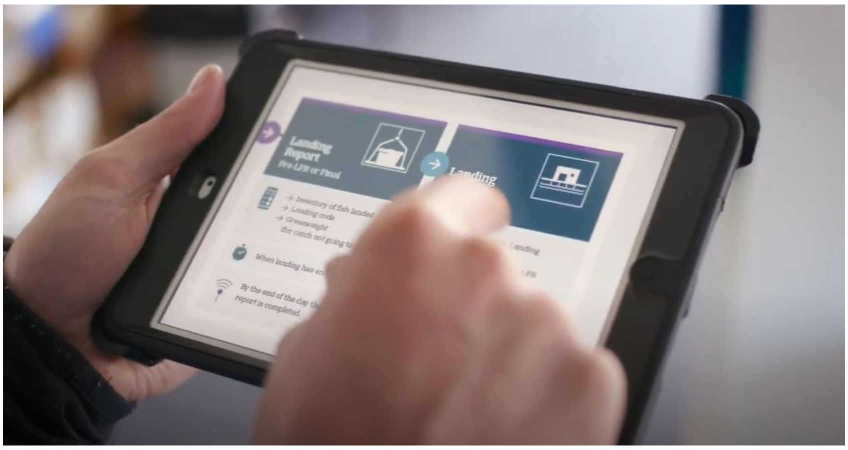

Figure 87: Electronic reporting cuts down on paperwork. Image credit: MPI/YouTube.

2017 there were over 1,500 commercial fishing vessels registered in Aotearoa New Zealand.

These improvements in digital monitoring enable:

- More timely and accurate data.
- Verification of when and where fishing occurs.

A key focus of this activity is on gathering data for compliance purposes. There is potential to expand to use the data for more environmental and commercial purposes (as discussed in section 6.4.1: Computers, cameras and AI could revolutionise catch monitoring). With the drastically increased frequency of reporting there are significant opportunities to enhance the use of fisheries catch data and increase transparency in fishing practices. This in turn will enable faster response in fisheries management practice in response to change.

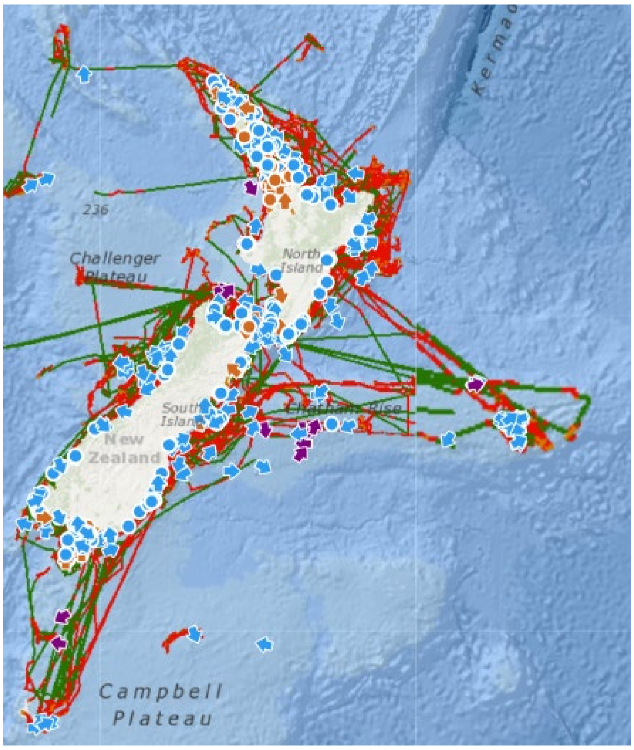

Figure 88: Electronic catch and position reporting. Image credit: Fisheries New Zealand.

A key focus of this activity is on gathering data for compliance purposes. There is potential to expand to use the data for more environmental and commercial purposes.

The position reporting shows where fishing has taken place as the speed and direction of a vessel provide information on when a fishing event occurred, and whether this was in an area where that type of fishing is allowed. This observation is independent of fisher reporting (though the type of fishing/gear used is reliant on fisher reporting). In circumstances where this real-time information is being monitored, this allows for compliance action (such as meeting the vessel at port to verify catch in person). There is also the possibility for discarded catch to be traced back to the vessel if it was released from in some circumstances. There have already been significant advances in the detection of illegal activity and consequent prosecution.[159] This represents a radical change in the compliance landscape and the regulator is considering the appropriateness of the current offences and penalties within this new context (see consultation in 2019).

[159] E.g. see reporting here, here and here.

5.5.2 ON-BOARD CAMERAS ARE BEING INTRODUCED

One key way Fisheries New Zealand monitors fishers' behaviour is through the use of observers. Observers will join a vessel for the duration of one or several voyages and record catch data.[160] Observer coverage varies from year to year and is low in some fisheries, particularly inshore fisheries where it may not be feasible to safely carry observers on smaller vessels. In deepwater fisheries the planned coverage ranges from 15-40% for most fisheries, and up to 90-100% in squid and southern blue whiting fisheries to monitor potential New Zealand sea lion bycatch (Fisheries New Zealand, 2020b). Observer coverage is resource intensive and a significant increase in observer coverage would likely not be feasible.

> There are differences in observed and unobserved behaviour when it comes to discarding and recording – the so-called 'observer effect'.

However, digital monitoring is expected to substantively change how fisheries are monitored in Aotearoa New Zealand. Cameras can supplement observer monitoring by providing an alternative method of independent oversight (particularly when combined with electronic catch and position reporting).

The primary purpose of cameras is to verify fisher reporting, which can facilitate use of that data to enumerate catch and protected species interactions. Key benefits Fisheries New Zealand hopes to achieve over time with the initiative include:

- Improved verification of commercial catch and impacts of fishing on protected species. This could have benefits for meeting market expectations for transparency and verified supply chains.
- Improved environmental performance (species and habitats) through this increased monitoring.[161]
- Improved resilience by increasing the agility and responsiveness of industry through improved real-time information.

Observers will still be required to collect biological data (such as fish otoliths), which cannot be captured with cameras. Fisheries New Zealand has introduced regulations for on-board cameras for commercial fishing vessels. While the regulations have been in place since 2018, they do not yet apply to the majority of commercial fishing vessels. The date for the regulation to apply more widely has been delayed several times. Most recently, the Minister of Fisheries has announced $40 to $60 million of funding to aid implementation of the initiative with a goal of 345 cameras to be installed by 2024. The approach to wider roll out would prioritise cameras on vessels in high-risk areas in the first tranche (e.g. habitats of Hector's dolphins, Antipodean and Gibson's albatross, black petrels, and hoiho/yellow-eyed penguins).[162] The second tranche would include lower risk areas where the protected species are still significant (e.g. New Zealand fur seals, common dolphins, flesh-footed shearwaters and Salvin's albatross).

> While the regulations have been in place since 2018, they do not yet apply to the majority of commercial fishing vessels.

[160] Observers' role also includes protected species monitoring, fishery-independent catch monitoring, and biological sampling.
[161] The key purpose of monitoring is for compliance purposes, with indirect environmental benefit, rather than for the purpose of environmental monitoring.
[162] *Megadyptes antipodes.*

The regulations currently only apply to select vessels in a limited fishing area on the west coast of the North Island where endangered Māui dolphins are found (20 vessels). The industry has also initiated and trialled cameras in the Snapper 1 (SNA1) fishery. However, there have been several camera trials in New Zealand including set net vessels off the east coast of the South Island, bottom trawl vessels targeting snapper off the northeast coast of the North Island (Snapper 1 programme), and bottom longline vessels targeting snapper and bluenose/matiri[163] off the northeast coast of the North Island (the black petrel programme).

5.5.3 POLICY CHANGES ARE UNDERWAY

INNOVATIVE TRAWL TECHNOLOGIES

In 2017, the Ministry for Primary Industries made changes to regulations for commercial trawlers to allow for trial and innovation in trawling techniques.[164] Trawling regulations contain prescriptive requirements on use and configuration of trawl nets, so the amendment allowed for approval of other innovation if evidence shows it performs at least as well as existing nets. So far the use of 'Precision Seafood Harvesting Modular System Trawl Net' has been approved for deepwater fisheries (May 2018) and North Island fisheries (April 2019) which has tested the regulatory system and highlighted how processes might be improved (6.3.4: case study: Precision Seafood Harvesting – Tiaki) notes some of the barriers to innovation that prescriptive regulations can have to innovation when they are predicated on existing technologies. There is a lot to be learnt from the experience of approving the Precision Seafood Harvester, with a key lesson that a permissive environment is required for gear innovation.

There is a lot to be learnt from the experience of approving the Precision Seafood Harvester, with a key lesson that a permissive environment is required for gear innovation.

These issues informed our recommendations in Themes 4 and 7.

LANDINGS AND DISCARDS

Most commercial fish are caught using bulk harvesting methods often resulting in many different species being caught together, while the QMS provides catch entitlements to fishers for individual species. This means fishers often catch species they are not targeting, resulting in unwanted fish. This is one of the fundamental challenges of fisheries management.

One size does not fit all as there is huge variation in the amount of bycatch according to the species targeted and the method. Pāua fishing is close to 100% selective (5.3.7: case study: Pāua fisheries and industry-led management), whereas scampi trawling is not very selective at all. While improvements in fishing practices are reducing the amount of unwanted fish being caught, there is scope for significant improvement (and resulting reduction in wastage and a higher value catch). Fisheries New Zealand consulted on proposals to improve the management of Aotearoa New Zealand's fisheries to ensure more efficient and sustainable commercial fishing in 2019. The consultation document noted that the current rules that set out what commercial fish must be

[163] *Hyperoglyphe antarctica.*

[164] NZ Government, 2017; Ministry for Primary Industries, 2017a.

landed and returned are complex, open to interpretation, difficult to comply with and monitor, and do not set adequate incentives. Proposed changes focus on simplifying and tightening the commercial rules relating to what fish is landed and what fish can, or must, be returned to the sea and aligning incentives to innovate to achieve best value from our fisheries.

CATCH LIMIT ADJUSTMENTS

There is work underway to allow more efficient adjustments to catch limits by streamlining and updating the decision-making processes. Currently Fisheries New Zealand has the capacity to adjust catch limits for around 30 to 40 stocks each year.[165] Other changes that require changes to regulation can take far longer. In 2019, catch limits were adjusted for 29 stocks. Where fish stocks are well understood, quicker responsiveness is important to respond to fish stock fluctuations and support sustainable fishing. Consultation was undertaken in 2019 proposing that harvest control rules be used to adjust catch limits, with benefits of greater responsiveness, certainty, and transparency. Harvest control rules are pre-agreed responses to a change in the health of a fish stock. When harvest control rules are in place they can also be more difficult to deviate from (for instance, if there is a lot of annual fluctuation in stock biomass) so they work best for more stable stocks that have robust and regular stock assessments. Management procedures (pre-agreed rules in response to monitoring from the fishery) have been used for many years as a key mechanism for responsive adjustments of catch limits in some fisheries, e.g. some rock lobster stocks.

Quicker responsiveness is important to respond to fish stock fluctuations and support sustainable fishing.

5.5.4 DATA TRANSFORMATION STRATEGY

Fisheries New Zealand collects and stores vast amounts of data related to fisheries and the marine environment. Better utilisation of this existing data – through alignment and integration of datasets – will strengthen fisheries management decision-making processes.

Fisheries New Zealand is in the process of implementing a data transformation strategy, building its capability and maximising benefits from the increased volume and diversity of fisheries data arising from new initiatives.

Beyond Fisheries New Zealand, there is a wealth of data related to the marine environment collected by other groups. Data from non-fisheries sources is crucial to provide independent validation of stock and ecosystem health – which is a key component of shifting towards EAFM.

However, historical data management methods have created a highly fragmented landscape that is resistant to integration (Brett *et al.*, 2020). The disparate nature of marine science related databases in Aotearoa New Zealand is a problem as it prohibits full utilisation of data to inform fisheries management and research. Successfully using information from a variety of sources requires a strategic approach and data standards. Stats NZ could be approached to support this work.

This section outlines who collects data on fisheries and the marine environment in Aotearoa New Zealand (not including Fisheries New Zealand), including a selection of existing databases. It describes issues of data storage, integration and accessibility that impede effective and powerful use of data collected.

This discussion underpins recommendations in Theme 5.

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[165] 29 stock assessments were undertaken in the October 2020 round. See consultation documents.

5.5.4.1 WHO COLLECTS DATA?

CENTRAL GOVERNMENT AGENCIES

Beyond Fisheries New Zealand, other government agencies hold data related to fisheries and the marine environment. This could be better integrated with the data captured and used by Fisheries New Zealand. Examples include the Department of Conservation, the Ministry for the Environment, and LINZ (the Marine GIS is of particular relevance). Multi-way sharing of this data between agencies would be mutually beneficial for different reporting requirements.

INDUSTRY

The seafood industry collects large amounts of data to inform their fishing practices, but this doesn't necessarily get used by fisheries managers to inform decisions. A prime example is seafloor mapping data. The fishing sector has undertaken seafloor mapping across much of Aotearoa New Zealand's territorial sea and EEZ to better understand the environments where they are fishing. This data could be collated and used as the basis to inform the needs of future mapping efforts to fill gaps (see section 3.3.3: Habitat). There are important privacy and anonymisation concerns, particularly around commercially sensitive information, that need to be worked through with industry. There is also work underway at FishServe to map out how existing modules within current and new electronic reporting systems could be integrated (see figure 89). Improving the culture of the sector and facilitating data sharing, aggregation and analysis offers huge advances through integration.

RESEARCH INSTITUTES

Research undertaken at universities and research institutes, and the knowledge housed within these places, may be relevant to fisheries management decisions. However, it is not always designed to feed into the decision-making process, as the motivations for the studies are not necessarily directly aligned with fisheries management needs, or the format required for the data to be useful to the regulator is not clear to researchers. In particular, there are lost opportunities to incorporate a wide range of research into stock assessments rather than just research commissioned for those assessments. Some research is known about but is not incorporated into decision making – fisheries managers could actively seek to include this data in the decision-making process.

Changing institutional and decision-making processes to enable data and evidence from these institutions to be incorporated into the assessed evidence would be a significant start in filling data and knowledge gaps but would also represent a significant culture shift in some institutions. Incorporating wider research on ecosystems and the environment will also be crucial to support the transition towards EAFM. Researchers proactively sharing relevant data and research with the regulator would assist these efforts and there needs to be a willingness on the part of the managers to access, uptake and work from this type of information.

LOCAL AND REGIONAL COUNCILS

Councils collect data to inform their coastal plans and marine spatial planning, including data on habitats (see section 3.3.3: Habitat). Two-way sharing of data between councils and Fisheries New Zealand would benefit both local and central management of the marine environment. For example, the Marlborough District Council has habitat maps from collaborative mapping of ecologically significant areas and multibeam surveys.

OTHER GROUPS

NGOs, community groups, recreational fishers, museums and others may collect and own relevant data that could feed into a marine science database.

5.5.4.2 FRAGMENTED DATA COLLECTION AND STORAGE

When data is held in multiple databases there are lost opportunities for combining and overlaying different datasets to identify patterns and trends. Table 12 below illustrates the fragmented nature of marine data in Aotearoa New Zealand, displaying a selection of the hundreds of databases that exist.

As explained above, there are many players in the marine data space, meaning that the best available knowledge on a particular issue is not necessarily held by the regulator. The more connected the research community is, the more different knowledge can be shared and considered in decision making.

Establishing and maintaining these connections can be achieved through multi-stakeholder and interagency networks. Well-developed networks can overcome fragmentation in the research community, and allow more proactive, flexible and collaborative approaches. Formalising collaboration can help to carve out a space for working through tensions around priorities and pace of work (see 3.3.5: case study: Managing land-based impacts through a multi-sector marine spatial plan and 4.4.4: case study: The Hawke's Bay Marine and Coastal Group took a collaborative approach to prioritise research needs for the region).

Information sharing requires a strong focus on privacy and guidelines around the release of data, but with this in place, data from a range of sources could be made more accessible to improve transparency and build trust.

Well-developed networks can overcome fragmentation in the research community, and allow more proactive, flexible and collaborative approaches.

Table 12: A selection of the many databases used to store fisheries and marine-related data.

Topic	Explanation
MPI & FNZ	E.g. National Aquatic Biodiversity Information System. MPI Geospatial Portal (Launched 2020), public access to data relating to the commercial fishing regulations. Coordinates FMAs, general statistical areas, QMAs, commercial fishing regulations (including closed seamount areas and Precision Seafood Harvesting 71(a) approvals), BPAs, fishery notices (including temporary closures that are not S186 closures), marine reserves Type 1, marine mammal sanctuary (one area closed for set netting), ministerial decisions, submarine cables and pipeline protection zones. Various databases managed by NIWA.
LINZ	EEZ, Topo50 Coastline, Te Kete Kerero a Te Takutai Moana, AusSeaBed, Petlab, LAWA, Ira Moana, New Zealand Petroleum Basin Explorer, E Tūhura – Explore Zealandia, LINZ Data Service.
Stats NZ	Data on a variety of marine indicators that underpin the environmental reporting series, including sea-level rise, marine economy, ocean acidification etc. See the Stats NZ website.
Department of Conservation	Marine geospatial data available via Department of Conservation geoportal. Have facilitated use of SeaSketch as a data collation, display and spatial planning tool.
FishServe	Commercial Fisheries Service (owned by Seafood NZ) – provides commercial fishing industry support and maintains registers required under the Fisheries Act 1996 (e.g. quota ownership, ACE ownership, vessel register).

Regional councils	e.g. Greater Wellington Regional Council, Hawke's Bay Regional Council national marine data inventory, Webportals.
MfE	Webportal, data service that host marine data commissioned or gathered for Environmental Reporting (and other datasets such as the MEC).
NIWA	Coastal and marine data portal (has non-fisheries marine data but also fisheries acoustic transects), NZ ocean data network (has non-fisheries marine data), and maintains the marine biosecurity data portal on behalf of MPI. NIWA-managed databases on behalf of Fisheries New Zealand that include data on trawls, acoustic, age, tag and conductivity, temperature and depth research databases, NIWA Centralised Observer Database (catch calculations and amounts for all species caught, details of fishing operations such as start and finish times, positions, fishing and bottom depths, devices and practices to protect non-targeted species, catch data for each tow or set).

5.5.4.3 ACCESSIBILITY OF DATASETS

While datasets held by Fisheries New Zealand are very valuable, there are calls to improve accessibility, which would facilitate greater analysis of this data (The Sustainable Future Institute, 2011; The Nature Conservancy, 2017; Ministry for the Environment and Stats NZ, 2019b).

While data access is not an issue for those directly involved in the regulatory process of fisheries management, this is not always the case for others, such as industry and researchers.

For example, commercial fisheries provide data to regulators. This data includes information on catch, bycatch, and location. However, once with the regulator this data is not automatically available to those who provided it. This means they lose the ability to run their own analytics to inform their management in timely manner.

Official Information Act (OIA) requests are sometimes needed to access data held by Fisheries New Zealand. This process does not foster trust or collaboration. From a user perspective it is slow and awkward, while from a government perspective it is time and resource intensive. Fisheries New Zealand commonly relies on email, webposting and data extraction and manual analysis to respond to questions or OIA requests. In many cases Fisheries New Zealand does not itself store the data, so responding to requests is difficult (Department of Conservation, 2019b). There are some examples of external parties having established data sharing agreements.[166]

Some databases are accessible through Dragonfly, i.e. for seabird, marine mammal and turtle bycatch and some other research. There is also limited data sharing through data.govt.nz and the Ministry for Primary Industries Open Data Portal.

Accessibility of datasets is further complicated by the fragmentation of data storage (discussed above), as well as the need to manage the sensitivity-levels of an extensive and complex range of data. Metadata on the data collection, processing and storage systems is diffuse. The regulator has principles for release of information, though these will likely need updating as the form of data changes as new technologies are used.

[166] Input from Fisheries New Zealand.

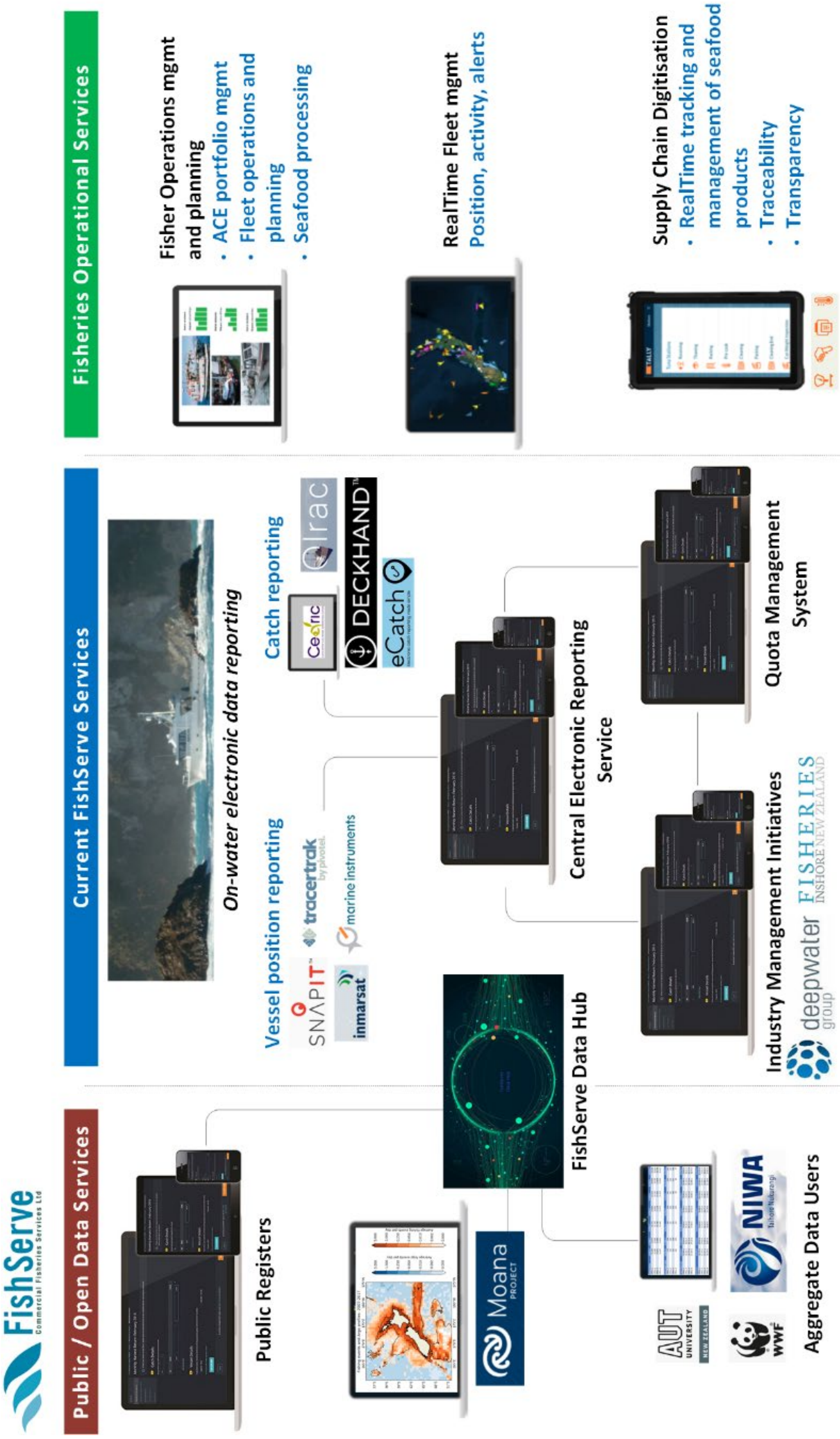

Figure 89: FishServe schematic of how current and new data systems could be integrated in Aotearoa New Zealand's fisheries management system to create a connected digital ecosystem.

5.5.5 TE MANA O TE TAIAO – AOTEAROA NEW ZEALAND BIODIVERSITY STRATEGY 2020

Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy Strategy 2020, sets out how Aotearoa New Zealand can expand and build on the strong foundation the country has already built, to "allow our natural world, and the people in it, to thrive".

The strategy (Department of Conservation, 2020) includes an objective to ensure that natural resources are managed sustainably, which includes a number of specific goals that are directly related to fisheries. Some of these are included in table 13 below, and form a valuable foundation for developing a strategic action plan for the ocean.

This features in recommendations in Theme 2 and 6.

Table 13: Tiaki me te whakahaumanu/protecting and restoring: Objective 12. Natural resources are managed sustainably.

2025 Goals	2030 Goals	2050 Goals
12.1.1 Environmental limits for the sustainable use of resources from marine ecosystems have been agreed on and are being implemented.	12.1.2 Marine fisheries are being managed within sustainable limits using an ecosystem-based approach.	2.1.3 Marine fisheries resources are abundant, resilient and managed sustainably to preserve ecosystem integrity.
12.2.1 The number of fishing-related deaths of protected marine species is decreasing towards zero for all species.	12.2.2 The direct effects of fishing do not threaten protected marine species populations or their recovery.	12.2.3 The mortality of non-target species from marine fisheries has been reduced to zero.
12.3.1 Environmental limits for the sustainable use of resources from freshwater ecosystems have been agreed on, and plans for the active management of fisheries have been developed with Treaty partners, whānau, hapū, iwi, Māori organisations and stakeholders.	12.3.2 Freshwater fisheries are being managed sustainably to ensure the health and integrity of freshwater species and ecosystems while retaining cultural and recreational values, including for valued introduced species.	2.3.3 Freshwater fisheries are not negatively affecting high priority biodiversity areas and threatened ecosystems and are under ongoing management in other places to maintain functioning ecosystems and cultural and recreational values, including for valued introduced species.
12.4.1 The potential for different sectors to contribute to improved Indigenous biodiversity is understood, and sustainable use practices that include benefits for Indigenous biodiversity are becoming more widespread.	12.4.2 Sustainable use practices that include benefits for Indigenous biodiversity are standard practice for biodiversity resource users (including tourism and recreation) and primary industry (including agriculture, forestry, fisheries, aquaculture and horticulture).	2.4.3 Sustainable use practices are providing benefits for Indigenous biodiversity and maintaining ongoing economic and wellbeing benefits for people.

5.6 INDUSTRY INITIATIVES

Some initiatives that Aotearoa New Zealand's fishing industry has taken to move towards fishing more sustainably are below. Innovations are discussed in more detail in part 6.

- **Changing how fisheries are managed without regulatory changes.** There are examples of times industry has proactively made a management change ahead of being directed to so by the regulator. For example:
    - Industry voluntarily lowered catch for certain species or stocks such as pāua (PauaMAC7, 2019), and have worked closely with the regulator on fisheries plans outlined in 5.3.7: case study: Pāua fisheries and industry-led management.
    - Fine-scale catch reporting in advance of regulatory requirements (e.g. CRA logbook programmes, PAU electronic data loggers, finfish catch spreading reporting).
    - Enhancement and translocation (PAU).
    - Area closures e.g. to protect spawning fish (e.g. PAU, finfish).
    - Increasing minimum harvest size (e.g. PAU).
    - Development and implementation of harvest control rules (CRA rules).
- **Gaining certification from sustainability schemes.** Sustainability schemes offer a way to benchmark fishing practices for a particular fishery against established standards,[167] resulting in accreditation or certification once met (discussed further in section 6.7.5.2: Sustainability schemes provide a way to benchmark and improve fishing practices). Aotearoa New Zealand's fishing industry engages with a number of schemes, including the MSC, Friend of the Sea, Ocean Wise, and Monterey Bay Aquarium Seafood Watch, as well as Sea Choice which works to improve the various labels. Aotearoa New Zealand has been a world leader in meeting MSC standards, with hoki becoming the first whitefish fishery to be certified in 2001 (though this is contentious, see 6.7.6: case study: The Marine Stewardship Council). Since then, eight species, which account for over half of the volume of Aotearoa New Zealand's wild-caught seafood, have been certified to the MSC Fishery Standard. This includes nearly three-quarters of deepwater fisheries.
- **Making fishing gear more sustainable.** Aotearoa New Zealand's fishing industry developed the Gear Innovations Pathway to drive innovation in this area (see 5.6.1: case study: Gear innovation pathway). There are several examples of industry partnering with researchers or driving innovation in gear technology themselves, some supported by this scheme, that are covered in section 6.3: How we fish.

Eight species, which account for over half of the volume of Aotearoa New Zealand's wild-caught seafood, have been certified to the MSC Fishery Standard. This includes nearly three-quarters of deep-water fisheries.

Figure 90: Skipjack tuna (*Katsuwonus pelamis*). Image credit: krw130lm/Wikimedia (CC BY-SA 3.0).

[167] This relies on an agreed definition of sustainability (and whether this applies to the environment or just a single stock).

5.6.1 CASE STUDY: GEAR INNOVATION PATHWAY

The Gear Innovation Pathway is a programme that has been developed by Fisheries Inshore New Zealand (FINZ) through a project with Seafood Innovations Ltd (SIL).

FINZ is an industry non-profit organisation established by fishers to advance their interests in inshore finfish, pelagic and tuna fisheries. Seafood Innovations Ltd is a research partnership owned by Seafood New Zealand Limited and Plant & Food Research.[168]

The programme is intended to facilitate a 'grass-roots' approach to gear innovation in inshore fishing in Aotearoa New Zealand. Innovation is wanted to reduce negative impacts, add value to products, and to increase productivity at either a regional or national scale (see section 6.3: How we fish).

The programme is intended to facilitate a 'grass-roots' approach to gear innovation in inshore fishing in Aotearoa New Zealand.

The project provides support, guidance and funding to innovation at all sizes, scopes and levels of development. This can allow smaller companies and fishers to access funding for their ideas where other funding may be difficult to source. Fishers are not required to self-fund the project as this is fully covered by Seafood Innovations Ltd and Fisheries New Zealand.

The project is not about developing a commercially viable product but aims to disseminate ideas and learnings from projects to the wider industry.

The research themes explored are:

- Vessel and gear efficiencies,
- Selectivity,
- Benthic impact, and
- Non-fish protected species interactions.

An example of a funding recipient is fishers Adam and Phil Clow, Department of Conservation seabird liaison officer Nigel Hollands and coastal engineer Peter Quilter, who are working together on a design for a hydraulic gear setting arm to reduce seabird bycatch in the bottom longline industry. The design would allow the bait to enter the water much closer to the stern of the vessel and push it two metres under the surface. The aim is to prevent seabirds from having an opportunity to dive onto baited hooks thereby reducing bycatch. The funding allows the design to be developed and installed on a fishing vessel.

[168] Note funding of Seafood Innovations Ltd by MBIE ceased in July 2020.

5.7 IWI INITIATIVES

Iwi and hapū have comprehensive mātauranga about their local marine environment, a responsibility to manage the oceans as kaitiaki, and a significant stake in the commercial fishing sector. Some iwi-owned commercial fishing companies are involved in the initiatives outlined in section 5.6: Industry initiatives. There are a number of additional ways that iwi and hapū drive change and strive for improvement in the marine space. Here we highlight some initiatives that are underway to illustrate the breadth of this involvement, noting this list is not exhaustive.

Figure 91: Iwi are involved in the Moana Project. Image credit: MetOcean Solutions.

Marine management

As discussed in section 2.7.1: Te ao Māori, Māori have a range of approaches for marine management. Examples of initiatives that iwi have taken to manage or protect their rohe moana include:

- Ngāti Konohi established the Te Tapuwae o Rongokako Marine Reserve in 1999 in partnership with the Department of Conservation, following 10 years of discussions. The reserve is adjacent to a mātaitai reserve.
- Hapū of Motiti were involved in the efforts that led to the Motiti Protection Areas via the Motiti Rohe Moana Trust (discussed in detail in case study 4.4.3).
- Te Tau Ihu Iwi Fisheries Forum help iwi develop plans that identify the customary, commercial, recreational and environmental objectives for fisheries of importance to that iwi.

Multi-stakeholder groups and planning processes

Several iwi and hapū have been key members in collaborative processes that have sought to improve the conditions of their rohe moana. Some examples are covered in the case studies as follows:

- Ngāti Kahungunu, Ngāti Kere and Ngāti Pāhauwere were part of the *Hawke's Bay Marine and Coastal group Research Roadmap* process (profiled in case study 4.4.4).
- Iwi of Hauraki and Tāmaki Makaurau were part of the *Sea Change – Tai Timu Tai Pari* (Hauraki Gulf Marine Spatial Plan, described in case study 3.3.5).
- Te Rūnanga o Ngāi Tahu are part of Te Korowai o te tai ō Marokura in Kaikōura, representing its community and business interests (described in case study 4.4.2).

Research

A number of iwi are involved in research projects in the marine environment that impact upon fisheries, drawing on mātauranga, and in some cases integrating this knowledge system with western science.

- Ngāti Kuri have partnered with Tāmaki Paenga Hira Auckland Museum, the University of Auckland, Massey University, NIWA and Manaaki Whenua on a five-year research programme starting in 2020 working on holistic approach to transform ecosystem wellbeing, Te mana o Rangitāhua.
- Whakatōhea are involved in the Moana Project which aims to better understand ocean dynamics (profiled in case study 6.2.3).
- Te Ahu o Rehua: A Network for Cross Cultural Ocean Knowledge.

5.8 RESEARCH PROGRAMMES, FUNDING AND PRIORITISATION

Aotearoa New Zealand has an active research community in the areas of fisheries and the broader marine environment. Research programmes range from government monitoring to multi-year collaborative national science challenges through to clinical trials for pharmaceutical products from fish by-products. There are many active researchers and research projects delivering within a cluttered landscape of institutional structures and funding schemes. The pathway to impact is not aided by the complexity of the research landscape.

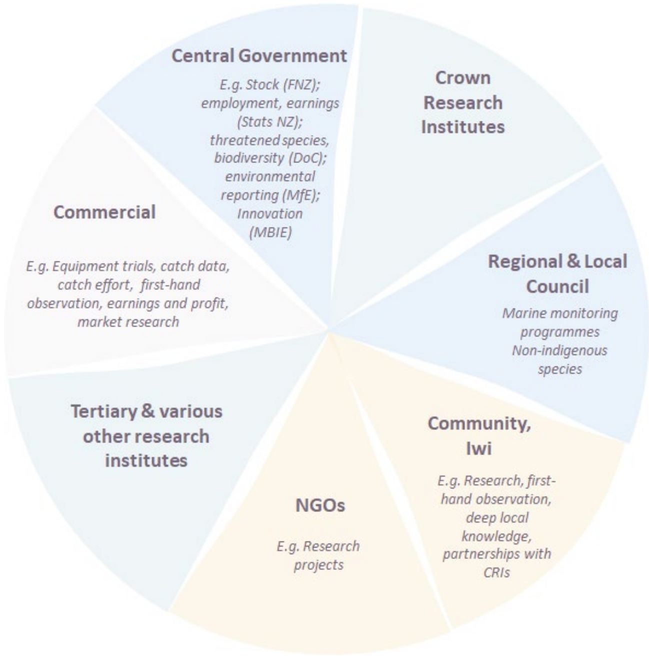

Figure 92: The range of groups involved in Aotearoa New Zealand's fisheries and marine research.

Fisheries and marine research is undertaken for a range of different reasons. The research on fisheries in Aotearoa New Zealand spans areas such as:

- Operational research to inform fisheries management.
- Innovative and translational research to improve processes.
- Basic research to understand the biology of our fisheries.
- Conservation approaches for species and habitats.

Biodiversity and ecosystem function research tends to be studied outside of fisheries research.

The pathway to impact is not aided by the complexity of the research landscape.

Funding opportunities for these different areas of research tend to remain separate (see table 14). The majority of research undertaken by Fisheries New Zealand is focused on supporting stock assessments of high-value commercial species, partly funded through industry levies to cost recover research. Projects that are important to fisheries management but not directly related to high commercial value fisheries, such as research to understand species biology, ecosystem impacts or species protection, are less likely to be funded through current fisheries-specific funding mechanisms and in many cases have to rely on general contestable research funds, which sometimes do not view such strategic research as appropriate for their fund. Some projects are otherwise reliant on research undertaken or commissioned by other agencies' levied funding (such as the Department of Conservation's Conservation Services Programme). This has meant that gaps in knowledge for many species remain.

The majority of research undertaken by Fisheries New Zealand is focused on research that supports stock assessments of high-value commercial species funded through industry levies to cost recover research.

Since 1994, Fisheries New Zealand has recovered costs from the commercial fishing sector for a range of activities, e.g. monitoring and managing commercial fisheries, including fisheries research; observer, registry, and conservation services; and compliance (Harte, 2007). Cost recovery is a regulated requirement and reflects that quota owners are either beneficiaries of the research services, i.e. the science underpins their quota levels, or their activities exacerbate risk, i.e. we need to undertake this research because of the risks caused by fishing. Over the last few years, around 60% of Fisheries New Zealand's research budget has been cost-recovered.[169] Though cost recovery aims to recover cost for research for all commercially exploited stocks (Aranda and Christensen, 2009), it does not currently achieve this. A consequence of how the cost recovery system functions is that limited, high-value species have been prioritised for scientific research. Concerns that the research agenda would be dominated by industry voices were raised prior to implementation (Harte, 2007) and remain.

Between 2017 and 2020, Fisheries New Zealand spent on average $22 million per year on fisheries research, with approximately 80% spent specifically on research to determine the health of fish stocks and sustainable catch levels.[170] Research into the effects of fishing on the marine environment and biodiversity research expenditure has grown from near zero in 1999 to around 20% of the current budget. This has occurred as the need for research to address key unknowns or uncertainties important to fisheries management were realised, e.g. population sizes of commonly caught seabirds. However, there remains a need for much more research to fill data and knowledge gaps in these areas.

There have been efforts to develop a research strategy – such as the National Marine Research Strategy – which is being drafted by the Ministry for Primary Industries on behalf of the Natural Resources Sector. The National Marine Research Strategy "has a shared vision of the marine research required in Aotearoa New Zealand over the next 20 years to guide and inform the development of Aotearoa New Zealand's marine economy, safeguard the marine environment for future generations, and co-ordinate marine research effort across the country as we increasingly look to the sea for food, energy, minerals, and other resources."

This feeds into our recommendations in Theme 7.

Research and innovation could go in many different directions, but limited funding and resources mean that prioritising and allocating funding to the most pressing issues is important. Within a low-trust sector with multiple competing interests, these priorities are highly contested. The ocean sector would benefit from coordinating research that improves environmental or sustainability outcomes and fills critical knowledge gaps about species, with research that promises short-term economic benefits, when prioritising scarce funding.

Limited funding and resources mean that prioritising and allocating funding to the most pressing issues is important. Within a low-trust sector with multiple competing interests these priorities are highly contested.

There have been successful funding initiatives where government and industry have come together to fund innovative projects on a large scale (see 6.3.4: case study: Precision Seafood Harvesting – Tiaki). Success has also been achieved on a smaller scale, through Seafood Innovations Ltd (SIL). The research partnership, established under the Ministry of Business, Employment and Innovations' now discontinued partnership funding scheme, is owned by Seafood New Zealand and Plant & Food Research. SIL's mission is to:

- Promote industry-initiated research and development projects primarily aimed at:
    - Increasing the value of existing harvests,

[169] Input from Fisheries New Zealand.
[170] Input from Fisheries New Zealand.

    - Reducing harvesting and processing costs, and
    - Enhancing consumer-driven product attributes.
- Be responsive to the dynamic nature of the seafood industry and adapt its research and development resources to such changes, provided that all seafood industry sectors shall remain eligible for research project funding at all times.

The partnership offers support to companies to develop proposals for funding, and has particular interest in novel ideas and projects with a higher degree of risk (and correspondingly higher potential reward). This is key to inspiring and nurturing real innovation in the industry. Funding is up to 50% of the contribution made by the company or project sponsor. A number of projects supported by SIL are highlighted throughout this report. There has reportedly been a massive jump in industry-initiated and sustainability-focused SIL projects in the last two to three years.[171] However, there is currently no further funding going towards this partnership, with only current projects continuing until development. The programme is seen as particularly valuable to an industry that operates in such a high-cost research environment.

Research institutes also have significant work programmes underway (see 5.8.1: case study: Sustainable Seas/Ko ngā moana whakauka). There is an opportunity to strengthen the relationship between these groups and expand funding opportunities for collaboration so that researchers can be more in tune to the needs and goals of fisheries management and help to fuel innovation and productivity through their research. An example of a collaborative project that demonstrates an academic-industry partnership in fisheries is outlined in the case study of potting as an alternative to bottom trawling on a small scale (see case study 6.3.10).

The need for a strategic approach to science prioritisation and collection underpins recommendations in Theme 7.

[171] Input from Seafood Innovations Ltd.

Table 14: Summary of key research funds in Aotearoa New Zealand that may fund fisheries or marine research.

Fund	Agency	Amount/info	Notes
Sustainable Food and Fibre Futures programme (SFFF)	MPI	$40 million/year across whole primary sector offering grants of up to $100,000 or large partnership projects of more than $5 million.	SFFF aims to deliver long-term environmental, social, economic and cultural outcomes.
Primary Growth Partnership (PGP, replaced by the SFFF but some projects still underway)	MPI	Varies – e.g. for Precision Seafood Harvesting – Tiaki project the PGP matched Industry funding of $24 million (see case study 6.3.4).	Not fisheries-specific – for whole primary sector Prioritises potential economic benefits to NZ.
Strategic Science Investment Fund (SSIF) – Marine Environment Platform	MBIE	$16.9 million per year for the marine environment platform (NIWA); a portion of Plant & Food Research's $42.7 million investment goes towards seafood research; $2 million per year to Cawthron's seafood safety platform.	SSIF not fisheries-specific but has dedicated funding to marine research.
Customary Fisheries Research Fund	MPI/FNZ	$180,000/year.	Targeted to support fisheries research to help Māori to manage their customary fisheries.
Fisheries Science Research	MPI/FNZ	~$22 million.	Funded by the Crown or through industry levies.
Seafood Innovations Ltd	Seafood NZ, Plant & Food Research, MBIE	Suggest budgets in range of $50,000 to $500,000 per annum. Funds up to 50% of project.	Not accepting proposals for funding at this time (check website for updates). Further details below.
Sustainable Seas National Science Challenge	MBIE	Up to $71.1 million over 10 years (since 2014). Includes innovation fund ($2 million for 2020).	See case study 5.8.1: Sustainable Seas/Ko ngā moana whakauka.
Gear Innovation Pathway	FINZ/SIL	No co-funding required.	See case study 5.6.1: Gear Innovation Pathway.
Non-fisheries-specific contestable research funds (e.g. Marsden, Endeavour)	MBIE/Royal Society Te Apārangi		Not fisheries-specific.
Conservation Services Programme	Department of Conservation	~$2 million in 2019/2020.	Monitors impact of commercial fishing on protected species, studies species populations and looks at ways to mitigate bycatch.
EnviroLink	MBIE/Regional councils	$1.6 million annually.	Funds research organisations to provide regional councils with advice and support on environmental topics.

5.8.1 CASE STUDY: SUSTAINABLE SEAS/KO NGĀ MOANA WHAKAUKA

The need for long-term strategically focused research funding in the marine environment was recognised when Sustainable Seas was established as one of the 11 National Science Challenges.

Sustainable Seas is a 10-year research program (2014-2024) that brings together around 250 biophysical scientists, economists, social scientists, and experts in mātauranga Māori and policy from across Aotearoa New Zealand. It has 52 active/completed projects, and around 15 more in development and a number of business-focused Innovation Fund projects. The vision is "for Aotearoa New Zealand to have healthy marine ecosystems that provide value for all New Zealanders".

There are many and growing competing uses of Aotearoa New Zealand's marine environment. Sustainable Seas' research addresses the question, "How can we best develop our marine economy, while protecting the taonga of our marine environment?" by focusing on:

1. Improving marine resource decision making and the health of our seas through holistic ecosystem-based management (EBM).[172]
2. Transforming Aotearoa New Zealand's ability to enhance our marine economy into a blue economy.

There are six research themes. Projects within these core research themes have been or are being co-developed with stakeholders and Māori partners.

- **Tangaroa.** Research that centres and is led by Māori, to explore the development of EBM that is founded on and informed by mātauranga and tikanga Māori.
- **Degradation and recovery.** Investigating ways to assess the effects of human activities and natural events on marine ecosystems, and the potential for recovery.
- **Blue economy.** Investigating opportunities for marine activities that create economic value and contribute positively to social, cultural and ecological well-being in Aotearoa New Zealand.
- **Risk and uncertainty.** Addressing how to improve decision making by investigating people's perceptions of risk and uncertainty, and the best ways to communicate them.
- **Enhancing EBM practices.** Investigating how practice, policy, regulation and legislation can be tailored to support EBM for Aotearoa New Zealand.
- **EBM in action.** Working with stakeholders and Māori partners to undertake real-world trials of the EBM knowledge and tools our research is generating.

Sustainable Seas has developed – with input from stakeholders and Māori partners – a definition of and principles for EBM for Aotearoa.

Sustainable Seas has recognised the importance of bringing in the very many stakeholders in the marine environment. Engagement with, and participation from, all sectors of society is critical to Sustainable Seas' success. The fraught relationships within the marine realm make this very challenging. The Challenge is working with Government (central, regional and local), businesses, Māori partners and communities to identify and develop the tools needed to enable EBM and a blue economy. Opportunities to work more closely with the fisheries industry would strengthen its potential to address the sector's biggest challenges.

This research programme has been an important start to address the need for long-term, strategic, collaborative and integrated approach to research in the marine environment, including fisheries. There is significant room to build upon this work, undertaken with significant co-funding, to fill the knowledge gaps about our marine environment and support more sustainable uses of this resource into the future.

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[172] For a discussion on the difference between EAFM and EBM see section 1.8: Some key technical terms and how we use them.

5.9 WE NEED A PLAN FOR OUR OCEANS

Our ocean will benefit greatly from a shared plan, refined regulatory tools and a permissive research environment. As discussed in section 3.4: Data and knowledge gaps, there are many stressors on our marine ecosystems and these complex problems require multifaceted and informed management responses. Here we reflect on some of the key issues and highlight avenues for improved processes and outcomes. While beyond the scope of science advice per se, this discussion informs our overarching recommendations on the system changes that are required to enable science to make a difference.

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WE NEED A SHARED VISION AND GOALS FOR THE OCEAN

Our specific recommendations can make a difference in the short term. However, a long-term approach is needed to ensure the health of our ocean endures. Collectively agreeing on shared aspirations and agreeing a path to reach these shared goals will be critical to achieve this. The large and diverse range of stakeholders from central and local government, iwi, large commercial fishing companies, smaller companies or independent fishers, recreational fishers, community groups and researchers all have a role to play (see figure 1).[173]

Even within central government, there are a range of relevant agencies who regulate the marine environment (see appendix 6).[174] Different stakeholders have divergent and often conflicting priorities. Cohesive oversight of all marine activities is required to facilitate the necessary multi-party conversations, improve the culture, and build trust.

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This underpins Theme 1 of the recommendations.

AN OVERARCHING STRATEGY IS NEEDED

The complexity of the regulation and management of fisheries, and the variable implementation of management plans, has led to some people having limited trust in the regulatory system - although key decisions are made publicly (Lundquist *et al.*, 2016).[175] A clear, overarching and transparent strategic action plan would be beneficial to guide long-term planning and action in the marine domain, making the environmental bottom line clear and setting our aspirations for the marine environment. The need to provide certainty to tangata whenua and other stakeholders around fisheries management was recognised as important during the development of the Fisheries 2030[176] Strategy released in 2009 and is still referred to occasionally (e.g. it is mentioned in AEBAR 2020), but does not appear to be widely referenced (e.g. not referred in recent fisheries plans and consultations) and is not readily available through the Fisheries New Zealand website.[177] The 2009 Fisheries 2030 Strategy

[173] Note that in the inshore fisheries, recreational fishers also represent a significant stakeholder. Recreational fishing is out of scope of this report but should be acknowledged as another challenge in developing a shared vision and goals.
[174] Some government organisations do already work together through the Marine Hub (a policy development and advice group).
[175] For example, see The Decision letter – Minister of Fisheries and Review of Sustainability Measures for selected stocks for 1 October 2020: Final advice paper.
[176] See report by PricewaterhouseCoopers and Ministy of Fisheries branded report.
[177] See Te Ohu Kaimoana comment that Fisheries 2030 seems to have been discarded.

followed a number of previous attempts to establish an Oceans Policy in Aotearoa New Zealand which began some useful thinking (see appendix 11).

As part of Fisheries 2030, fisheries plans are described as an integral component of the wider strategic context. They are key for increasing transparency and putting into action longer-term strategy. Fisheries plans are provided under section 11(a) of the Fisheries Act 1996 (and are approved by the Minister) and can apply to a stock, multiple stocks, fishing years, or areas, or any combination of these. The provision gives flexibility for the regulator to provide a rapid and highly customised response to emerging issues. However, there appears to have been a lack of consistent use and update of fisheries plans. For example, the deepwater and middle-depth fisheries plan from 2010 was to provide an overarching framework for management of deepwater fisheries for a five-year period (Ministry of Fisheries, 2010), though was not formally updated until 2019. In the inshore fisheries, a plan was developed in 2011 and reportedly trialled but never finalised (i.e. never approved by the Minister). Consultation on a new inshore fisheries plan was underway in 2020, but does not include shellfish. The extent to which finalised (or un-finalised) fisheries plans actually inform fisheries management and are implemented is unclear, particularly in a medium-to-long term view. This erodes trust.

… there appears to have been a lack of consistent use and update of fisheries plans.

A clear integrative framework to coordinate and implement more specific localised plans would better enable stakeholders to develop and implement their own fisheries plans (subject to approval by the Minister). While development and approval of a fisheries plan has been achieved by the pāua industry (see 5.3.7: case study: Pāua fisheries and industry-led management), the processes to enable future initiatives could be streamlined (Te Ohu Kaimoana, 2020b).

More integration and oversight would also enable a conversation to harmonise definitions across stakeholders and legislation. For example, there is currently no agreed definition of sustainability.

… there is currently no agreed definition of sustainability.

Our legislative environment has advantages in providing multiple tools that can be used in management (e.g. from taiāpure at a local level to national regulatory changes) which is critical to manage a complex biological system at the appropriate management scale. However, overarching policy to drive how and when these tools are used might reduce future conflict. The recent *Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020* provides an example of a national strategy, developed through local collaborative process led by the Department of Conservation.

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In the Aotearoa New Zealand context, the basis for what an overarching strategy or plan for the oceans would look like has already been developed through legislation and policy statements, including the RMA, EEZ Act, Marine and Coastal Area (Takutai Moana) Act 2011, *New Zealand Coastal Policy Statement*, *Te Mana o Te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020*, and the Ministry of the Environment's environmental goals published in 2015 (Scott, 2016). Future work could build on these foundations.

A key limitation of taking a collaborative, multi-stakeholder approach to region-specific management is that progress can be slow, despite action sometimes being urgent. However, there are many provisions with the current Fisheries Act 1996 that could be better used to enact immediate change, in parallel with the broader conversation (see section 2.6: We can build on the QMS to improve sustainability).

Overall, a strategic action plan that provides a clear framework for annual reporting, decision making, future planning and lead agency responsibility could be used to coordinate all efforts in this space and guide collaborative, localised plans. This could improve the clarity, transparency and future focus of Aotearoa New Zealand's fisheries management system.

This discussion underpins Themes 1, 2 and 3 of the recommendations.

REFINING OUR MANAGEMENT TOOLS AND INCREASING TRANSPARENCY

Globally, there has been a widespread decline in the populations of fish we catch that has largely been driven by fishing (Palomares *et al.*, 2020) (see discussion in section 5.3.1: Known impacts of fishing on the sustainability of target stocks). Research indicates that fisheries recovery would ultimately increase fisheries biomass, profits and food security (Costello *et al.*, 2016). From data on stocks that are scientifically assessed in Aotearoa New Zealand, stock levels have generally trended up since the 1980s (though there are exceptions by individual stock). Inshore fisheries had been heavily depleted in the decades preceding introduction of the QMS in 1986, so the baseline from which improvements have been made is an important contextual factor. Estimates of original biomass will always be contested, but new scientific techniques may enable more refined estimates.

During this project, we heard calls for increased transparency around the stock assessment process and how decisions are made. Given the limited data for a significant number of fished stocks, and the lack of assessment for even more, it is crucial that how allowable catch is decided is clear. Providing accessible information around the assumptions made and knowledge gaps during decision making may drive the necessary research to enable better informed stock assessments, to ensure stocks are being fished at a sustainable level. Detail on this process is discussed further in section 3.4: Data and knowledge gaps, and section 5.5: Regulator initiatives and data transformation.

Regulations and management decisions can also play a role in facilitating innovation and bringing good ideas to the fore so that they can be implemented as best practice across the industry. High-level clarity around regulatory direction will provide reassurance to industry (McClurg, 2002).

> Providing accessible information around the assumptions made and knowledge gaps during decision making may drive the necessary research to enable better informed stock assessments to ensure stocks are being fished at a sustainable level.

In Aotearoa New Zealand, the plenary reports summarise the information held and used in stock assessments (Fisheries New Zealand, 2019b, 2019c, 2019a, 2020d). However, as reported in *Our Marine Environment 2019* (Ministry for the Environment and Stats NZ, 2019a), half of our stocks have too little information to be scientifically assessed. These are mostly minor fished species, but represent around one third of the catch volume in 2019. In addition to this, there are almost 300 'nominal' stocks that are not evaluated (see figure 56 and figure 57). While many of these stocks are 'nominal' as they are not generally found in a given QMA, others may be nominal due to low economic value or commercial potential. These stocks may still have high ecological importance, in which case impacts of overfishing these species could be highly significant (including to customary and recreational fishing). The magnitude of this issue is not clear from the data available but warrants further attention. At a high level, it is clear from these figures that there are significant improvements that could be made to increase the proportion of stocks that are scientifically assessed.

… half of our stocks have too little information to be scientifically assessed. These are mostly minor fished species, but represent around one third of the catch volume in 2019.

Despite the challenges, there are many opportunities to increase data, synthesise what we know, improve knowledge that could strengthen more reliable assessment of stocks, and make these assessments and their uncertainties more widely accessible. There is a wealth of data for both single-species assessment and ecosystem monitoring that could be more routinely used for stock assessment. Reportedly, useful data that could be used in stock assessments is not accessed because it sits outside of the formal research system that feeds into these assessments. While researchers who sit outside of the formal system are reportedly frequently invited to Science Working Group meetings and may also present at these, there seems to be a disconnect in how inclusive participants perceive this process to be.

… there are many opportunities to increase data, synthesise what we know, improve knowledge that could strengthen more reliable assessment of stocks, and make these assessments and their uncertainties more widely accessible.

Data that may not feed into stock assessments includes research on fisheries impacts on benthic food webs (van der Reis *et al.*, 2018), the role of fishers in the spread of disease in fisheries (Zha, 2018), catchability and abundance (Kane, 2015), and how overfishing has led to major ecological shifts in coastal ecosystems (Shears and Babcock, 2003b; Shears and Thomas, 2014a). Data on observations of non-Indigenous species is held in tertiary institutes, as well as other technological institutes, regional councils, and other research organisations (Seaward and Inglis, 2018). This data is valuable at a national management level, so a system that allowed it to be shared between organisations would add value (see section 6.2.2: Data-driven knowledge is the cornerstone of effective and sustainable fisheries management). When considering data held by regional councils there are also issues of scale in terms of the data (given they are generally confined to smaller boundaries than used in the QMS).

There can be disagreement between conclusions reached by the regulator compared to research undertaken by other researchers, given the data available to each differs (as demonstrated in 5.3.5: case study: Mixed messages: Are we overfishing our rock lobsters?). With different methods, models and assumptions used, and high uncertainties, estimates will differ. Where the regulator has less information about a stock or species, consideration of fisheries-independent research would be particularly valuable.

Fisheries New Zealand acknowledges this is an issue and is working to make information more accessible (e.g. by including summary tables at the end and start of chapters of the comprehensive Fisheries Assessment Plenary documents and the AEBAR reports and developing webpages) but this work in in its early stages.[178]

With different methods, models and assumptions used, and high uncertainties, estimates will differ. Where the regulator has less information about a stock or species, consideration of fisheries-independent research would be particularly valuable.

This underpins Themes 4 and 5 of the recommendations.

[178] Input from Fisheries New Zealand.

MOVING TOWARDS AN EAFM

As discussed in section 2.6: We can build on the QMS to improve sustainability, the current fisheries management regime has mechanisms that can enable an ecosystem approach and some aspects have already been incorporated.

This view is also reflected in a report commissioned by Seafood New Zealand which explores whether our legislation enables an EAFM (Fathom, 2019 - see also appendix 6 and footnote 23). The research found that "there are no situations in which the Act does not require or enable a management approach that is consistent with the identified principles of EAFM" – in other words, there is nothing in the Act that prevents a shift towards EAFM (see appendix 1: EAFM principles and relevant Fisheries Act 1996 provisions).

The report also notes that "the existence of legislative provisions that require or enable EAFM does not indicate the extent to which our fisheries management processes, policies and decisions reflect EAFM in practice – either generically or on a fishery by fishery basis". Much could be achieved in the short term by implementing the provisions already in the Act. See 5.3.7: case study: Pāua fisheries and industry-led management for an example of an ecosystem approach that is already being applied.

"The existence of legislative provisions that require or enable EAFM does not indicate the extent to which our fisheries management processes, policies and decisions reflect EAFM in practice – either generically or on a fishery by fishery basis". Much could be achieved in the short term by implementing the provisions already in the Act.

There are many opportunities to increase our use of EAFM within the confines of the Fisheries Act 1996. For example, the operationalisation of HPSFM (as discussed in section 4.2.1.3), research prioritisation (as discussed below), the need for ecological indicators (see section 3.3.7.3), alignment with overarching strategy (as discussed above), and through implementation of other recommendations and considerations as described in some detail in the Fathom report (Fathom, 2019). Ultimately, an EAFM must focus on objectives, not only on the use of specific tools, and can be accelerated within the confines of the current legal frameworks. Several sections of the Act could be applied in addition to Section 9(c): for example, Section 9 more widely covers environmental principles, section 11 covers sustainability measures, and Section 15 covers fishing-related mortality of marine mammals and other wildlife.

An EAFM can be accelerated within the confines of Fisheries Act.

This underpins recommendations in Theme 6.

BETTER INTEGRATION AND COLLABORATION IS NEEDED TO GET THE MOST OUT OF OUR RESEARCH INVESTMENT

Science could be used much more efficiently to address the challenges facing our oceans and fisheries within a more integrated system. Aligning research objectives more closely with the needs of industry and fisheries managers is an important step in this improved use of science, and could be established during the process of developing a shared plan.

Science could be much more efficiently used to address the challenges of the oceans within a more integrated system.

A more integrated approach to research and innovation in the marine domain is needed to fill existing knowledge gaps and enable innovation to thrive, which in turn will support more sustainable fishing. Stronger relationships between research programmes across disciplines, the regulator, and industry would enable strategic priorities to be more clearly identified to support both fisheries management and conservation goals. It is also important that people outside the research sector, including fishers, have clear pathways to bring their significant knowledge, experience and ideas to address the complex challenges faced in the marine environment.

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Better facilitation of interactions between fishers, particularly those from smaller companies with local knowledge of the ecosystems in which they fish, and organisations undertaking research and development, will ground ideas in local contexts. For example, many questions about the basic biology of commercial species remain unanswered, and yet would strengthen an EAFM.

An overarching Oceans Strategic Action Plan would provide a framework in which to prioritise knowledge gaps to be filled and new technology to be pursued when updating research plans. Currently, most fisheries research services are generally negotiated as annual. This approach does not necessarily incentivise long-term investment by research providers to invest in assets and staff. Clarity on what is funded by the industry and what is funded by government would enable more constructive relationships between different aspects of the marine research sector. Clear prioritisation of research questions to be answered, and technology to be explored, can both inform and be informed by an Oceans Strategic Action Plan.

This underpins Theme 2 and 7 of the recommendations.

PART 6:
A FUTURE FOCUS: SCIENCE, TECHNOLOGY AND INNOVATION

Image credit: Gravity Fishing.

6.1 STRUCTURE OF PART 6

Over the past three decades, Aotearoa New Zealand's fisheries management system has evolved somewhat to support more sustainable fishing and reduce some of the adverse effects of fishing. Data and science has helped to shine a light on parts of our fisheries to inform these improvements. However, our knowledge of ocean dynamics and ecosystems and how these influence our fish stocks remains poor. Without this knowledge, we will remain largely in the dark about what, where, when and how we can fish in order for the fishing to be sustainable.

With such a complex and inaccessible system as the ocean, action cannot wait for the perfect dataset, which is why we have recommended changes to the regulatory framework and the research system suggested in part 5. In parallel, science and technological innovation will enable improvements in the sustainability of our commercial fishing sector on a longer timeframe. Innovation is not yet part of the Aotearoa New Zealand global fisheries brand, but it could be. There are many innovative ideas and scientific solutions to help address sustainability issues in the commercial fishing sector – some old and some new. In a challenging environment characterised by poor information, high infrastructure costs, and divergent and sometimes conflicting priorities, these ideas face many barriers to implementation. A policy and regulatory environment in which innovation can thrive and information can rapidly feed into more responsive management decisions on shorter timescales will be fundamental to achieving better outcomes for our fisheries and the marine environment more broadly in the long term.

There are many innovative ideas and scientific solutions to help address sustainability issues in the commercial fishing sector – some old and some new. In a challenging environment characterised by poor information, high infrastructure costs, and divergent and sometimes conflicting priorities, these ideas face many barriers to implementation.

The marine environment faces significant challenges in 2020 – it is under considerable stress from fishing, sedimentation, climate change, pollution and more (as discussed in part 3). These challenges cannot be solved with science alone. A systems change is required that brings together a raft of solutions, some scientific but many relating to a culture change to improve relationships within, and management of, the marine environment. Despite science not providing all of the short-term answers, the application of a raft of scientific innovations may collectively provide improvements in the health of our fisheries and the marine environment. In this part of the report we focus on the tools that may help to achieve these desired improved outcomes. Some of these tools have been available for some time, but not widely adopted. Others are new and not yet ready for implementation. All have something to offer a vision of future fisheries management if prioritised within an overarching strategy for the ocean.

Drawing on the experience of our panel, we highlight select examples that could shift how we fish commercially to reduce the stress it causes within the marine environment. We recognise that research and innovation relating to fisheries and the marine environment is expensive – the feasibility and prioritisation regarding implementation falls beyond this report. Not all of these ideas are will be implemented at scale by 2040, but we take a deliberate future focus to highlight a raft of changes that could improve and better inform:

- How we respond to changing fisheries.
- How we fish.
- How much we fish.
- Where and when we fish.
- How we ensure a healthy ocean.
- Using the whole fish to develop high-value by-products.

6.2 HOW WE RESPOND TO CHANGING FISHERIES

A big challenge associated with making commercial fishing more sustainable is managing fisheries that are ever-changing. Both the regulator and industry need extensive data and information about fisheries changes to inform faster and more effective decision making.

Some biological variations that occur are known and expected, while others are not. Variations in stock numbers may be evident through fluctuations in recruitment that occur years to decades apart, but the phenomena that causes the fluctuation may remain unknown. An example is hoki (Francis *et al.*, 2006; Bradford-Grieve and Livingston, 2011) where western science has not explained a phenomenon acknowledged through mātauranga Māori.[179] Recognising biological variations in the natural world is essential to accommodate them in fisheries strategies and management and further basic research in this area would be beneficial.

Climate change, ocean acidity, marine heatwaves and other anthropogenic stressors amplify the need to be able to respond to changing fisheries. As discussed in section 3.1.1: Climate change is a huge threat to our oceans, climate change will drive many changes across fisheries by both disrupting ecosystems and moving species into different regions in response to changing temperatures and ocean circulation. Though a changing climate is already upon us, far more significant changes are expected to come. The climate changes to date have already highlighted the need for greater data collection and analysis to feed into more rapid and responsive decision making. The management system will need to be able to urgently respond to challenges such as shifting stocks, disrupted food webs, changes in fish productivity and recruitment patterns, and ocean acidification.

Climate changes to date have already highlighted the need for greater data collection and analysis to feed into more rapid and responsive decision making.

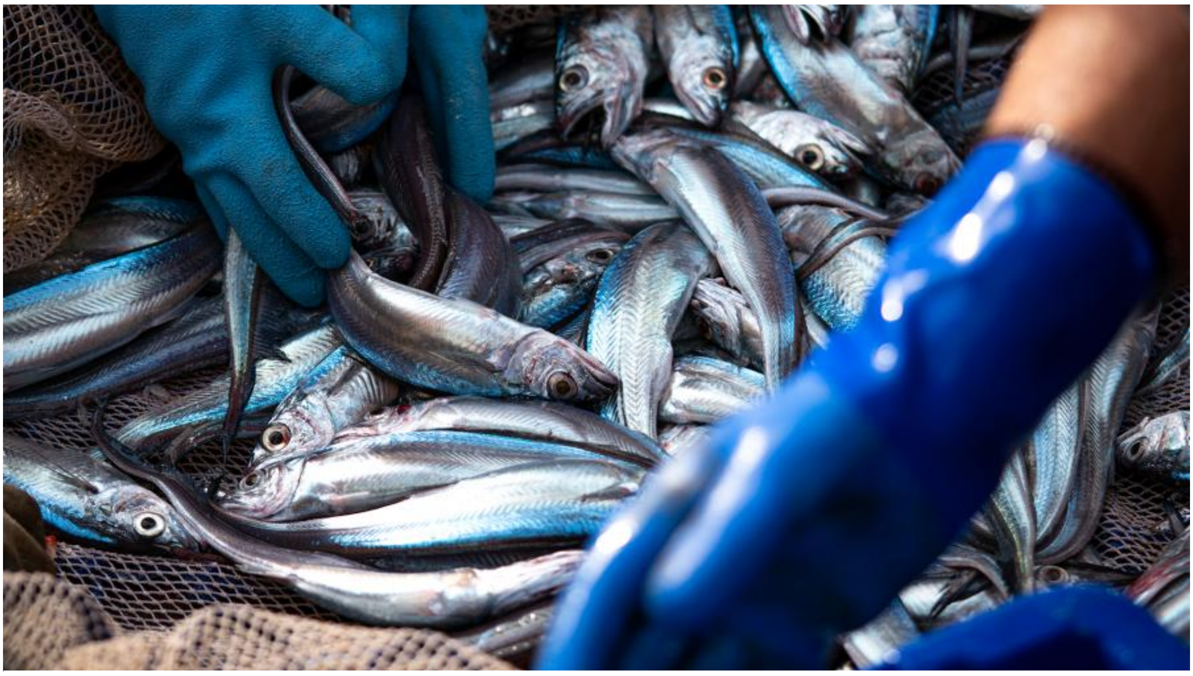

Figure 93: Hoki harvested during a research trawl. Image credit: Stu Mackay/NIWA.

[179] Input from Tā Tipene O'Regan

The marine environment and fisheries will continue to be further impacted by the other stressors outlined in sections 3.1.2-3.1.5, including sedimentation, plastic pollution and invasive species, with their cumulative effects contributing to ongoing changes in fisheries that will be felt by the commercial sector.

The resulting changes in fisheries require management that is flexible and adaptable to changing situations, at pace. It is essential that Aotearoa New Zealand's fisheries management system accelerates rather than encumbers adaptation to a changing environment. To make our fisheries management system responsive to these inevitable changes we need to draw on innovative ways of collecting and managing data to make it more widespread and efficient. This data needs to be rapidly turned into useful information and be acted on without delay. Keeping pace with the increasing volumes of data and extracting knowledge from it will be a challenge, but we can draw on the emerging fields of artificial intelligence (AI) and machine learning to do so.

Changes in our fisheries require management that is flexible and adaptable to changing situations, at pace. It is essential that Aotearoa New Zealand's fisheries management system accelerates rather than encumbers adaptation to a changing environment.

While data is fundamental to being able to make informed decisions, a lack of data should not be a roadblock to making decisions. There will still be times where there is a need to make decisions without a complete evidence and the system should be able to account for uncertainty while we endeavour to fill in knowledge gaps.

There will still be times where there is a need to make decisions without a complete evidence base and the system should be able to account for uncertainty while we endeavour to fill in knowledge gaps.

In the following sections we discuss how innovation can help us respond to changing fisheries:

- Changing fisheries demand nimble and responsive decision making.
- Data-driven knowledge is the cornerstone of effective and sustainable fisheries management.
- AI and machine learning have the potential to increase efficiencies.

6.2.1 CHANGING FISHERIES DEMAND NIMBLE AND RESPONSIVE DECISION MAKING

In a changing environment, fisheries management needs to be able to respond to variations so that an accurate picture of stock and ecosystem health forms the basis of decisions. Many stakeholders we engaged with during this project emphasised the need for a nimbler fisheries management system, highlighting that the TAC system (described in section 5.2.2: Setting catch limits and allocating catch allowance) is not sufficiently responsive.

Figure 94: The once highly productive scallop fisheries of Golden Bay have diminished substantially. Image credit: Tata Bay, Geof Wilson/Flickr (CC BY-NC-ND 2.0).

Detecting and responding to changes in the distribution and productivity of species requires both good monitoring and a responsive fisheries management system. The system needs to be able to respond quickly to changes in abundance, as well as situations where there is new need for catch entitlement (e.g. if the bycatch of a species increases significantly due to shifts in distribution or a population boom) or where catch entitlement is ineffectual (e.g. because the species is no longer present). Enabling early signals of changing stock structure or presence to be rapidly investigated to quickly inform decisions around TAC in that region or management area would support this, though the success partly relies on having a solid foundation of species knowledge. Information and knowledge from a range of different sources could also be drawn on to trigger a stock assessment, including locally held knowledge from fishers and the mātauranga held by local iwi (mostly relating to our inshore fisheries). The effort to evaluate the information and develop responsive management is likely of most benefit to short-lived species, whose abundance fluctuates largely year-to-year.

Information and knowledge from a range of different sources could be drawn on to trigger a stock assessment, including locally held knowledge from fishers and the mātauranga held by local iwi.

Taking a regional approach to management at an appropriate scale for the fishery will also enable greater flexibility in decision making and more responsive management. The issues that need to be addressed may be unique to an area and require a holistic local approach to tackle a range of stressors that are causing changes to fisheries. Regional approaches to fisheries management are more resource intensive but can provide greater input and satisfaction for local communities (within the context of broader fisheries management). These are already showing promise throughout Aotearoa New Zealand (see 4.4.1: case study: Fiordland created a novel model for managing the marine area and 4.4.2: case study: Te Korowai o te tai ō Marokura in Kaikōura shows how regional responsibility can streamline fisheries management), and could be built on by making sure the process is able to respond to new data and knowledge in a rapid fashion. Locally held knowledge will play a critical role in more flexible decision making, specifically for inshore fisheries. Once time has been spent establishing local involvement in marine management, combining place-based evidence at an appropriate scale with a management framework that is fast and responsive will help to provide optimum management for each unique scenario.

Combining place-based evidence at an appropriate scale with a management framework that is agile and responsive will help to provide optimum management for each unique scenario.

Existing management processes could be modified to sharpen the response capacity. The recent shift within the fisheries management system to use digital technology for EM provides a strong foundation on which to build a more responsive system. Information about harvested catch gleaned from these processes can be built into models and ongoing monitoring efforts to observe changes in near real time to support 'moving management options'. The innovations highlighted in sections 6.4: How much we fish, and 6.5: Where and when we fish will also be critical components of a more responsive system. Faster decision making will also support consistency in the application of new software and technologies in the industry, with guidance from the regulator being received prior to purchasing decisions.

The recent shift within the fisheries management system to use digital technology for electronic monitoring provides a strong foundation on which to build a more responsive system.

Regulatory swiftness underpinned by a stronger evidence base to inform decisions will be the foundation of a responsive management system. Such a framework would enable researchers to more efficiently provide input into the decision-making process and identified risk indicators could ensure rapid action to protect ecosystem health. A far greater understanding of basic fisheries science and ecosystem dynamics is a prerequisite to enable this more responsive system, along with ecosystem indicators. This in turn will enable the ongoing and sustainable use of Aotearoa New Zealand's fisheries for generations to come.

These considerations underpin our recommendations in Theme 4.

6.2.2 DATA-DRIVEN KNOWLEDGE IS THE CORNERSTONE OF EFFECTIVE AND SUSTAINABLE FISHERIES MANAGEMENT

Improving how we collect, curate, use and share fisheries and marine science data is crucial to advance Aotearoa New Zealand's fisheries management system and enable research to answer critical questions in the marine environment. In sections 5.3: Commercial fishing has impacts on target species sustainability, and 3.3: Fishing effort has wider ecosystem impacts, we highlighted what we know and the gaps in our knowledge for Aotearoa New Zealand's fish stocks and ecosystems.

Figure 95: Deploying an Argo float, part of a worldwide network of ocean sensors collecting data. Image credit: NIWA.

As discussed in section 5.5.4: Data transformation strategy, Fisheries New Zealand is working to improve data collection, handling and storage; however, the marine data landscape in Aotearoa New Zealand is currently fragmented and often inaccessible. A useful step forward would be to aggregate existing datasets from within and outside government, determine data and knowledge gaps, and prioritise efforts to fill these gaps. Some data gaps urgently need to be filled using the methods widely used in fisheries science (i.e. stock assessments for priority stocks that are currently not assessed (see section 5.3.2: Data collection on target stocks and accessibility of this information). Some other decisions rely on out-of-date data or would benefit from research to better understand the basic biology of the commercial fish species. Systems should be in place so that data is strategically collected to fill knowledge gaps, data is collected regularly, decisions are based on the present not the past, and full datasets are available for extrapolations to predict outcomes. Transparency of the data used in fisheries management is vital to the scientific scrutiny of the management decisions.

Systems should be in place so that data is strategically collected to fill knowledge gaps, data is collected regularly, decisions are based on the present not the past, and full datasets are available for extrapolations to predict outcomes.

There are also areas where we are data rich and information poor – that is, the data is not being used to its full potential to extract knowledge. The use of electronic reporting primarily for compliance purposes is an example of this, where we have rich data that could be used more widely (see section 5.5.1: Electronic catch and position reporting is live). Best practice examples where we have robust long-term data that informs decision making, such as in the Chatham Rise (McGregor *et al.*, 2019a) (see 5.3.6: case study: Chatham Rise is a unique fishery with consistent, long-term data), are what we should strive for in all other priority fisheries management regions throughout the country.

Data needs to be integrated in a way that it is easily accessible for decision makers, commercial fisheries, researchers and other stakeholders. Improving how we integrate and manage data, and opening up access so data is widely utilised, will help to turn data into information. The real value of the (long-term, time-stamped) data will then come from the interpretation and analyses of it, and the risk assessments and decision support tools that are driven by the data. The suggestions below can feed into the data transformation strategy that is currently underway within Fisheries New Zealand (introduced in section 5.5: Regulator initiatives and data transformation).

6.2.2.1 THERE ARE OPPORTUNITIES TO COLLECT DATA FOR FISHERIES IN NEW WAYS

There are innovative approaches that can be applied to broaden how and when we collect data for management, research and monitoring. Collecting fisheries independent data is particularly important for validation and building trust in industry data. These data collection approaches can build on and complement the existing systems that mostly rely on fisheries scientists and catch monitoring.

- **Draw on mātauranga.** As is demonstrated in section 2.7.1: Te ao Māori, Māori knowledge and ways of knowing have an essential role to play in fisheries management. Connecting with local iwi for region specific co-management of marine resources, especially inshore fisheries, will support this knowledge feeding into management decisions.
- **Engage more fishers in data collection and innovation.** Data collected by fishers on their catch and effort are already fundamental to the system. Some fishers would like to contribute more to science and have their observations used to support environmental monitoring. Fishers can also lead data collection, with the Moana Project illustrating the efficacy of fishers taking on this role (see 6.2.3: case study: The Moana Project – Arming vessels with sensors to help validate ocean models). There is also a need to bring qualitative information into formal systems and the (sometimes intergenerational) knowledge held by fishers is invaluable in this regard. There are perceptions that data collected by fishers may be of lower quality, and evidence of an observer effect discussed in section 5.5.2: On-board cameras are being introduced, highlights the need for verification. EM systems will go some way to reducing these issues and lessons from citizen science can also be drawn on to support high-quality data collection and ensure data is robust and validated (Wiggins *et al.*, 2011; Bonter and Cooper, 2012). Similarly, experienced fishers have deep knowledge of fishing practices that can be vital to key innovations, if they are enabled to innovate.
- **Opportunistic data collection.** Vessels that are in the ocean for non-fishing purposes can be used to collect data to inform marine science and fisheries management. Many of the costs of conducting marine monitoring could be reduced by using these vessels and resources already operating in the marine environment. For example, acoustic information (described in section 6.4.12: Acoustic technologies) that was collected on merchant ships over seven years was used in conjunction with information on species distribution from research trawls to make the first estimates of mesopelagic[180] fish density in the Southern Ocean (Flores *et al.*, 2020), demonstrating the utility of opportunistic data collection to inform biomass estimates, even if what is able to be surveyed is more limited than a research vessel (Schmidt *et al.*, 2019). Plankton monitoring can also take place on a range of vessels (see section 6.6: How we ensure a healthy ocean).
- **Involve citizen scientists.** People from the community who want to engage in a particular issue may collect data as part of a citizen science project. Some local examples already exist, such as the use of citizen sightings to independently validate the spatial predictions that are made from habitat modelling (see 6.2.4: case study: Supporting the community to engage in science to protect Māui Dolphins). There are ongoing perceptions that data or samples collected by citizen scientists may be unusable because of lower quality. However, a great local exemplar of how to standardise data collected by citizen scientists so that it meets the requirements of government reporting shows how collection of high-value data is possible. Sustainable Coastlines' Litter Intelligence programme is a citizen science-based initiative to measure litter on Aotearoa New Zealand's coastlines and collate data in a national coastal litter database. The initiative follows a standardised method based on international best practice (UNEP/IOC guidelines on surveying and monitoring of marine litter), with citizen scientists surveying

[180] Inhabiting the intermediate depths of the sea around 200-1,000 m.

coastal sites and recording the type and weight of each piece of litter found. The data meets Statistics NZ Tier 1 data standards, meaning it can feed into government environmental reporting, as highlighted in *Rethinking Plastics* (The Office of the Prime Minister's Chief Science Advisor, 2019). A similar approach could be replicated in the fisheries sector.

- **Automated data collection.** AI and machine learning present new ways to process larger volumes of data with less resource-intensive methods (expanded on in section 6.2.6: AI and machine learning have the potential to increase efficiencies).
- **Innovative use of observers**. As aspects of the role of observers become automated, there is opportunity to employ observers in more innovative research tasks on-board the vessel or to extend the types of data they capture using new tools and technology.
- **Monitoring surveys**. Better coordination and structuring of routine monitoring of inshore fisheries would ensure better coverage across the inshore fisheries around the country and fill data gaps of significant benefit to fisheries management.

As technology use increases and cost decreases, and it becomes easier to automate methods or build in transparency and verification processes, it should become increasingly viable to use data collected from a range of sources in marine science and fisheries management, with confidence that it is robust and high-quality. For the data collected from a range of sources to be useful, it will need to be well organised and integrated.

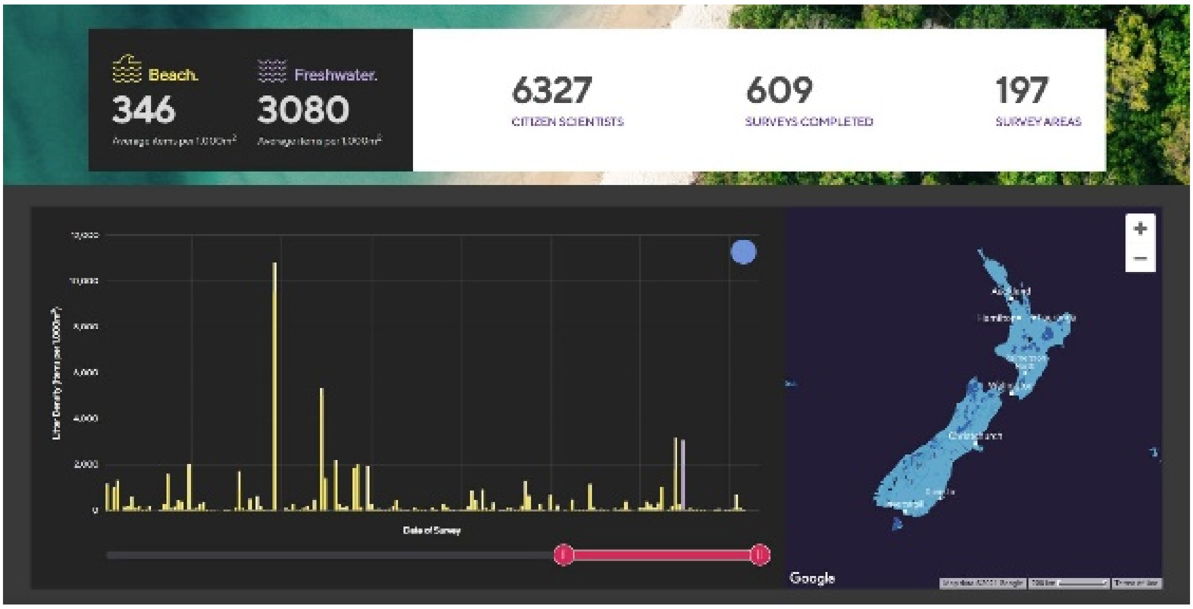

Figure 96: Screengrab from the Litter Intelligence website: a citizen science effort to measure litter on Aotearoa New Zealand's coastlines.

6.2.2.2 AN IMPROVED DATA SYSTEM CAN HELP US MOVE FROM DATA TO INFORMATION

Gathering more data and collating and integrating existing datasets is essential to guide sustainable management of Aotearoa New Zealand's fisheries. But doing so is only going to be beneficial to fisheries management if there is a robust data management system which facilitates analytical processes to turn the data into knowledge through ongoing monitoring and scientific research. The full benefits of a rich dataset will be realised when a wider range of stakeholders is able to access the data, test theories, and build up scientific knowledge and a clear understanding of its associated uncertainties.

AOTEAROA NEW ZEALAND NEEDS A ROBUST DATA MANAGEMENT SYSTEM FOR THE MARINE ENVIRONMENT

Data management techniques have improved over the years and present opportunities for greater accessibility and analysis of data. Figure 97 shows what data collection used to be like in fisheries on top, and below a scenario of a high-tech fishery-dependent data collection system (Bradley, *et al.*, 2019b). In the old scenario, data is collected through the use of logbooks and reports, through fisheries observers, and other records and surveys. Processing this data is resource intensive and slow, and is then generally assessed by the regulator or a scientific institute to inform management decisions. It can take a year or longer to implement changes such as area closures.

In the high-tech fishery-dependent system, in near real time, data is collected from fishers (this would include recreational fishing, although this is out of scope for this report), synthesised with quality control measures and integrated with environmental data, and accessed by the management agency and scientific bodies who integrate and share their data as well. Data is fed back to the fishers who input, and management decisions can be made on a much shorter timeframe – within days, weeks or months.

Aotearoa New Zealand's fisheries management system is currently on a journey towards a more high-tech system, having started to collect a lot of data electronically, but there are still obstacles (discussed in section 5.5: Regulator initiatives and data transformation). The high-tech science-driven system needs to have a bridge to the observational system embedded in mātauranga so that both types of information can be integrated into decision making. Additional challenges to moving towards a high-tech system include (Bradley *et al.*, 2019b):

- **High upfront costs**. Switching to a new system can be very expensive compared to continuing with the status quo. Adopting new software and hardware for data collection, processing, analysis and storage has purchase, installation and training costs. The New Zealand Government has already invested in some of the EM equipment needed to move to a more high-tech system.
- **Regulatory barriers.** The types of data collected in a high-tech system may not align with government requirements for reporting. For example, requirements for paper-based reporting may hinder uptake of electronic reporting. Aotearoa New Zealand is already past this particular hurdle but regulation needs to continue to keep up with new ways of capturing and reporting data so as to not hold back uptake of improved systems.
- **Implementation of data collection standards.** Some data collection efforts may be redundant because the data is not viewed as legitimate or it does not meet the needs or technical and performance standards required by the user. Agreeing on guidelines and standards for fisheries data would enable better utilisation of externally collected data in fisheries management.
- **The need for trust and buy-in from fishers.** If fishers cannot access and do not benefit directly from data, they may resist being involved in data collection efforts, especially where requirements are burdensome. Concerns around privacy and commercial sensitivities may also come into play.

Aotearoa New Zealand's fisheries management system is currently on a journey towards a more high-tech system, having started to collect a lot of data electronically, but there are still obstacles.

Getting new data systems set up correctly from the beginning requires having the data experts and end users involved and informing what questions need to be answered by the system. For example, having end-users input early would have helped to ensure fishers are reporting how they use seabird mitigations in a way that answers vital science questions. Similarly, it will be important to ensure video data (from cameras on boats) is reviewed in ways that will meet particular statistical requirements of risk assessment modelling. In some instances, fishers need data to validate new fishing approaches and there needs to be a simple connection into the system to enable this (see 6.3.5: case study: The importance of connecting fishers to researchers).

As we streamline, link up, and set up new data systems, it is important to effectively involve stakeholders or end-users in data system design. While establishing new data systems will always be a somewhat iterative process, where there is a lack of early stakeholder or end-user input, this can result in lost opportunities for setting up effective systems for data analysis from the start, and results in unnecessary amendments. This provides opportunities for win-wins between all participants in a data system (Bradley *et al.*, 2019b).

Efforts to improve the fisheries and marine science data systems could align with the recommendations of the Parliamentary Commissioner for the Environment relating to environmental reporting and the coordinated and long-term funding of environmental research (Parliamentary Commissioner for the Environment, 2019, 2020a).

This underpins recommendations in Theme 5.

NEED FOR LARGE AND SECURE DATA STORAGE

Aotearoa New Zealand has secure data storage for current fisheries data, but if collection and access is to expand the current system may need to change. Large amounts of data (often in terabytes) must be stored – this requires either physical hard-drives that are manually exchanged, or cloud storage/wireless transmission that may be difficult for fisheries operating in remote areas (van Helmond *et al.*, 2020). Costs of data transfer and storage are also non-trivial. Data storage must be secure and access to data must be clearly defined. The format of data will also need to be considered, for example, increases in video imagery and multibeam echosounder.

NEED FOR IMPROVED ANALYTICAL PROCESSES

A broader and more automated data collection and management approach will generate a wealth of information. Ongoing monitoring efforts will see these datasets continue to grow. Some new or complementary data collection methods may also collect more data than previous approaches. For example, acoustic data collection generates much greater volumes of data than trawl samples.

New analytical processes will be required to get through this sheer volume of data. Software that is able to automate or streamline analyses in a reproducible fashion will be an essential tool to utilise data to inform fisheries management, with a quick turnaround being critical to support fast and responsive decision making (see 6.2.5: case study: Software to streamline acoustic data analysis). These efficiencies will potentially be further improved by the use of AI and machine learning in analytical processes (discussed below in section 6.2.6: AI and machine learning have the potential to increase efficiencies).

NEED FOR DATA TO BE WIDELY ACCESSIBLE

Transparency and access are essential to enable the quality and integrity of science and analysis and good peer review. Data transparency is also beneficial for traceability and market access (see section 6.7.5: Improving traceability to add a premium to products). The move to proactive anonymised data release, including metadata and context alongside the raw data, is long overdue. There are multiple benefits from making aggregated data more widely accessible within a shorter timeframe. Doing so can facilitate greater responsiveness in fisheries management actions by both industry and regulators, support researchers to develop new insights about the marine environment, and enable greater transparency and accountability for all stakeholders. Greater transparency can help those in fisheries who want to more actively manage their impacts on the environment.

Providing access to datasets could allow for novel analysis and new insights. Reciprocated data sharing between different groups could provide a fuller picture of the state of the marine environment and fisheries and could prevent duplicating data collection efforts. There is also opportunity to make some data even more widely available, such as in public online databases, so that it can be accessed for different research and management needs. Requiring publicly funded research to have open access datasets may be a first step to achieving this goal. It also would allow the public access to information that provides a more complete picture on the state of our fisheries and environment, which may build trust.

There is also opportunity to make some data even more widely available, such as in public online databases, so that it can be accessed for different research and management needs. Requiring publicly funded research to have open access datasets may be a first step to achieving this goal.

Data privacy and intellectual property is a major concern that must be addressed through consultation with fishers, iwi and other stakeholders. Commercial sensitivities may be managed through data anonymisation and data aggregation. However, some concerns around data privacy relate more to surveillance and the risk of sensationalisation of imagery. For example, camera footage from boats currently depicts people in a workplace. There may also be privacy concerns related to identifying locations of protected or threatened species. Unrepresentative imagery of a dead protected species could also be taken and used out of context which influences industry buy-in. Future developments for camera technology might help to reduce these concerns. The Datalink system being built into Tiaki to develop a release-at-depth strategy may provide a first step to remove some intrusion in the workplace by capturing footage underwater (see 6.3.4: case study: Precision Seafood Harvesting – Tiaki). The specific concerns of iwi relating to data rights, data privacy and intellectual property must be factored in to any processes that make data more widely accessible. Establishing trust and appropriate conditions for sharing of data is important and it may not be appropriate for that to be wholly accessible. A data trust is a possible way to provide stewardship over data while enabling wider access.

There would be great benefits in aligning with *Te Mana o Te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020* goal that "national, agreed common data standards and open data agreements are ensuring that everyone has access to a federated repository of biodiversity information".

Improving access to data could build on the existing systems. See section 5.5.4.1: Who collects data? for a list of some existing databases.

There would be great benefits in aligning with *Te Mana o Te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020* goal that 'national, agreed common data standards and open data agreements are ensuring that everyone has access to a federated repository of biodiversity information'.

NEED FOR EFFECTIVE DATA VISUALISATION TOOLS

A significant volume of data is available from four standardised time series of research trawl surveys conducted for the regulator over the last 30 years. This data can be used to develop indicators of fisheries ecosystem health and change, but access to, and communication of, this data has mostly been via individual lengthy survey reports, making it challenging to determine trends over time. Data visualisation tools that are able to be used across common platforms will be more accessible than specialist programmes.

Access to, and communication of, this data has mostly been via individual lengthy survey reports, making it challenging to determine trends over time.

Some visualisation tools already exist, such as Sea Sketch – a publicly accessible tool for visual marine planning that was used in *Sea Change Tai – Timu Tai Pari*. The web-based platform, Fishecoviz, in the early stages of development[181] is another step towards making data more visually accessible. The prototype includes Chatham Rise trawl survey data but could be expanded to include other ecosystem components (e.g. oceanographic

[181] NIWA is developing Fishecoviz in conjunction with Catalyst.

indices) and other areas. The portal currently includes several interactive pages where the user will be able to explore and compare species and ecosystem indicators, biomass trends and feeding relationships and view species distribution on a map. In order to be effective, the portal needs to be publicly accessible and user friendly.

A web-based delivery platform, DOC2.0,[182] is being developed to provide data that is currently only accessible as pdf or hard copy versions of *New Zealand Fisheries Assessment Reports* to Fisheries New Zealand and other users. The concept is for searchable delivery (and download) of peer-reviewed published outputs (rather than of raw data). A beta testing version has been developed and is currently being reviewed by users with further implementation planned in 2021.

The need to improve Aotearoa New Zealand's fisheries data system is addressed in recommendations in Theme 5.

[182] DOC2.0 is being developed by NIWA.

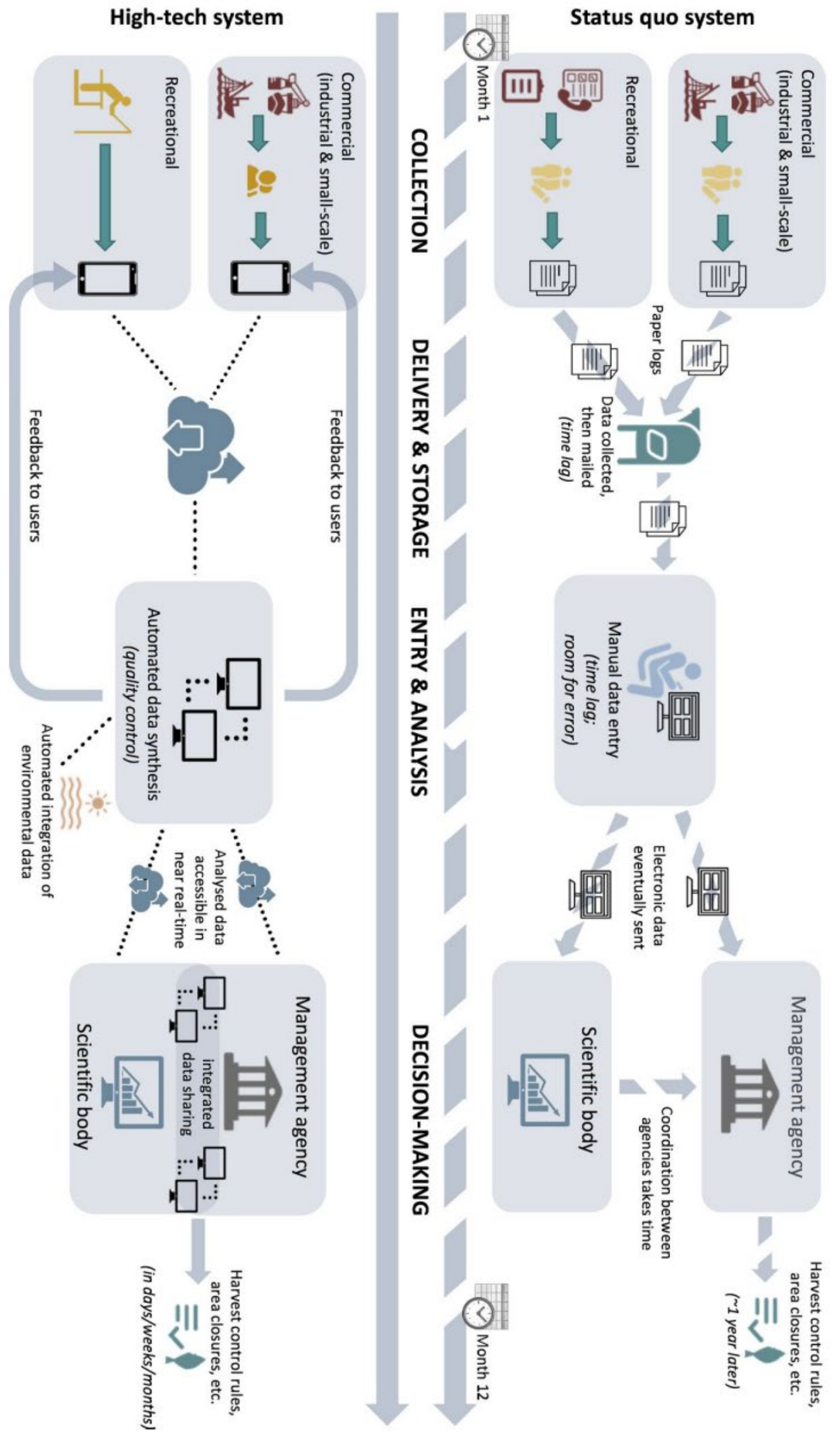

Figure 97: A conceptual diagram taken from (Bradley, *et al.*, 2019b) showing one example of a status quo (top) and possible high-tech (bottom) example of a fishery-dependent collection system for data such as stock and bycatch data, whereby decision making could happen on a faster time scale. Aotearoa New Zealand is already on the path to the high-tech system, though, in practice, decisions may be limited by regulatory processes such as ministerial decision making. Note that recreational fishing is out of scope for this report but would need to form part of a comprehensive fisheries data platform.

6.2.3 CASE STUDY: THE MOANA PROJECT – ARMING VESSELS WITH SENSORS TO HELP VALIDATE OCEAN MODELS

In response to a rapidly changing ocean impacted by marine temperature extremes and shifting currents, a new ocean monitoring and forecast programme is underway in Aotearoa New Zealand. The Moana Project is in its early stages and aims to increase understanding of how the marine environment is changing by improving local knowledge about coastal ocean circulation connectivity and marine heatwaves. This information will help Aotearoa New Zealand's seafood sector prepare for imminent changes and be more responsive in a changing environment, which will help the industry retain its competitive edge.

Figure 98: A temperature sensor used in the Moana Project. Image credit: 2018 MetOcean Solutions/ Meteorological Service of New Zealand (CC BY-NC-SA 4.0).

WHO COLLECTS THE DATA?

The seafood industry is at the heart of the system, with fishing communities gathering the data, with no cost or ongoing actions required of them. Fishing vessels are equipped with low-cost temperature sensors that collect data as the fishers go about their normal practices. These sensors, designed specifically for fishing gear and to handle rough conditions, are made in Aotearoa New Zealand by local company ZebraTech. In theory, these could be deployed 'on all vessels, at all times'. The resulting data is much more fine-scale than what is captured via international models allowing for more detailed resolution, at around 5 km^2 blocks rather than 10 km^2.

The seafood industry is at the heart of the system, with fishing communities gathering the data, with no cost or ongoing actions required of them.

It is not only the quantitative scientific data captured by these sensors that informs the project. Transdisciplinary methods from kaupapa Māori research and social sciences are also used. The Moana Project draws on mātauranga Māori held by the local Eastern Bay of Plenty iwi, Whakatōhea. The iwi has local knowledge about the land and the sea from around 900 years in the area.

The Moana Project draws on mātauranga Māori held by the local Eastern Bay of Plenty iwi, Whakatōhea. The iwi has local knowledge about the land and the sea from around 900 years in the area.

HOW IS IT PROCESSED?

The sensors are connected to the internet and when transported aboard the data is automatically offloaded to data storage on-board and then uploaded to a cloud server. From there the data is transferred to a secure MetService database to be integrated into the newly developed ocean circulation models. Work is underway to determine the best modelling system to use locally (Azevedo *et al.*, 2020). The oceanographic knowledge gained from sensor data is triangulated with knowledge from te ao Māori.

WHO CAN ACCESS IT?

A key feature of the Moana Project is that the forecast system is open access and user friendly, meaning that industry can act on the information their data has informed. The datasets and tools to analyse it are also open access, though other information about vessel and catch will remain confidential.

HOW DOES IT FEED INTO MANAGEMENT DECISIONS?

For Whakatōhea, the plan is to use the new technologies to inform an ocean knowledge exchange platform that supports marine spatial planning and impact assessments to inform iwi governance of multi-sector activities in their rohe moana. Collaboration and involvement of the Ministry for Primary Industries in the process helps to support this new knowledge to inform regional marine policy and management.

WHAT ARE THE PROJECT'S STRENGTHS?

- **Cross-disciplinary** joint research teams that include people from the community as well as scientists allow for two-way knowledge sharing as well as co-designing the project (Kaiser *et al.*, 2019).
- **Cross-cultural** exchange of mātauranga and western science (Kaiser *et al.*, 2019).
- **Collaborative** approach between researchers, industry, iwi, central and local government, and international experts (Kaiser *et al.*, 2019). Uptake and participation by interest groups is incredibly important in the success of using new technologies for ocean monitoring (Kaiser *et al.*, 2019).
- **Cost-effective** approach that reduces costs by using an existing network of fishing vessels that are already out in the ocean, making data collection possible where it may have been cost-prohibitive otherwise.
- **Accessible information** so that fishers and others can act on the new data that comes to light and be responsive to a changing environment.

Improved local knowledge about ocean circulation will help grow our understanding of the changing marine environment, which will in turn be useful to inform responses to changing fisheries. The Moana Project highlights how new approaches to data collection may be able to support sustainability in commercial fisheries. The approach provides an exemplar for future-focused innovative data collection methods to inform a responsive fisheries management system.

6.2.4 CASE STUDY: SUPPORTING THE COMMUNITY TO ENGAGE IN SCIENCE TO PROTECT MĀUI DOLPHINS

Māui dolphins are endemic to Aotearoa New Zealand and are found on the west coast of the North Island.

The New Zealand Government recently developed a 'spatially explicit fisheries risk assessment' (SEFRA) that maps the distribution of Māui dolphins and compares it to the areas where fishing that can pose a risk to Māui dolphins occurs (e.g. set netting) (Roberts *et al.*, 2019). The SEFRA model is based on sightings recorded through standard scientific approaches.[183] This allows the overlap between dolphins and fishing to inform our understanding of risk of interaction (and consequent injury).

As a 'surfer scientist', sightings of Māui dolphins can be reported by phone, app, or web form. Aside from surfers, sightings are reported by many different people, including boat users and recreational fishers.

A key use of this data is to corroborate the spatial predictions that are made from the habitat model. The programme also raises public awareness and engagement.

However, only a select number of sightings are used in the model to estimate the relative density of Māui dolphins in harbours. The reason why many are not used is because to estimate density there needs to be an understanding of the 'effort' that has gone into the sightings (Roberts *et al.*, 2019). In practice this means that only sightings from recreational fishers are used in estimates, as in this case effort can be estimated from aerial surveys of numbers of recreational fishing vessels in the areas.

Currently a large number of validated sightings, including rare ones, are discarded because of the lack of effort information. A recent study looked at whether surfer 'effort' could be estimated so that data collected by surfers could also feed into density estimates (Beeman *et al.*, 2019). Surfer effort would be based on the density of surfers, how likely they are to report a sighting, and the number of days surfers were available to make a sighting. The research showed that in-person survey of surfers allowed for appropriate data to be gathered to estimate effort and include surfer-collected data in SEFRA. These findings indicate that there are ways to enable the use of more surfer sightings to increase applicability of this tool to protect Māui dolphins and support sightings recorded through standard scientific approaches.

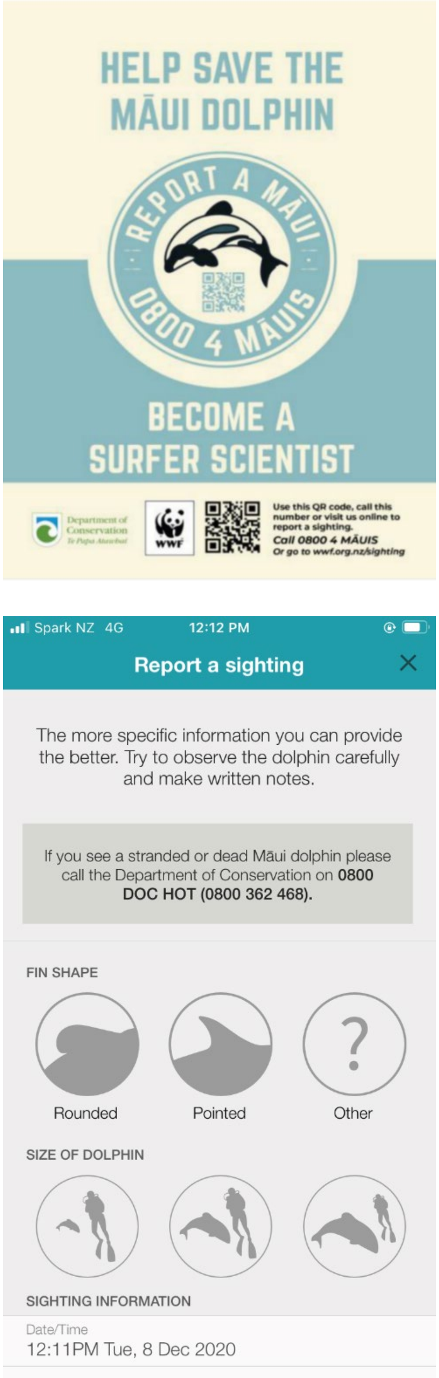

Figure 99: Poster advertising Māui dolphin project (above) and screenshot of the app where people can report a sighting of a Māui dolphin (below).

[183] Note that limitations of the SEFRA model have been discussed in (Taylor *et al.*, 2018), including the need for further validation of inputs.

While public sightings are not a substitute for validating the SEFRA habitat model with data collected by scientists in a controlled fashion, surfer scientist data has the potential to grow the knowledge base around Māui dolphins and also expand to support wider data collection, such as collecting eDNA (see section 6.4.16: Environmental DNA (eDNA) can grow ecosystem knowledge).

Figure 100: Māui dolphins. Image credit: Laura Boren/DOC (CC BY 4.0).

6.2.5 CASE STUDY: SOFTWARE TO STREAMLINE ACOUSTIC DATA ANALYSIS

One of the challenges associated with using acoustic technologies to inform fisheries management is getting through the large datasets with efficiency and reproducibility. To address this challenge, researchers designed open-source software, ESP3, to process large hydroacoustic datasets (Ladroit *et al.*, 2020).

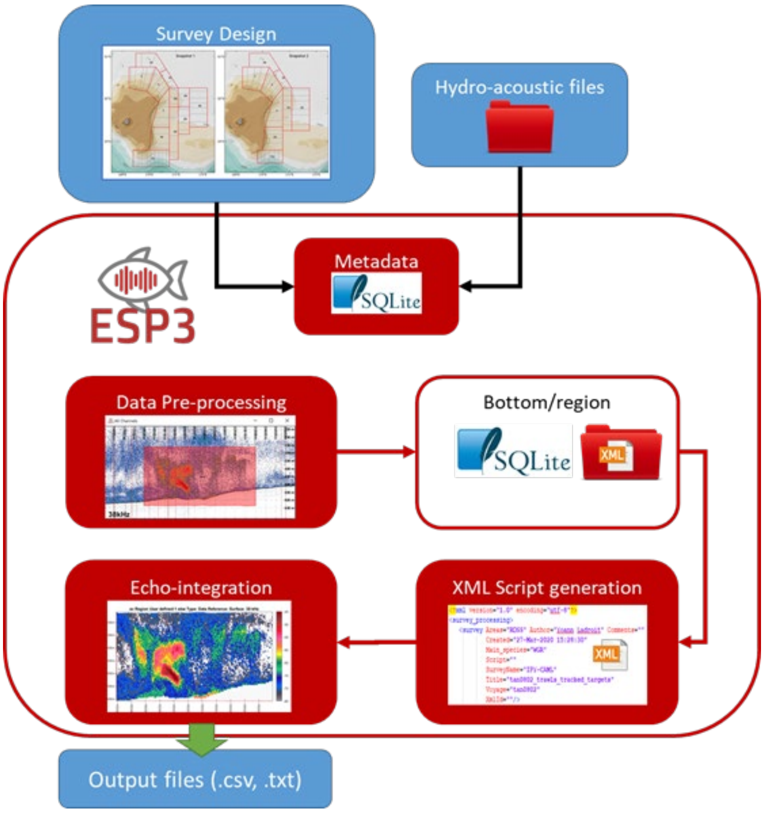

Figure 101: Standard workflow for hydroacoustic data analysis using ESP3.

The software can be used to process data generated by active acoustic technologies such as echosounders that send out sound pulses underwater and measure the echo response (backscatter) to identify the organisms or structures in the area. ESP3 can be applied to echosounder data to inform biomass estimates, large-scale studies of marine ecosystems and marine geophysical applications. There is flexibility – parameters and algorithms can be changed and multiple different datasets can be integrated. The user needs to make decisions around these parameters to design a robust workflow that will then apply automated methods to do the quantitative analysis of the echo.

To date, ESP3 is the only open-source software with a graphical interface to support processing of acoustic datasets. The open-source nature of the software is a key strength as it both guarantees transparency in the analysis pipeline and also opens up access to those groups that have been prohibited by cost. The user interface also opens up accessibility as it allows people who don't have coding expertise to scrutinise and process acoustic data.

To date, ESP3 is the only open-source software with a graphical interface to support processing of acoustic datasets. The open-source nature of the software is a key strength as it both guarantees transparency in the analysis pipeline and also opens up access to those groups that have been prohibited by cost.

Figure 102: Deep tow body being deployed.

NIWA uses ESP3 to process all the hydroacoustic data captured from their fisheries acoustics surveys, supporting a broad range of research in fisheries, ecology and geophysics. There was clearly a demand for such software elsewhere as well, as it has been downloaded more than 1,600 times from 63 countries since it was first released in 2017. The researchers who developed the software have trained numerous people from around the world on how to use it, provided assistance to others, and take on board suggestions from users to improve the software and add functionality.

Developing open-source software to streamline the process of analysing acoustic data has facilitated the use of acoustic technology in Aotearoa New Zealand's fisheries management system, such as in the survey of hoki in Raukawa Moana Cook Strait that fed into the stock assessment (Ministry for Primary Industries, 2018). The open-source software also supported increased uptake and use of acoustic datasets worldwide. Streamlined, open-source analytical tools such as ESP3 will play a crucial role in the future of sustainable fisheries management as we continue to increase our reliance on large datasets and recurring collection to inform management decisions in real time.

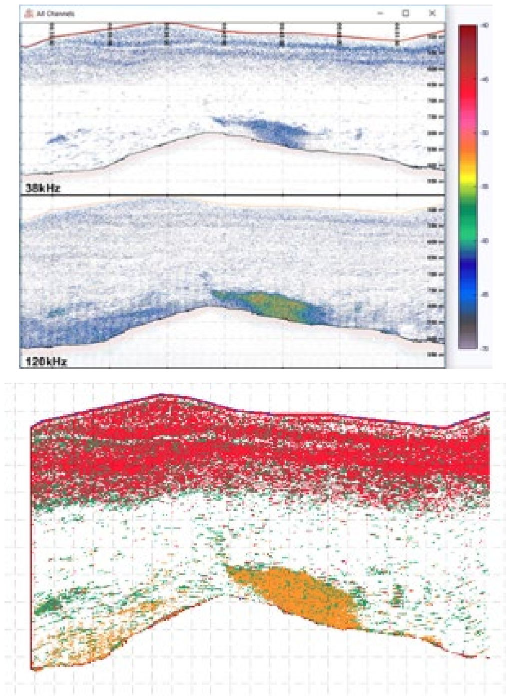

Figure 103: Example of species classification of orange roughy based on data collected by CSIRO during the AEX1701 voyage to Graveyard Hill (Chatham Rise). The top panel shows the data acquired at both frequencies. The bottom panel shows the results of the automated classification. The orange colour represents signal attributed to orange roughy.

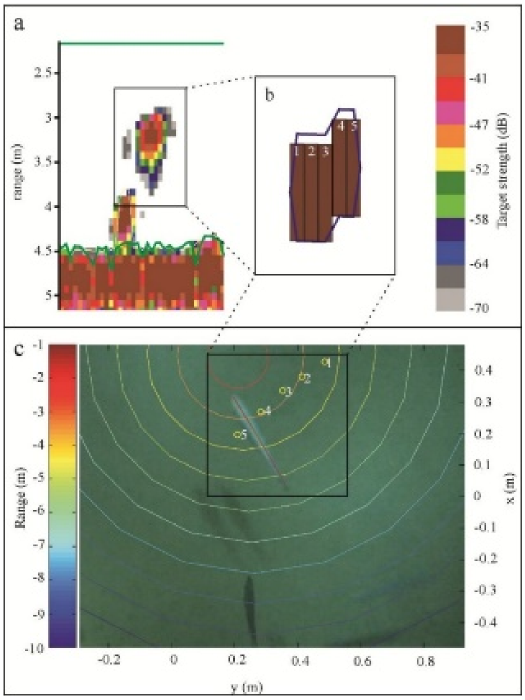

Figure 104: In situ target strength measurements from a visually verified southern blue whiting using an AOS. Figure shows: a) raw ping echogram; b) the single target detection; and c) the equivalent image on the AOS analysis software.

6.2.6 AI AND MACHINE LEARNING HAVE THE POTENTIAL TO INCREASE EFFICIENCIES

Increasing computer power combined with improved technology means we have the potential to gather more data about our oceans than ever before. But this data is only useful if we can analyse and extract meaning and knowledge from it. Our ability to analyse data has not kept pace with the data collection explosion, resulting in an 'analysis bottleneck' (Malde *et al.*, 2019). Besides the sheer volume, the data collected is increasingly complex and can vary substantially in quality. This poses further challenges for data analysis efforts.

AI and machine learning can widen the analysis bottleneck and accelerate the shift to responsive data-driven fisheries management. AI technology has the potential to make fishing more precise, cost-effective, transparent and sustainable by improving the efficiency of manual work. It can also enhance marine and fisheries science by providing new approaches to analyse complex datasets.

However, most AI-related fisheries projects – both in Aotearoa New Zealand and overseas – are still at the proof-of-concept stage. Examples of pilot and early-stage applications are discussed throughout this section. Several hurdles must be overcome in order to progress this emerging technology beyond small pilot projects. Progress in this area will be critical to being able to fully utilise the wealth of data that will come from projects in the pipeline, such as cameras on boats.

Most AI-related fisheries projects – both in Aotearoa New Zealand and overseas – are still at the proof-of-concept stage.

6.2.6.1 WHAT IS AI AND HOW CAN IT HELP US FISH SUSTAINABLY?

The AI Forum of New Zealand defines AI as, "Advanced digital technologies that enable machines to reproduce or surpass abilities that would require intelligence if humans were to perform them" (AI Forum of New Zealand, 2018). Currently, AI can perform specific, narrow tasks very well, like playing chess, working out a protein structure (Wang *et al.*, 2020) or operating a self-driving car. However, we are still a long way off generalised, creative AI that can perform any task, like a human brain (Berruti *et al.,* 2020).

AI is an umbrella term that encompasses a range of different approaches. Some of the approaches relevant to fisheries are defined below.

MACHINE LEARNING

Machine learning is an application of AI where algorithms learn and improve from experience, rather than being explicitly programmed (Hao, 2018). These computational methods sift through vast amounts of data, identify patterns in the data, and then apply these patterns.

Most machine learning is supervised. This is where the algorithm is 'trained' on human-labelled input and output data – effectively telling the algorithm what patterns to look for. When the input data does not have labels, the machine learning is unsupervised. In this case, the algorithm looks for whatever hidden patterns it can find. Reinforcement learning sits somewhere between supervised and unsupervised learning, building on both exploration of the unknown and exploitation of current knowledge (Budek and Osiński, 2018). Through trial and error, the algorithm attempts to achieve a goal. Its actions are either rewarded or penalised and by striving to maximise the reward, the machine 'learns'.

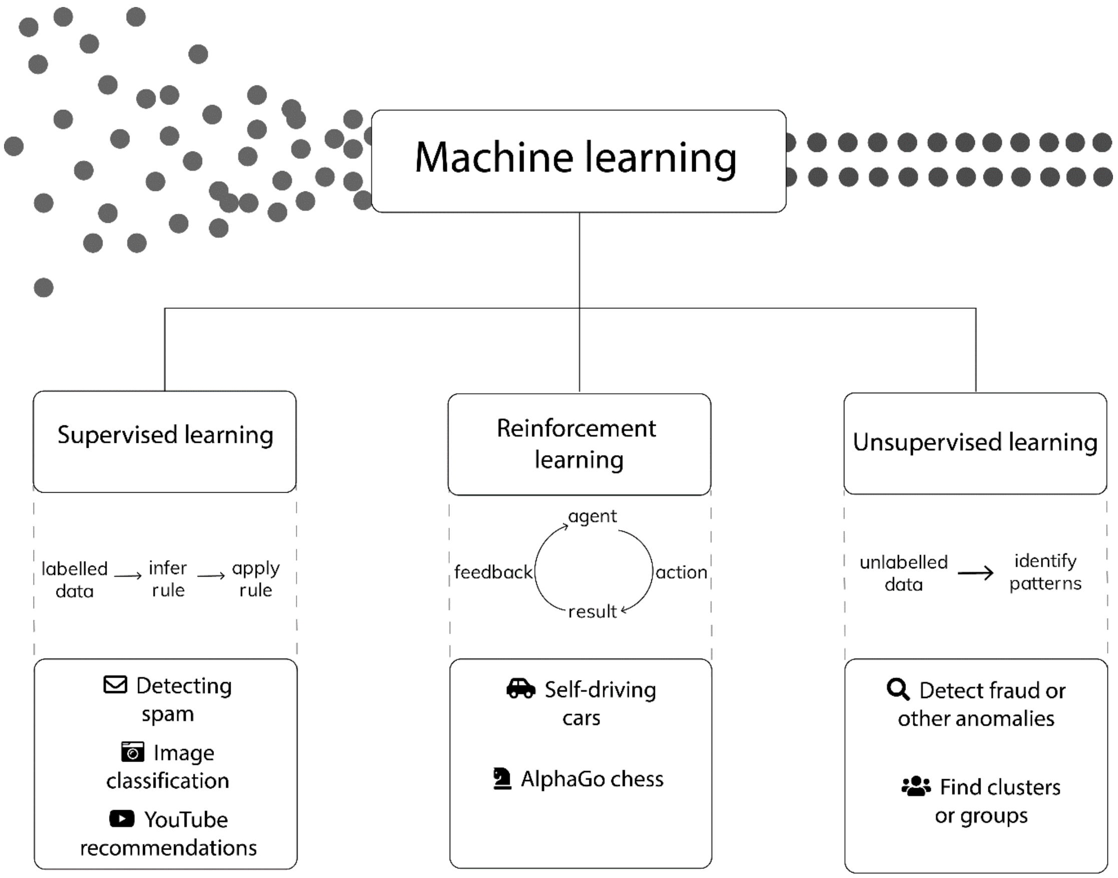

Figure 105: Schematic of the different approaches to machine learning.

DEEP LEARNING AND ARTIFICIAL NEURAL NETWORKS

A neural network is a type of machine learning system inspired by the structure of a human brain. It consists of computational nodes that are interconnected (Hardesty, 2017). Deep learning is a method that employs nodes arranged in layers, where the outputs of one layer feed into the next layer (Lecun *et al.,* 2015). For example, the first layer of a deep neural network might identify corners and edges in an image, which then feeds into another layer that identifies higher-level shapes, and so on. A convolutional neural network (CNN) is a type of deep neural network inspired specifically by the human vision system (Allken *et al.*, 2019). Most deep learning systems for image analysis use CNNs.

These methods could help us fish more sustainably by expanding opportunities for data collection and automating processing of fish data, greatly increasing the amount of data and information that can be drawn on to inform fisheries management decision making. For example, US company, CVisionAI, is working on AI

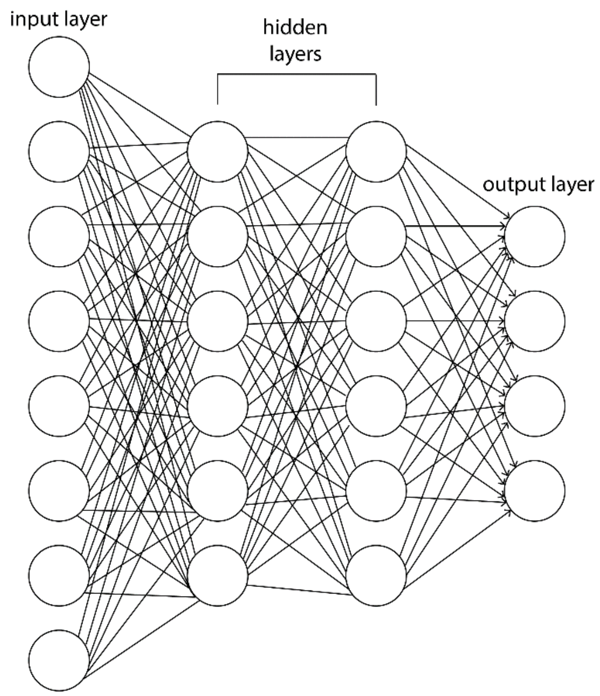

Figure 106: Visual representation of a simple neural network.

solutions to automate trawl survey video review, detect scallops and recognise activities on-board fishing vessels.

US company, CVisionAI, is working on AI solutions to automate trawl survey video review, detect scallops and recognise activities on-board fishing vessels.

6.2.6.2 AI OPENS UP OPPORTUNITIES TO AUTOMATE PROCESSING OF FISH DATA

Measuring fish length is one data collection aspect that lends itself to a computer vision solution and may present a suitable first step towards widespread AI implementation in fisheries.

In Aotearoa New Zealand, Pisces Research Ltd is developing a fish measurement app ("Snappy"). The app could be used in onshore processing facilities, which have less variable photography conditions than on vessels at sea. The length data collected can inform both stock assessment and add useful product information to benefit companies.

Fish age is an important parameter in stock assessments (see section 5.3.2: Data collection on target stocks and accessibility of this information). The age of a fish is determined by inspecting its otolith – similar to counting rings in a tree trunk. Otolith interpretation is time- and labour-intensive, requiring specialist knowledge. But computer vision can now be deployed to measure fish otoliths (a structure in the inner ear).

A study from 2018 used deep learning to estimate age from Greenland halibut otolith images (Moen *et al.*, 2018). The resulting CNN performed at level comparable to human accuracy.

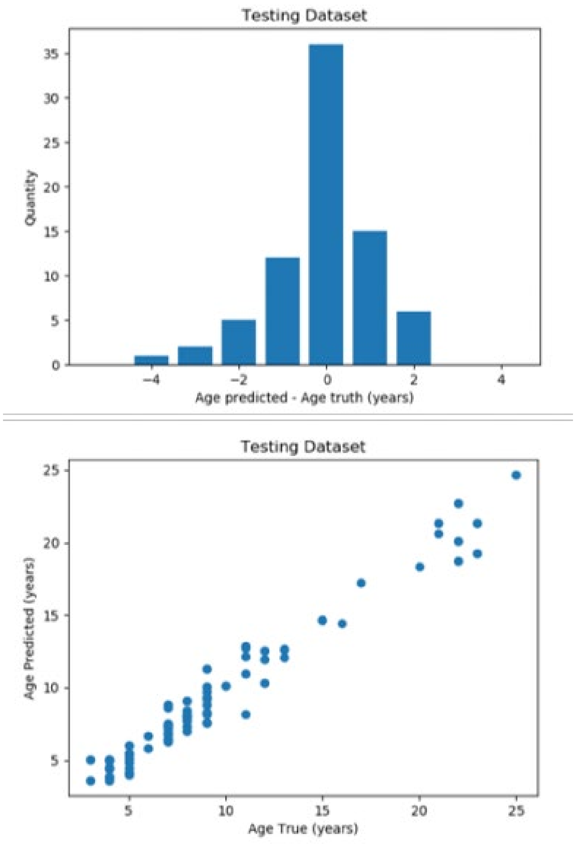

Figure 107: Differences in annuli counts (top) and age bias (bottom) between annuli estimations via machine learning and human age estimations in the machine learning trial of Moore *et al.* (2019).

In Aotearoa New Zealand, tens of thousands of otoliths are collected from commercial fisheries and research surveys every year (at least 27,000 in 2019/20). A feasibility study on automatic image processing for hoki, ling and snapper otoliths has been carried out (Moore *et al.*, 2019) and concluded that researchers will still need to be involved in the process prior to age estimation and the technology required to estimate age from CT scanned otoliths needs further refinement, but there is significant potential for automating age estimation from otolith images using machine learning. This could speed up the age estimation process overall.

While the technology required to estimate age from CT scanned otoliths needs further refinement, there is significant potential for automating age estimation from otolith images using machine learning.

6.2.6.3 THERE ARE LIMITATIONS AND CHALLENGES IN APPLYING AI IN THE COMMERICAL FISHERIES SECTOR

Successful scaling up of AI technology across the fisheries sector will require collaboration and dialogue between fishers, academic researchers, NGOs and the private sector. While AI has the *potential* to effect change in fisheries, in practice there are several hurdles that are currently limiting implementation to small research projects and pilots.

- **Transparency and privacy.**
    - Data privacy and intellectual property (as discussed in section 6.2.2.2: An improved data system can help us move from data to information) is important in considering how AI is used to capture and interpret data.
    - Neural networks are essentially 'black-box' systems and it is often unclear how such models make decisions, or what information they are capturing (Allken *et al.*, 2019; Malde *et al.*, 2019).
    - Transparency in the use of algorithms and how decisions are made are important. Government agencies that are signatories to the Algorithm Charter for Aotearoa New Zealand have committed to the transparent use of decisions made informed by algorithms.
- **Retaining the human touchpoints and building trust.**
    - The Nature Conservancy reported in 2018 that some experts "are sceptical of the near-term impact of AI" (Michelin *et al.*, 2018). They believe that human involvement in certain technologies – such as the implementation of EM – is necessary to build trust and achieve buy-in from fishers.
    - As with many other industries, AI and automation may make manual human labour obsolete. This is of concern for small, coastal communities that rely on fisheries for their livelihood (Garcia and Rosenberg, 2010), although potentially people could then be involved in more meaningful work.
    - Development in the AI and fisheries space should focus on *collaboration* between human and machine – a partnership that takes the best parts of both – rather than replacing humans with AI.
- **Cost and funding.**
    - Although there may be mid- to long-term financial benefits to AI, there is an up-front cost associated with hardware, and ongoing costs associated with data transfer and data storage that may be prohibitive (van Helmond *et al.*, 2020). This may be an area where government support makes a significant difference to improve sustainability of fisheries management.
    - Sustained investment is required to progress the technology from small-scale to wide rollout and stay up-to-date as the technology evolves. The current cost-recovery model of fisheries research funding in Aotearoa New Zealand is not effective for advancing blue-skies innovation into practice.
    - There is a limited market size, especially in Aotearoa New Zealand, but we could sell our technology to other jurisdictions.
- **The right data must be available and useable.**
    - The data we need to make decisions needs to be collected in the first place.
    - Machine learning requires training datasets, often with annotations. Datasets with adequately labelled metadata are few and far between (Malde *et al.*, 2019). Some research using CNNs is aiming to develop solutions for sparsely labelled data (Allken *et al.*, 2019).
    - Different fisheries will require custom training datasets depending on the species they target.
    - Image recognition in a fisheries context is particularly challenging, with environmental conditions that may include rough seas, changeable weather and moving objects.
- **Image libraries are critical for the development of AI.**

    - Image libraries are a crucial part of the application of AI and machine learning in computer vision solutions and developing these is a critical step to being able to apply these technologies widely in the industry.
    - One example of a dataset with labelled fish images designed to train AI systems is Fishnet, a library of over 100,000 tagged EM images.
    - All government-mandated EM programmes could require provision of source-anonymised labelled images to an appropriate publicly accessible dataset. Organisations operating non-government EM systems could also be encouraged to provide suitable labelled images and images may also be obtained from fisheries trawl surveys.
- **Data must be stored.**
    - The issues around data storage (discussed in section 6.2.2.2: An improved data system can help us move from data to information) are particularly relevant to AI.
- **Development of AI expertise.**
    - To date, AI and machine learning expertise has largely been concentrated in big data companies such as Google. Fisheries and marine scientists must build and enhance connections with experts in the AI space, in order to attract talent and interest in fisheries-specific issues.
- **Biases.**
    - Depending on the code, inherent biases may be programmed into the application and perpetuate biases.

6.3 HOW WE FISH

There is a fine balancing act between fishing at scale economically and fishing to minimise social, environmental and ecosystem harm and maintain a sustainable harvest for future generations. Gear innovation is a key way to help strike this balance and ensure that fishing activities do as little damage to the marine environment and ecosystems as possible.

Responsible sourcing of seafood is fundamental to a sustainable fisheries sector because it means that there will be healthy ecosystems and habitats and strong juvenile populations of fish, with the added benefit of high quality catch due to less damage during harvest. It will also help to industry maintain social and cultural license to operate. The key issues that relate to fishing gear that need to be addressed by innovation are:

- **Selectivity.** Being able to catch target species of a particular size is critical to maintain healthy ecosystems because it selects for the size of fish and avoids unintended species. Selective fishing approaches can be designed based on conventional approaches of targeting specific fish above a certain size, or alternatively be designed for balanced harvesting (applying a moderate fishing intensity across as much of the ecosystem as feasible, as defined by (Zhou *et al.*, 2019)) thus expanding the range of sizes and species considered as the target. As discussed in section 5.2: Fisheries management involves the use of many different tools, selectivity also has economic implications due to the deemed value associated with fish that are caught without ACE. Mesh sizes, hook sizes and configurations, net configuration, and jigging technology all have the potential to improve selectivity.
- **Bycatch.** As well as not wanting to catch non-target fish species, there is huge effort to reduce the bycatch of protected species and vulnerable benthic habitats, in line with the bycatch reduction goals of *Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020*. The degree to which bycatch is an issue is hugely species and location specific (section 3.3.2: Bycatch of non-target and protected species) demanding bespoke management and innovation solutions. Innovations relating to how gear is used and adding on

equipment that deters non-target species or reduces benthic impacts can help to reduce bycatch, which can sometimes be mandated for certain protected species and habitats. Trawls can capture bycatch while ropes and lines from other methods may entangle species underwater or at the surface. Innovations that are effective at avoiding, detecting or deterring protected species and benthic habitats vulnerable to fishing gear have the potential to allow fishers to continue to fish where these species and habitats are present or be better informed about where not to fish.

- **Damage to environment.** Fishing gear such as trawls, dredges and seines can damage the environment by coming into physical contact with habitats. One innovation challenge is to be able to harvest bottom-dwelling fish with minimal damage to the seafloor. Loss of fishing gear in the ocean can also damage the environment, particularly gear made of plastic which gradually degrades into microplastics (see section 3.1.4: Plastic pollution is building in the ocean, or section 2.4.4 of *Rethinking Plastics in Aotearoa New Zealand* (The Office of the Prime Minister's Chief Science Advisor, 2019)).
- **Survivability.** Whether fish are alive when landed on deck or damaged or killed from the catch process has significant bearing on whether it is viable to return unwanted catch (for discussion see section 5.2.2.2: Discards) and also the quality of the fish, which can dictate price-point (6.7.7: case study: How a commitment to transparency and traceability has generated a premium product). Again, this must be approached species by species as some species cannot be brought to the surface alive. There are significant economic benefits to be realised from landing fish in better condition and returning live bycatch – gear innovations in all fishing methods are working to address this issue.

Innovations can also address other needs to change how we fish.

- **Reducing harm from 'ghost gear'.** Lost or abandoned fishing equipment is a significant threat to marine animals and can also damage the environment. Gear innovations that improve identification to retrieve gear if lost can help to address this issue. The choice of materials used in gear can also make a difference to the harms caused (see section 2.4.4 of *Rethinking Plastics in Aotearoa New Zealand* (The Office of the Prime Minister's Chief Science Advisor, 2019)).
- **Locating fish to reduce fuel use.** Technologies that locate fish can increase efficiencies of fishing trips and therefore have positive climate change implications. This can also reduce fishing effort and therefore impacts on associated and dependent species. Uptake might be increased if government support were available. Notus Electronics (Canada) have developed a wireless microphone which can hear shrimps 'ping' off a grid as they enter the trawl, enabling detection of hotspots along a tow. This technology could potentially be applied to Aotearoa New Zealand's scampi fisheries.
- **Moving away from fossil fuels.** Shifting to lower fuel use methods and incorporating alternate energy sources where possible is beyond the scope of this report, but an important climate change consideration for the sector.
- **Understanding fish behaviour.** A better understanding of how target and non-target species respond to fishing can help the industry design gear that is more selective.

Fostering more gear innovation will help to make fishing fit for the future (see 5.6.1: case study: Gear innovation pathway). Gear innovation doesn't always rely on inventing completely new ways of fishing, it can also involve incremental improvements in the traditional ways we have fished, using nets, lines, hooks and traps. A range of innovations in the existing fishing equipment and methods, as well as some additional new features, can change their environmental, economic and social impacts.

Figure 108: Left – A fish made from abandoned fishing gear ('ghost gear') by artist Lynette Griffiths. Right – Fishing nets. Image credit: Hans Hillewaert/Wikimedia (CC BY-SA 3.0).

In this section we outline the current innovations and potential for improving the commonly used commercial fishing methods to make these more sustainable:

- Knowing how fish behave is essential for gear design of the future.
- Future nets, trawls and dredges could be more selective with reduced impacts.
- Innovations could increase efficiencies and reduce harms from line fishing.
- Traps and pots could be redesigned to eliminate entanglements and gear loss.
- Gear add-ons will be essential to deter non-target species.
- Technological advances in fish detection could reduce fuel costs and time at sea.

The technologies surveyed in this section inform our recommendations in Themes 4, 5 and 7.

6.3.1 KNOWING HOW FISH BEHAVE IS ESSENTIAL FOR GEAR DESIGN OF THE FUTURE

Fishers have long analysed fish behaviour and response to different gear to develop more efficient approaches to fishing (Hemmings, 1973; Pitcher, 1986). However, new challenges facing fishers today demand gear that is highly selective and maintains conditions that support fish welfare before the catch is landed. Knowledge of fish behaviour in relation to fishing gear is a prerequisite to design, construct and operate new responsible fishing gears.

Historically, observations and lab-based studies have been relied on to understand fish behaviour in the context of capture methods because of the difficult and costly nature of studying this in the field. However, technological developments with underwater video cameras (see section 6.4.14: Underwater and surface cameras give a wider and sharper view of the ocean) are opening up new opportunities to ascertain how fish behave in the natural setting because it is now cheaper and more accessible to study (as demonstrated in 6.3.2: case study: Fish behaviour and catchability in fishing gear).

With a better understanding of how both target and non-target species respond to fishing gear and methods, gear can be designed to be less harmful and more selective for size and species. This information can also feed into improved trawl survey design so that these methods are non-lethal.

Aspects of fish behaviour that need to be understood to inform gear design include:

- **Swimming speed and movement patterns.** The speed and movements of fish need to be understood in order to design non-lethal trawl methods so that the fish harvested are top quality and the bycatch can be returned unharmed.

- **School movements.** Japanese researchers developed a simulation model of fish-schooling behaviour to determine the most effective set net design to be selective and reduce bycatch (Takahashi and Komeyama, 2020)**.**
- **How fish respond to visual cues.** Understanding more about what fish see and how they react to gear will help to attract certain species.
- **How fish respond to sounds.** Innovations to improve the use of sound to selectively attract fish could be beneficial, but only if developed with consideration of the need to minimise anthropogenic ocean noise as it can impact marine life (Putland *et al.*, 2017; Putland *et al.*, 2018). The use of sound to guide fish to another location could possibly be applied in a way that shifts schools of fish away from a protected habitat before fishing effort takes place. Sounds can also be used to deter non-target species (as discussed in section 6.3.11: Gear add-ons will be essential to deter non-target species).
- **How fish respond to olfactory stimuli.** Understanding how olfactory queues could be used to select for some species and deter others may also open avenues to use these methods in new gear. Bait analysis tests for scampi that fed into potting methods are an example of this in action (Major and Jeffs, 2018).
- **Diet.** Knowledge of fish diets can inform approaches to fishing such as identifying effective baits for trap fishing. A local study that used DNA analysis (specifically metabarcoding) identified the diet of deep sea scampi and found that scampi have a varied diet, with a high reliance on scavenging a diverse range of species from the seafloor (van der Reis *et al.*, 2018). Analysis of diet also enables a way to detect if diet is changing in response to environmental shifts.

Fish behaviour has already informed some design aspects of innovative gear in use in Aotearoa New Zealand's commercial fisheries. The net design and trawl speed of the Precision Seafood Harvester – Tiaki, were designed such that fish swam and survived until landed on deck (see 6.3.4: case study: Precision Seafood Harvesting – Tiaki). The potting technique profiled in 6.3.10: Case study: Potting as an alternative to trawling, also based its design on prior behaviour studies (Major *et al.*, 2017). Some challenges still need to be overcome so that fish behaviour can inform gear design, with multi-species fisheries posing a particular issue.

Figure 109: Understanding fish movement and behaviour is important for gear design. Image credit: Koheru (*Decapterus koheru*) school, Sarah Milicich/iNaturalist (CC BY-NC 4.0).

6.3.2 CASE STUDY: FISH BEHAVIOUR AND CATCHABILITY IN FISHING GEAR

Surveying of fish stocks is possible through the use of cameras. One example of an important use is for estimating scampi abundance at depths of over 400 m.

Cameras can be low cost. For example, GoPro cameras have been increasingly used to survey fish to understand fish behaviour in and around sampling gears (gear used for research purposes, such as nets or traps).

A study undertaken in the Persian Gulf by NIWA used GoPros to estimate fish abundance and behaviour in pots and at baited underwater video stations (Finucci *et al.*, 2019a). The research found that counts with use of the cameras were consistent with catch sampling, making it an effective method. Additionally, useful observations on behaviour could be made – like a species' disposition to guard bait in traps, which in turn could make it more easily catchable. This information is important when assessing CPUE and consequently the abundance of a species (as discussed in section 5.2.2.6: The relationship between catch per unit effort and abundance).

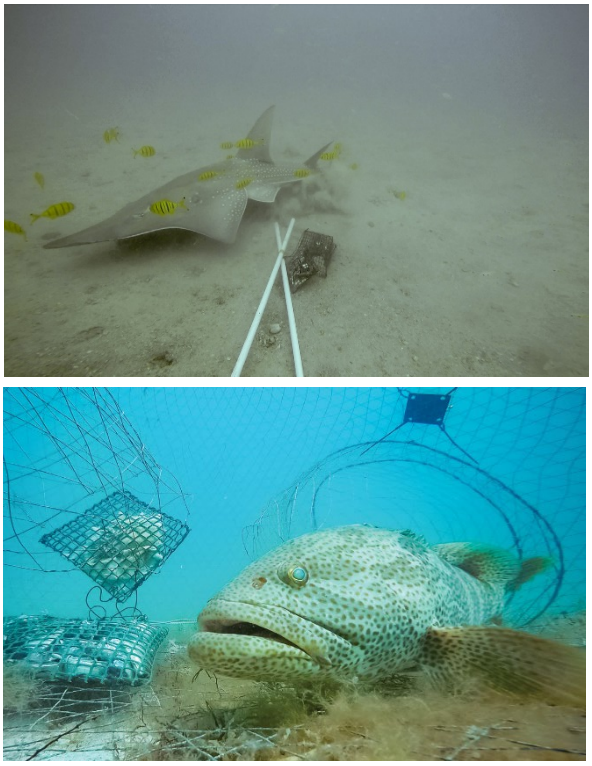

Figure 110: Go-pro observations on a baited underwater video station (top) and a trap (bottom).

Cameras present a practical sampling alternative in areas where fishing is prohibited – for example, in marine reserves. Regulations need to adapt to enable video footage to be used as evidence when monitoring fisheries and fishing methods.

6.3.3 FUTURE NETS, TRAWLS AND DREDGES COULD BE MORE SELECTIVE WITH REDUCED IMPACTS

Full contact bottom trawling can cause damage to the marine environment when it drags along the seafloor, as discussed in section 3.3.3: Habitat. The impacts on the physical habitat depend in part on the weight and structure of the 'trawl doors' and the use of other things such as chain and rigging, as well as the specific nature of seafloor ecosystem (Eayrs *et al.,* 2020). Midwater trawling has less impact on the benthic environment but cannot catch bottom dwellers (such as blue cod, tarakihi and ling) and can still damage and kill unwanted species, including those that are bycatch. There is also some evidence that midwater trawls can sometimes come into contact with the seafloor depending on the target species, though contact is not extended (Tingley, 2014).

Figure 111: Underwater screen shot of a snapper attempting escape in a trawl fitted with a novel escape panel. Image credit: NIWA.

Midwater trawling has less impact on the benthic environment but cannot catch bottom dwellers.

SELECTIVITY

Much of the focus in trawling innovation relates to selectivity by selecting for fish that are a marketable size. For nets and trawling, this is largely determined by the size and shape of mesh openings in the net, particularly at the end of the net where the fish accumulate (the 'cod-end'), and fish behaviour during the capture process (see section 6.3.1: Knowing how fish behave is essential for gear design of the future). The simplest way to reduce the catch of undersized fish is to increase the size of meshes in the cod-end or use selectivity grids where appropriate and allow the fish to escape. Some fish that pass through the nets die during the process (Suuronen, 2005). In the future, greater selectivity could also be achieved if bycatch is caught alive and healthy and released back to the ocean unharmed.

In the future, greater selectivity could also be achieved if bycatch is caught alive and healthy and released back to the ocean unharmed.

After many years fishing with traditional gear, in recent years some in the fishing industry have shown leadership and taken steps to increase mesh size above the minimum legal mesh size in some fisheries or adopt the use of different mesh types such as square or 'T90' that allow mesh to remain more open during fishing than traditional diamond mesh. Napier-based skipper Rick Burch uses T90 mesh and has demonstrated the effectiveness of this simple change to reduce catches of undersized gurnard by 61% (Wade, 2013). The different mesh sizes and configurations that work will depend on the target species and size of fish targeted.

In recent years, some in the fishing industry have shown leadership and taken steps to increase mesh size above the minimum legal mesh size in some fisheries or adopt the use of different mesh types.

Even with larger or more open apertures in a trawl, the selection process is relatively passive, and is currently only effective if the target species is larger than the unwanted catch, or a shape that prevents it escaping as easily. For example, square or T90 openings are very effective for species that are round in cross section such as red gurnard but may be less selective for more elliptical or compressed body shapes such as flatfish, snapper or tarakihi. Fisheries generally encounter multiple species of different sizes and shapes, which can make selective, targeted fishing particularly difficult in our ocean, where there are often a large number of species in the same area compared to some fisheries overseas.

Other tools such as sorting grids and exclusion devices also provide a way to select for the target species and reduce bycatch by allowing for the escape of larger animals when they come into contact with grid bars at the top or bottom of the trawl net, but not ejecting the smaller target species. An example is the sea lion exclusion devices (SLEDs) used in the squid fishery near Maungahuka the Auckland Islands (SQU6T) and the southern blue whiting fishery near Motu Ihupuku Campbell Island. A review concluded SLEDs have contributed to reduced rates of observed sea lion mortality (Hamilton and Baker, 2015), though these findings are contested (Meyer *et al.*, 2017). Separator panels with multiple cod-ends of different mesh sizes have achieved successes in some fisheries in Aotearoa New Zealand. However, these approaches are not applicable to smaller bycatch species. There is room for improvement in bycatch reduction innovations in Aotearoa New Zealand's commercial fisheries industry.

Combining gear innovations with other technologies such as acoustic and video technology could in future facilitate more selective methods and reduce the trawling impact as the trawling effort needed is reduced (McConnaughey *et al.*, 2020). Advances in computer vision (discussed in section 6.2.6: AI and machine learning have the potential to increase efficiencies) coupled with more selective design will allow for selection to take place at depth and allow for underwater release to reduce discard mortality. Video imaging and acoustic technologies could be coupled for pre-catch identification and catch monitoring to potentially increase catch rates of target species and reduce the trawling footprint (McConnaughey *et al.*, 2020). Among a range of international examples is a local project that aims to develop a video-guided active sorting device (see 6.3.5: case study: The importance of connecting fishers to researchers). On a larger scale, a collaborative, multimillion dollar project led to the development of a modular harvesting system that offers significant advantages over traditional nets but does not address seabed impacts (see 6.3.4: case study: Precision Seafood Harvesting – Tiaki). Development of underwater computer vision to add to the harvesting system is currently underway.

REDUCING BOTTOM IMPACT

There are also opportunities to innovate in trawl design and materials to lighten the weight of equipment so that it doesn't drag along the seafloor and damage habitat (the impacts of this are discussed in section 3.3.3: Habitat) (Eayrs *et al.,* 2020). Innovations to change the extent to which these gears contact the seabed have dual conservation and production gains in that as well as avoiding habitat and species disturbance, they reduce fuel consumption and expensive damage to trawling gear.

A number of techniques have been developed overseas to reduce the impact of trawl fishing on benthic habitats, including semi-pelagic trawl where trawl doors are lifted off the bottom rather than in contact with the seabed, and raised fishing line trawls. These are thought to be suited to application in some of Aotearoa New Zealand's fisheries and could be tested in our setting (Eayrs *et al.,* 2020), building on early testing of semi-pelagic trawls (Jones, 2015).

A precision robotic shellfish picker is under development by researchers at the University of Canterbury to address the issues related to dredging (as discussed in 6.3.6: case study: Scallop surveys and harvest).

TRIALLING GEAR

Understanding and quantifying the selective properties of trawl fishing gear and its impact on the seafloor is an important tool in achieving sustainable fisheries. Trialling different gear innovations at sea can be costly and time consuming. There are two ways to address this.

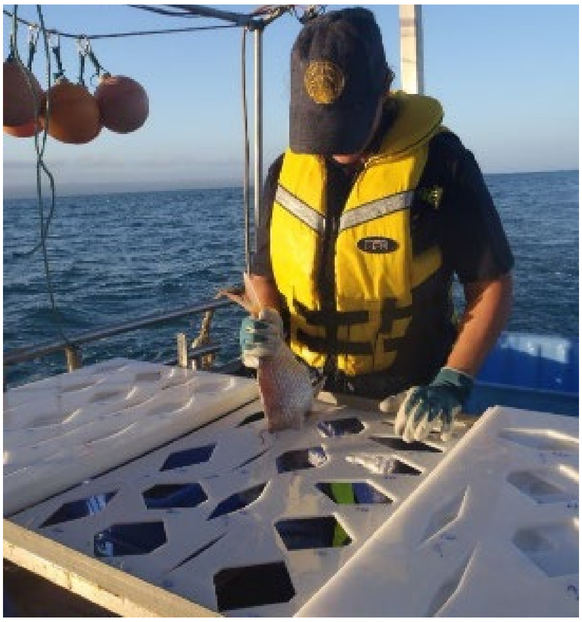

Figure 112: Collecting "artificial" selectivity data from "fall-through" experiments. Photo credit: Jure Brčić /NIWA.

The first is to model and predict the selectivity outcomes of changes in mesh sizes and openings to refine the proposed method until predicted selectivity is optimised. Researchers at NIWA are working on a project to achieve this, combining conventionally collected experimental selectivity results with 'artificial' selectivity data for a range of different mesh sizes and opening angles created by performing 'fall through' experiments (see figure 112) (Herrmann *et al.* 2007). So far this project has developed predictive models for four species (snapper, red gurnard, New Zealand sole/pātikirori[184] and yellowbelly flounder/patiki-totara[185]), providing quantitative information on the changes in selectivity that could be expected from the inshore vessel shifting from the minimum legal mesh size (4" or around 100 mm) to larger mesh sizes of 5" (125 mm) and even 6" (150 mm) diamond mesh. Data on fish sizes and shapes has also been collected for sand flounder/pātiki[186] and tarakihi, as a basis for future trials. Once predictive selectivity models are finalised, the data can be summarised into an interactive app which shows how changes to mesh size and opening affect selectivity across different species.

The second approach is to use flume tanks to test systems. Flume tanks provide a physical environment to carry out performance evaluations of the new gear and simulate underwater and near-surface conditions. There are only a handful around the world for testing trawling gear and Aotearoa New Zealand's researchers and industry collaborate with these institutes. Independent fishers who supply Talley's have visited the flume tank at the Marine Institute at Memorial University in Newfoundland, which is the world's largest flume tank, to test gear innovations. A flume tank is going to be built at Plant & Food Research which may be able to be used for testing gear locally.

There are remaining challenges in testing net and trawl innovations in the marine setting. In particular, it is challenging to capture data about survivability following escape from the net. Video footage is helpful in distinguishing between live and dead bycatch being released, but cannot capture subsequent events, such as predation. Tagging of fish may give some clues, but is extremely resource intensive. Beyond the benthic impacts, we also need to study the impacts of the gear on the ecosystem more broadly. A more permissive regulatory environment that maintains rigour is needed to enable controlled fishing trials of innovative gear with careful monitoring of the impact on stock numbers and the ecosystem over time. This could be achieved through special permits to support innovation.

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[184] *Peltorhamphus novaezeelandiae.*
[185] *Rhombosolea leporina.*
[186] *Rhombosolea plebeia.*

This underpins recommendations in Theme 6.

A more permissive regulatory environment that maintains rigour is needed to enable controlled fishing trials of innovative gear with careful monitoring of the impact on stock numbers over time. This could be achieved through special permits to support innovation.

Looking to the future, towed capture methods will need to continually embrace technology that allows more active selection, identifies unwanted catch before or during the capture process, avoids or releases species at depth unharmed, and doesn't come into contact with the seafloor. Alternative methods also need to be evaluated for differences in fuel use or emissions. Facilitating this gear innovation would be assisted by review and amendment of the Enabling Innovations in Trawl Technology regulations to better facilitate the development and use of innovative fishing technology. Funding and technological support for gear trials could also reduce barriers to gear innovation, as would a review of how the 'third wire' regulations can restrict innovative uses of technology.[187]

This underpins recommendations in Theme 7.

Not every new innovation will work first time and a permissive environment is needed to allow fishers to iterate and optimise new gear within their local context to give a fair comparison to established technology.

[187] The use of net sonde cables, also known as 'third wires' (i.e. where a cable is hard wired to a trawl sonar attached to the net head rope to allow monitoring of the nest position and catch entering the net) have been prohibited in Aotearoa New Zealand waters by regulation since 2008 to prevent seabird mortalities because of observations that the third wire increased the risk of 'warp strikes', where seabirds run into the wire and are injured or killed (Acoura Marine, 2018). FNZ can (and has) grant special permits to trial gear with a third wire, with a requirement for observer coverage during trial.

6.3.4 CASE STUDY: PRECISION SEAFOOD HARVESTING – TIAKI

Shared aspirations for a more precise alternative to full-contact bottom trawling within Aotearoa New Zealand's fishing industry led to the design of a new harvesting technology, Precision Seafood Harvesting.

The collaborative project between Moana New Zealand, Sanford, Sealord Group, Plant & Food Research and the Ministry for Primary Industries was a 'Primary Growth Partnership' and was aimed at developing harvesting technology that would allow more targeted catches of fish in a better condition, fresher and of higher commercial value (Wilson *et al.*, 2019).

The outcome of years of research is a modular harvesting system made of PVC that can be used as an alternative to traditional full-contact bottom and midwater trawling techniques.

Inside the system is a low-flow environment where fish can swim freely and smaller fish can escape from the system unharmed, or be returned live to the ocean after the gear is brought on-board (Wilson *et al.*, 2019). The expectation from the use of such technology is that undersized discards would have higher survival rate than traditional methods. The system has commercial benefits, as the fish caught are less likely to be damaged or stressed. While economic benefits are often the driver for research investment, there are key benefits from an animal welfare perspective too (the importance of which is discussed in section 2.5.5: Society's expectations are changing).

The technology has been trialled and approved for use in a number of different fisheries, including deepwater fisheries such as hoki, hake and ling, and inshore fisheries such as John dory, red gurnard, snapper, tarakihi and trevally in the North Island (Moore and Smith, 2017; Ministry for Primary Industries, 2019b). Fish caught with the system can be sold under the branding of 'Tiaki', which comes from the Māori language and means the duty of guardianship, care, protection and conservation.

The experiences of the Precision Seafood Harvesting technology have shone a light on some of the challenges that need to be overcome to support more gear innovation in Aotearoa New Zealand:

- **The regulatory approval of new fishing technologies is a significant hurdle** (Moore and Smith, 2017). The current regulation precludes gear improvement as the regulation is framed so that new gear performs exactly the same as the current standard for a given fishery for indicators like selectivity. This process has had barriers and frustrations and has illustrated that the regulatory system needs to adapt to enable gear innovations. These barriers could be removed by a process that evaluates innovation based on desired outcome taking a risk-based approach to evaluate the appropriate approval pathway for each innovation.
- **There's a tension between commercialising vs open-source tech.** The commercial approach to technological development is a barrier to wide uptake, but if the technology was open-source that would create a barrier to initial investment. There is reportedly interest from other countries in this technology (Sanford, 2019), suggesting that there can be commercial benefits beyond the catch itself to be realised from investing in gear tech. This benefit is offset by the lack of access to the technology for other Aotearoa New Zealand companies.
- **Continued iteration must be supported to optimise results in different environments.** Some criticisms of the system relate to perceived limited improvement compared to the current standard. Acceptance of the iterative nature of development and testing of new technology in specific settings to improve outcomes will help to achieve the best results for gear innovation in Aotearoa New Zealand's fisheries.

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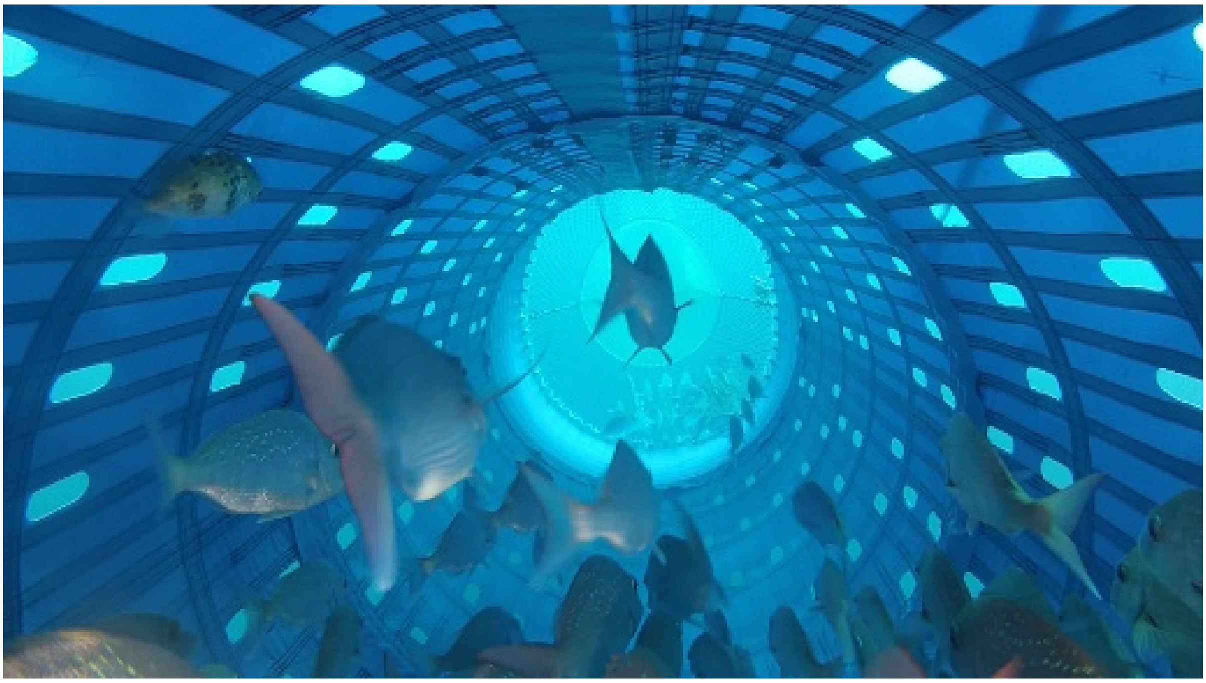

Figure 113: Tiaki modular harvesting system.

6.3.5 CASE STUDY: THE IMPORTANCE OF CONNECTING FISHERS TO RESEARCHERS

Selective trawl gear is also of interest to innovative small fishing companies, with a growing interest in gear that can reduce the bycatch of undersize and unwanted fish. In response to this issue, Karl Warr – the owner/operator of Better Fishing Ltd in Te Matau-a-Māui Hawke's Bay – came up with an idea for a rigid steel trawling cage with square mesh panels to replace the narrow end of the tapered trawl net where the fish accumulate. The aim was to selectively catch fish based on their size and create a low water flow area so that fish in the cage are in a less stressful environment. In 2013, he worked with a local engineer to build it and opted for open-source model so that wider industry could also access the technology to maximise the sustainability benefits.

Figure 114: Rigid cod-end with rectangular openings. Image credit: Karl Warr/Better Fishing Co.

Trials of the cage demonstrated an 80-90% reduction of undersized sand flounder compared to a conventional trawl net and a 95% reduction in juvenile fish mortality.[188] After validating the approach, Karl now exclusively uses the selective fishing method, changing out the side panels to a particular gate size to match the species he is targeting.

His desire to continuously improve the sustainability of his operation led Karl to think of further ways he could refine his approach to be even more selective. Ultimately, he was aiming for a mechanism that could help him fish precisely for his orders that day. Recognising what was in the trawl and choosing to keep or release it in real time underwater could achieve just that.

Karl initially faced a few setbacks in taking this idea further, with unsuccessful applications to various local funding rounds. As a small independent fisher, he did not have the capital to invest in the idea himself, nor did he have experience in applying for research funding, or the support or backing of industry that the larger companies may have. Aside from limited access to capital, a key barrier was not having connections to researchers to progress his vision.

Karl's nomination as a finalist for the Innovation Category of the US Seafood Champion Awards, a global event run by the Seafood Choices Alliance, garnered recognition for his innovative approaches to fishing both here and overseas and helped facilitate connections with researchers from Aotearoa New Zealand and the US.

Within two years, a collaborative project that aims to develop a video-guided active sorting device was granted a Ministry of Business, Innovation and Employment Smart Ideas grant of $1,000,000 over two years, with further support from NOAA, Fisheries Inshore New Zealand, Ngāti Kahungunu Iwi Incorporated, and Fisheries New Zealand. Karl is a key member of the NIWA-led project, along with the University of Canterbury, the University

[188] Jones, *et al.,* 2017: Voyage Report CHIPS1601; inshore trawl gear selectivity trials. Unpublished Report prepared for Fisheries Inshore New Zealand. 29p.

of Washington, NOAA, Craig Rose, FishNext Research and Ngāti Kahungunu. Researchers will draw on state-of-the-art video camera, computer vision and underwater engineering technology to allow the skipper to programme an 'underwater shopping list' in advance.

This collaboration highlights the opportunities when fishers and researchers come together to improve fisheries sustainability. Fishers know the requirements and practicalities of fishing operations and their markets and have many innovative ideas to address the range of issues faced on the water. Researchers are at the leading edge of technological advances and can help to progress ideas even further. Making it easier for these groups to connect with one another will be fundamental to realising a more sustainable fishing future.

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6.3.6 CASE STUDY: SCALLOP SURVEYS AND HARVEST

Scallops are scientifically surveyed and harvested worldwide using dredges that damage the seafloor and risk fishery collapse in vulnerable areas (Thrush and Dayton, 2002; Ferraro *et al.*, 2017; Stewart and Howarth, 2016; Williams *et al.*, 2019). New fishing methods are required that avoid environmental impacts and bycatch.

In a preliminary case study, NIWA is collaborating with the University of Canterbury to develop a machine learning approach (explained in section 6.2.6: AI and machine learning have the potential to increase efficiencies) to autonomously identify New Zealand scallops in visual imagery of the seafloor (Williams, 2020).

Using the range of imagery collected to date, scallops in the images were manually annotated by scientific divers using an interactive annotation app developed by the University of Canterbury (Batchelor and Green, 2019), and the resulting annotation data was used to train a convolutional neural network to differentiate scallops from other seafloor features (see section 6.2.6.1: What is AI and how can it help us fish sustainably?).

This approach has the potential to underpin the future development of an innovative scallop harvesting system that does not damage the benthic environment, as well as a non-invasive camera-based method of surveying scallops and habitats. The initial work has formed the basis of a collaborative Ministry of Business, Innovation and Employment Endeavour Smart Idea research proposal 'Transforming scallop fishing: Non-destructive surveying and harvesting for economic acceleration and kaitiakitanga' and a PhD study 'Autonomous identification and sizing of scallops in situ'.

While being a long way from application, the idea highlights how AI and robotic technology can disrupt the traditional ways of thinking about harvesting seafood and open up opportunities to resolve the ecosystem impacts of fishing and enhance stocks.

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Figure 115: Underwater stereo-camera used for image capture fieldwork. The camera was operated by NIWA scientific divers, 'flying' the camera along pre-deployed transect lines at each site, with the camera set at forward looking and vertical face-down angles. Image credit: James Williams.

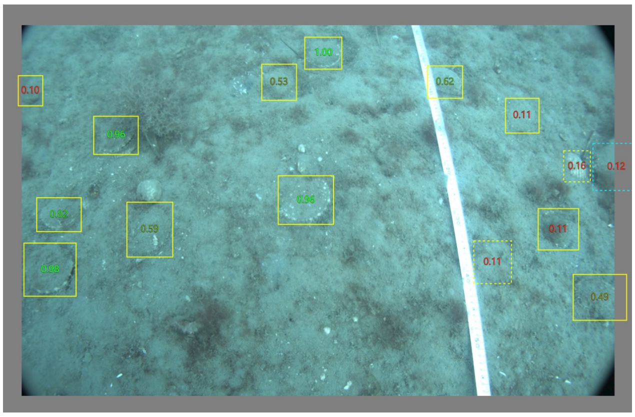

Figure 116: An example an annotated image from Whangārei Harbour. Image credit: NIWA.

6.3.7 INNOVATIONS COULD INCREASE EFFICIENCIES AND REDUCE HARM FROM LINE FISHING

Innovations to improve the efficiency of non-trawl methods will be essential to make them more economically viable and enable wider use to minimise environmental harm from fishing. Compared to trawl and net methods, line fishing is less efficient for large commercial catches, but it can be more selective, land fish of higher quality and have less benthic impact. The ability to catch fish on a hook and line system is also dependent on the behaviour of the fish species in response to baited hooks as well as its physical ability to take a hook. Line fishing will not necessarily be effective for all species.

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ELECTRONIC JIGGING TECHNOLOGY

Innovations in electronic jigging enable more efficient and precise hook and line fishing. A computer-controlled motor on the side of a boat drops a weighted line into the water, automatically finds the bottom, retracts enough to avoid seafloor contact, and then moves the line up and down in a jigging pattern to attract fish. The line is reeled back up when pressure sensors detect that a set weight of fish has been reached. Specific line movements, depth and lures can be used to attract a particular species of fish by mimicking prey movements, enabling selective fishing. For example, some fish will follow a lure to the surface while others won't. This makes it a particularly useful innovation to support fishers to catch their quota and avoid non-target species. This method is used widely in the inshore fisheries in Iceland (Þórðarson and Viðarsson, 2014). Murihiku Southland-based fisher Nate Smith uses computer-driven jigging technology (see 6.7.7: case study: How a commitment to transparency and traceability has generated a premium product). A Nature Conservancy project supporting fishers to fish sustainably in the Gulf of Maine has equipped nine boats with this technology at no charge so that they can test it before purchasing at a discounted rate if they want to continue to use the method. Though one fisher could manage a number of electronic jiggers at once via an on-board computer, the current cost of the technology may hinder uptake at a scale that would make it economically viable to adopt this method over alternatives such as trawling. However, it does enable the harvest of selected quality fish for appropriate small, premium markets, and could be more widely adopted with investment to help operators find a route to these markets.

UNDERWATER HOOK RELEASE

Gear innovations are required to address a key issue with line fishing – bycatch (see section 3.3.2: Bycatch of non-target and protected species). Hooks floating on the ocean's surface are commonly mistaken for food by seabirds, which can get caught by the hook. This is a particular issue in longlining where hundreds or thousands of hooks are used at once. Changes in fishing practice, such as setting longlines at night, weighting lines, and bird-scaring decides go some way to reducing these impacts, but gear innovation has the potential to further reduce risks to seabirds. Innovations to address this issue focus on releasing the hook underwater out of accessible reach of seabirds. An underwater bait setter innovation developed by local fishermen is showcased in 6.3.8: case study: A collaborative effort to protect vulnerable seabirds. A separate but similar innovation developed in the UK, the Hookpod, encloses baited hooks in a case and then releases hooks at depth. These have been tested by commercial operators in Aotearoa New Zealand and are approved by the Ministry for

Primary Industries as a standalone seabird bycatch mitigation measure. These innovations mitigate the risks of seabird bycatch on the sea surface during setting of the gear, but underwater risks of hooks or entanglement still exist for other seabirds and other marine animals.

Figure 117: Fishing lures called 'jigs' come in a variety of shapes, sizes and colours.

6.3.8 CASE STUDY: A COLLABORATIVE EFFORT TO PROTECT VULNERABLE SEABIRDS

Figure 118: Sign on the door at Lee Fish in Leigh.

Aotearoa New Zealand is home to one-third of all species of seabird and the breeding ground for the highest number of seabird species worldwide (Department of Conservation, 2017). In recent times, many seabird species have become threatened or endangered (Department of Conservation, 2017). Fishing practices are a contributor along with other pressures such as pollution, diseases, invasive predators and habitat degradation (Croxall *et al.*, 2012).

Seabirds can be killed on baited hooks or become trapped in the long line that trails for many kilometres behind a boat. Around 30 years ago, Leigh fisher Dave Kellian thought up a solution to reduce the risk of this happening – an underwater bait setting system that sets longline hooks out of sight for seabirds.

Such a system could minimise bycatch and reduce bait loss, making longlining more sustainable. But for years, the solution sat idle. As a busy fisher, Dave faced barriers to translating his idea into a functional device – navigating funding applications, designing, prototyping, trialling and validating the technology would all need to happen in his own time, unpaid, which was not feasible.

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Dave shared his idea widely and over time, various systems were designed by others, with much trial and error. Trialling underwater bait setting systems at sea is expensive and securing funds to trial systems in Aotearoa New Zealand has proved challenging, until recently.

The collaborative charitable trust Southern Seabird Solutions has been instrumental in bringing the idea to fruition here in Aotearoa New Zealand. The alliance focuses on protecting seabirds and as part of that mission they championed the underwater bait setting system and helped to find funding to get trials underway. Having fishers, scientists, conservationists and government officials within the group meant that it was well connected to the opportunities and processes that could help secure funding and get buy-in throughout the industry.

Because of these efforts, Fisheries Inshore New Zealand is now leading work to trial an underwater bait-setting system in the surface longline fishery in Aotearoa New Zealand. Skadia Technologies' device has so far been trialled by Altair Fishing and was due for final testing in late 2019, but has faced delays due to the COVID-19 pandemic.

Finally reaching the stage where this innovation is close to implementation in the industry is a significant achievement, but some consider it long overdue. The experience shines a light on some of the barriers that prevent good ideas becoming best practice.

- Often the best solutions are those developed by fishers themselves, but it is particularly challenging for small-scale fishers to get their ideas off the ground and a lack of resources makes it even harder.
- Connections to and support from the wider industry, researchers and NGOs are crucial and can be facilitated by groups like Southern Seabird Solutions. Wider connectivity across the sector would lower the barriers to innovation.
- The criteria and focus of funding need to change to support innovation in fisheries. Improved access for fishers to progress good ideas could have significant sustainability outcomes.
- Focusing on innovations that provide economic benefits may mean that innovations that significantly improve environmental or sustainability outcomes are overlooked, delaying the protection of vulnerable species and habitats.

Often the best solutions are those developed by fishers themselves, but it is particularly challenging for small-scale fishers to get their ideas off the ground and a lack of resources makes it even harder.

6.3.9 TRAPS AND POTS COULD BE REDESIGNED TO ELIMINATE ENTANGLEMENTS AND GEAR LOSS

Trapping and potting methods are traditionally used to catch crustaceans such as rock lobster but innovations in how these methods are applied open them up to a wider range of fisheries.

ROPELESS GEAR

Figure 119: Pots on Rēkohu Wharekauri the Chatham Islands.

Work is underway to develop and test ways to use pots and traps without the ropes that are traditionally used to bring the pot to the surface. These efforts aim to reduce the harm to marine life that ropes can cause through entanglement and gear loss in the marine environment, which is both costly and damaging. The pots sit on the seafloor and are released when an acoustic signal is sent (see section 6.4.12: Acoustic technologies). The acoustic modems can also record sounds to identify the locations of protected species such as whales, so that vessels can avoid these locations. The state of California has proposed new regulations for ropeless gear driven by the need to reduce entanglement of protected marine species, which will accelerate research and development of this technology. Several ropeless fishing solutions already exist but may need to be refined and improved for application in specific fisheries.[189] Pilot applications of ropeless gear are underway in North America and Australia and there are concerns around the many technical challenges to overcome and that the new technology may be cost prohibitive for the industry, though these issues will likely reduce over time.[190]

The cost of implementing these systems might be cost prohibitive and the types of fishing locations may limit viability in some areas. However, if further fisheries expand to using potting (such as in 6.3.10: Case study: Potting as an alternative to trawling) there will be more ropes in the water and a higher chance of entanglement. It will therefore be even more pertinent to development ropeless gear to minimise the impacts on non-target species.

[189] See Desert Star Systems; Fiomarine; Edgetech; Smelts; Ashored.

[190] See 'New 'Pop-Up' Fishing Gear Could Reduce Whale Entanglements', SeaSense; 'Shellfish sector tests innovative fishing gear to address concerns about mounting marine mammal deaths'.

6.3.10 CASE STUDY: POTTING AS AN ALTERNATIVE TO TRAWLING

Potting is a fishing technique that generally uses a baited pot or cage – creatures are attracted to the pot and can easily enter but cannot leave as easily. Potting avoids many of the direct environmental harms of bottom trawling (Fisheries New Zealand, 2017), and has the potential to be more targeted and less damaging to catch (Chambers, 2012). It can also provide live seafood, which if unsuitable can be returned to the wild, or sold into premium live seafood markets.

Tāruke (crayfish traps) were used traditionally by Māori to catch crayfish, by using a mix of natural materials such as mānuka stems, supplejack vine, and flax. Modernised potting is used extensively in the rock lobster industry in Aotearoa New Zealand. The fishery has comparatively low rates of bycatch – most frequently octopuses/wheke[191] (which prey on rock lobsters) and conger eels/ngōiro[192] (Breen, 2005; Kane, 2015; National Rock Lobster Management Group, 2019). Interactions with seabirds and mammals are also relatively low, though pot lines can create an entanglement risk (Abraham and Richard, 2020). Rock lobster are a high-value product and most are unharmed on capture (see 5.3.5: case study: Mixed messages: Are we overfishing our rock lobsters?).

Figure 120: Taruke kōura (crayfish trap), maker unknown. Purchased date unknown. Taonga Māori collection, Te Papa Tongarewa Museum of New Zealand (ME003080).

[191] Forty-two species in the order Octopoda.
[192] *Conger verreauxi* and *Conger wilsoni*.

Given that potting can present many advantages to bottom trawling, there's been interest in Aotearoa New Zealand about whether the technique could be applied to other fisheries. New Zealand scampi is a type of lobster that lives in the offshore areas of Aotearoa New Zealand at about 200-600 m depth. Scampi are mostly harvested by bottom trawling, which can cause damage to the seabed as well as presenting issues such as bycatch, including of non-target fish species, seabirds, and marine mammals. Scampi has the highest bycatch rate of any New Zealand fishery, with scampi making up less than 20% of scampi-targeted trawls (Ogilvie *et al.*, 2016; Ministry for Primary Industries, 2020a). This means that a large proportion of catch is discarded – thousands of tonnes a year. There are currently no species from this genus that are harvested using potting methods (Major *et al.*, 2017).

Figure 121: New Zealand scampi. Image credit: Rob Major.

Overseas, pots are used extensively to catch another type of scampi known as Norway lobsters.[193] While Norway lobsters have many small differences to New Zealand scampi and are part of a different genus, the similarities between the species provided inspiration for the possibility of a commercially viable potting operation in Aotearoa New Zealand inspired by traditional Māori potting methods.

The Waikawa Fishing Company is owned and operated by a Māori family that has been fishing the northern most part of the South Island for many generations (Ogilvie *et al.*, 2018). As the company became more aware of some of the negative environmental impacts of their operation, they saw that it did not align with their responsibilities as kaitiaki. This responsibility drove their desire to innovate, experiment and learn.

Figure 122: Ling caught in pots. Image credit: Waikawa Fishing Company.

Waikawa Fishing Company and Cawthron Institute worked together to develop a research programme along with Zebra-tech Ltd and the University of Auckland. The result was a research programme 'Ka Hao te Rangatahi: Revolutionary Potting Technologies and Aquaculture for Scampi'. The programme aims to link Māori innovation with leading edge research, design and engineering. Part of the programme focuses on how to employ innovative Māori-based potting technologies. This change in technology would herald the first major advance in this fishery in thirty years. The potting technologies developed during this research were based on designs used overseas, using local ecological knowledge and application of mātauranga approaches to modify a design suited to the Aotearoa New Zealand fishery. Research continues to

[193] *Nephrops norvegicus.*

overcome the challenges to potting local scampi and has emphasised the need to understand more about the species. The success of potting for a fishery depends heavily on understanding the biology and behaviour of a species. For scampi, the method of potting can only be successful when scampi are foraging (when they can be found outside of their burrows (Major and Jeffs, 2017)). It can takes years of research to understand behaviours, physical design, baiting and other factors that allow us to achieve a successful and less harmful alternative to traditional technologies (Major *et al.*, 2017) but the benefits are enormous.

While work on scampi continues, the potting method was reconfirmed as a viable harvesting method for the large bottom-dwelling fish ling. Ling, an increasingly valuable commercial species (see 6.7.3: case study: Trade limitations hindering the sale of a high-value fish by-product), would readily enter pots without need for specific attractants. Ling are high-level predators which means that once they are inside the pots, smaller fish (that would be prey of ling) do not enter the pots, or if they do they are eaten. By using this method for ling, bycatch has reportedly reduced to less than 1% by weight, with no seabird or mammal bycatch (Ogilvie *et al.*, 2019). In addition to this there is reportedly little to no seabed damage and a large reduction in fuel use (Ogilvie *et al.*, 2019). The design means that the fish caught are not crushed and the lack of bycatch means there is no longer a need to sort through the catch when landed. Further studies to understand the ecosystem impacts of potting for ling instead of trawling would be beneficial.

Waikawa Fishing Company has now converted all ling harvesting to the potting method. This is a success story where an alternative that causes less environmental and ecological harm can be commercially viable.

It also emphasises the importance of understanding the characteristics of different species. The success with ling, a bottom-dwelling and predatory species, provides insight into other fisheries in which a potting approach could be successful, but as learned for scampi, success is species-dependent.

Success is species-dependent.

Gurnard and rig were suggested by the researchers involved as two potential fisheries where potting could be an alternative to traditional harvesting methods (trawl and set netting) due to their similar behaviour. The utility of the potting method is especially relevant when considering the recent introduction of restrictions to catch methods in habitat areas deemed critical to Māui and Hector's dolphins and other taonga species. Research and trials in this area could provide the first steps towards wider use of potting technologies, and potentially identify other fisheries where potting could be applied.

Figure 123: Red gurnard. Image credit: jmartincrossley/ iNaturalist (CC BY-NC-SA 4.0).

6.3.11 GEAR ADD-ONS WILL BE ESSENTIAL TO DETER NON-TARGET SPECIES

In addition to the commonly used bycatch mitigation measures such as tori lines to prevent seabird bycatch, there are opportunities to innovate and develop new ways to deter non-target species from fishing activities. New devices can be added onto existing gear to deter species and protect non-target species. These include:

Figure 124: A fisher holding a banana pinger. Image credit: Fishtek Marine.

- **Acoustic deterrents.** Active sound emitters ('pingers') can be used to deter bycatch from regions where there are nets to avoid entanglement, but at a frequency that doesn't deter the target fish (Dawson *et al.*, 2013). Evidence is mixed for the effectiveness of pingers as it depends on the species, area and fishing methods (Omeyer *et al.*, 2020; Dawson *et al.*, 2013). Though there have been limited trials, the available evidence indicates that this technology may be effective for dolphins (Childerhouse *et al.,* 2020). Future developments in the area of acoustic deterrents may be beneficial but need to be precise and closely consider the benefits against the issues of acoustic pollution.
- **Visual deterrents.** Light-emitting devices such as Pisces can be used to deter non-target species. Nets illuminated by LED lights have been shown to be effective at deterring turtles and reducing bycatch in gillnet fisheries (Wang *et al.,* 2010; Bielli *et al.*, 2020). However, these methods are not applicable to all bycatch situations. For example, high contrast panels and lights failed to reduce seabird bycatch (Field *et al.*, 2019). There may be potential uses for such an approach in local fisheries and any future developments could draw on these experiences in using visual deterrents.
- **Olfactory deterrents.** A local study tested a bycatch reduction method suggested by a local fisher – sensory-based conservation of seabirds. Putting shark liver oil on the ocean surface behind fishing vessels was found to be effective in reducing the numbers of black petrel around the vessel and dives on baits compared to control treatments (Pierre and Norden, 2006). Caution is needed when considering deterrents of any kind so that the fisher is not impacted by the reduction in catch of commercially important species, as well as consideration of other unintended effects on the wider ecosystem.
- **Olfactory stimulants.** Olfactory baits could be developed to reduce non-target capture (Wagner *et al.*, 2006; Johnson *et al.*, 2013).

Uncertainty around the use of any new devices should be highlighted to decision makers.

TECHNOLOGICAL ADVANCES IN FISH DETECTION COULD REDUCE FUEL COSTS AND TIME AT SEA

Acoustics

To reduce the burden of time and fuel spent searching for fish and associated environmental damage from unproductive activity, a high-definition omnidirectional sonar on an unmanned fishing vessel can be used to look for biomass and then send that information to land-based receivers or fishing vessels.

AI

Fish aggregate based on a range of seasonal and environmental factors. By collecting this data, advanced analytics such as machine learning (introduced in section 6.2.6: AI and machine learning have the potential to increase efficiencies) could be deployed to produce more accurate predictions for the distribution of target species (Christiani *et al.*, 2019). In turn, this could reduce fuel costs and time at sea, as well as informing resource management. For example, the company Aker BioMarine Antarctic harvests krill from Antarctic waters. They have turned to digitalisation and machine learning to reduce their carbon footprint. Aker BioMarine have designed and deployed an unmanned, solar-powered ocean data drone called the Sailbuoy, kitted out with environmental sensors.[194] Data gathered by the Sailbuoy can be combined with historical and other information, and fed into machine learning models.

Matts Johansen, CEO of Aker BioMarine, told McKinsey & Company in December 2019, “We are only testing it [the model] now… So far, the model produces pretty good correlations. The model will learn as it gets more and more experience. We now spend about 10% of our time searching for krill. With this model, we expect that to be close to zero”(Christiani *et al.*, 2019).

Similar projects are in development in Aotearoa New Zealand, including a proposed system that automatically integrates electronic catch and environmental reporting data and outputs continually updated maps, showing predicted locations of target and unwanted species in real time.

Advances in underwater image capture and analysis can also improve precision and targeting of desired species. For example, the Deep Vision system combines computer vision with image analysis in a robust, subsea enclosure to enable identification and measurement of fish species underwater. Developed in Norway, it is currently used for marine research trawls, but a version suitable for commercial trawl fisheries is under development (Allken *et al.*, 2019). Deep Vision could be combined with an in-trawl sorting mechanism so that only fish of the target species and correct size are captured, while non-target species and undersize fish are released.

Figure 125: A fish with length measurement captured by the Deep Vision system. Image credit: Deep Vision.

[194] An Interview With Matts Johansen, Chief Executive Officer Of Aker BioMarine - Tech Company News

Deep Vision could be combined with an in-trawl sorting mechanism so that only fish of the target species and correct size are captured, while non-target species and undersize fish are released.

There is similar research underway in Aotearoa New Zealand to develop technologies for species identification, trait measurement and individual fish identification, which may in future be able to be employed underwater to collect data and be integrated with trawl capture and release.

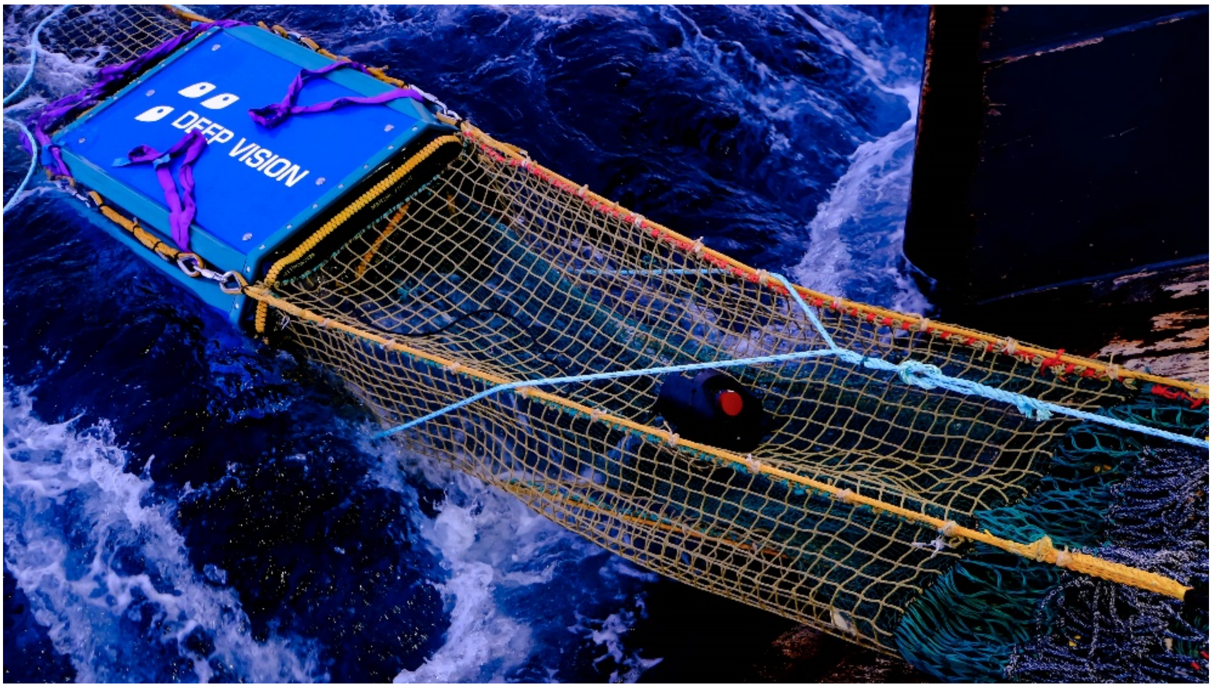

Figure 126: The in-trawl camera and image recognition system Deep Vision being deployed. Image credit: Tim Petter Hansen.

6.3.12 CHALLENGES AND OPPORTUNITIES WITH GEAR INNOVATION

Gear innovation has the potential to radically reduce the negative impacts of fishing through reducing bycatch, improving selectivity, enabling fishers to return unwanted catch that will survive, and eliminating the negative impact of gear on habitats.

New gear needs to be an economically viable alternative so that it is possible for large commercial fisheries companies and smaller independent fishers to adopt it. It can be costly to develop new gear and undertake studies to determine its effectiveness relative to the status quo. Further costs come from installing, optimising and using the new gear. Fisheries technological development has been found to have a positive influence on fisheries production, when guided by government investment (Chang and Lee, 2019) and this creates an opportunity for Aotearoa New Zealand to support our fisheries to operate in a way that is more environmentally sustainable.

New gear also needs to be practical and rooted in the needs of fishers and their practices. Part of the way to address these challenges is through enabling fishers themselves to lead the innovation, as demonstrated in 6.3.8: case study: A collaborative effort to protect vulnerable seabirds, and 6.3.5: case study: The importance of connecting fishers to researchers. The Gear Innovation Pathway (described in case study 5.6.1) takes this idea and applies to the Aotearoa New Zealand industry. While some technologies may not be affordable for smaller fishers, many invest in their own bycatch reduction technology such as using different mesh sizes, orientations and escape panels (Telesetsky, 2016). In addition to the local funding opportunities and initiatives such as the Gear Innovation Pathway, there are other programmes that Aotearoa New Zealand could take advantage of such as the WWF Smartgear Competition, which is to be revived.

Policies exist to support innovative trawl technology, but in some instances the prescriptive requirements are actually hindering innovation rather than fuelling it. True innovation needs to be assessed within a flexible monitoring framework that is not encumbered by monitoring methods inherited from old techniques. Providing a permissive environment for innovation, coupled with a requirement for monitoring stock levels and bycatch, will encourage more industry players to adopt new techniques. Extra incentives could be provided by fast tracking the special permit process through the Enabling Innovations in Trawl Technology regulations to enable simpler trial of new gear through the special permit process, so as to reduce barriers to trialling new gear within quota. Well-designed regulation that signals the need to shift to less damaging gear could incentivise technological development in this area and expedite adoption of new technologies.

True innovation needs to be assessed within a flexible monitoring framework that is not encumbered by monitoring methods inherited from old techniques

6.4 HOW MUCH WE FISH

We could have a much deeper understanding of stock status, ecosystem health and exactly what is being taken from the marine environment to inform decisions around how much fish is allocated to commercial catch. That extra knowledge will enable an EAFM.

Here we discuss how different innovations – some already in play and others that may support fisheries management in the future – can help us to better understand the commercial fishing catch and inform management decisions around how much to catch going forward:

- Computers, cameras and AI could revolutionise catch monitoring.
- Technical and analytical advances will help stock assessments.
- Innovations that expand ecosystem knowledge will add an extra dimension to fisheries management.

The technologies surveyed in this section inform our recommendations in Themes 4-7.

Figure 127: Electronic monitoring cameras onboard a fishing vessel. Image credit: AFMA.

6.4.1 COMPUTERS, CAMERAS AND AI COULD REVOLUTIONISE CATCH MONITORING

It's important to know precisely how much of the allocated catch is caught to ensure that future management decisions about catch allocation are sustainable. Shifting from manual to electronic methods to gather information about catch is a key way to improve accuracy. These electronic methods generate far more data than prior approaches and AI may provide a useful tool to streamline analysis so that catch monitoring can inform fisheries management in real time. In some cases, the inshore and deepwater contexts may require different technologies because of their inherent differences.

As discussed in section 5.5.2: On-board cameras are being introduced, at-sea observer programmes tend to be accompanied by both deployment and observer effects that skew collected data (Hilborn *et al.*, 2009).

6.4.1.1 ELECTRONIC MONITORING (EM) AND REPORTING

Over the course of the 20th century, increasing recognition of impacts on marine resources prompted requirements for fishers to report their catch. This collected data could then inform management of marine resources. Now, fisheries around the world are in the next phase of modernisation: shifting away from old-school pen-and-paper logbooks towards digital solutions. As discussed in section 5.5.1: Electronic catch and position reporting is live, an EM system is underway in Aotearoa New Zealand but is in its infancy.

EM with digital technology enhances the transparency, traceability and sustainability of commercial fisheries. The same data is required of commercial fishers, but a major benefit of EM is that the quality and reliability of commercially reported data is likely to improve and is verifiable, which will support better and more nimble decision making by the regulator. Though currently primarily used for compliance, it has the potential to enable more efficient and robust data collection to inform decision making and sustainable management of our ocean, as well as generating economic value for industry.

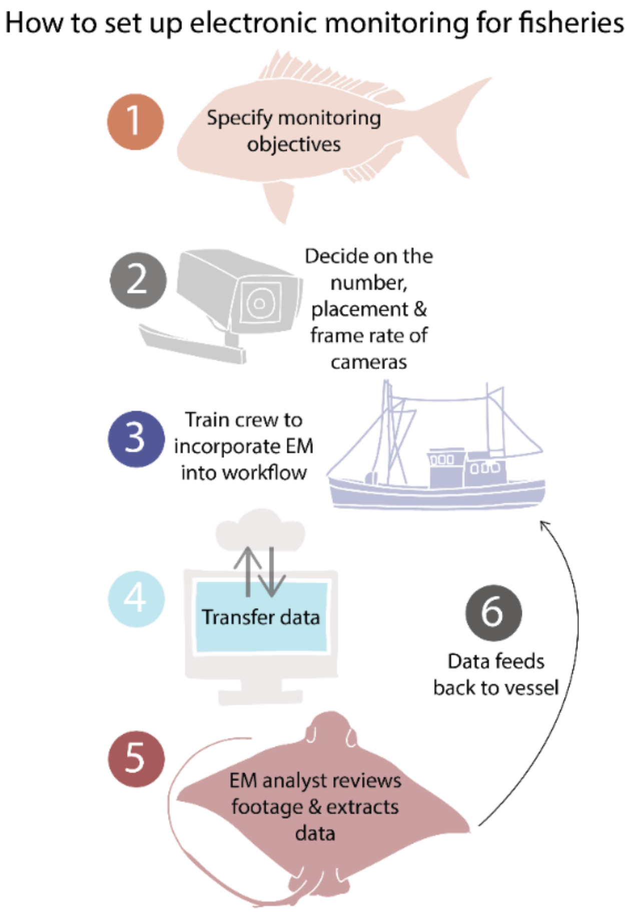

Figure 128: Schematic of the process for implementing an EM programme for fisheries.

There are three basic elements of EM:

- An e-log book to report catch (replaces traditional paper-based logbooks).
- A GPS system to report location to keep track of where and when people are fishing.
- On-board video cameras to verify reported catch data and activity.

Different tools are used for different sized vessels. For example, the electronic reporting for the pāua vessel featured in 5.3.7: case study: Pāua fisheries and industry-led management, was done on a mobile phone.

An EM system often also incorporates activity sensors that can detect when fishing gear is deployed. These sensors can be integrated with the camera system, such that the camera starts recording only when fishing is in progress. The resulting data and footage are often stored on hard drives that must be physically transferred to reviewers onshore, although some programmes are now moving to Wi-Fi, satellite or cellular network transfer and cloud storage. The footage is reviewed onshore by a trained observer – either in full, or a random portion is cross-checked for consistency with self-reported data.

It must be emphasised that simply putting cameras on boats is not the end goal for EM efforts. The promise of EM systems will be realised when the detailed data they generate is channelled into efficient and adaptive management decisions – including in real time – that enhance fisheries for all. This will include allowing these rich datasets to be mined for both commercial and environmental benefit. Some commercial fishing companies are already using their EM data to inform their own decisions, but there is potential for much wider benefit. In this way, the most successful EM programmes will have specific objectives and standards that invite collaboration and integrate with management and information systems.

The promise of EM systems will be realised when the detailed data they generate is channelled into efficient and adaptive management decisions – including in real time – that enhance fisheries for all.

OVERSEAS EM PROGRAMMES

Around the world, there are approximately 1,000 fishing vessels across 30 different fisheries outfitted with an EM system. This represents just 0.25% of all fishing vessels over 12 m in length (Michelin *et al.*, 2018). The world's first EM programme was trialled in British Columbia, Canada, in the late 1990s (Michelin *et al.*, 2018). An industry-led initiative, EM was rolled out across the intensely competitive Dungeness crab[195] fishery to tackle catch and gear theft and to ensure compliance with trap limits.

North America continues to lead the world when it comes to EM, with the majority of comprehensive and fully implemented EM programmes based in the US and Canada (van Helmond *et al.*, 2020). In some fisheries, such as Canada's British Columbia Groundfish Hook and Line Catch Monitoring programme, there is 100% EM coverage (Stanley *et al.*, 2015). Others use a mix of EM and human observers. Funding also varies: some programmes initially operated under co-funding arrangements between industry and government, before transitioning to industry-only funding.

In the US, pre-existing at-sea observer coverage influences the receptiveness of a fishery to EM (Michelin *et al.*, 2018). Fisheries with higher observer coverage see a cost benefit to switching to EM, whereas fisheries with little observer coverage may incur higher costs by implementing EM.

Across the Tasman, the AFMA runs an EM programme with coverage across four fisheries (Australian Fisheries Management Authority, 2020). Coverage is expected to expand into other fisheries over the next 5-10 years.

BARRIERS AND BENEFITS

Video monitoring is the most challenging component of EM to implement – but for the most part, the challenges are not technical, but rather to do with people, relationships and communication. A collaborative, co-design approach is needed to develop EM programs that suit the needs of fishers and thus ensure buy-in by enabling commercial and environmental goals to be met as well as being simply a compliance tool.

[195] *Metacarcinus magister*.

"A major contributor to the success of EM in Alaska was the switch from a top-down to an all-hands approach with all stakeholders at the table developing the details."

- Dan Falvey, Alaska Longline Fishermen's Association, National Electronic Monitoring Workshop 2016, NOAA Fisheries (National Oceanic and Atmospheric Administration, US Department of Commerce and National Marine Fisheries Service, 2016).

Cost

There is a significant up-front cost associated with installing cameras and computer hardware and the set-up must be tailored to the specific characteristics of the vessel. This cost is especially problematic for small-scale or independent fishers. There are also ongoing costs associated with data storage and transfer that are non-trivial. Cost varies substantially depending on the goals of the EM programme, the number of cameras required, the level of review required, and the amount and duration of data storage.

A 2016 report found that in the US, EM costs range from 50% to 150% of human observer costs depending on specific aims and characteristics of the fishery (Sylvia *et al.*, 2016). Generally, as fishing effort increases, EM becomes more cost effective. Observers may be retained to provide other uses on-board so the costs may actually be even larger with implementation of EM.

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Changes in practices

The presence of on-board cameras for EM may drive a change from the portion of the industry that is misreporting and illegal practices to more accurate reporting and changed fishing practices. EM may also require fishers to alter their workstream in ways that may add labour and costs. For example, fishers may need to present their catch to the camera view, slowing down the sorting process.

Privacy

Many fishers feel that video monitoring is intrusive and that such surveillance represents a distrust in them from government (Mangi *et al.*, 2015; Plet-Hansen *et al.*, 2017). Guidelines for the use and retention of EM data, especially imagery, must be clearly defined and communicated: who owns and has access to the data?

"Numerical data is hard to manipulate but video images and pictures can be altered and misinterpreted… one image taken out of context could negatively impact a fisherman or the entire industry."

- Mike Russo, New England Groundfish Fisherman, National Electronic Monitoring Workshop 2016, NOAA Fisheries.

Suggested uses of drones to monitor fishing effort, including the two hypothetical case studies presented in a 2019 paper involving using drones to monitor recreational fishing effort and use of public lands (Nowlin *et al.*, 2019), also raise privacy and ethical issues that must be considered if unmanned autonomous vehicles are used for human surveillance purposes – whether of the general public or of commercial fishers.

Data review

Video monitoring also creates large volumes of data that must be reviewed – either in full, or a random selection to corroborate self-reported data. The amount of data to be reviewed, and the speed of review, depend on the objectives of monitoring – for example, if the aim is to monitor rare events such as seabird captures, it is likely 100% of the footage will need to be reviewed, but can be watched at higher speed (Pierre, 2018). Automated and AI solutions are being investigated to deal with this vast amount of data (see section 6.2.6: AI and machine learning have the potential to increase efficiencies). Until these technological solutions eventuate, EM analysts (who may be former on-board observers) should be trained to an assured standard to ensure reliability of and confidence in datasets produced.

> Automated and AI solutions are being investigated to deal with this vast amount of data. Until these technological solutions eventuate, EM analysts should be trained to an assured standard to ensure reliability of and confidence in datasets produced.

Demonstrating business benefits beyond compliance

EM acceptance among fishers will improve if there are demonstrated benefits beyond its use as a compliance tool (Michelin *et al.*, 2018). This can be supported by specifying clear management-derived objectives for EM and reporting from the outset. Currently, costs of EM are very clear to fishers, while benefits are much more uncertain. Conversations about EM should broaden beyond compliance to encompass possibilities for value enhancement and innovation.

"Without the camera, my information is viewed as anecdotal to managers but a camera makes the observations more substantive. This gives fishermen power that they did not have before."

- Mike Russo, New England Groundfish Fisherman, National Electronic Monitoring Workshop 2016, NOAA Fisheries.

Some limitations compared to what observers can achieve

The additional scientific tasks that observers undertake on board a fishing vessel (e.g. tissue sampling or otolith extraction) cannot be replaced by EM. There may also be some limits to what EM can identify compared to an observer where features are not discernible with current technology, though this may improve over time.

Benefits

Although EM is an important tool for enhancing compliance with regulations, it has other less obvious benefits. EM can also:

- Ensure all fishers are operating on a level playing field.
- Empower fishers by providing concrete evidence that can back up their assertions in conversation with regulators and the public, building trust (see 6.4.3: case study: Livestreaming commercial fishing catch).
- Improve quality of life at sea, by removing the necessity for an on-board observer who requires a berth, food etc. or, if observers are retained, expand monitoring of ecosystem health via tracking non-commercial index species.
- Verify claims about sustainability and traceability, allowing fishers to market an eco-certified, net/hook-to-plate product that is higher-value.
- Enable more flexible management of fisheries (discussed in section 6.2.1: Changing fisheries demand nimble and responsive decision making). For example, identifying individual vessels with issues, meaning fishery-wide area closures can be avoided or scaled back. Fisheries managers can switch to more targeted management measures (e.g. fleet-wide, individual trip or vessel caps).
- Allow analysis of the product handling process, with a view to enhancing quality and value of the catch.
- Enable skippers to monitor activity on the vessel from multiple camera views, which has both operational and safety benefits.
- Monitor whether fishers are using the best practice mitigations (defined in regulations and the new *National Plan of Action Mitigation Standards*).
- Possible future benefits could be achieved through linking EM data with other real-time data to inform fishers about the environment to mitigate risks and/or enhance fishing effort.

Examples of these benefits in action are highlighted in section 6.5.5: Dynamic ocean management will help protect non-target species in real time, and 6.5.6: case study: EcoCast – an app that can help fishers decide where to fish.

6.4.1.2 IMAGE PROCESSING

Improved computing can also enable rapid processing and analysis of images. This has a range of potential applications in fisheries and the information gleaned from it can inform fisheries management. Awalludin *et al.*, (2020) reviewed image processing techniques for fisheries, listing the following applications: fish classification, counting and abundance, fish weight and length, fish tracking, fish disease, fish tissue properties, and fish habitat identification.

The marine environment can be very challenging for computer hardware – with issues relating to power, access to the internet, and generally rough conditions. Sea-going hardware needs to be robust and resilient. Schoening (2019) describes the development of a mobile sea-going high-performance computing cluster (ShiPCC), robustly designed to operate with electrically impure ship-based power supplies and based on off-the-shelf computer hardware. The SHiPCC units are envisioned to generally improve the relevance and importance of optical imagery for marine science.

6.4.2 CASE STUDY: eCATCH APP AND THE CALIFORNIA GROUNDFISH FISHERY

In 2006, environmental non-profit The Nature Conservancy purchased 13 permits to trawl for groundfish off the coast of California (Merrifield *et al.*, 2019). The West Coast groundfish fishery, which includes more than 100 species, had just been declared a "federal economic disaster" with several species officially designated as overfished. The Nature Conservancy wanted to manage the fishery in a way that was sensitive to at-risk species and habitats. At the time, vessels used paper logbooks to collect and report data in a process that had a lag time of several months. In order for data to effectively and efficiently inform management, this process needed to speed up significantly.

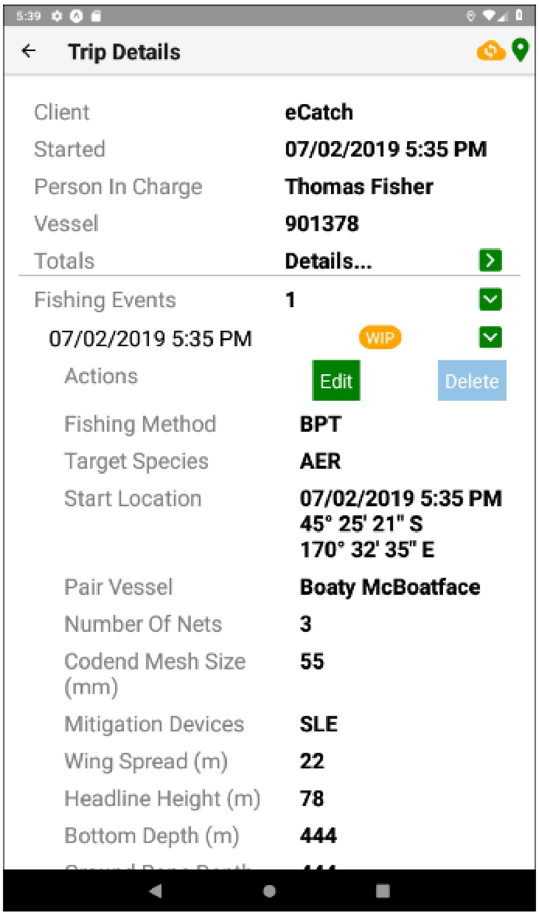

Figure 129: Screengrab from the eCatch app.

The solution was to develop an app called eCatch, which allows users to "capture, visualise and share logbook data" on any smartphone or tablet. The development of eCatch was facilitated by the emergence of mobile technology, cloud storage and accessible mapping interfaces on the internet. Vessels that used eCatch were required to share their data and in return could join a 'risk pool', where participants pooled together their quota of bycatch of overfished species. Through the data provided in eCatch, fishers collaboratively mapped their fishing efforts and identified areas with greater risk of bycatch. As a result, fishers using eCatch caught 22.5% less overfished species than other groundfish trawlers. The collective of fishers was able to use this data to attain certification from Seafood Watch. In this way, eCatch demonstrates how "locally-owned data and explicit information sharing is an effective way to empower fishermen".

"Locally-owned data and explicit information sharing is an effective way to empower fishermen."

The eCatch app is available in Aotearoa New Zealand and complies with Fisheries New Zealand reporting regulations (eCatch New Zealand, 2020).

6.4.3 CASE STUDY: LIVESTREAMING COMMERCIAL FISHING CATCH

A local fisher from Te Matau-a-Māui the Hawke's Bay took video monitoring one step further: livestreaming his fishing expeditions to the world.[196]

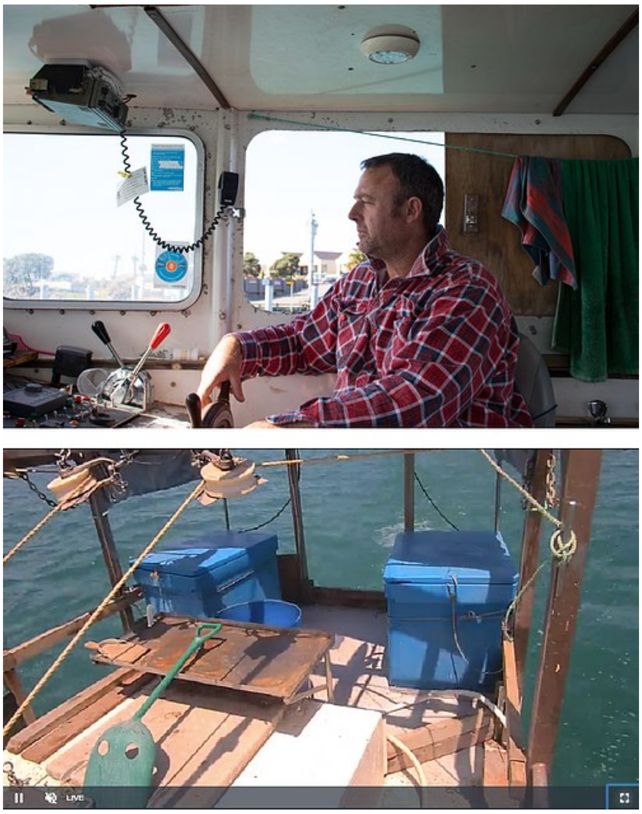

Figure 130: Screengrab from Karl Warr's livestreaming efforts. Image credit: Better Fishing.

Karl Warr operates his small commercial fishing company out of Ahuriri Napier. Recognising a disconnect between peoples' views of the industry and his own fishing practices, Karl opted to let people see behind the scenes to observe the fishing methods and deck operations on his vessel, and better understand what happens to get the fish from sea to plate. This could help people make informed decisions when buying or eating fish from wild fisheries.

Karl isn't the first fisher to use a camera on a boat. It is becoming more common for vessels to have video cameras installed to collect data for later use for monitoring, compliance and enforcement purposes. What was unique about the approach from Karl's company, Better Fishing, was the level of voluntary transparency to the general public. The video stream was available online in real time, 24/7, thanks to camera technology from Nelson-based SnapIT – local leaders in EM and AI tech for fisheries.

An added benefit of the open approach is that it provides an opportunity for people to see real-life fisheries processes and from these insights develop innovative ideas to help improve fisheries practices.

There are future plans to implement AI that can alert people when there's action happening on the boat, such as hauling or sorting, and to livestream other aspects of the fishing like seeing what happens in the net underwater.

Recognising a disconnect between peoples' views of the industry and his own fishing practices, Karl opted to let people see behind the scenes to observe the fishing methods and deck operations on his vessel, and better understand what happens to get the fish from sea to plate.

[196] Post-script: Karl has since ceased his livestreaming operation.

6.4.3.1 AI HAS POTENTIAL TO STREAMLINE REVIEW OF EM

There have been some small pilot projects related to AI and fisheries in Aotearoa New Zealand and overseas, with more currently in development.

EM can help generate reliable and transparent fisheries data at a lower long-term cost than on-board human observers. However, this information still needs to be sorted and analysed. Manual review of video footage is time-consuming and costly (Wilcox, 2018).

Instead, we could use AI to review video with a combination of computer vision and machine learning to count and measure fish and identify species. This tech has the potential to make EM more efficient and cost-effective (Michelin *et al.*, 2018) and is being actively pursued by officials in Aotearoa New Zealand (Ministry for Primary Industries, 2020).

In 2017, The Nature Conservancy collaborated with the Gulf of Maine Research Institute to crowdsource AI solutions to the fisheries video review problem (The Nature Conservancy and Gulf of Maine Research Institute, 2017). They offered a first prize of US$50,000 for the best algorithm, attracting 620 entries. The winning entry was able to identify five out of seven target species at 90% accuracy. Its counts were accurate to within one fish 83% of the time and average measurement errors were just below 2%.

The winning entry was able to identify five out of seven target species at 90% accuracy. Its counts were accurate to within one fish 83% of the time and average measurement errors were just below 2%.

While this may seem promising, scaling up AI for video review remains problematic. It is difficult to design a single AI solution that works across different fisheries and vessels, each with a unique set of species and environmental conditions.

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But even if a machine learning system does not match human performance, it can still expedite the review process (Malde *et al.*, 2019). Less accurate programmes can weed out irrelevant data or perform rudimentary sorting, making human review more efficient (and interesting).

Similar systems can be used for streamlining marine research. To address a backlog of imagery data collected by NOAA, the fisheries division of NOAA partnered with Kitware Computer Vision Inc. to develop the Video and Image Analytics for Marine Environments (VIAME) software (Dawkins *et al.*, 2017). VIAME has been used in underwater fisheries surveys, streamlining analysis of still and moving images and resulting in significant cost savings (Allken *et al.*, 2019). It can detect scallops on the seafloor (similar to the work profiled in 6.3.6: case study: Scallop surveys and harvest), track and classify reef fish, and count and classify seal and sea lion species from aerial surveys.

6.4.4 CASE STUDY: SNAPIT'S VIDEO CAPTURE SYSTEMS

Award-winning, Whakatū-Nelson-based company SnapIT combines high-definition image capturing with a system to process, transmit and analyse data. EM produces data that can enhance the traceability and transparency of fish products and build trust between fishers and consumers – thereby increasing the market value of the fish products. The importance of a credible, traceable product story for fish is reportedly increasing for consumers.[197] SnapIT provide EM services to various fishers around the world.

Figure 131: Camera for electronic monitoring in the fishing industry developed by SnapIT. Image credit: SnapIT.

The company pivoted to developing cameras for the fishing industry after a serendipitous encounter with Sanford. SnapIT developed hardware suited for the unique and extreme environment on-board a fishing vessel, as well as appropriate software. The company has rolled out New Zealand-made cameras and hardware across North America, the Pacific and Aotearoa New Zealand – including equipping fisher Karl Warr with the hardware necessary for his livestreaming efforts (see 6.4.3: case study: Livestreaming commercial fishing catch). SnapIT also provide EM review software for governments that is compatible with multiple camera suppliers. This platform is used by the US government and has recently been picked up by two states in Australia. SnapIT work closely with Canada-based Teem Fish Monitoring, who also provide EM programme management. Teem and SnapIT are collaborating with FINZ and the Ministry for Primary Industries on a project based here in Aotearoa New Zealand.

SnapIT are actively developing AI-driven analytics. So far, the operational camera systems have yielded more than 200 years' worth of footage with plenty of human annotations – a source of training data to build AI capability. With their SnapAI model, the company uses machine learning to train software to observe fishing catches – reporting back on size, species and vessel activity classification. AI trials are currently ongoing on some North American fishing vessels. SnapIT are also developing AI-driven analytics to cut down on the footage for manual review: differentiating 'action events' from the footage where nothing of interest is happening, so that human reviewers don't have to sift through as much footage.

SnapIT are also keen to emphasise that EM is not just about compliance. They are embarking on a project that uses EM and other data to enhance the relationship between primary producers and consumers, building trust through transparency. The data is leveraged to increase the market value of products.

EM is not just about compliance. The data is leveraged to increase the market value of products.

In their latest project, SnapIT are developing a platform to connect fishers with AI developers. This would give fishers the opportunity to commercialise their data, as well as connecting AI developers to data, allowing them to design models specific to a supplier. It is envisioned that such a system will provide the connections and wealth of data needed to accelerate the development of effective AI analytics for EM.

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[197] Input from Mike Egan at the Seafood Industry Workshop in 2020.

6.4.5 TECHNICAL AND ANALYTICAL ADVANCES WILL HELP STOCK ASSESSMENTS

Innovations can improve understanding of stock status and structure to inform accurate catch limits. As discussed in section 5.3: Commercial fishing has impacts on target species sustainability, there are well-established methods to undertake stock assessments that are applied in Aotearoa New Zealand's fisheries, to some but not all commercially fished stocks. There is significant room for improvement and new tools and technologies can augment the current approaches. Ensuring there is adequate data and information to achieve annual stock assessments of every commercially fished species by 2040 would go a long way to support the sustainable management of these fisheries. In order to meet this target, a broader suite of scientific approaches will need to be drawn on.

Ensuring there is adequate data and information to achieve annual stock assessments of every commercially fished species by 2040 would go a long way to support the sustainable management of these fisheries. In order to meet this target, a broader suite of scientific approaches will need to be drawn on.

Here we outline how three scientific approaches – genetic technologies, biochemical analyses and acoustic technologies – could add to our knowledge base on the health of fish stocks and support more informed fisheries management. Though the technologies themselves are not new, innovative applications, decreasing costs and improvements in analytical capabilities will render these tools invaluable for fisheries scientists to assess the sustainability of a fishery in the years to come. There is a consensus that no single tool will address all of the questions on fisheries/ecosystem management, instead a toolkit approach will be needed whereby the right suite of tools are selected to address the specific fisheries question. The integration of new methods/tools into fisheries monitoring can disrupt long term data collection approaches so there needs to be a fine balance of if and when to integrate new approaches as the implementation of new methods often means stopping another form of data collection.

6.4.6 GENETIC TECHNOLOGIES

Although genetic technologies have been used in fisheries science since the 1980s (Ovenden, 1990; Bernatchez *et al.*, 2017), they have only recently started to be actively incorporated into the management of fisheries for some of the key commercial species (Casey *et al.,* 2016). Since the first use of population genetic characterisation for stock assessment, there have been remarkable advances in the field of genetics with the technological capabilities (notably, next-generation sequencing technologies or NGS) increasing at rapid pace and cost decreasing at a similar rate. The most common genetic technology that is used on wild fisheries is population genetics whereby the genetic diversity, population 'health' and interconnectedness of population can be determined with high precision. Historically, most applications use microsatellite markers that profile genetic information at less than 20 specific data points. More recently, NGS approaches have been used that can capture thousands of data points and capture much more nuanced data on population structure, sex ratios and migration (Bernatchez *et al.*, 2017). Furthermore, recent epigenetic technologies are starting to use DNA methylation data to determine age of an animal – a technique that has been used successfully on whales using minimally invasive biopsies.

Genetic profiling, genetic mark/recapture, fish diets, epigenetic ageing, fish microbiomes and eDNA therefore have largely untapped potential that is not being capitalised on in the active management of fisheries across Aotearoa New Zealand. This was recently highlighted at a Fisheries New Zealand workshop on the utility of genetic analyses (Mace *et al.*, 2020). Even since this workshop fisheries-based genetic tools have advanced. In the case of land-based farming, genetics has been a key tool in active management of farms including stock selection – the industry has been at the leading edge of applying genomic technologies in practice. Wild fisheries could look to the application of genetic technology in aquaculture and agriculture for inspiration and learn from their experiences (Tuck *et al.*, 2014; Symonds *et al.*, 2018).

Genetic technologies may be able to replace conventional methods or augment other methods to improve outcomes in fisheries management (eDNA technology is covered in section 6.4.16 and appendix 12: Methods and applications of genetic technology in fisheries, has further detail). Several genomic applications can provide fundamental data to support the sustainable management of fisheries. They can be used to:

- **Identify and assess fisheries stock structure and connectivity.** Genetic data can be used to quantify the number of genetically discrete and thus reproductively isolated populations, and how related different populations are, and help us understand the geographical area over which a stock resides. The ability to genetically sex individuals is also useful in understanding population structure and sustainability. The data can also be used to measure the extent of movement and sharing of individuals between the populations. This information could inform decisions around whether genetically distinct populations need to be managed in separate stocks (Verry *et al.*, 2020).
- **Resolve mixed-population fisheries.** Genetic markers or whole-genome sequencing (WGS) can be used to delineate populations accurately, identify source populations, and determine the percentage of fish that breed separately but are exploited as one stock. This information can facilitate appropriate harvest strategies by season (see 6.4.7: case study: Real-time genetic management of a marine fishery). This information could be used to assess, and where necessary redraw, boundaries of QMAs to ensure these align with biological stocks to enable more informed management.
- **Better understand population demographics and dynamics.** Genetic information can be used to estimate effective population size (as a 'window' to estimate of census population size), genetic diversity and mortality rates, and track changes in abundance through time, including prior to commercial fishing. This can be broken down into year classes if age data is available and thus can provide insights into recruitment dynamics. This information can help us better understand evolutionary responses to fishing (Bernatchez and Wellenreuther, 2018), which may inform management choices (see 6.4.8: case study: What does ancient DNA tell us about the snapper population?). Genetic information can be gathered at a population level or an individual level. Data on genetic diversity, parent-offspring relationships, sibling relationships and sex ratios can provide population-level information (Mace *et al.*, 2020). Genetic tagging of individual fish (as an alternative to physical tagging) can provide information about abundance, population biomass, and growth as well as movement behaviour, and how these change through time (see 6.4.9: case study: Genetic tagging to understand bluefin tuna population dynamics). Improvements in technology and analytic techniques mean these estimates are improving. Genetic data can also be used in tandem with other data on maturation, size-at-age and biomass to improve our understanding of and ability to monitor fisheries-induced evolution (Heino *et al.*, 2015).

BARRIERS TO USING GENETIC TECHNOLOGIES IN FISHERIES AND POSSIBLE SOLUTIONS

While genetic technologies show a lot of promise for application in fisheries management, several barriers currently limit the ease of application in an industry setting. Some could be addressed in the present, while others may require further work to support uptake of these technologies.

- **Lack of genomic reference material.** The success of many genetic applications in fisheries management can be streamlined and improved with appropriate reference and baseline data. In an ideal case, core resources of the species in question would be compiled to ensure optimal data capture and resolution (e.g. a reference genome) (Dahle *et al.*, 2018). However, progress can also be made without the key resources. For example, spatial sampling of a species could take place without such *a priori* knowledge. Ideally, however, reference genome assemblies are compiled and single nucleotide polymorphism (SNP) chips developed, particularly when starting long-term research studies or large projects, as time and data quality benefits from these resources would then outweigh the initial costs of setting these up. Doing so requires local efforts to support our local commercial fisheries sector. Some commercially significant fisheries species have had reference genomes developed, including snapper and trevally. Tarakihi and blue cod are underway. Some protected fish species and marine mammals have also been prioritised through conservation efforts, including great white shark, whale shark,[198] spine-tailed devil ray,[199] oceanic whitetip shark,[200] basking shark[201] and bottlenose dolphin/terehu[202] (Mace *et al.*, 2020). However, for the vast majority of New Zealand fisheries species no genomic resources exist at this stage. Collaboration and education between researchers, industry and communities to continue this trend of building up DNA databases and reference genomes will help to interweave genetic tools more seamlessly into the fisheries management toolkit.

Some commercially significant fisheries species have had reference genomes developed, including snapper and trevally. Tarakihi and blue cod are underway.

- **Perception that genetic studies are expensive.** Costs have been reducing rapidly for genetic sequencing, including newer genomics (NGS) approaches, but people often think these technologies are prohibitively expensive (Bernatchez *et al.*, 2017). Depending on the genome size and depth of the genomic data required, one sequenced individual typically costs between NZ$20-40. For spatial analyses one typically aims to sample 30-50 individuals, and meaning that the costs per population sample are around NZ$2,000. It is more expensive to generate the reference genome (currently NZ$20-30,000 for the sequencing) and baseline work (e.g. developing a SNP chip panel) than to undertake the ongoing, routine sequencing. For genetics studies designed to address many of the more important questions for fisheries management, this perception may often be correct; however as costs are expected to keep declining, this may change in the future. Improved communication of the costs and benefits of such approaches and sharing examples of successful implementation will be important to increase uptake for appropriate applications throughout industry.
- **Lack of experience integrating genetic data into decision-making processes.** Depending on the application and findings, genetic data may provide key information to inform practices or it may have smaller weight in the decision-making process. It has been reported that the industry has negative perceptions around genetics results not being important (Bernatchez *et al.*, 2017). Pilot studies to address these issues may help to iron out how new information gleaned from genetics studies can feed into fisheries management decisions. Upskilling of staff in management positions is needed and a good dialogue between scientists and managers. There needs to be awareness of data that is available to inform decisions and ensure it gets to the decision makers and they know how to integrate it. The recent high-profile use of genomics in the COVID-19 response may have helped to normalise the use of genetic data in real-time decision making. Greater training and education surrounding the utility, cost and benefit of genetic tools is needed across the sector.

The recent high-profile use of genomics in the COVID-19 response may have helped to normalise the use of genetic data in real-time decision making.

- **Genetic tagging can be invasive.** The invasive nature of taking biopsies for genetic tagging can be risky depending on the methods needed, making it difficult to gain permits to use this approach. Using specific

[198] *Rhincodon typus*.
[199] *Mobula mobular*.
[200] *Carcharhinus longimanus.*
[201] *Cetorhinus maximus.*
[202] *Tursiops truncatus.*

approaches for taking tissue biopsies for different species and refining these further to reduce risk can address this issue. For example, using biopsy hooks for samples collected at depth as this is associated with negligible mortality. This is particularly true for deepwater species that cannot be simply brought to the surface alive. Skin swabs have been demonstrated as a viable alternative to sample fish for genetic studies (Monteiro *et al.*, 2014; Le Vin *et al.*, 2011).

- **Need to consider genetic data rights.** In Aotearoa New Zealand, genetic data rights and interests need to be factored into any genomic studies. Genomics and data sovereignty are of particular significance to Māori and in marine research the impact on taonga species should be considered.

Collaboration and education between researchers, industry and communities to continue this trend of building up DNA databases and reference genomes will help to interweave genetic tools more seamlessly into the fisheries management toolkit.

USING GENETIC TECHNOLOGIES IN AOTEAROA NEW ZEALAND'S FISHERIES

The use of genomic technologies is not commonplace in Aotearoa New Zealand fisheries management, but several workstreams are currently underway that will pave the way for such applications (see appendix 13: Genetics in fisheries in Aotearoa New Zealand). Building on the efforts of the Fisheries New Zealand workshop (Mace *et al.*, 2020), researchers, industry, iwi and community should work together to address barriers, prioritise applications based on sustainability concerns and economic/cultural value. Feasibility studies which aim to determine where using genetics could be a cost-effective approach to inform sustainable management of our fisheries. We can also draw on the experiences of other countries who are beginning to integrate genetic technology in fisheries management, including Norway (see 6.4.7: case study: Real-time genetic management of a marine fishery), Australia (see 6.4.9: case study: Genetic tagging to understand bluefin tuna population dynamics) and the US (see 6.4.17: case study: Managing great white shark conservation through eDNA). Because the application of genetic technologies in fisheries management is in its relative infancy, there is opportunity for local work to push the frontiers in this space, especially considering the strong international scientific footprint that Aotearoa New Zealand has in the areas of bioinformatics and phylodynamics.

To maximise on the potential of these applications, efforts need to be made to ensure that the various samples being collected now can be repurposed for genetic studies. For example, marine mammals that wash up on shore, become stranded, or are caught in trawls usually have small tissue samples taken. These are stored by various Aotearoa New Zealand institutions, often in an ad hoc way in university or museum freezers. However, some samples may be compromised due to poor handling and processing. The animals that strand may not be fully representative of the genetics of the population, which also needs to be factored in when using such samples. There is an emerging need for a more centralised repository of tissue samples and environmental samples (akin to a biobank). Such an initiative would have to play close attention to issues of data sovereignty and sample use especially in the case of taonga species.

Increasing demand for these technologies will also require more local capacity and capability to do high-throughput sequencing and store data. These efforts would need to be connected to other efforts within the fisheries sector to aggregate and use data to inform fisheries management decisions. There are also initiatives underway across Aotearoa New Zealand to familiarise communities and iwi with genetic technologies in environmental applications, these include the Wai Tūwhera o te Taiao (Open Waters Aotearoa) initiative led by the EPA, and the Lakes380 and biosecurity initiatives led by the Cawthron Institute.

6.4.7 CASE STUDY: REAL-TIME GENETIC MANAGEMENT OF A MARINE FISHERY

A meal of fish and chips in the UK or US is likely to include a fillet of Atlantic cod.[203] Fishers use many different methods to catch these fish from the open waters or near the seabed in the Atlantic Ocean.

Cod caught off the coastal regions of Norway could be from a population with relatively stable numbers (Northeast Atlantic cod) or it could be from a severely depleted one (Norwegian coastal cod). Catching a fish from the fragile fish stock may contribute to irreversible damage to that population that could lead to collapse, but catching a fish from the abundant stock is sustainable.

How can technology help?

Genetic technology provides a solution to help tackle this problem, as demonstrated by a trial in Norway that used a 'real-time' genetic management programme to actively manage this economically important fishery (Dahle *et al.*, 2018). Despite spawning in the same area, the Northeast Atlantic cod and Norwegian coastal cod populations are from different locations and are genetically different. This is referred to as a 'mixed stock fishery'. The genetic differences mean that we can use DNA technology to differentiate between the stock populations rather than relying on approaches traditionally used such as looking for microchemical markers of difference. For these particular fish stocks, a single genetic marker indicates which population the fish come from – 90% of the Northeast Atlantic cod have one type of allele and 81% of Norwegian coastal cod have the other.

How did genetic technologies improve cod fishing in Norway?

Every week over an 11-year study period, researchers analysed the genetics of the commercial catch, which amounted to 200 independent samples including more than 18,000 cod. The researchers took samples from dead fish captured as part of the commercial catch, sent it off for sequencing and, based on the genetic markers, estimated the proportion of Northeast Atlantic cod – all within 24 hours. The regulator set a minimum limit of 70% of the catch to be Northeast Atlantic cod, the highly abundant stock. The genetic results verified whether the cod sampled from commercial catch met these requirements.

The researchers took samples from dead fish captured as part of the commercial catch, sent it off for sequencing and, based on the genetic markers, estimated the proportion of Northeast Atlantic cod – all within 24 hours.

The regulatory body was able to use the findings to regulate the fishery in real time and to make longer-term decisions about where and when fishing for cod could occur to target the abundant stock and leave the fragile stock to replenish. For example, the regulators reopened a previously closed area for commercial cod fishing after sampling showed that the proportion of the stable stock was above 70% for an extended period. Genetic data also fed into decision making around when commercial operations could fish for cod in certain regions by highlighting how the fish population changed during different months at different locations. For example, in the same month in 2007 Northeast Atlantic cod made up 91% and 50% of the catch at two different regions. The

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[203] All varieites of Atlantic cod, including Norwegian coastal cod and Northeast Atlantic cod are *Gadus morhua.*

following year it was 100% and 20% at the same regions. This data makes clear that during that month, fishing in the first location would be acceptable but at the second location, it would not.

What currently limits use of this technology in our fisheries?

There are very few examples of fishers routinely using this approach to manage fisheries in real time – though there are mixed population stocks where such an application may prove beneficial such as the east/west split for hoki. The Norwegian trial estimated the DNA-analytical costs to be 0.02% of the landing value of the fishery during the study period. Another limitation includes needing known genetic markers that distinguish between populations in a mixed stock fishery. These limitations can be overcome with a small pilot study that would develop protocols for rapid DNA extraction suitable for that species, sample a reference group of individuals, ideally from a large spatial area, and then sequence the whole genome of these individuals. It could then be investigated which genetic variants may prove useful in delineating stocks, regions etc., and those could be subsequently targeted.

What might happen between now and 2040?

Genomic approaches will replace traditional approaches, moving from using only a handful of genetic markers to upwards of 1,000 across all of the organism's genes, differentiating different stocks with higher accuracy. For example, the Atlantic cod study only tested one genetic marker, which didn't have 100% accuracy to segregate the two stocks, meaning that roughly 10-20% could have been classified as the wrong stock. Incorrect classification could be reduced by testing more markers to be surer which stock the fish was from.

Advances in the field mean that genomic technology will be an important tool to help ensure the long-term sustainability of wild fisheries by providing real-time data that supports commercial catch of abundant stocks while limiting the exploitation of fragile stocks. Because genetic information will be unique to our local fisheries, we will need local projects to be able to apply these methods to inform our fisheries management. Close collaboration between fisheries scientists and managers will be crucial for identifying the mixed stock fisheries where we should prioritise using genetic technology in active management.

Close collaboration between fisheries scientists and managers will be crucial for identifying the mixed stock fisheries where we should prioritise using genetic technology in active management.

6.4.8 CASE STUDY: WHAT DOES ANCIENT DNA TELL US ABOUT THE SNAPPER POPULATION?

People have been fishing for snapper around Aotearoa New Zealand for over 700 years. When Māori initially harvested this fish species as kaimoana the population remained healthy and abundant. It was the introduction of industrialised fishing after the arrival of Europeans that saw the population dwindle. In the late 19th century, snapper stocks had been so exploited that it was the first fishery to be regulated with a minimum catch size. By the 1980s, snapper stocks were on the brink of collapse with an estimated just 10% of the biomass of the original population (the limitations of these estimates are discussed in section 5.2.2.3). Evidence suggests that these population decreases led to changes in genetic diversity (Hauser *et al.*, 2002) potentially making the stock less resilient to the many stressors in the marine environment (outlined in section 3.1).

The government brought in new management systems to protect this important fishery and rebuild the stocks – through the QMS and Fisheries Act 1996 a cap was put on total catch and people can keep larger snapper but have to throw the smaller ones back overboard, though there are concerns about survivability after being released. Population size may not be the only factor impacted by these rules. There is evidence that different species of fish are getting smaller, maturing at a younger age, and there is less genetic variation among the population because of human influence (Darimont *et al.*, 2009). This suggests that our fishing practices may be causing other unintended consequences and genetic studies can help determine what these are.

There is evidence that different species of fish are getting smaller, maturing at a younger age, and there is less genetic variation among the population because of human influence.


Figure 132: Left – Analysing ancient DNA from fish bones found in middens can tell us about how our fish stocks and ecosystems have changed over time. Right – Tāmaki Paenga Hira Auckland Museum archaeology curator Louise Furey points out the different layers of a midden on Ōtata Island in the Hauraki Gulf's Noises island group, watched by the OPMCSA team. The top layer dates to around 600 years ago, when Rangitoto erupted. The middle layer is ash from the Rangitoto, below which is a thin layer representing the earliest occupation of the island.

Genetic signatures will show whether fishing has changed the evolution of snapper

An Aotearoa New Zealand study is underway to attempt to determine whether our fishing methods have changed the evolution of our local snapper. The study is comparing the DNA from ancient snapper remains that are around 600 years old to DNA from modern-day snapper collected across the entire local fishery. Snapper can live to be up to 60, but mature at 3-5 years old, so there could have been over 100 generations between these samples. The historical snapper samples are bone samples taken from archaeological excavations of Māori middens. Researchers can sequence the DNA from these samples using special techniques that account for the degradation of DNA that happens over time. Advances in technology have made it easier to get good quality DNA from these old samples, making it possible to sequence genes across the whole genome to gain a more complete picture of the changes (Oosting *et al.*, 2019).

The team of researchers will compare the genetics of the old and new samples using the snapper genome that was assembled as part of a research programme to investigate snapper as a potential species for aquaculture. The differences will tell a story. For example, there may be evidence of lots of genetic variation among the ancient samples, but limited diversity in the modern samples. That would tell us that population decline removed a lot of variation from the population, and is changing the species as a whole. As another example, there may be evidence that the current snapper population has variation at genes known to control size, growth and maturation, which differ to those in the ancient samples. This would suggest that the changes have occurred more recently in response to environmental pressures in order for the snapper to survive.

Figure 133: Australasian snapper. Image credit: lcolmer/iNaturalist (CC BY-NC 4.0).

Clues from the past can inform future management of fisheries

Understanding how the genetics of the snapper population has changed due to intensive fishing is important for sustainability. If it becomes clear that the way we manage our snapper population is influencing the evolutionary process by making the population become smaller, we could change the management of this species to preserve the remaining diversity – for example, by taking smaller ones and returning bigger ones and reversing a practice introduced by Europeans, or selecting for medium-sized fish through the use of harvest slots (Gwinn *et al.*, 2015).

6.4.9 CASE STUDY: GENETIC TAGGING TO UNDERSTAND BLUEFIN TUNA POPULATION DYNAMICS

Southern bluefin tuna consist of a single highly migratory stock (Proctor *et al.*, 1995; Grewe *et al.*, 1997). Juvenile fish spawn in one area in the Indian Ocean south of Java and the adults move far and wide, with those caught in Aotearoa New Zealand's EEZ being the easternmost. The broad reach of this species requires a collective effort across the regions to ensure the sustainability of southern bluefin tuna. The Commission for the Conservation of Southern Bluefin Tuna (CCSBT) is an intergovernmental organisation responsible for managing this species, of which Aotearoa New Zealand is a member.

Figure 134: Southern bluefin tuna (*Thunnus maccoyii*). Credit Dave Muirhead/iNaturalist (CC BY-NC 4.0).

The Commission requires a robust understanding of the size and demographics of the population when setting the total allowable global catch. Traditionally, the Commission relied on physical tagging markers to track individuals and understand population dynamics. However, the loss of tags in the environment and non-reporting by fishers led to data and knowledge gaps and undermined efforts to sustainably manage southern bluefin tuna across the various fisheries (Bravington *et al.* 2016).

CSIRO developed an alternative tagging method using genetic technologies to provide better understanding of the stock's status. The genetic tag is essentially a DNA 'fingerprint'– it establishes a unique genetic signature for each individual. The tag is lifelong (because the individual's DNA won't change) and invisible (because there is no physical tag attached to the fish). It does not rely on reporting from individual fisheries and therefore provides independently verifiable estimates of abundance. Sequencing can be performed quickly in large numbers with high-throughput technologies. However, there is still the need to tag and recapture thousands of individuals, which requires sea time and robust experimental design.

The genetic tag is essentially a DNA 'fingerprint'– it establishes a unique genetic signature for each individual. The tag is lifelong (because the individual's DNA won't change) and invisible (because there is no physical tag attached to the fish). It does not rely on reporting from individual fisheries and therefore provides independently verifiable estimates of abundance.

The researchers tagged individual juvenile southern bluefin tuna and released them back to sea. A year later, samples were taken from the tuna caught by Australian commercial fishers. The researchers estimate how abundant the population is by comparing how many captured fish match the juvenile fish sequenced a year earlier. A high overlap indicates that a high proportion of fish were originally captured, suggesting a smaller overall population size. A low overlap shows that the population is bigger than the number captured earlier. After the first two years of data collection, the researchers estimated that there were approximately 2.3 million age two fish, based on finding 20 matching DNA fingerprints between 3,000 tagged and 15,000 harvested fish. These findings were similar to the median estimate in 2017 stock assessment models of 2.1 million, corroborating this approach. This sampling method is now happening every year so that an annual estimate of species abundance can inform management decisions about the global catch.

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Mark-recapture programmes can be used to understand stock recruitment, movement, growth and survivorship (Mace *et al.*, 2020). A similar approach could be used for other fisheries to determine population size to inform TAC. It's important for the biopsy sampling technique to be suited to the species of interest to reduce the possible harms from this invasive sampling approach. For example, Fisheries New Zealand have evaluated genetic tagging technologies for use with snapper in mark-recapture programmes (McKenzie *et al.*, 2015). While not considered feasible in the short term, it was considered that investment in their development was worthwhile given potential efficiency and precision gains. Research into suitable markers, protocols, development of a biopsy hook and hook deployment protocols would be required before genetic tagging for snapper could be implemented.

6.4.10 BIOCHEMICAL TECHNOLOGIES

Figure 135: Otolith (earbone) of an Antarctic toothfish (*Dissostichus mawsoni*). Image credit: NIWA.

Analysing the chemical properties in fish is a valuable tool that fisheries scientists have used to inform fisheries management (as shown in case study 6.4.11) (Tzadik *et al.*, 2017). Used routinely since the 1980s, the approach traditionally relied on taking otoliths (a structure in the inner ear of the fish) and performing microchemical analyses on these. More recently, similar applications have been applied to other structures in the fish, including scales, fin spines, fin rays, eye lenses and the skeleton, and expanded to analyse a broader range of chemical elements (Tzadik *et al.*, 2017).

These methods can be used to measure concentrations of diagnostic molecules, which tell us about biological processes. For example, the concentrations of specific chemicals in bone relates to the age of the organism (Kalish, 1989). We can also infer details about an organism's particular environment or diet based on the chemical properties present in a sample. For example, the ratio of nitrogen to carbon and sulphur can be a proxy for trophic level (Rowell *et al.*, 2010).

Microchemical analyses are very powerful tools to use in fisheries science but they don't necessarily work every time. The extent to which various questions about a fish's environmental, ecological and life-history changes can be answered using microchemical analyses depends on the specific species, structure, and available technology.

In order to apply these techniques to a species we first need a thorough understanding of its species-specific biology (e.g. details of bone remodelling and collagen turnover) and to validate the method in that species. For some species, these knowledge gaps may need to be filled before microchemical techniques can be used to their full potential and premature use of the method can results in a lack of trust in the data.

Different structures within the fish have varying potential to address questions about ageing, migration and diet because of their chemical and physiological differences (Tzadik *et al.*, 2017). There are also different requirements for how to mechanically and chemically process each structure. Depending on the structure, the process may be lethal. This is a particularly important consideration for taonga or vulnerable species, and efforts to improve and expand techniques to focus on structures that are non-lethal and minimally invasive will increase the possible application of this approach.

Analytical capabilities of microchemical techniques are continually improving and researchers are now able to obtain high-resolution chemical profiles across diverse marine species, which could help to inform fisheries management decisions. As technology advances further, these techniques are likely to become more precise, the range of structures able to be analysed will expand, and new chemical signatures that document other changes in the life history of the fish may be uncovered. Future applications could also look at using multiple complementary structures and techniques to address limitations in interpretation and causes of chemical shifts that come with using only one method (e.g. linking with genetic markers, see section 6.4.6: Genetic technologies).

Currently, microchemical analyses of fish are able to inform:

- **Stock assessment and delineation.** The chemical signatures of otoliths or other structures can identify and delineate fish originating from distinct geographical origins to classify fish stock units, but are currently best used as part of an integrated approach with other markers (Tanner *et al.*, 2016).

- **Migration patterns**. Chemical signatures can show where the fish originated, where it moved and when, which has informed understanding about Atlantic salmon's[204] migratory patterns (Kennedy *et al.*, 2002). These techniques have also been applied to connect larvae from aquaculture to restoration of bivalve reefs in the wild (Norrie *et al.*, 2020).
- **Age and growth rates.** In addition to the traditional use of otolith structure to assess age, various chemical signatures can be used to determine the age of a fish and other details around age at maturity to inform management decisions, as demonstrated in studies on orange roughy (Fenton *et al.*, 1991).
- **Dietary patterns.** Researchers can assess diets and determine trophic level based on chemical signatures by looking at amino acids to reconstruct dietary patterns and shifts over time (McMahon *et al.*, 2011; Walther, 2019).

[204] *Salmo salar.*

6.4.11 CASE STUDY: HOW A CHEMICAL FINGERPRINT IDENTIFIED AOTEAROA'S MOST SIGNIFICANT SNAPPER NURSERY

The otolith is an archive of the growth, environmental and ecological history of that fish. Its size and shape can be used to determine the age of the fish. The chemicals in each layer within the otolith change depending on surrounding factors such as water and provide a signature to mark time and place.

Back in 2003, researchers from NIWA applied this method to study snapper – one of Aotearoa New Zealand's largest and most valuable commercial coastal fisheries. Snapper have been heavily fished over time and there were knowledge gaps around the significance of snapper nurseries on the west coast of the North Island, which needed to be filled in order to better manage this fishery.

Figure 136: Baby snapper. Image credit: Crispin Middleton/NIWA.

The researchers used otolith microchemistry to determine whether estuarine nursey grounds for snapper generated unique 'chemical fingerprints' and whether these could be used to match adult snapper in the open sea to their nursery ground in a west coast harbour.

Juvenile snapper were taken from seven estuaries along the west coast of the North Island that are known to be nursery grounds for snapper. They measured eight different chemical elements in the otolith of each fish and were able to find a robust 'chemical fingerprint' that could distinguish Kaipara, Manukau and Whangapae harbours uniquely, and group Hokianga, Whāingaroa/Raglan, Aotea and Kawhia harbours together.

Because it takes snappers around 3-4 years to reach maturity and swim away from the nursery ground out into the open sea, the researchers waited four years before undertaking the second part of the study.

In part two, they collected many adult snapper from commercial catches from four zones over 700 km of coastline from Ninety Mile Beach in the far north down to Mana Island in Pōneke Wellington. The researchers aged the fish by analysing the otolith structure to find four-year-old snapper, as it is possible that changes in the environment could mean the signatures from each nursery changed each year. They selected 140 snapper with 20-30 snapper from each zone.

Comparing the chemical fingerprint of these snapper to the harbour-specific patterns established earlier in the project showed that 98% of the adult snapper were originally juveniles from Kaipara Harbour.

The implications of these findings are that the Kaipara Harbour appears to sustain most of the adult coastal snapper populations on the west coast of the North Island. Environmental damage or habitat changes in that harbour could have widespread negative impacts on snapper populations the length of the North Island. Fisheries management for snapper therefore needs to look beyond fishing limits to also consider ways to protect the high quality nursery habitat that exists in the Kaipara Harbour.

The Kaipara Harbour is known to be heavily impacted by land-based activities, including accelerated sedimentation due to changing land use (discussed in section 3.1.2: Land-based activities impact coastal fisheries) (Morrison *et al.*, 2009). There is increasing recognition of the importance of remediating and protecting the Kaipara Harbour, with the government announcing in July 2020 that the Kaipara Moana Remediation Programme would get $100 million towards these efforts.

Microchemical analysis has uncovered details about snapper habitat use on the west coast of the North Island that shows clearly that ongoing and future efforts to manage this fishery and ensure sustainable stocks for years to come need to focus on keeping the Kaipara Harbour healthy. This is relevant to the range of estuaries and harbours that are nursery grounds for our fisheries.

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Figure 137: Genetic and microchemical studies revealed that the Kaipara Harbour is a nursery ground for young snapper. Image credit: PhillipC/Flickr (CC BY 2.0).

6.4.12 ACOUSTIC TECHNOLOGIES

Since standard GPS signals do not work underwater due to radio waves breaking down rapidly in liquids, most underwater positioning systems rely on acoustic signals. Acoustic technologies have been used in fisheries and marine research for over 50 years and already play a role in informing fisheries management in Aotearoa New Zealand (Mace *et al.*, 2014). The approach is not new, but innovative acoustic technologies are under continuous development and have significant potential to support more sustainable management of our fisheries through existing and novel applications (Ryan and Kloser, 2016).

Acoustic technologies can be broadly divided into active and passive methods. Active methods rely on sending out sound underwater to gather information. A common approach is using a tool called an echosounder to send a pulse of sound down to the seafloor via an underwater transducer. If the pulse encounters something along the way, it is reflected back as an echo and converted to electrical energy via the transducer. The time it takes between sending out the pulse and receiving the echo tells us how far away the organism is. The echo is displayed as a 2D picture known as an echogram and the details can be used to infer the types of fish or other organisms in the area.

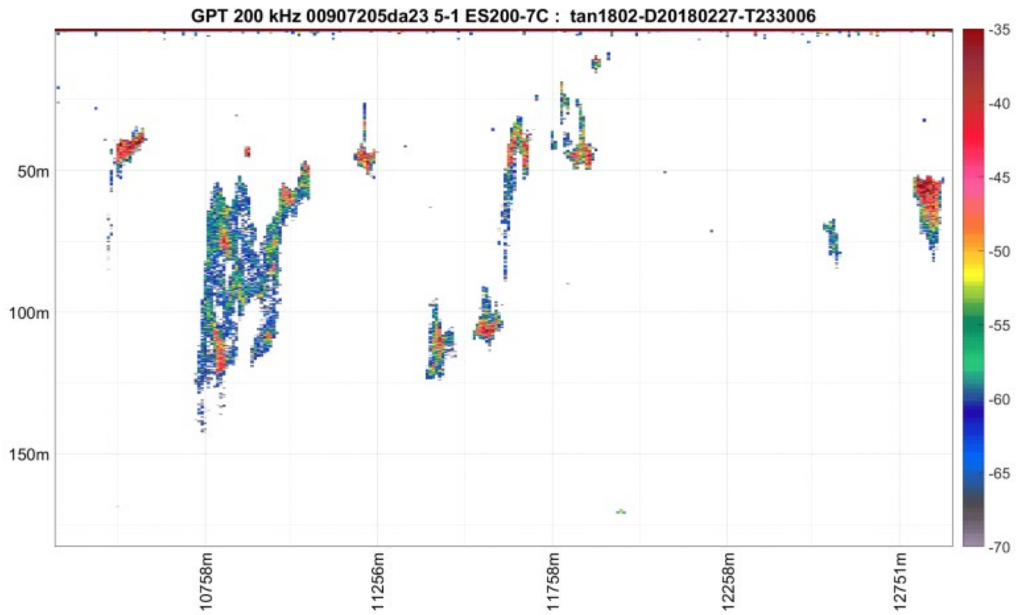

Figure 138: An echogram of acoustic marks for krill swarms in the Ross Sea. Image credit: NIWA.

Originally, the technology was only able to operate at a single, discrete frequency. This limited resolution and range and therefore what could be detected. Advances led to the use of multiple, discrete frequencies at once to simultaneously measure different groups, where groups could be distinguished based on their biological or acoustic properties. A further development involved moving from a discrete burst to a continuous response around a central frequency which provides greater information and better resolution of the data, so it is easier to discriminate between species. These are known as broadband ('chirp') echosounders. Active devices can also send out acoustics that act as deterrents.

In contrast, passive acoustic methods are used to listen to and record sounds underwater (Luczkovich *et al.*, 2008). These approaches use underwater microphones (hydrophones) to pick up sounds known to be associated with specific marine organisms, such as whales or sound-producing fish, but their application relies on prior work to identify and 'sound-truth' species-specific sounds through verification with other methods. Scientists can identify, record and study underwater animals using passive acoustic technologies, either in the absence of visual information or coupled with optical technologies such as underwater or surface cameras to make biomass estimates (see section 6.4.14: Underwater and surface cameras give a wider and sharper view of the ocean).

The technique provides a way to perform non-invasive, non-destructive surveys of marine life, generating information to locate fish to understand habitats, spawning times and other behaviours.

Acoustic technologies are used in a range of ways in fisheries:

- **Abundance estimates.** Acoustic technologies provide a non-destructive method of estimating fish densities and – with the right survey design – abundance, which can feed into stock assessments (Fisheries New Zealand, 2020b; Rowell *et al.*, 2019). Fisheries-independent acoustic surveys are currently used in Aotearoa New Zealand to estimate orange roughy, southern blue whiting, hoki, oreos, and mesopelagic fish abundance. Specialised towed acoustic systems, including deep-tow bodies and a net-mounted acoustic-optical system (AOS), have been developed by NIWA and CSIRO to improve sampling of these deepwater fish (Ryan *et al.*, 2009).

  Species composition and distribution. Acoustic techniques can be used to locate individuals and concentrations of particular species, including during their vulnerable spawning stage (O'Driscoll *et al.*, 2016). This in turn allows spawning habitat to be identified, mapped and protected (Rountree *et al.*, 2006). Researchers have applied a semi-automated process to better understand fisheries areas, such as assessing the micronekton community on the Chatham Rise (Escobar-Flores *et al.*, 2019), using the open-source software ESP3 (see 6.2.5: case study: Software to streamline acoustic data analysis).

In order to broaden the application of acoustics in fisheries management some key challenges need to be addressed. An initial hurdle is classifying the acoustic properties of a species before active acoustic technology can be used to monitor or study it. This relies on studies to identify the species and its target strength.[205] For some species or in particular habitats (e.g. deep water) this can be more difficult, but methods are constantly developing to improve in these two areas and validation steps are performed to ensure accurate data. Further research on the non-target effects (e.g. impacts on cetacean communication) should also be investigated before deploying the technology.

6.4.13 INNOVATIONS THAT EXPAND ECOSYSTEM KNOWLEDGE WILL ADD AN EXTRA DIMENSION TO FISHERIES MANAGEMENT

In an ecosystem, nothing exists independently (McGregor *et al.*, 2019a). Fish are intimately and completely dependent on marine ecosystems for their prey and habitat. Consequently, changes in ecosystem structure and function will affect commercially important fish and fisheries.

Globally there is an increasingly shared view that steps towards EAFM are needed (see section 2.7.5: Ecosystem thinking). Such an approach would rely on information about the health of an ecosystem to inform how the fisheries within it are managed. One of the key aims of EAFM is to move from a single-species management (i.e. deciding what the catch of species A should be without considering the status of or effect on species B, C and D) to a framework that recognises these as interacting components. Thus, increasing fishing pressure on one species may cause other species to decrease or increase and will therefore change the amount of fishing pressure these can sustainably withstand. Applying this requires a better understanding of the inter-species interactions via predation, competition and recruitment and that these are highly size-dependent (e.g. large individuals of species A may be predator of small individuals of species B and vice versa) so a food web type approach is not sufficient.

Use of cameras, both underwater and on the surface, can gather essential information about ecosystem health and dynamics. Other techniques introduced earlier, including genetic and acoustic technologies, can also be applied to fill gaps in our knowledge and inform EAFM. In addition, eDNA collected from the water can provide

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[205] Acoustic target strength is the amount of sound scattered by an individual fish and is the denominator in the equation used to estimate fish density (i.e. the total amount of sound scattering attributed to the species is divided by the target strength to calculate density).

deep multi-trophic detail on the organisms that live in any given environment – from microbes to mammals (Compson *et al.*, 2020), as discussed in section 6.4.16.

Innovative modelling approaches that draw on data from these and other techniques are changing the way that ecosystems are monitored and managed. Used alongside the catch limits, these tools offer the potential to monitor ecosystem health in a predictive and more holistic way, adding an extra dimension to fisheries management.

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6.4.14 UNDERWATER AND SURFACE CAMERAS GIVE A WIDER AND SHARPER VIEW OF THE OCEAN

As discussed for EM with on-board cameras, (section 6.4.1: Computers, cameras and AI could revolutionise catch monitoring), camera imagery is a key, non-destructive tool for monitoring habitats and species, and improving management of the marine environment across different temporal and spatial scales. Over recent decades, our eye on the ocean has widened and sharpened, with marked improvements in camera technology.

Camera imagery is affected by water clarity and visibility issues, which are worsened by sedimentation.

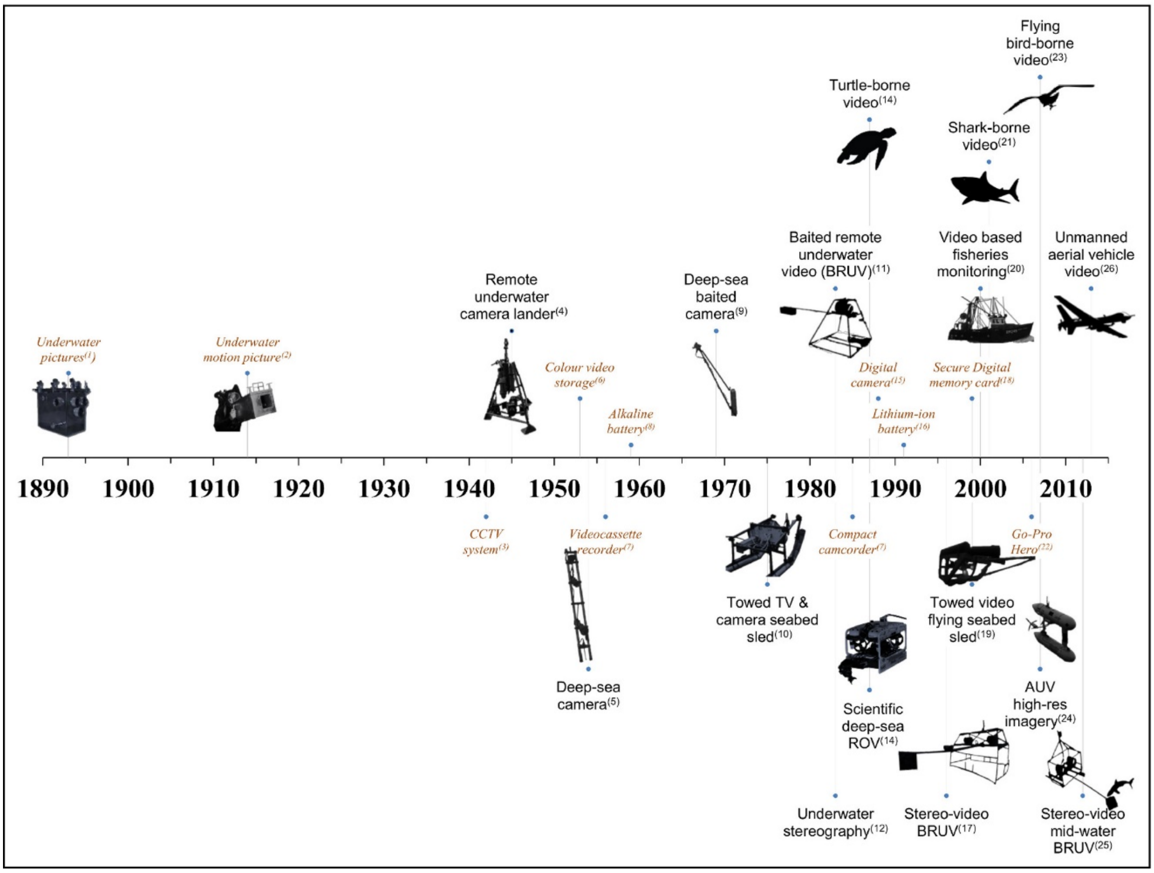


Figure 139: Timeline of development of cameras for studying marine biodiversity (Bicknell *et al.*, 2016).

Converting imagery to data that can be used is often slow and laborious. Automation may be able to speed up this process, but the technology is, for the most part, still in the pilot stage. Current regulations that limit a third wire to protect seabirds are a barrier to using innovative underwater camera technology as an extra wire is needed to transmit imagery back to the boat, though special permits can be given to trial gear.[206]

This section discusses underwater and surface cameras. For discussion on satellite imagery, see section 6.5.1.2: Satellite technology allows us to track marine species in detail.

There are different types of cameras available for different applications.

Towed cameras and remotely operated vehicles (ROVs) allow us to collect data over large areas underwater. For example, a camera towed on a sledge on the seafloor can photograph the surrounding benthic environment, allowing scientists to estimate recovery rates and resilience of these habitats to bottom trawling and dredging (Lambert *et al.*, 2014). The American research vessel EV *Nautilus*, owned by the Ocean Exploration Trust, has a number of submersible ROVs. These are outfitted with high-definition cameras and other sensors to perform biological, geological and archaeological exploration of the ocean. The expedition ROV footage is livestreamed via YouTube with commentary from on-board experts, beaming real-time discoveries into classrooms and onto smartphones around the world (Ocean Exploration Trust, 2020). We also have developed a deep towed imaging system in Aotearoa New Zealand (see 6.4.15: case study: NIWA's Deep Towed Imaging System (DTIS)). Some of the challenges associated with these operations, such as the need for vessels to be present to deploy them and the associated costs of that, can be addressed through the use of robotics and unmanned autonomous vehicles (see section 6.5.1.1).

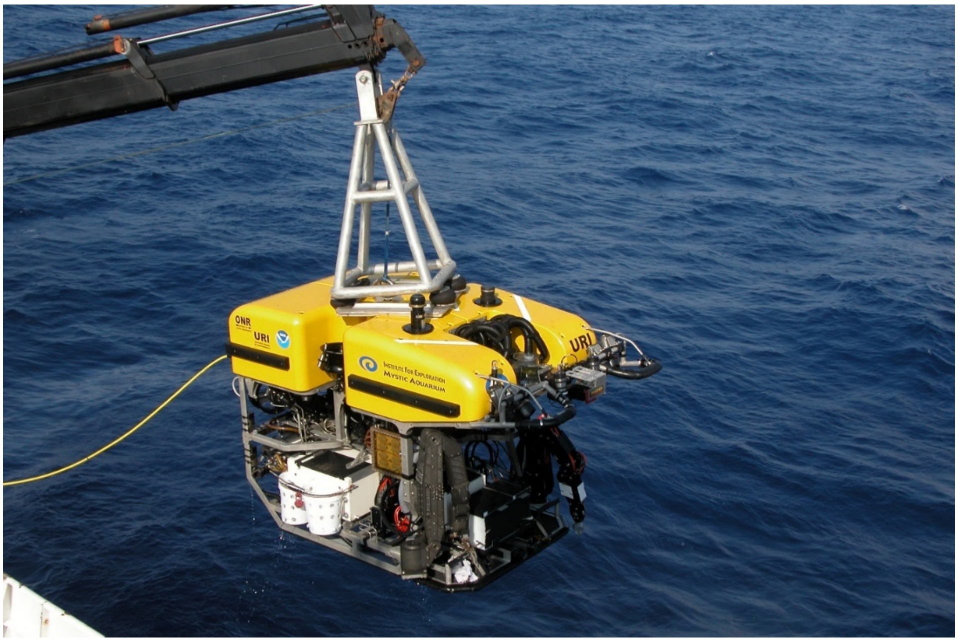


Figure 140: The Hercules remotely operated vehicle (ROV), one of the submersibles used by the EV *Nautilus* for underwater exploration and research.

[206] The use of net sonde cables, also known as 'third wires' (i.e. where a cable is hard wired to a trawl sonar attached to the net head rope to allow monitoring of the nest position and catch entering the net) have been prohibited in Aotearoa New Zealand waters by regulation since 2008 to prevent seabird mortalities because of observations that the third wire increased the risk of 'warp strikes', where seabirds run into the wire and are injured or killed (Acoura Marine, 2018). FNZ can (and has) grant special permits to trial gear with a third wire, with a requirement for observer coverage during trial.

Camera traps can reveal the different species living in a habitat, with some designs triggering only when an animal moves into the camera's field of view (Williams *et al.*, 2014). Some cameras may be baited to attract fish or other species, these are known as Baited Remote Underwater Video Stations (BRUVS) (Whitmarsh *et al.*, 2017). These can tell us what species are present at a site and allows estimation of the length of individuals when stereo video is employed – which in turn enables understanding of biomass, population dynamics and fecundity. Some species may avoid baited camera systems, while choice of bait can affect the species that approach a camera (Bicknell *et al.*, 2016). There are challenges in scaling up the use of stereo-BRUVS because of the amount of boat space taken up by the BRUV itself and its retrieval gear. This may limit the pace of a study and increase field costs (Whitmarsh *et al.*, 2017).

Animal-borne cameras are attached directly to animals and can tell us about the behaviour, distribution and ecology of the species, especially when combined with other sensors such as GPS (Bicknell *et al.*, 2016). Animal-borne cameras can also provide a way to monitor the status and health of important fisheries habitats, such as seagrass (Thomson *et al.*, 2015). Animal welfare must be considered as well as the potential for littering and marine pollution.

In-trawl cameras are attached to nets or gear underwater. These can help to identify and quantify catch and bycatch (including threatened and protected species) and estimate seafloor impacts of bottom contacting fishing gear (Rosen and Holst, 2013; Jaiteh *et al.*, 2014). They can also reveal fish behaviour, which in turn informs stock assessment and gear design. For example, flatfish in the Northeast Pacific were observed to 'herd' in response to a bottom trawl, and if this behaviour had not been accounted for, their stock could have been overestimated (Bryan *et al.*, 2014). The local research underway described in section 6.3.11 which aims to achieve species identification, trait measurement and individual fish identification using in-trawl cameras highlights the potential utility of this technology in fisheries. AI developments may allow for automated recognition of species to allow for release of non-target catch.

Flatfish in the Northeast Pacific were observed to 'herd' in response to a bottom trawl, and if this behaviour had not been accounted for, their stock could have been overestimated.

Non-research camera imagery is also a source of information. Hundreds of hours of raw footage filmed in the waters around Rangitāhua the Kermadec Islands for Natural History New Zealand's *Our Big Blue Backyard* series was analysed by researchers (Liggins *et al.*, 2020). Three species new to the area were discovered. There have also been suggestions that documentary out-takes can help researchers determine how an environment might be changing over time (Hancock, 2020). Imagery collected by recreational divers can also give insights, like the Ocean Sunfish Research initiative that catalogues the sunfish on the Nusa Penida reefs near Bali, Indonesia. This project determined that the sunfish present on the reefs were not *Mola mola* but were in fact *Mola alexandrini* (Nyegaard, 2018).

Figure 141: A bump-head sunfish (*Mola alexandrini*) on the Nusa Penida reef near Bali, Indonesia. Imagery collected by recreational divers has advanced our understanding of these enigmatic creatures. Image credit: Albert Kang/iNaturalist (CC BY-NC 4.0).

6.4.15 CASE STUDY: NIWA'S DEEP TOWED IMAGING SYSTEM (DTIS)

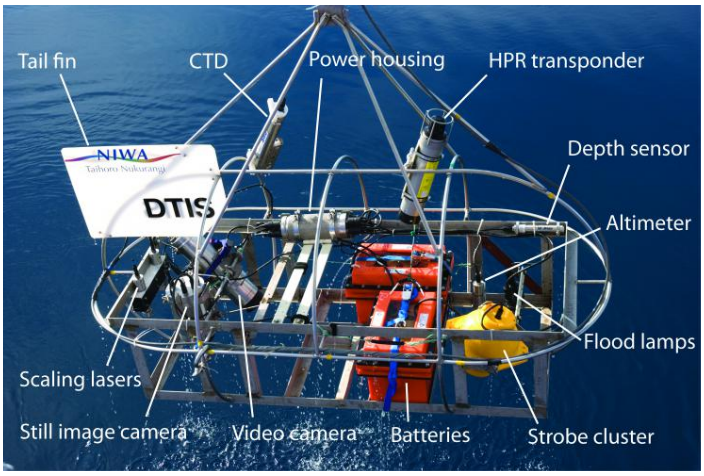


Figure 142: NIWA Deep towed imaging system (DTIS). Image credit: NIWA.

The Deep Towed Imaging System (DTIS) has been used in Aotearoa New Zealand since 2006 to take pictures and video of deep-sea biodiversity and seafloor habitats. This is essential to better understand potential ecosystem effects of fishing. It has high-definition still and video cameras, lights, strobes, laser pointers and batteries mounted in a rectangular frame. This frame is attached to the research vessel carrying it – often the RV *Tangaroa* – by a conducting wire. This wire allows the DTIS to communicate with the vessel, enabling researchers to see a live video feed, control its cameras and lights, and see information on depth and distance from the seabed. The DTIS runs in transects (or stripes) taking video continuously. The full length of each video transect is analysed and assessed for substrate (seabed) type, algae, benthic invertebrates (invertebrates which live on the seafloor), and fish. This sort of technology has not been widely deployed due to the 'third wire' restriction on commercial vessels, which was put in place to protect seabirds.[207] Because of the unintended consequence of the restriction, there are lots of lost opportunities to collect data and this has posed a barrier to innovation.

With the recent establishment of the Ross Sea Region MPA, it is no longer appropriate to carry out random trawl surveys in this region. Therefore a new survey method is required to monitor the status of rattails (grenadier), which are an important bycatch of the toothfish longline fishery within the Ross Sea. Comparing visual counts of rattail abundance from DTIS with results from acoustic and trawl surveys enables researchers to determine whether the DTIS is a possible alternative approach to monitor rattails.

Figure 143: Left – DTIS image of the rattail species the Caml grenadier (*Macrourus caml*) in the Ross Sea in 2019. Image credit: NIWA. Right – Associated trawl catch. Image credit: NIWA.

[207] The use of net sonde cables, also known as 'third wires' (i.e. where a cable is hard wired to a trawl sonar attached to the net head rope to allow monitoring of the nest position and catch entering the net) have been prohibited in Aotearoa New Zealand waters by regulation since 2008 to prevent seabird mortalities because of observations that the third wire increased the risk of 'warp strikes', where seabirds run into the wire and are injured or killed (Acoura Marine, 2018). FNZ can (and has) grant special permits to trial gear with a third wire, with a requirement for observer coverage during trial.

6.4.16 ENVIRONMENTAL DNA (eDNA) CAN GROW ECOSYSTEM KNOWLEDGE

The application of environmental DNA (eDNA) methods offers a way to monitor the complex interactions between fisheries and the environment by providing a high-level overview of community composition across any given area or depth area (Salter *et al.*, 2019; Lacoursière-Roussel *et al.*, 2016; Knudsen *et al.*, 2019). DNA is collected from the environment (e.g. filtered seawater) and diagnostic parts of the DNA (barcodes) are sequenced, in an approach known as DNA metabarcoding.

eDNA enables researchers to simply and non-invasively monitor ecosystems through species detection, determining species diversity and further details about ecosystem function, including diet, pathogens and invasive species (Ficetola *et al.*, 2008; Zaiko *et al.*, 2018). The technique can be used to detect rare or elusive species (discussed further in section 6.4.6 and case study 6.4.17). eDNA metabarcoding is cost effective in that it only sequences the 'barcode' region of the sample. To cite one example, a nine-litre water sample from the Ningaloo Reef yielded over 60 genera of fish and over 287 families of marine taxa (Stat *et al.*, 2017). Similar approaches are being used across Aotearoa New Zealand (see figure 144). The wide biotic lens of eDNA is the method's core strength, and the primary reason why eDNA is quickly becoming a key component of marine surveys across the globe.

eDNA enables researchers to simply and non-invasively monitor ecosystems through species detection, determining species diversity and further details about ecosystem function, including diet, pathogens and invasive species.

The eDNA approach overcomes many limitations when studying more complex biological systems, including time-consuming microscopy, extractive sampling, difficulties identifying different life stages and sexes, and cryptic species identification. In a fisheries management context, a one-year New Jersey study comparing eDNA and monthly trawl estimates were well correlated across fish species richness, composition, seasonality and relative abundance (Stoeckle *et al.*, 2020).

A key strength of eDNA is that it is a non-invasive sampling method and can provide a high-level overview of genetic biodiversity, including presence/absence data, and detect ecosystem changes over time. eDNA has also been shown to be effective in detecting anthropogenic disturbances (DiBattista *et al.*, 2020) and detecting rare marine taxa from seahorses (Nester *et al.*, 2020) to sharks (Bakker *et al.*, 2017). The hope is that in the future eDNA sampling methods will enable further quantitative precision (using absolute and relative abundance), noting that 'catch', acoustic and video surveys all have intrinsic strengths and weaknesses when it comes to quantitative analysis.

There are several limitation, comparative and proof-of-principle studies when implementing eDNA in aquatic environments, and these have been at the core of the >1,500 papers on this topic, see Compson *et al.* (2020). In a fisheries context, there's potential for contamination from fishing gear, lab contamination and the vectoring of DNA by animals. Moreover, eDNA data provides no direct information on age, weight, life-stage or fecundity (Hansen *et al.*, 2018). However, the potential for eDNA to move beyond 'just barcodes' to measure population-level metrics is being actively explored (Andres *et al.*, 2021).

The hope is that in the future eDNA sampling methods will enable further quantitative precision (using absolute and relative abundance), noting that 'catch', acoustic and video surveys all have intrinsic strengths and weaknesses when it comes to quantitative analysis.

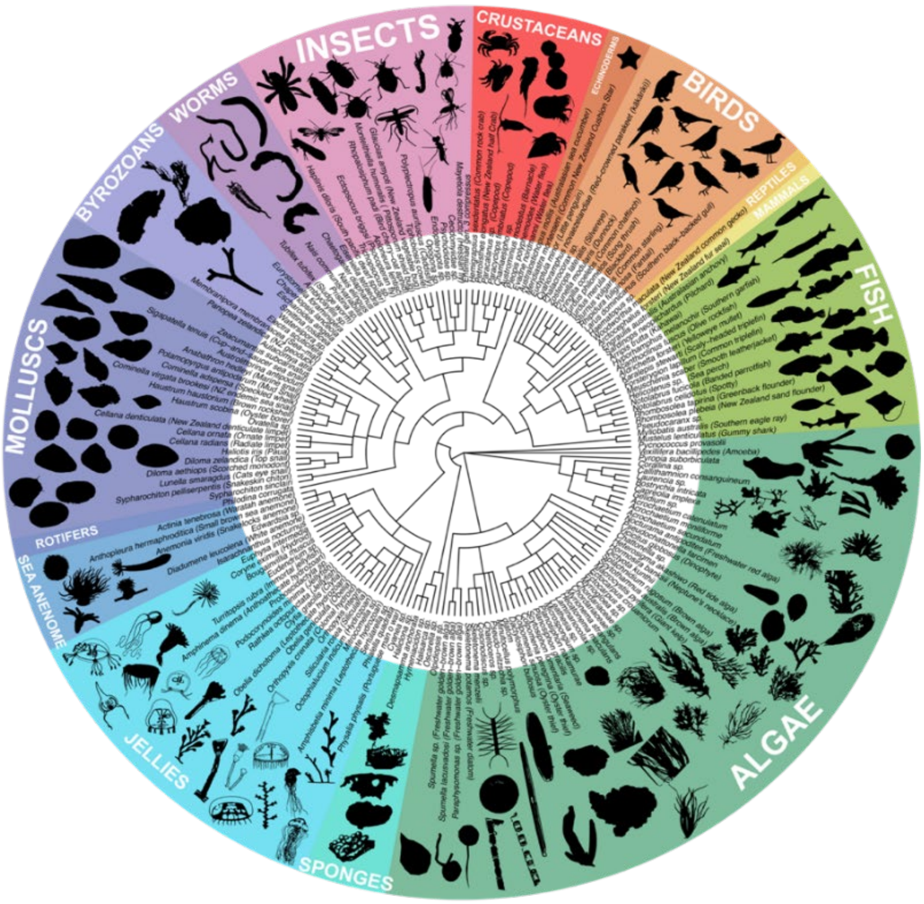


Figure 144: A biotic survey of Wellington harbour using eDNA metabarcoding. Such methods could play a role in baselining a variety of marine biota. Image credit: EPA/Wilderlab.

eDNA methods in the ocean are still relatively new and require ongoing optimisation in many areas of the workflow to ensure sampling and analytical consistency (Zaiko *et al.*, 2018). Being able to apply these techniques also relies on species having a reference barcode in databases to match the sample – reference barcodes are much easier to generate than whole genomes (see section 6.4.6) and relevant barcodes for key genetic markers (e.g. COI, 16S, 12S) exist for most fish species across Australasia. We expect these databases to continue to grow over time (underpinned by a robust taxonomic framework) making this application more powerful. Increasingly the genetics community is seeking to integrate eDNA data more seamlessly into databases with other biotic data (e.g. the Atlas of Living Australia), one key will be to make eDNA data more accessible to other discipline areas (see commentary by Berry *et al.* (2020)).

Lastly, the true power of eDNA methods will come from structured time-series data that extends across seasons, years and decades – the research community is beginning to assemble just such datasets (see (Berry *et al.*, 2019)).There is a growing need and willingness to collect eDNA samples now for future use with data, technological and analytical advances. It's important to ensure samples are collected and stored correctly so that DNA does not degrade (Hansen *et al.*, 2018, Berry *et al.*, 2019; Jarman *et al.*, 2018).

Other genetic tests, aside from eDNA discussed above, can be applied to individuals and environments for disease surveillance and to understand disease epidemiology. Gene expression assays can be used to rapidly diagnose multiple pathogens. Techniques such as DNA metabarcoding provide an efficient means of tracking the spread of invasive species. Genetic applications can also support protection of vulnerable, protected or taonga species through better understanding of the genetic diversity in small populations, and through the discovery of genetically distinct species or stocks (how different genetic techniques can be applied in fisheries is described in appendix 13).

6.4.17 CASE STUDY: MANAGING GREAT WHITE SHARK CONSERVATION THROUGH eDNA

Figure 145: d

Great white sharks are an endangered top oceanic predator. Low reproductive and growth rates make the species vulnerable to overfishing and population depletion. Despite becoming a protected species in Aotearoa New Zealand in 2007, many great white sharks are bycatch each year because of accidental capture in set nets and other fishing gear.

Knowing the location and movements of great white sharks can inform fisheries management approaches to protect this species by telling fishers what areas to avoid and when. In Aotearoa New Zealand, a number of high-tech electronic tagging approaches have been used to understand great white shark movements to reduce fisheries bycatch. These tagging approaches rely on first capturing the sharks and then implanting a tagging device in order to track the movements. Non-invasive genetic techniques such as eDNA may provide a complementary or alternative method to track the whereabouts of great white sharks to protect this species.

A recent study in California illustrated the potential for this eDNA approach to inform fisheries management of great white sharks in real time (Truelove *et al.,* 2019). Rather than waiting and having the sample sequenced in a lab, the fishing vessel had a portable sequencing machine on-board so that samples could be processed immediately and have results turned around in 48 hours. This meant that the presence of great white shark DNA could rapidly inform management strategies by telling fishers that the protected species was either in the area – and therefore fishing should not occur – or was not present and therefore fishing could proceed.

This non-invasive genetic approach has the potential to rapidly survey for threatened or rare species in remote ocean regions to inform conservation efforts and fisheries management. It is important that sequencing is previously validated in a lab to ensure results are robust. Other knowledge about current and movement patterns are a prerequisite to ensure accurate sampling is taken to effectively inform management. The application of such technology is also limited by the reference databases of genetic material. Great white sharks have already been sequenced, so there are barcodes and reference genome to match the DNA samples to.

This non-invasive genetic approach has the potential to rapidly survey for threatened or rare species in remote ocean regions to inform conservation efforts and fisheries management.

In the future, fishers could use similar approaches to understand more about the habitats, movement and migratory patterns of other endangered, threatened or taonga marine species to support conservation efforts. Ongoing advances in sequencing technology will likely make a big difference to the application of real-time genetic information by increasing the capacity of these machines and improving turnaround times.

6.4.18 MODELS CAN SUPPORT ECOSYSTEM APPROACHES TO FISHERIES MANAGEMENT

Models are key tools that can be used in fisheries management to integrate a wide range of system information in a common framework (Fulton *et al.*, 2011). Commercial fishing has long relied on modelling to determine how much to fish. These models have largely been single species focused and single-species models remain the dominant tool for informing the management of commercially valuable stocks in practice (Plaganyi, 2007). This is true for many of Aotearoa New Zealand's major fisheries where a generalised age- or length-structured fish stock assessment model, CASAL, is used for stock assessments, though not all assessments use it (Doonan *et al.*, 2016). Most of these models rely on the outputs from current stock assessments and often rely on assumptions that are contested (see section 5.2.2: Setting catch limits and allocating catch allowance).

The growing recognition of the complexity of ecosystems and need to understand dynamics within them has heralded a new era in modelling that expands beyond a single-species focus to the wider ecosystem, which aims to address the acknowledged limitations of existing models. Along the continuum of complexity for models used in fisheries management, the mechanistic models used for stock assessments sit at one end, with models of intermediate complexity forming the bridge to the full ecosystem models at the other end (Collie *et al.*, 2016). Innovative ecosystem models can support sustainable fishing by improving system understanding, identifying major processes, drivers and responses of change, highlighting major knowledge gaps, and providing a way to test management strategies before implementation (Fulton *et al.*, 2011). However, they are extremely complex and resource intensive, depending on significant datasets for stocks and their environment over time.

Innovative ecosystem models can support sustainable fishing by improving system understanding, identifying major processes, drivers and responses of change, highlighting major knowledge gaps, and providing a way to test management strategies before implementation.

There are a number of whole ecosystem modelling approaches of marine ecosystems and these are being increasingly used as a tool for analysis of ecosystem structure and function (Bradford-Grieve *et al.*, 2003; Pauly *et al.*, 2000; Plaganyi, 2007). However, while full ecosystem models are desirable they are not always practical to be implemented because of data and knowledge gaps (Collie *et al.*, 2016). The cost of implementing full ecosystem models can also be prohibitive due to the significant data needs. By 2040, increased data and knowledge regarding our marine ecosystems will support wider application of the more complex models in the stock assessment and broader fisheries management process. Readily available and up-to-date data will also help the development, testing and deployment of more reliable models with fewer assumptions, and reduce the cost burden of running such models.

A high level overview of the different types of modelling approaches in the toolbox that can be applied, depending on available data, and some examples of these are discussed below. Additional examples are briefly described in appendix 14: Further examples of models.

- **Mechanistic/dynamic models** are used to inform year-to-year management decisions, such as stock assessments. The model is designed based on what we know about the ecosystem, which is simplified to the available, and often limited, knowledge. Structural assumptions and parameters are put into the model and then changes in ecosystem properties can be simulated over time, allowing for the model to predict the future but only for small changes and only if the basis of the model remains valid. The model's output tends to be highly dependent on the assumptions about how the ecosystem functions so knowledge gaps can be limiting and the more knowledge feeding into it the better.
  - **Casal2** is population modelling software that is used for quantitative assessments of marine populations, including fish stock assessments (Doonan *et al.*, 2016). It can project population status into the future or simulate observations from a set of given model structures, and can allow for relationships between species, such as predators and prey. Observational data can be input from many different

sources, for example removals-at-size or -age from fishing or other human impact, scientific survey, and mark-recapture data. There is flexibility in specifying population dynamics, the parameters used and model outputs – for example, for the first accepted stock assessment using Casal2, completed for New Zealand blue cod in 2020, the model assumed some blue cod could change sex (which they are believed to do, from female to male), and at the same time change their growth rate and longevity.

- **Mass balance models** such as Ecopath with Ecosim (EwE) are a type of ecosystem model that focus on trophic transfers of material i.e. the feeding of one organism on another. They act as a basis for future ecosystem modelling, for example, the development of models that are seasonally resolved, spatially resolved, and capable of being run dynamically. The model may also allow identification of sub-systems (for example, groups of interconnected species) that should subsequently be modelled in more detail. Mass balance ecosystem models are beneficial because they force the critical assembly of a large amount of data on all components of the ecosystem in a form where they may be combined and intercompared. The model tests whether our current understanding of the ecosystem structure and function is complete and consistent. In assessing completeness, the model allows us to identify critical gaps in our knowledge, data, or approach. They formalise our conceptual model of ecosystem interconnectedness giving a quantitative model of energy flow through the system. This may be useful for suggesting system-level characteristics or properties of the system. For example, the model is used to identify key species or groups on which the system depends. Models help to identify candidate indicators of ecosystem state, which will be useful in monitoring for major changes in ecosystems over time. Aotearoa New Zealand has developed mass balance models for the Southern Plateau (Bradford-Grieve *et al.*, 2003), Chatham Rise (Pinkerton, 2011), Tīkapa Moana Hauraki Gulf (Pinkerton *et al.*, 2015), Te Tapuwae o Rongokako marine reserve (Pinkerton *et al.*, 2008), and Ross Sea (Pinkerton, 2010).

Figure 146: Blue cod (*Parapercis colias*) are able to change sex (from female to male) and this needs to be accounted for in models. Image credit: Sarah Milicich/iNaturalist (CC BY-NC 4.0).

- **Size-based models** are ecosystem models in which key life history traits such as feeding, mortality and reproduction are governed primarily by size, rather than species identity. Size based models range in complexity, from whole community models without resolved species (Law *et al.*, 2009), up to multi-species models in which individual species traits are also captured and resolved (Blanchard *et al.*, 2014). Some models capture the links between pelagic and benthic organisms (Blanchard *et al.*, 2009), and some even consider the role that habitat plays in mediating predation and supporting fisheries productivity (Rogers*, et al.*, 2014). These models predict ecosystem-level dynamics including, but not limited to: the size-structure of communities, the productivity of fisheries, the average trophic level in an ecosystem, or the maximum size of different species. The benefit of this modelling framework is that it requires significantly less data than mass-balance models, or full ecosystem models, but has the capacity to answer some of the same management questions. The reduced data need is driven by the key assumption that big organisms eat smaller organisms, thus avoiding the need for detailed diet data for all species, which is rarely known, and expensive to generate. Size-based models have been applied to many pertinent questions in the field of fisheries science, including the impact of climate change on global fisheries productivity (Blanchard *et al.*, 2012), the trade-offs between fisheries targets and marine conservation (Blanchard *et al.*, 2014), and the impacts of habitat loss in tropical fisheries (Rogers *et al.*, 2014; Rogers *et al.*, 2018). Size-based models have a great potential as a management tool to support the move towards EAFM. Models are currently being developed for two key Aotearoa New Zealand fisheries, and their predictions are being validated and compared to both mass-balance and full-ecosystem models to understand which tools can answer which questions.
- **Models of intermediate complexity** (MICE) are ecosystem models that are question-driven and contain a limited number of components and ecological processes. Intermediate complexity models rely on the most important aspects with the most data. The Chatham Rise MICE model includes two commercially fished species (hoki and hake) and assesses their population dynamics simultaneously, using a functional response formulated by representing predator-prey interactions.
- **Full ecosystem models** are strategic models that are used to support longer-term planning. These models can include some or all of the following aspects – population structures, environmental influences on populations, non-linear species interactions, and human interactions (e.g. beyond harvest) (Collie *et al.*, 2016). The increasing complexity of these models requires an increasing number of parameters and with that can come heightened uncertainty, until more knowledge is gained.
    - **Atlantis** is a modelling framework to explore ‘what-if’ type questions for marine ecosystems. It can be used to understand possible drivers of ecosystem components and states and to simulate how ecosystem components may respond to various management interventions. The model simulates the ecosystem through time, calculating each new state based on the previous state and events since. It integrates biology, physics, chemistry and human impacts (e.g. the effects of fishing) to provide an overview of marine ecosystem function. The Atlantis modelling framework consists of sub-models that incorporate both the biogeochemical components of the marine ecosystem in question and the human realm into model predictions. Atlantis modelling is a substantial task, with a single application typically taking between six months and two years to develop. Two Atlantis models have recently been constructed, one for Te Tai-o-Aorere Tasman Bay and Mohua Golden Bay and another to represent the Chatham Rise area (McGregor *et al.*, 2019a; McGregor *et al.*, 2019b) – see 5.3.6: case study: Chatham Rise is a unique fishery with consistent, long-term data. Both models have been tested and validated. Scenarios could include varying levels of climate change impact, or alternative fishing (exploitation level, spatial patterns, target species and gear changes) approaches, and single- versus multi-species maximum sustainable yields. The model does not account for seafloor damage and sensitive benthic

habitats and some question whether the model is practical for wide deployment given how much funding would be required to fulfil the data needs.

- **Size spectrum models** take body size as the most important variable determining predator-prey interactions, mortality, and growth and reproduction rates (Andersen, 2020; Jacobsen *et al.*, 2016; Petrik *et al.*, 2019). They then track the transfer of biomass between species and sizes as a result of these processes. This enable more realistic capturing of the way changes in one species or ecosystem component affect other components.

The increasing complexity of these models requires an increasing number of parameters and with that can come heightened uncertainty, until more knowledge is gained.

Need for indicators

Ecosystem indicators are crucial to understand ecosystem dynamics because it is impractical to measure every species to inform management decisions. Ecosystem indicators can be physical, chemical or biological. Physical and chemical indicators are measures of the physical and chemical components of the ecosystem, whereas biological indicators (or bioindicators) refer to organisms, species, or communities whose characteristics show the presence of specific environmental conditions. For example, measuring the most sensitive species can indicate whether the rest of the ecosystem is healthy (discussed in section 3.3.7.3: Ecological monitoring). The opportunities to collect data in new ways (outlined in section 6.2.2.1) could provide valuable indicators for ocean health and ecosystem dynamics.

Filling data gaps is essential to improve models

The reliance on modelling stems in part from many of the data and knowledge gaps discussed in section 3.4 and in section 5.3: Commercial fishing has impacts on target species sustainability. Consequently, many of the opportunities to improve in these areas will improve the accuracy of modelling. Currently, a smaller number of datasets feature heavily in stock assessment models, particularly time series data on relative abundance. Some of this data is independent (such as research surveys), while other data is fisheries-dependent (e.g. CPUE). The more data we have the less assumptions need to be modelled and the more certain we can make estimates of a species or species group status and how they will respond to changes in fishing pressure or environmental conditions. Having regional models can also lead to more fine-scale knowledge to inform fishing, as is the goal for 6.2.3: case study: The Moana Project – Arming vessels with sensors to help validate ocean models (Azevedo *et al.*, 2020).

Currently, a smaller number of datasets feature heavily in stock assessment models, particularly time series data on relative abundance. Some of this data is independent (such as research surveys), while other data is fisheries dependent (e.g. CPUE). The more data we have the less assumptions need to be modelled and the more certain we can make estimates of a species or species group status and how they will respond to changes in fishing pressure or environmental conditions.

Validating models

There are opportunities to improve our modelling by strengthening validation and data inputs. Issues with overreliance on modelling and a lack of validation, particularly in stock assessment, are well-acknowledged and are not limited to Aotearoa New Zealand (Maunder and Piner, 2015). New research at NIWA is developing methods to use stable isotope analyses of tissue of multiple species to validate and tune food web models to reduce uncertainty and improve reliability. At present, the data required to develop robust, dynamic predictive ecosystem models is lacking. Long-term data collection at multiple trophic levels is needed to use these structural food web models to project ecosystem changes into the future in response to climate change and human activities such as fishing.

> Issues with overreliance on modelling and a lack of validation, particularly in stock assessment, are well-acknowledged and are not limited to Aotearoa New Zealand … At present, the data required to develop robust, dynamic predictive ecosystem models is lacking. Long-term data collection at multiple trophic levels is needed to use these structural food web models to project ecosystem changes into the future in response to climate change and human activities such as fishing.

Use going forward

- Innovative modelling and spatial analysis tools for identifying vulnerable and sensitive habitats allow for assessment of spatial management configurations and trade-offs to maximise biodiversity protection benefits and minimise costs to bottom trawling fisheries.
- It's essential that all parties have a clear understanding of the strengths and weaknesses of a model at all stages of development, and the level of uncertainty where the model can be used for fisheries management decisions.
- Models need to be fit-for-purpose, deployed in stages for continuous refinement, and able to be effectively communicated so that people understand how the evidence is generated and the level of uncertainty.
- Models that can be modified and applied to new questions will be most beneficial to support a responsive management system.
- Models can support the basis of multispecies harvest control rules.
- Long computer run times usually preclude more complete exploration of the parameter space but as computing capacity increases this might be possible.
- These models should be fully integrated into the decision-making process and always ground-truthed with real-life fisheries experience.

These issues are pertinent to recommendations in Themes 5, 6 and 7.

6.5 WHERE AND WHEN WE FISH

There are a number of factors that determine where and when fishing can occur, including weather, market opportunities, land-based impacts such as sedimentation, and any regulatory constraints.

With a specific focus on improving the sustainability of fishing operations, here we consider how technology can help refine where and when fishing takes place to reduce the impact on other species and habitats. The target species of commercial fishing operations often overlap with protected species and habitats and other target or non-target species. By knowing where protected or threatened species are, interactions can be better managed. Likewise, knowing which habitats to avoid and when will provide benefits to commercial fisheries stocks and the ecosystem as a whole.

Figure 147: Understanding the interactions of fisheries with species and habitats is important. Image credit: white-capped mollymawks/toroa (*Thalassarche steadi*), Jody Allair/iNaturalist (CC BY-NC 4.0).

Understanding the interactions of fisheries with species and habitats is important for three reasons:

- We can better estimate the magnitude of the impact of fishing on threatened species, and therefore better assess the conservation status of these species,
- We can understand the nature of the interactions and devise solutions to mitigate these impacts, and
- We can determine which habitats to avoid and when.

Clear species-specific spatial and seasonal variability in bycatch per unit effort has been identified for seabird bycatch in gillnet fisheries, highlighting high-risk situations occur that could be avoided, while full fishing activity is appropriate at other times (Glemarec *et al.*, 2020). Significant closures to set netting have been regulated in Aotearoa New Zealand because of this.

The timing and location of commercial fisheries operations plays a large role in dictating the impacts of fishing on marine ecosystems. Some of the issues relating to fishing sustainability – catching protected species as bycatch and damaging significant habitats – could be managed by changing where and when fishing occurs. This approach has already been applied in some fisheries where, for example, fishers set their longlines at night to avoid seabird bycatch. The FAO guidelines interpreting UNGA 61/105 on the protection of vulnerable benthic ecosystems include limited spatial extent of bottom fishing as a method to mitigate significant adverse impact (FAO, 2009).

Some of the issues relating to fishing sustainability – catching protected species as bycatch and damaging significant habitats – could be managed by changing where and when fishing occurs. This approach has already been applied in some fisheries where, for example, fishers set their longlines at night to avoid seabird bycatch.

There is significant opportunity to use innovative tools and techniques to make these changes more specific, dynamic and precise.

First we need to more holistically study the oceans and biota within it. There are knowledge gaps that need to be filled about habitats, lifetime and seasonal movements of marine species, and fisheries interactions with protected species to better understand how to target some species and avoid others (Letessier *et al.*, 2017). New tools such as drones, autonomous vehicles and satellites are making it possible to gather data from otherwise inaccessible areas. Advances in biochemical techniques can further grow the knowledge base to inform management, and EM can expand data collection efforts and validate observer data.

Next, we can use this information to predict patterns of movement and behaviours. Those predictions can feed into spatial decision support tools that model the risks of coming into contact with protected species. These are already relied on in fisheries management in Aotearoa New Zealand but improving frequency and pace of data collection and analytical processes would allow quicker decision making by fisheries managers. Advances in data science can strengthen the evidence base that feeds into decision making, such as the work by Dragonfly Data Science (Abraham and Thompson, 2020). The predictions will need to also incorporate projections about how species might respond to changing climates and oceans, as well as evolutionary changes in response to various factors, including fishing (Guerra *et al.*, 2020).

Ultimately, the goal is for this knowledge and new tools to come together to enable dynamic ocean management, with the goal of near-real-time decision making in the marine space. Being able to dynamically manage the ocean with more precise spatial and temporal management of commercial fishing could support fishing to continue at sustainable levels while minimising impact on non-target species or particular habitats.

In this section, we discuss how innovative tools and new scientific approaches can be used to study, predict and inform in real time where and when fishing should take place, and monitor illegal fishing.

- New tools can refine spatial and temporal knowledge of marine life to inform fisheries management.
- Comprehensive models can inform predictions about population and protected species.
- Dynamic ocean management will help protect non-target species in real time.
- Innovative tools can also be used to detect illegal fishing.

These issues are pertinent to recommendations in Themes 4, 6 and 7.

6.5.1 NEW TOOLS CAN REFINE SPATIAL AND TEMPORAL KNOWLEDGE OF MARINE LIFE TO INFORM FISHERIES MANAGEMENT

In order to manage our marine environment better we need to build on our knowledge of ecosystems, habitats and species-specific movements and behaviours, to improve the temporal and spatial resolution. This will allow for fisheries management that is more flexible and adaptable to the changing conditions in the ocean, thus enabling fishing to take place with a far reduced risk of adverse impacts on species and habitats. Data can be collected at a finer scale and captured over time to better understand dynamics so that these can be taken into account for the dynamic management of fisheries. There are new tools that can help grow this knowledge base and generate data to inform predictive and real-time management of protected species and habitats:

- **Drones and unmanned aerial vehicles (UAVs)** (see section 6.5.1.1).
- **Genetic tools (eDNA and wildlife forensic tools)** (see sections 6.4.6 and 6.4.16).
- **Satellites** (see section 6.5.1.2).
- **EM** (see section 6.4.1.1).
- **Acoustic transmitters** (see section 6.4.12).
- **Underwater backscatter localisation.** A battery-free 'underwater GPS' tracking technology has been developed at a proof-of-concept level using piezoelectric materials (Ghaffarivardavagh *et al.*, 2020). The technology provides an alternative to acoustic location technologies that require batteries and can be bulky and limit the tracker's lifespan – in contrast these systems could be low power, low cost, and scalable. The materials generate their own charge in response to receiving soundwaves and the receiver translates the backscatter into a low-bitrate binary code. However, the technology is in its infancy and requires further development to be able to be applied more widely in ocean exploration applications.
- **Biochemical techniques.** Chemical signatures derived from biochemical techniques (described in section 6.4.10: Biochemical technologies) can provide insight into species habitats, as shown in 6.4.11: case study: How a chemical fingerprint identified Aotearoa's most significant snapper nursery. The information from these studies can inform approaches to protect certain areas to sustain healthy fish stocks. As these analytical techniques become more refined and the cost declines over time they could be applied more widely.

6.5.1.1 DRONES AND AUTONOMOUS VEHICLES EASE ACCESS TO DIFFICULT-TO-REACH PARTS OF THE OCEAN

Technological innovation is opening up new opportunities to map, assess and monitor habitats using UAVs, such as drones. Marine habitats are vast and can be difficult to access. UAVs can allow access to areas of interest from the air, sea surface or underwater. This allows researchers to explore new frontiers in the marine environment because of their ability to access otherwise hard to reach places. Technological advancements and decreasing costs are making unmanned vehicles increasingly accessible and easy to use. These vehicles can combine cameras and/or sensors to record a multitude of data.

UAVs can be used for mapping, assessing and monitoring habitats. After the 2016 Kaikōura earthquake, scientists deployed drones to survey the rocky reef and intertidal habitats affected by uplift (Schiel *et al.*, 2019). The drones were equipped with visible and infrared cameras to investigate the recovery of kelp and other macroalgae, and the extent of juvenile pāua loss. In Western Australia, an autonomous underwater vehicle has been used to survey benthic habitats with the aim of contributing to ecosystem-based fisheries management (Smale *et al.*, 2012).

After the 2016 Kaikōura earthquake, scientists deployed drones to survey the rocky reef and intertidal habitats affected by uplift. The drones were equipped with visible and infrared cameras to investigate the recovery of kelp and other macroalgae, and the extent of juvenile pāua loss.

UAVs can also be used to track, count and measure marine mammals (see 6.5.2: case study: Māui Drone Project). Unmanned aerial systems have been used to survey Antarctic fur seals[208] and leopard seals[209] in Antarctica, and to count and measure gray and harbour seals[210] in the UK (Goebel *et al.*, 2015; Pomeroy *et al.*, 2015). They have also been deployed to measure and photograph southern right whales/tohorā[211] (Christiansen *et al.*, 2018).

There are regulatory and safety hurdles relating to the use of autonomous vehicles. New Zealand's Civil Aviation Authority regulates the use of Aotearoa New Zealand's airspace. The Civil Aviation Authority administers specific aviation rules including aircraft weight restrictions and flying height restrictions. They also specify that aircraft must be within visual line of sight – that is, you must be able to see the aircraft at all times with the naked eye. This distance can range from 500 m to about 1.4 km (Shelley and Andrews, 2015). When operators will not be able to meet the requirements of these rules, they can gain an exemption to operate their craft under different rules (Civil Aviation Authority New Zealand, 2015). This requires a risk assessment that shows how risks will be mitigated. Two reports have identified potential economic benefits from developing the capability for safe beyond line of sight use of drones – particularly in farming, forestry, transport, construction and utilities contexts (Shelley and Andrews, 2015; M.E. Consulting, 2019). At the time of the report, there were no automated systems that could meet the safety equivalent of manned aircraft so beyond line of sight drone use could not be achieved.

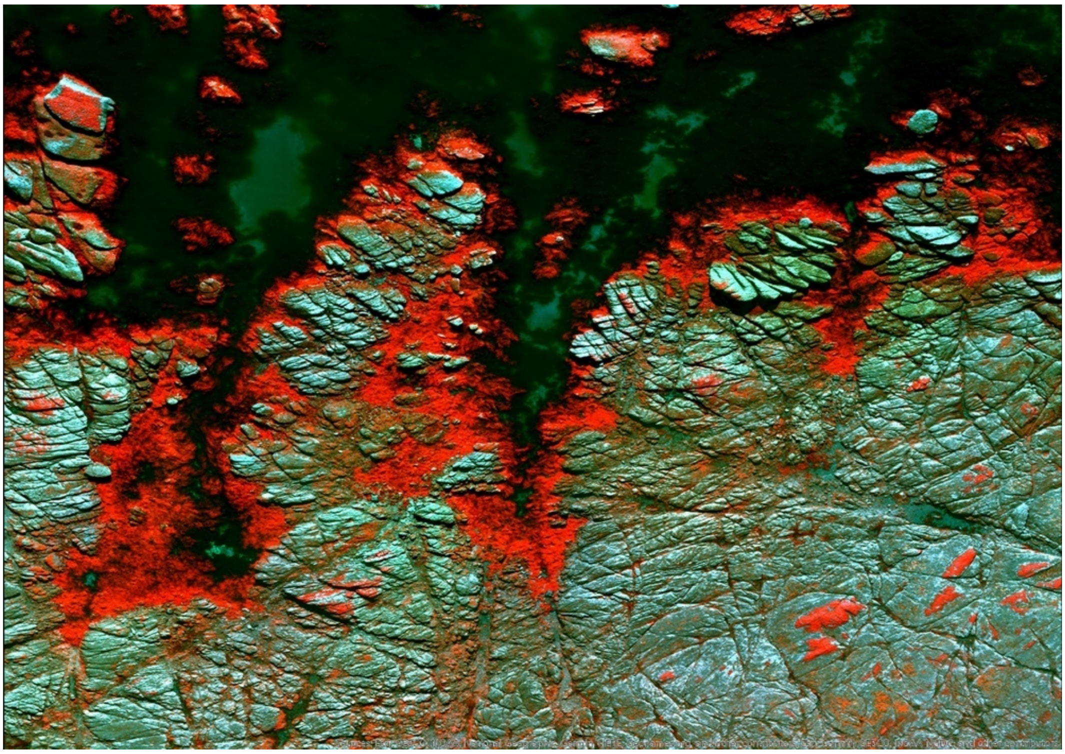


Figure 148: Multi-spectral drone image of uplifted kelp along the Kaikōura coastline. Image credit: Leigh Tait.

[208] *Arctocephalus gazelle.*
[209] *Hydrurga leptonyx.*
[210] *Halichoerus grypus* and *Phoca vitulina.*
[211] *Eubalaena australis.*

Autonomous vehicles can also be used to track invasive species. Coral-devouring crown-of-thorns starfish[212] are a threat to the Great Barrier Reef. Researchers have designed an unmanned robotic system known as 'RangerBot' to automatically identify crown-of-thorns starfish, and administer a lethal injection of bile salts (Dayoub *et al.*, 2015).

Figure 149: The autonomous RangerBot that can identify invasive crown-of-thorns starfish on the Great Barrier Reef. Image credit: Queensland University of Technology.

6.5.1.2 SATELLITE TECHNOLOGY ALLOWS US TO TRACK MARINE SPECIES IN DETAIL

Using satellite sensors allows wide-ranging observations of movements around the ocean over various spatial and temporal scales (Yang *et al.*, 2013). Satellite tagging and tracking in the ocean has emerged through technological advances in batteries, hardware and software, which have facilitated the development of smaller devices, enabling organisms across a vast range of habitats in the ocean to be monitored (Hussey *et al.*, 2015).

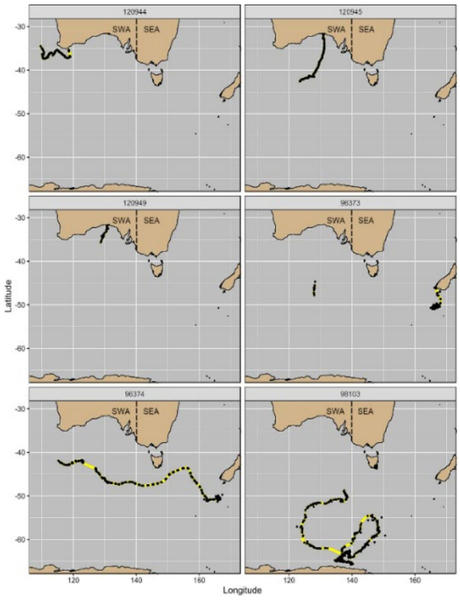


Figure 150: Satellite tracking routes of southern right whales in the Southern Ocean. Image credit: PLOS One.

Improving and emerging satellite technologies have promising applications in fisheries management. Species can be tagged with satellite tags and their movements monitored. Pop-up satellite archival tags have been used for nearly 20 years to track species movements and behaviours (Wilson *et al.*, 2005). Developments in satellite technology are enabling more refined characterisation of the horizontal and vertical movements of individuals, populations and entire communities over wide-ranging spatial and temporal scares – from metres to tens of thousands of kilometres and from hours to years, and in some cases the lifetime of individuals (Hussey *et al.*, 2015). This can be coupled with oceanographic data to

[212] *Acanthaster planci.*

understand what drives movement and behaviour. Some examples of innovative applications of satellite technology are outlined below.

- Satellite technology has been integrated with other research tools to determine the spatial patterns of humpback whales[213] and southern right whales and other baleen whales[214] (Riekkola *et al.*, 2018, 2019; Carroll, 2020). Satellite tags have been used in conjunction with genomic and chemical analyses to follow the migration and feeding grounds of southern right whales around the subantarctic Maungahuka Auckland Islands (Carroll, 2020). Chemical analyses of stable isotopes in the skin provide information on foraging, along with DNA, RNA and epigenetic analyses which show the whale's sex, age and identify individuals. The researchers also use drones to measure the whales' size and fatness and use integrative statistics to combine insights from these different methods to estimate (a) how many whales there were before whaling and (b) how many whales there are now. The information garnered from these studies is useful for projecting future management of potential entanglement issues and proactive fisheries management based on this evidence.
- Data from satellite remote sensing technologies was integrated to understand environmental factors, habitat use and movement patterns of sharks and rays to support conservation and management (Williamson *et al.*, 2019).
- Satellite tags were used to remotely sense and monitor cases of illegal fishing in a shark sanctuary in the Republic of the Marshall Islands (Bradley *et al.*, 2019a). Illegal fishing is discussed further in section 6.5.7.
- Information gathered from satellite tracking has been used to identify areas suitable for a fishery closure (Block *et al.*, 2011).
- A study using satellite tags on killer whales[215] in Norway found that the whales were attracted to herring[216] fishing vessels which suggests deterrent approaches may be the most effective fisheries management solution (Mul *et al.*, 2020).

Limitations and opportunities

- Satellite tagging is labour intensive and tags are expensive (Letessier *et al.*, 2017).
- Currently there is limited spatial resolution of satellite remote sensors (Williamson *et al.*, 2019), but this is likely to be able to be improved over time.
- Similarly, there can be temporal limitations depending on how the study or system is designed. Short studies may miss capture events or dynamics and things like cloud cover can interrupt data collection.
- Satellite tagging requires species to be caught once to deploy the tags but doesn't require recapture, which is an advantage over mark recapture method.
- Developments with batteries and hardware will continue to reduce the size of tags.

[213] *Megaptera novaeangliae.*
[214] Mysticeti.
[215] *Orcinus orca.*
[216] Forage fish of many different species from the Clupeidae family.

6.5.1.3 ELECTONIC MONITORING CAN BE USED TO COLLECT DATA ON INTERACTIONS BETWEEN FISHING AND PROTECTED SPECIES

The oceans around Aotearoa New Zealand are biodiverse. With this rich natural heritage, EM trials in Aotearoa New Zealand have often explicitly aimed to assess interactions with threatened, endangered or protected species – a focus not as central in EM trials elsewhere.

Table 15: Selected EM trials in New Zealand that detected threatened, endangered or protected species interactions.

Fishing method(s)	Protected species detected using EM	Reference
Demersal longline **Pelagic longline**	Seabirds, turtles, fish including sharks and rays	(McElderry *et al.* , 2008)
Trawl	Seabirds, cetaceans, sharks and rays	(McElderry *et al.*, 2011)
Set net/gillnet	Seabirds, cetaceans, fish including sharks and rays	(McElderry *et al.*, 2007)
Set net/gillnet	Seabirds, cetaceans	(Pria *et al.* , 2014)

In Australia, EM for threatened, endangered or protected species has progressed beyond the trial stage and is part of at least two full-scale, operational programmes: seabird captures are monitored in pelagic longline fisheries, and pinniped and cetacean captures are monitored in gillnets (Australian Fisheries Management Authority, 2020).

A 2018 review of EM for monitoring interactions with threatened, endangered or protected species found that EM is effective for detecting a range of events across different fishing methods, including deployment of mitigation devices, bycatch events and unusual behaviour. It is possible to identify species from EM imagery, even with the challenging conditions that can include wet or obscured specimens (Pierre, 2018).

EM can change the behaviour of fishers. For example, fishers in an electronic-monitoring trial increased their reporting of seabird captures (see 6.5.3: case study: Using cameras to protect threatened seabirds) (Tremblay-Boyer and Abraham, 2020). Digital monitoring is expected to greatly improve the information on seabird capture events across a broad range of fisheries (Department of Conservation and Fisheries New Zealand, 2019).

The 2018 review made recommendations for next steps to improve threatened, endangered or protected species monitoring via EM in Aotearoa New Zealand (Pierre, 2018). Most of these centred on the review component of EM: developing training materials and programmes, as well as developing quality assurance and data standards. Key among these was the creation of bespoke ‘fishionaries’ that catalogue and store photos taken by fisheries observers to use in EM training.

6.5.2 CASE STUDY: MĀUI DRONE PROJECT

MAUI63 is developing and testing innovative drone and AI technology for monitoring distribution and habitat use of critically endangered Māui dolphins. Māui dolphins are the world's rarest dolphin, found only on the west coast of Aotearoa New Zealand's North Island.

The project aims to enable more effective conservation of Māui dolphins and the closely related, nationally vulnerable Hector's dolphin, found around the South Island. The purpose of MAUI63 is to provide new science, knowledge and technology that will support decisions about effective threat management and conservation actions for Māui and Hector's dolphins.

Using this drone technology, the Māui Drone Project is a collaboration running from May 2020 to July 2021, involving the Ministry for Primary Industries, MAUI63 Charitable Trust, WWF-New Zealand, Moana New Zealand, and Sanford Ltd.

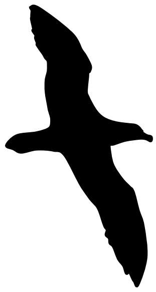
The project outputs include:

- A statistically validated model and methodology for drone-based aerial surveys of Māui dolphin population abundance and spatial distribution. This will enable use of the drone in future year-round assessments of Māui dolphin distribution.
- Drone capability to predict dolphin movements, and track dolphins – enabling more accurate and fine scale (spatially and temporally) habitat models. This can be achieved through object recognition AI to automate detection of the species to find and track them.
- Exploration of the drone as a tool to enable responsive management of remaining fisheries threats. This will include supporting the industry partners to develop effective communication links from the drone to fishing vessels.
- A publicly accessible data sharing platform – to enable access to data from the project.

Figure 151: Top – Māui dolphins. Image credit: University of Auckland/DOC. Middle – A drone. Bottom – Example of how the drone identifies Māui dolphins. Image credit: MAUI63.

The project will build Aotearoa New Zealand's marine coastal science capacity, and enable more effective conservation of Māui and Hector's dolphins initially, but will be used for other marine species. This technology can be harnessed to support a range of robust scientific studies.

6.5.3 CASE STUDY: USING CAMERAS TO PROTECT THREATENED SEABIRDS



Black petrels are a threatened seabird. They breed on Aotea Great Barrier Island and Te Hauturu-o-Toi Little Barrier Island and nowhere else in the world. Fishing is undertaken in this area, meaning the birds are at risk of capture while foraging at sea.

A collaborative trial, driven by the Black Petrel Working Group tested whether cameras could be used to detect seabird capture on fishing vessels as accurately as human observers (Hauraki Gulf Forum, 2020).

Cameras were shown to be as reliable as human observers in detecting seabird captures. However, there were some discrepancies in species identification (McKenzie, in press). Additionally, fishers increased their reporting of seabird captures (Tremblay-Boyer and Abraham, 2020). An audit of the trial, funded by Fisheries New Zealand, validated the results.

The collaborative effort between the fishing industry, government, iwi and environmental groups illustrates how new technologies can improve our knowledge of the magnitude of the impact of fishing on threatened species. That knowledge can then inform solutions to protect black petrels.

Figure 152: Black petrel off the coast of Whangārei. Image credit: Oscar Thomas/iNaturalist (CC BY-NC-ND 4.0).

6.5.4 COMPREHENSIVE MODELS CAN INFORM PREDICTIONS ABOUT POPULATIONS AND PROTECTED SPECIES

Fisheries threats to marine mammals can be reduced through effective spatial management. This requires knowledge about where the animals are and how they are interacting with fishing operations. Data and knowledge generated from the tools discussed in section 6.5.1 can be integrated into models and risk assessments that can predict where bycatch events may occur and use that to inform fisheries management. Our ability to predict organism and community responses to changes in our oceans will be dependent on knowledge of animal movements, interactions, and how the physiological and environmental processes underlying them shape species distributions (Hussey *et al.*, 2015), which is why filling the knowledge gaps is an important first step.

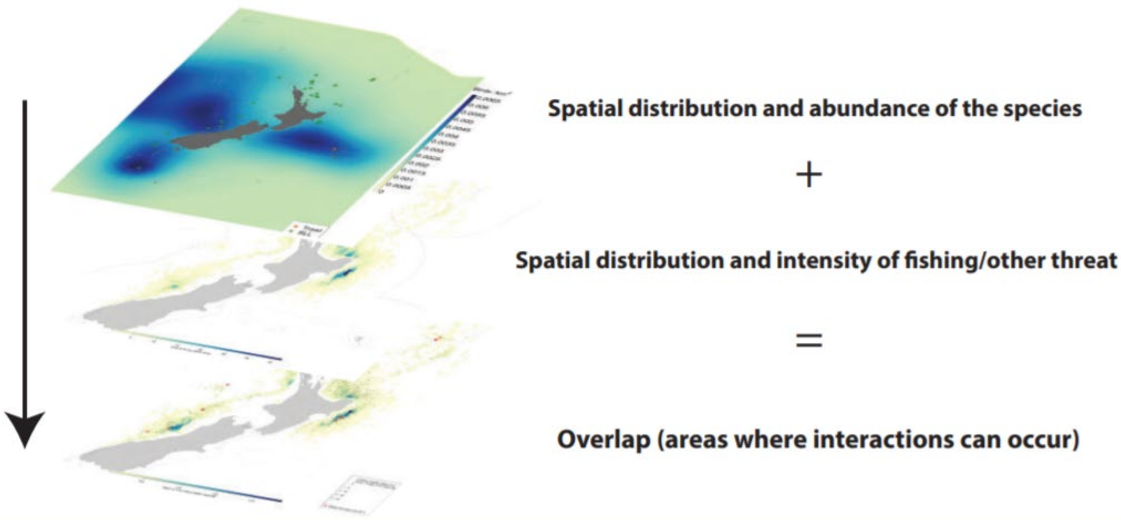


Figure 153: Schematic of spatially explicit fisheries risk assessment (SEFRA).

There are a range of tools that model data to estimate the probability of bycatch, to inform conservation measures and fisheries management:

- **Bycatch prediction tools.** A tool that combines species distribution models with oceanographic data to predict bycatch of pilot whales[217] in a longline fishery was strongly and significantly correlated with observed rates of bycatch in space and time, demonstrating that such tools could be accurately predict times and places with a high risk of bycatch (Thorne *et al.*, 2019). Models to study bycatch of seals identified water turbidity was a major driver of seasonal trends in bycatch which could inform bycatch mitigation efforts (Luck *et al.*, 2020).
- **Spatial decision support tools** weigh up different spatial management scenarios and optimise spatial plans for maintaining ecosystem health and biodiversity. There are frameworks that can be used to assess the risk of encountering protected species during fishing to determine whether fishing can take place in a region. These tools are likely to become more refined over time as further data from the methods described above feed into them. Examples include:
    - The **SEFRA** is an assessment that has been developed to estimate the risk to protected species posed by fishing activities (Ministry for Primary Industries, 2020a). The assessment can be used when there is little data available on mortality (for instance, where the species is rare, or fisheries

[217] *Globicephala macrorhynchus* and *Globicephala melas*.

observer coverage is very low). The assessment uses the spatial distribution and abundance of a species and combines it with the distribution and intensity of fisheries activities (or other threats) to estimate their overlap. It has been used to inform fisheries closures to protect Māui and Hector's dolphins (Roberts *et al.*, 2019).

  - The **Risk Atlas tool** enables querying of fisheries risk to protected species and what the risk reduction benefits and costs are of different spatial management configurations.
  - Freely available **decision-support tool software** such as Marxan (Ball *et al.*, 2009) and Zonation (Lehtomäki and Moilanen, 2013) are also used for conservation planning. These tools help to define a system of protected areas using ecological, social and economic criteria. Both of these tools have been used in Aotearoa New Zealand to support marine management.

Other tools can be used to understand population dynamics.

- **Models of spatial population dynamics and species distribution/habitat suitability.** Models have been used for spatial distribution of cetaceans in Aotearoa New Zealand waters (Stephenson *et al.*, 2020) and habitat suitability for corals and vulnerable marine ecosystems (Georgian *et al.*, 2019). Integrating tagging and fisheries data into a spatial population dynamics model can improve its predictive skills (Senina *et al.*, 2020). These models have the same caveats outlined in section 6.4.18: Models can support ecosystem approaches to fisheries management.
  - **Spatial Population Model (SPM)** is a modification of the CASAL software (see section 6.4.18), which models fish and fisheries distribution at a higher level of spatial resolution. SPM simplifies spatial distribution of fish over time and space using 'preference layers' to determine the probability that fish occur in each area at each time, and can be, for example, sea surface temperature, depth, or the distance from one cell to another. SPM is valuable because this simplified and unique way of modelling spatial distributions and movements allows it to operate as an estimation model. Therefore, rather than being just a tool for investigating the potential effect of space on fish stocks and fisheries (which most spatially resolved models are), it can estimate model parameters, including those controlling spatial movement, and be directly used in stock assessment. SPM has been used as part of the stock assessment of Antarctic toothfish,[218] and more recently for investigating potential distributional changes in tuna associated with climate change.

Ideally these tools will be adapted to inform management in real time, as discussed below in section 6.5.5: Dynamic ocean management will help protect non-target species in real time. Their use will grow once we have more data to refine the models.

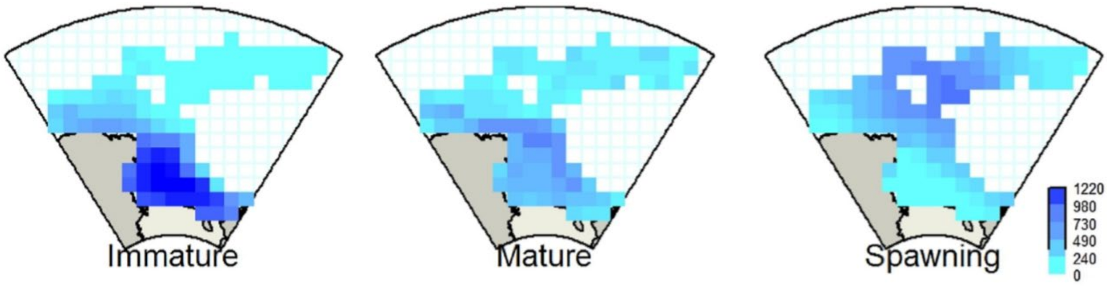


Figure 154: Spatial distribution of biomass (in thousands of tonnes) for immature, mature, and spawning Antarctic toothfish as estimated by SPM. From Mormede *et al*. (2017).

[218] *Dissostichus mawsoni.*

6.5.5 DYNAMIC OCEAN MANAGEMENT WILL HELP PROTECT NON-TARGET SPECIES IN REAL TIME

The ocean is not a static environment so effective fisheries management needs to be fluid in space and time to respond to the changing locations of marine species and its users. A number of tools can help to monitor the patterns of movement of protected species to first predict, but ideally inform in real time, the areas to avoid while fishing. Methods and tools previously described for other applications in fisheries can also be drawn on to inform dynamic ocean management to protect non-target and threatened species. The challenge lies in rapidly collecting and pulling relevant data together to inform decisions.

- **Modelling.** The Ecocast app (see 6.5.6: case study: EcoCast – an app that can help fishers decide where to fish) highlights how a model can be applied to inform where fishers choose to fish to avoid bycatch in real time. FaCeT (Fisheries and Climate Toolkit) is another dynamic ocean management tool under development in the US that aims to provide real-time and forecasting information for fishers, bringing together fisheries and climate science.
- **UAVs.** Real-time communication from drones or autonomous vehicles to fishing vessels could enable responsive management. This is one aim of the Māui drone project (see 6.5.2: case study: Māui Drone Project).
- **Genetic technologies.** eDNA tools can support protection of vulnerable, protected or taonga species by recognising where these species are and changing management practices accordingly (see 6.4.17: case study: Managing great white shark conservation through eDNA).
- **Acoustic technologies.** Acoustic tags can be applied for real-time monitoring for direct conservation. Canada is using near-real-time acoustic technology, in addition to aircraft and vessel surveillance, to detect North Atlantic right whales.[219] Once a whale is detected, fishery closures are put in place to help protect them from entanglements.
- **EM, including use of cameras.** EM data can inform fishers of bycatch hotspots that should be avoided. In Alaska, pollock[220] fishers have banded together under the Pollock Conservation Cooperative, agreeing to stop 'the race for fish'. Since opting for "a more rational, deliberate pace", the pollock fishers have produced about 50% more products per pound of fish harvested. To reduce their bycatch of non-pollock species, the Pollock Conservation Cooperative have contracted private company Sea State. Cooperative members share their data with Sea State, who analyse this data and advise vessel operators of bycatch hotspots to avoid, in real time.
- **AI.** Automating video review could also be applied to detecting interactions with non-fish species, such as seabirds or marine mammals. In Aotearoa New Zealand, automated detection of seabird catches in video footage from longline fisheries has been trialled. By understanding how often bycatch occurs, we can better estimate the effect on threatened seabird populations, which in turn informs their conservation. However, this approach had a 'rare event' issue: out of thousands of fishing events captured in footage, only tens were seabird captures. This lack of data made it tricky to train an algorithm, and the difficulties were further compounded by changing operating conditions over time e.g. frame rate and resolution improvements. Combining AI technology with UAVs such as drones is another approach to monitoring fisheries interactions with threatened species.

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[219] *Eubalaena glacialis.*
[220] *Pollachius spp.*

6.5.6 CASE STUDY: EcoCAST – AN APP THAT CAN HELP FISHERS DECIDE WHERE TO FISH

There's an app for fishers that acts much like a weather forecast – it pulls in data from a range of sources and forecasts where fishing operations could take place to fish sustainably and avoid endangered species.

Mandated bycatch reduction measures in the Californian swordfish fishery provided the impetus to design the EcoCast app (Hazen *et al.*, 2018). Fishers used an indiscriminate drift gillnet method in the Californian swordfish fishery, which led to high rates of bycatch of critically endangered leatherback turtles[221] and beaked whales.[222] In 2001, there were two management tools applied to address this – establishment of a static conservation area and mandated gear modifications.

These management tools led to a significant reduction in swordfish catch, well below levels that could maintain sustainable harvest, and challenged the economic viability of the fishery.

The issue in California highlighted an ongoing tension in fisheries management – it's difficult to balance sustainable target catch with species protection using static approaches. The dynamic nature of fisheries means that opportunities to fish sustainably and economically may be lost with enduring area closures. Researchers sought to address this issue by designing a tool that supports dynamic ocean management (Hazen *et al.*, 2018).

Launched in 2017, EcoCast takes an array of live ocean conditions and known species distribution patterns for target and bycatch-sensitive species into account to generate a fluid map to guide fishing efforts.

Satellite data for an array of ocean conditions such as sea surface height, temperature and chlorophyll concentration is collected daily. Mathematical models are then used to predict where species of interest would be distributed based on these conditions. The predictions are then overlaid for different species to create a map with predictions designed to help fishers figure out where they are most likely to find the species they want to catch and least likely to find the species they want to avoid. The map is updated daily and scaled for the day's data (see figure 155). Importantly, users can weight the importance of different species. For example, if turtles are breeding users can ask the app to prioritise avoiding turtles in issuing guidance on where to fish. Essentially, the app guides fishers towards areas of high concentration of their target species and away from protected ones.

The app is now used to allow fishers exemptions to fish in certain protected areas in California. This demonstrates the utility and power of being able to integrate multiple datasets in near real time to inform management decisions (the need for which is discussed in section 6.2.1: Changing fisheries demand nimble and responsive decision making). The modelling software integrates complex data but presents through an easy-to-understand interface that is openly accessible to fishers. This means that the benefit to fishers is obvious and easily realised. Fine tuning of the model and app is ongoing and integrating information from different spatial and temporal timescales, derived with different tools, continues to be challenging.

The app is now used to allow fishers exemptions to fish in certain protected areas in California.

Novel tools like EcoCast could be applied in Aotearoa New Zealand fisheries so that sustainable fishing operations can continue alongside protection of endangered and non-target species. It's easy to imagine the use in our local context, where species like Māui dolphins would be given extra high weight to avoid.

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[221] *Dermochelys coriacea.*
[222] At least 22 species of the Ziphiidae family.

Having more data and information about our oceans, marine species and fisheries practices will open up new opportunities to implement moving management options. Through these approaches the most sustainable and economic fishing methods can be utilised while protecting vulnerable species.

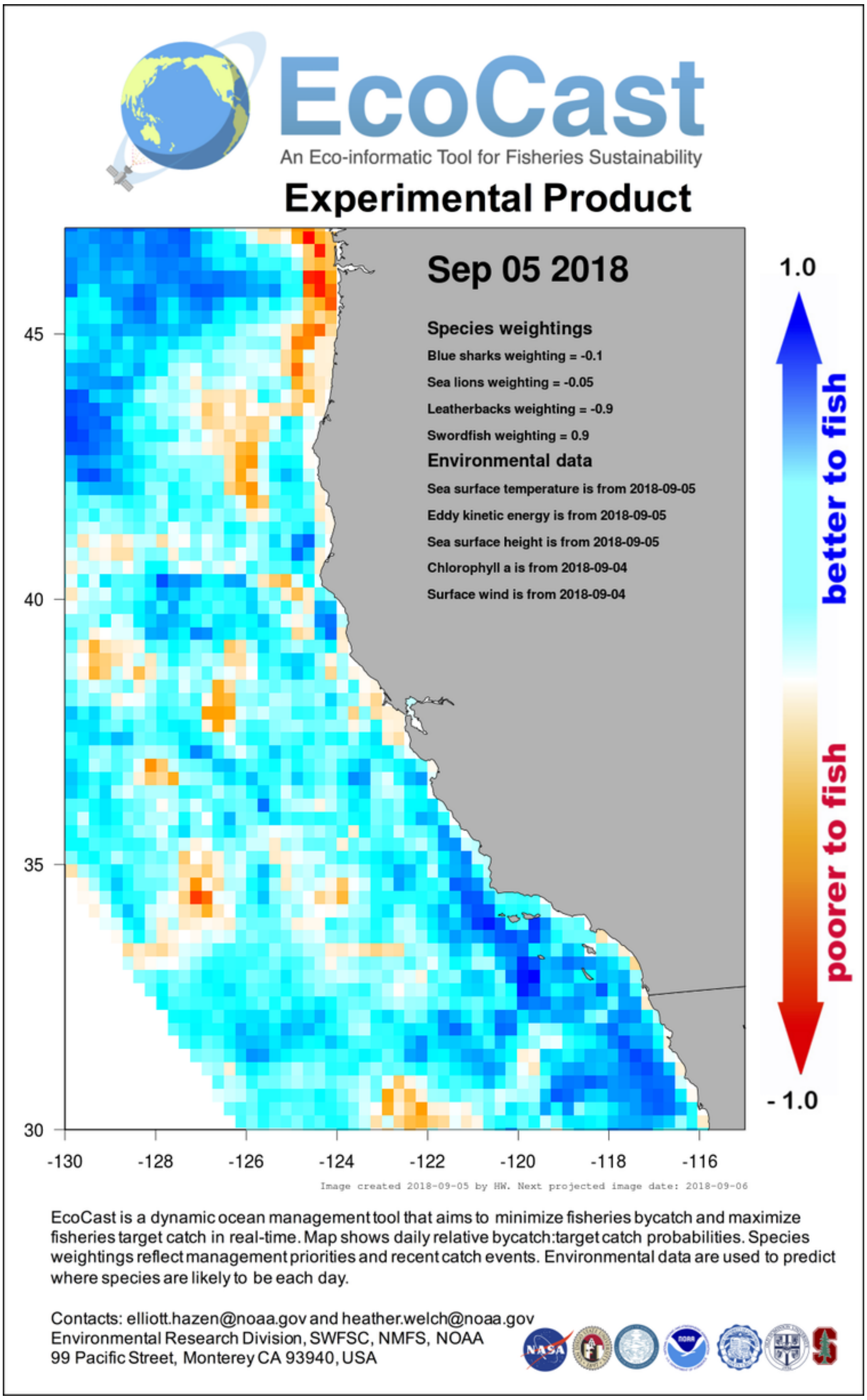

Figure 155: The EcoCast map from Sept. 5, 2018, showing waters that are better and poorer to fish. Image credit: http://oceanview.pfeg.noaa.gov.

6.5.7 INNOVATIVE TOOLS CAN ALSO BE USED TO DETECT ILLEGAL FISHING

Nearly two-thirds of the world's oceans lie outside of any country's jurisdiction or control. It is difficult to observe activity across these vast regions using conventional methods. A number of tools described previously in this chapter can also be used to monitor fishing vessel movements to detect illegal, unreported and unregulated (IUU) fishing and poaching.

- **UAVs.** Drones have been used to monitor fishing activities by countries including Belize, Jamaica and Costa Rica, and NGOs such as Sea Shepherd (Toonen and Bush, 2018). Recently an unmanned vehicle completed circumnavigation of Antarctica, surviving extreme conditions, and highlighting the potential for such vehicles to be used for other purposes. A strength of this technology is that it doesn't require expensive boat time or crews.
- **Acoustics.** Acoustics can also be used for detecting IUU, such as incursions of vessels within MPA areas. In New Caledonia, they have deployed triangulated acoustic devices that detect vessels within an MPA area that then cues further activity, such as deployment of a patrol boat to investigate the incursion.
- **Satellite monitoring of boats.** The application of satellite-related tracking systems is widespread in fishery management, exemplified by the massive and intensive use of vessel monitoring systems (Toonen and Bush, 2018). As part of the automatic ship identification system (AIS), some ships are fitted with a transponder to broadcast the ship's identity, position and course (McCauley *et al.*, 2016). The worldwide AIS for monitoring solutions on the high seas is ostensibly aiming to prevent ship collisions, but satellites have enabled the detection of AIS data en masse. Satellite monitoring of vessels has been used to monitor fishing activity, observing compliance with regard to MPAs in particular (Rowlands et al., 2019). In another study, four satellite technologies, combining AIS data, optical imagery, infrared imagery, and satellite radar were integrated to create the most comprehensive picture of fishing activities in North Korean waters to date and identified illegal fishing activities from Chinese fishing boats (Park *et al.*, 2020).
- **Data science, machine learning and AI.**
    - Aotearoa New Zealand company Xerra Earth Observation Institute (Xerra) have developed a cost-effective way to monitor fishing activities and detect potential IUU fishing. The platform, known as Starboard™ Maritime Intelligence combines datasets from multiple sources to derive insights about the vessels fishing in an area. The visual presence of a vessel (through synthetic aperture radar and optical imagery data) and emissions from a vessel's marine navigation radar (through radio frequency data) are compared to AIS data to uncover which boats are reporting their location and those that aren't. To help determine which species vessels are targeting, Starboard incorporates sea surface temperature data. The integrated data can also be used to detect unusual and noteworthy vessel behaviour. A proof-of-concept pilot operation to detect IUU fishing of southern bluefin tuna in the Tasman Sea was successful at detecting a dark fleet of vessels. The cost of monitoring the area using satellites over a two week period was roughly equal to a typical eight-hour, maritime surveillance flight.
    - Researchers used machine learning to verify whether FADs were used in purse seine fishing, which could have useful applications where such use is banned (Hare *et al.*, 2015).
    - Non-profit organisation Global Fishing Watch uses AIS data to increase the transparency and sustainability of fishing on the high seas. Algorithms can separate fishing activity from non-fishing behaviours such as transiting from AIS data. In this way, Global Fishing Watch can track fishing activity and intensity across areas of the ocean that may be otherwise inaccessible. This approach

revealed fishing activity before and after the establishment of an MPA near Kiribati, where all fishing activity ceased upon closure bar one vessel, which was fined by Kiribati. In 2016, Indonesia partnered with [Global Fishing Watch](), making data from their vessel monitoring system available publicly. This allows Global Fishing Watch to track Indonesian vessels over a certain size that do not use AIS. Other countries such as Peru, Costa Rica and Chile have subsequently followed suit. The Global Fishing Watch algorithms have also been used to identify when fishing vessels are setting longlines, with the aim of assessing how many vessels adopt best-practice night-setting to mitigate albatross bycatch (Bladen, 2019).

- Innovative New Zealand company, X-craft have developed an alternative approach to patrolling the high seas: the Proteus, an unmanned sea vessel powered by solar panels and a mini wind turbine. The Proteus is equipped with a range of sensors, an on-board drone, and an AI system that allows the vessel to make decisions – about whether to follow or track a vessel of interest, for example (Dreaver, 2020).

Starboard™ Maritime Intelligence combines datasets from multiple sources to derive insights about the vessels fishing in an area. The visual presence of a vessel (through synthetic aperture radar and optical imagery data) and emissions from a vessel's marine navigation radar (through radio frequency data) are compared to AIS data to uncover which boats are reporting their location and those that aren't.

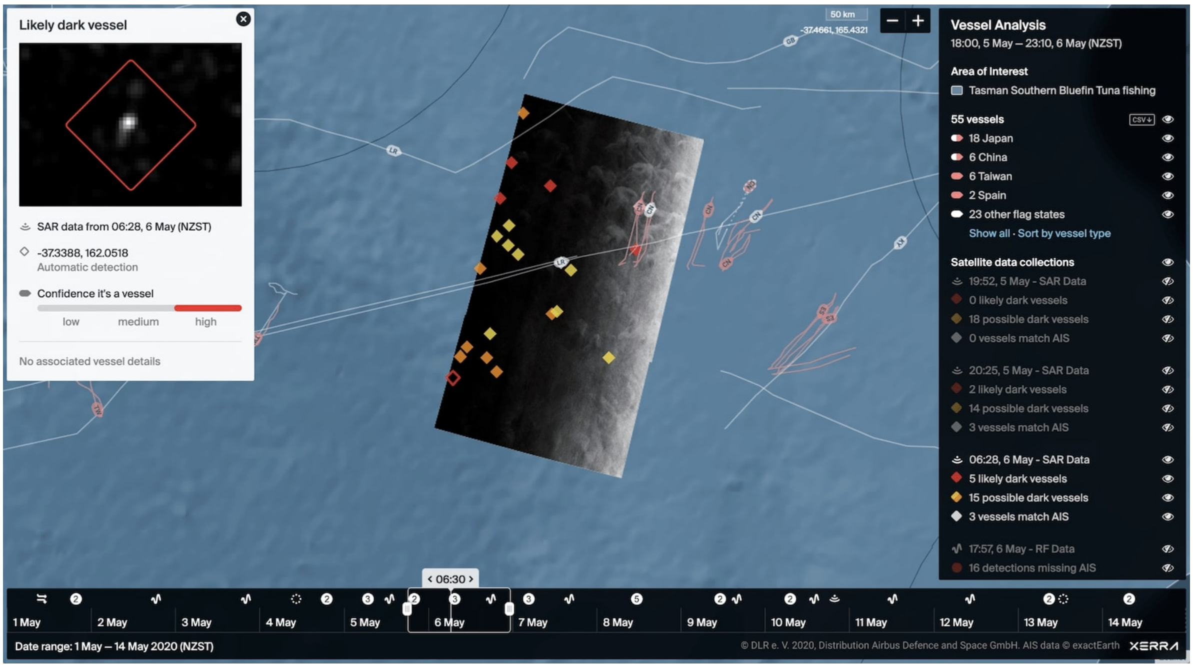

Figure 156: Screengrab of the Starboard interface. Image credit: https://starboard.nz/

6.6 HOW WE ENSURE A HEALTHY OCEAN

Sustainable fisheries depend on a healthy ocean. As discussed in section 3.1, there are a range of stressors beyond fishing that impact the health of the ocean. An understanding of the wider ecosystem is critical to understand how these stressors will drive oceanographic changes, including changes in temperature, salinity, circulation, primary production and acidification.

Monitoring changes within the ocean is crucial to understand and respond to the downstream impacts on the commercial fishing sector. We can use new techniques and technological advances to build on and improve current datasets. Monitoring our ocean systems and ensuring a healthy ocean will in turn promote healthy fish stocks and ecosystems.

In this section we discuss how:

- New technology can make it easier to monitor the marine environment, and
- An ocean observing system can address the challenge of managing multiple stressors.

6.6.1 NEW TECHNOLOGY CAN MAKE IT EASIER TO MONITOR THE MARINE ENVIRONMENT

Long-term monitoring of our oceans is very important, particularly with the inevitable changes caused by a changing climate. Several important indicators can be measured to track of the health of our oceans. Prior to a range of technological developments, ocean measurements had to be made by research vessels which was painstaking and expensive. The result was that the global ocean was poorly sampled. The southern hemisphere ocean region was particularly poorly measured because of the large sizes and remoteness of the South Pacific, Indian and Southern Oceans, together with the relative lack of local wealthy nations funding oceanography.

Technological developments have opened up new opportunities to monitor our vast oceans. We can draw on these developments to build on Aotearoa New Zealand's existing monitoring efforts. In table 16, we highlight the data types of importance for monitoring the marine environment, any current initiatives that contribute to monitoring in Aotearoa New Zealand and opportunities to improve monitoring. Data collected from this range of tools could be coordinated and collated into an ocean observing system, as discussed in the following section (section 6.6.3). Monitoring of all ocean measures could be improved through a nationwide series of inshore surveys that collect a range of environmental and fisheries data and there are also opportunities to utilise existing efforts (e.g. tagged animals) to gather further information, which are not explored further here.

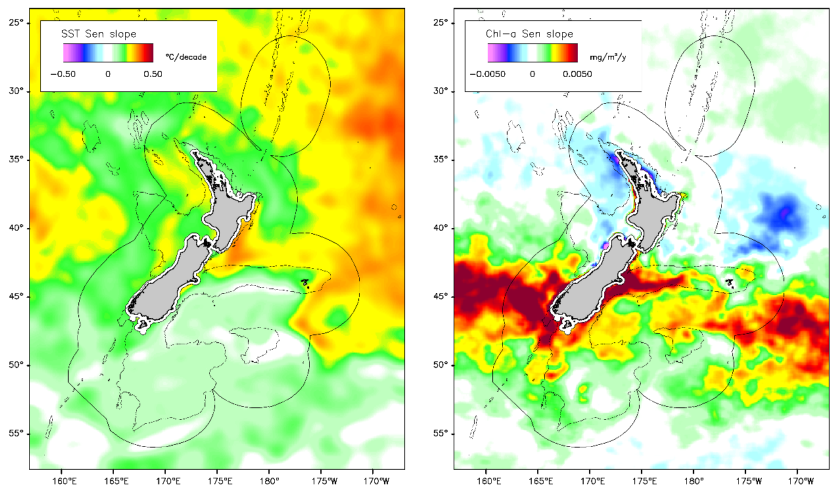

Figure 157: Long term trends in (a) sea-surface temperature (1981-2018) and (b) phytoplankton abundance (1997-2018). Pinkerton *et al.* (2019), report to MfE for *Our Marine Environment 2019*.

Table 16: Examples of ocean measures that are captured in Aotearoa New Zealand and how these could be improved.

Ocean measure	Significance	Current NZ initiatives	Opportunities to improve monitoring
Temperature (on surface and at depth)	Changing temperature can lead to species movement and can also have indirect effects on fish recruitment, fish productivity, ecosystem services (biodiversity) and water quality (e.g. nutrient supply for plankton productivity and source of food for pelagic fish). Higher temperatures may also result in stratification – with eutrophic conditions inshore and oligotrophic conditions offshore; harmful algal blooms and higher rates of disease; and species invasion and biosecurity risks. Extreme events such as marine heatwaves may have greater impact than long-term trends.	Satellite surface temperature (SST) observation is the longest time-series for NZ's ocean monitoring; it started in around 1981 and will continue for the foreseeable future. Two stations measuring SST and five coastal SST stations. Argo (see case study 6.6.2). EXpendable Bathy Thermographs (XBTs). Temperature sensors deployed on boats through the Moana Project (see case study 6.2.3). Autonomous underwater vehicles (Slocum gliders) that carry sensors to measure temperature, salinity, light, oxygen, turbidity and fluorescence below the surface of the ocean. Part of GOOS (see section 6.6.3).	**UAVs** can collect data on weather conditions and surface temperature (Toonen and Bush, 2018). Reinstate buoyed moorings.
Ocean acidification (changes in saturation horizon, aragonite, calcite)	Ocean acidification can cause harm to marine ecosystems, having direct and indirect impacts like changes to the behaviours and physiology of creatures. Ocean acidification can: cause dissolution of organisms with calcareous shells or exoskeletons (e.g. plankton, shellfish – particularly juveniles, crustaceans, algae, deep-sea corals); and change the behaviour responses of invertebrate and fish species. Shallowing of saturation heights and dissolution of deep-sea coral fisheries habitats. Data on ocean acidification is important for improving our climate modelling (see section	NZ has the longest running ocean acidification records in the southern hemisphere taken off Otago, along a transect that samples surface waters of the coast, the subtropical front and subantarctic water. Limited monitoring sites with long-term data (Ministry for the Environment and Stats NZ, 2019b). Other coastal monitoring, but not long enough to determine longer-term trends. New Zealand Ocean Acidification Observing	

Ocean measure	Significance	Current NZ initiatives	Opportunities to improve monitoring
	3.1.1: Climate change is a huge threat to our oceans).	Network established (see appendix 15). 14 sites now measuring ocean acidification (Vance *et al.*, 2020). A *Munida* transect (established in 1998). Argo (see case study 6.6.2).	
Circulation		Sensors deployed on boats for the Moana Project (see case study 6.2.3) also monitor circulation. Sea surface height, sea surface temperature, (and other satellite data), drifter studies, current metres, acoustic Doppler current profilers all provide circulation data.	**Satellites** can be used to monitor circulation in the upper ocean.
Primary production	Plankton are a critical component of ecosystems with high importance to food web functioning (Pinkerton *et al.*, 2020). The production rates of plankton underpin the productivity of the ocean including providing the energy or food source for fish. They also ultimately determine the biological carrying capacity of the ocean in a given area. Primary production rates are a function of many combined factors such as circulation, wind, upwelling, bathymetry, topography, latitude, geographic location, oxygen, nutrient and iron availability, and temperatures. Characterising plankton communities in space and time and monitoring for change is challenging because of the ecological complexity and spatial heterogeneity of communities, short intergenerational periods and the current analytical inability to identify genus or species out of the lab, though recent	The current time-series of satellite measurements of phytoplankton abundance started in 1997 and is ongoing (see figure 157). Continuous Plankton Recorder (CPR)[223] transects have been run regularly between Lyttelton and the Ross Sea since 2008, but only occasional CPR transects have been carried out elsewhere in the NZ EEZ CPR data can then be related to environmental data such as water temperature, ocean mixing and primary productivity (Pinkerton et al., 2020), enabling trend-analysis to investigate patterns of long-term change.	A project with the Antarctic Science Platform aims to develop a **high-throughput genetic and optical (size-based) analysis method** for CPR data to reduce the cost and time of laboratory analysis and improve data quality. Establishing a **regular CPR transect** through across the Chatham Rise would be extremely valuable for characterising zooplankton communities in this key area and understanding variability and change in this crucial ecosystem component in a major fisheries area. It would be useful to expand regular CPR data collection from other parts of NZ, not just the Chatham Rise. E.g. going north from Lyttelton, and also from Wellington to Sydney. It is a cost-effective way of ground-truthing remote collected satellite data on primary productivity.

[223] The CPR can provide wide-area, long-term and cost-effective information on zooplankton communities. This plankton-sampling instrument is towed from the back of ships and samples water at about 10 metre depth (which represents plankton assembly at other depths) (Hosie *et al.*, 2003). Water is filtered through silk, then the silk and plankton are preserved for later counting and identification of species in different regions in the lab. Collection takes place at normal cruising speeds so the recorders can deployed from any vessel and opportunistic collection is possible.

Ocean measure	Significance	Current NZ initiatives	Opportunities to improve monitoring
	developments are promising (Ohman *et al.*, 2019; Lombard *et al.*, 2019). Satellite measurements of phytoplankton abundance is usually species specific. Monitoring changes in magnitude and patterns in NZ's EEZ is likely to provide valuable context for understanding change in fisheries, changes to NZ's marine biogeochemistry and climate-related changes to ocean productivity.		
Invasive species	Algal blooms, toxic algal blooms, disease, nuisance species can all have a detrimental impact on marine ecosystems.	Port surveys, satellite data as existing indicators; monitoring of harmful algal blooms by Cawthron.	**eDNA tools are able to detect invasive species** and early biofouling communities and screen for pest taxa and support biosecurity management (Zaiko *et al.*, 2016; 2020) and targeted detection of high-profile marine pests around shipping hubs. It can be coupled with eRNA to reduce false positives. **Acoustic techniques** have the potential to detect invasive species. The research relating to this is in its infancy, but acoustic technology may be able to be applied for early detection of invasive species for biosecurity purposes (Juanes, 2018).
Pollution	Marine litter and plastic pollution in the ocean have been identified as a burgeoning problem worldwide and Aotearoa New Zealand is not exempt.	Ocean Plastics Simulator Sustainable Coastlines Litter Intelligence FNZ project to identify density of seabed litter from DTIS camera surveys CPR series analysed for microplastics in surface waters between Lyttelton and the Ross Sea. DOC monitors sightings of plastics in seabird nests, seabird stomachs.	**Efforts to reduce plastic entering the ocean most important** **For monitoring:** **UAVs** can monitor plastic pollution in the environment (Toonen and Bush, 2018). **Satellite sensors** have been used to detect oil spills overseas (Brekke and Solberg, 2005). New methods needed to detect microplastics on the seabed.

6.6.2 CASE STUDY: ARGO – A GLOBAL NETWORK OF PROFILING FLOATS

Argo is an international programme that has maintained a global ocean network of profiling floats since 2004. Presently there are about 3,900 operational floats with each float sampling the ocean as shown in (figure 158). Initially, the float sinks to 1,000 m depth, where it parks for 10 days, drifting with the ocean currents. The float then sinks to before rising to the surface, measuring temperature and salinity as it ascends. Once on the sea surface, the float transmits its location and profile data via satellite before sinking and repeating the cycle. Thus, each Argo float provides measurements of the top 2,000 m of the ocean every 10 days, and the floats last for around five years**.** Argo now gives global coverage in all seasons. Argo data is widely used for many other applications, with their coverage, the increasing length of the time series and the near-real-time access making them invaluable for regional environmental studies.

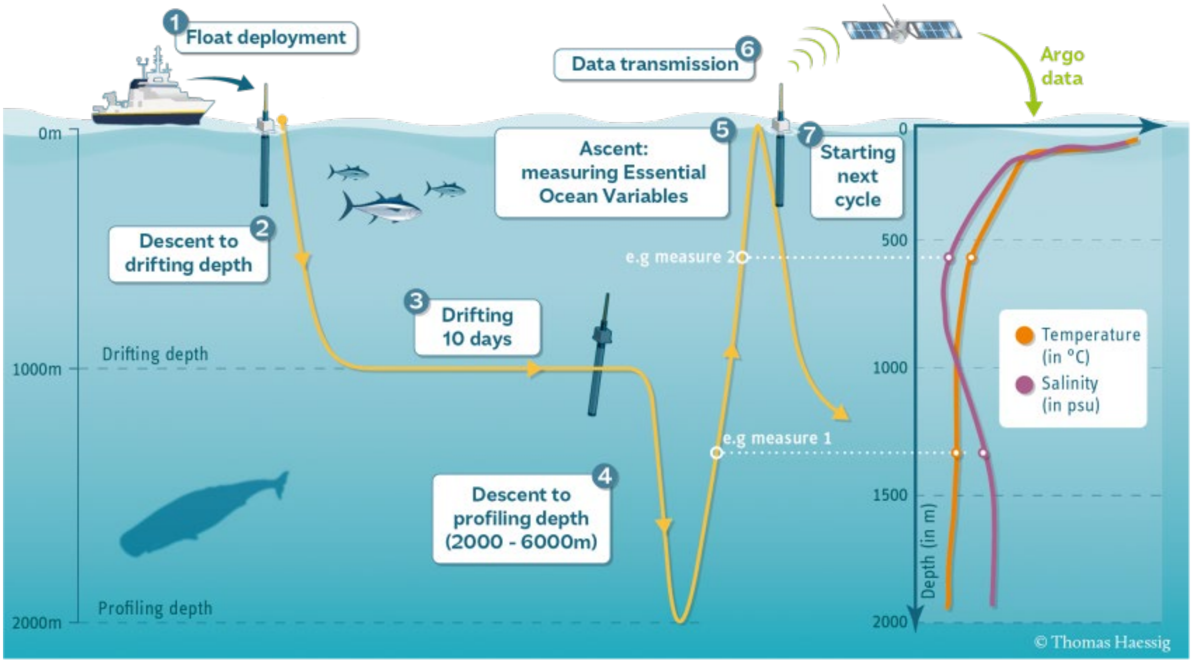

Figure 158: An Argo float cycle. Image credit: https://argo.ucsd.edu/how-do-floats-work/

Argo is the only means of describing the subsurface ocean conditions at any point in the global ocean. In the Aotearoa New Zealand context, Argo data has been used to study inter-annual to decadal variability in ocean conditions and currents and in numerous studies of possible impacts of environmental changes on ecosystems and fisheries. Argo is currently expanding into two new domains. Deep Argo floats which profile to 6,000 m are being deployed to capture almost all of the ocean heat content change and biogeochemical sensors including dissolved oxygen, nitrate and pH are being added to floats. The first is the trend in ocean heat content between 2006 and 2013.

An example of output from analysis of Argo data is shown below in figure 159, which shows that large changes in ocean heat content are occurring north east of Aotearoa New Zealand. Indeed, southern hemisphere changes dominate the global signals.

Further utility of the Argo data would come from integrating it with other local data at the regional level to get informed data for issues such as climate change effects on fisheries and ocean health, and MPA placement.

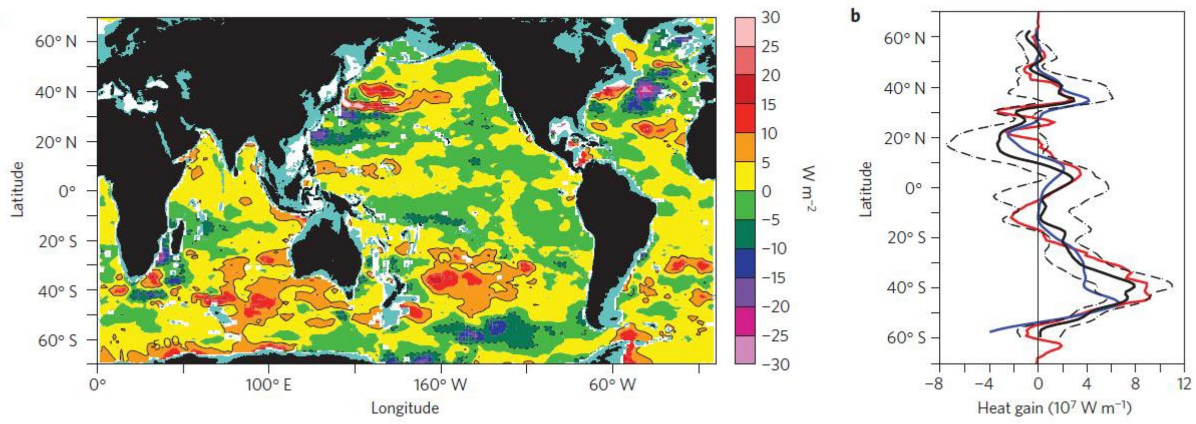

Figure 159: The trend in 0-2,000 m ocean heat content, 2006-2013. From Roemmich *et al*., 2015.

6.6.3 AN OCEAN OBSERVING SYSTEM CAN ADDRESS THE CHALLENGE OF MANAGING MULTIPLE STRESSORS

The data and tools described in the previous section can form the basis of an ocean observing system (OOS). An ocean observing system collects and coordinates ocean-related observation data like temperature and salinity. It is an ongoing and collaborative system. At a high level, ocean observing systems collect data on climate, provide data for services like weather forecasting, and monitor marine ecosystem health.

On a global scale, the United Nations established a Global Ocean Observing System (GOOS) in 1991, which Aotearoa New Zealand participates in through the Pacific Islands Ocean Observing System.[224] There are many other systems feeding into GOOS, including OceanSITES (sustained interdisciplinary time series environment) observation system, which measures variables from sea-air interactions down to 5,000 m depth. NIWA is a member of OceanSITES.

Fisheries management and ecosystem services are stated to have been significant drivers for the requirements of GOOS over the last decade (Moltmann *et al.*, 2019). However, commentary detailing the trend towards EBM and the need for GOOS to service this need goes back 20 years in the literature (Gislason *et al.*, 2000; Summerhayes, 2002). The OceanObs'19 conference canvassed the aspirations of what an ocean observing system can provide – including addressing the needs of fisheries and EBM practitioners (Lee *et al.*, 2019). At the global level, many of the benefits of an ocean observing system cannot be directly applied to fisheries management because data isn't localised enough, though there are wider benefits – for example, improving early warnings of severe weather events like floods, droughts and storms (IOC, 2019).

At the global level, many of the benefits of an ocean observing system cannot be directly applied to fisheries management because data isn't localised enough, though there are wider benefits – for example, improving early warnings of severe weather events like floods, droughts and storms.

There are many other forms of OOS – regional, coastal, and national systems – which collect detail at a finer scale. Some of this data feeds into GOOS while other data is collected for other purposes. Australia has the Integrated Marine Observing System and the US has the Integrated Ocean Observing System.

Aotearoa New Zealand does not currently have an OOS but would benefit from one as it would assist prediction, mitigation and management of the effects of multiple stressors, including climate change, sea-level rise, ocean acidification and impacts from changing terrestrial fluxes (O'Callaghan *et al.*, 2019). Current ocean monitoring efforts in Aotearoa New Zealand could be built on to establish this (O'Callaghan *et al.*, 2019). The local research community has work underway to plan for this. In 2018, there was a planning workshop for a New Zealand OOS involving research institutes, government, and businesses (Sustainable Seas National Science Challenge, 2019a). Outcomes from the workshop are presented in a paper by O'Callaghan *et al.* (2019). The paper describes how an integrated OOS for Aotearoa New Zealand can be developed in Aotearoa New Zealand that integrates mātauranga Māori with western science. The NZ-OOS would be "bottom-up community-driven" and success

[224] The system is co-sponsored by the Intergovernmental Oceanographic Commission of UNESCO, the World Meteorological Organization, the United Nations Environment Programme, and the International Science Council. There is also a framework for ocean observing (last updated in 2017) (Task Team for an Integrated Framework for Sustained Ocean Observing, 2017) and most recently they have published a 2030 strategy for the GOOS (IOC, 2019).

requires inclusiveness and cross-institutional engagement. The biggest hurdle would likely be sufficient and sustained prioritisation of the system, with government data streams being the backbone of the system. Details of the plan and overarching structure are included in figure 160 and appendix 16.

An OOS adds a more sophisticated dimension (in space and time) to enable a 3D view which is dynamic instead of spatial tools such as MPAs (section 4.2).

An OOS adds a more sophisticated dimension (in space and time) to enable a 3D view which is dynamic instead of spatial tools such as MPAs.

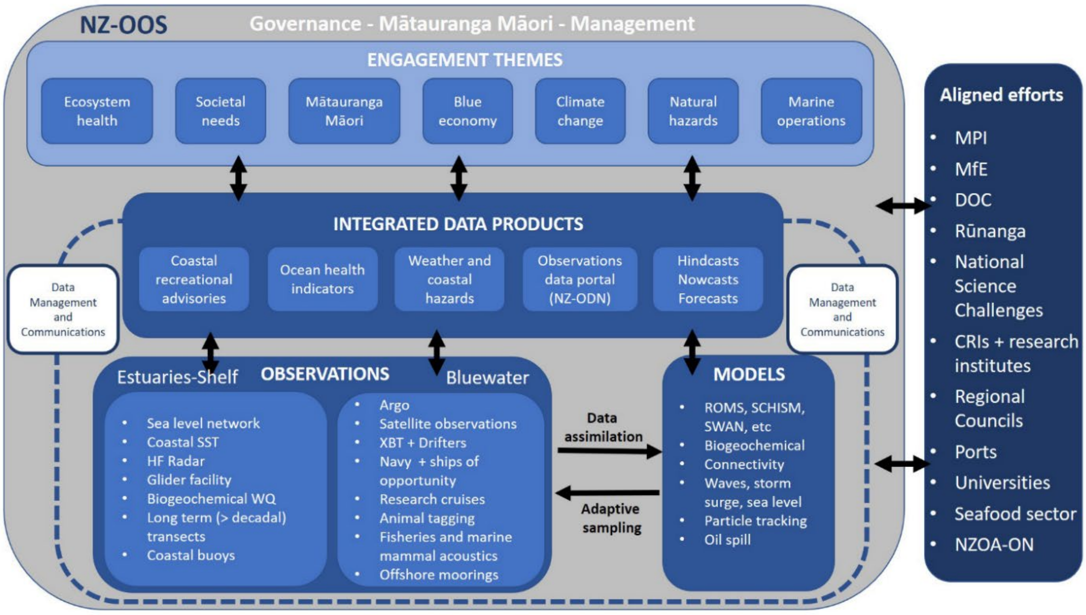

Figure 160: Framework for the NZ-OOS building on existing efforts in Aotearoa New Zealand, from (O'Callaghan *et al.*, 2019).

6.7 USING THE WHOLE FISH TO DEVELOP HIGH-VALUE BY-PRODUCTS

Because there is limited scope for harvesting more fish, adding value to the existing harvest is an attractive path to increasing revenue for the commercial fishing industry. One way to achieve this is through developing high-value by-products.

Over the past 30 years there has been significant research and development activity in Aotearoa New Zealand directed at development of high-value marine products. Despite successful research and product/process development, progress to market has been slow and much raw material is still sent to low-value fish meal and oil. Recently the situation has started to change as the larger fishing companies (particularly Talley's and Sanford) seek to generate more value from the same or decreasing catch volumes. The industry recognises that significant potential remains, but full realisation needs a change in approach. A path to transformation of the Aotearoa New Zealand industry and making full utilisation and maximised value the norm are to be investigated within the 2020 Cyber-Marine programme funded by the Ministry of Business, Innovation and Employment, a collaboration between industry, research organisations (Aotearoa New Zealand, Norway) and universities (Aotearoa New Zealand, Australia). It takes a very similar approach to that discussed earlier in part 6, with a focus on using real-time data, AI, automation and new technology to provide flexibility and rapid response to the diverse raw materials that are characteristic of the Aotearoa New Zealand fishing industry.

Iceland arguably lead the world in their use of fish by-products and we can look to them as an exemplar for how to unlock this potential in a national commercial fisheries industry. Most fisheries nations use around 50% of the fish but Iceland's fisheries use over 80%, with many of the applications being high value. Leading fisheries companies in the country have publicly stated that their goal is to use 100% of the fish (Sigfusson, 2019).

The seafood industry is one of the pillars of the Icelandic economy. It is a dynamic 'base industry' which now forms the foundation for a diverse range of other industries (Sigfusson, 2019). Over the past few decades, the volume of catch in Iceland has decreased but this has not translated to a loss in revenue across the industry. Instead, export value has increased thanks to efforts to maximise use of fisheries resources by using more of the fish. Taking cod as an example, between 1981 and 2011 landings decreased from 460,000 tonnes to 180,000 tonnes, but the total export value of cod products increased from US$340 million to $680 million (Sigfusson, 2019). This increase in revenue despite a reduction in landings is due to progression from only selling fillets at around $12 per fish to using by-products from the whole fish. There is an ambitious estimate that full utilisation of the fish into high-value products could attract up to $3,500 per fish. A proprietary scientific process to develop wound care products from cod skin is responsible for the significant increase, increasing the value to over $2,500 per skin (Sigfusson, 2019). Taking a more conservative estimate would still see a significantly increased value per fish than what is generated without high-value by-products. In the Aotearoa New Zealand context, even production of relatively simple products as part of a 100% utilisation cascade could make a significant improvement to value recovery. Using predicted values from the Cyber-Marine research programme, the value of jack mackerel, currently sold whole into very low-value markets, could easily move from <$1.95/kg to $8.50/kg (figure 161).

Iceland's roughly 3000% increase in by-product use has generated around US$500 million per year and around 700 direct jobs – many of which are in rural coastal towns. For a population of around 360,000 people, there are more than sixty companies in Iceland working with by-products and processing of seafood (Sigfusson, 2019). Further growth of the industry will mean more jobs and even greater economic gains.

This success is in part due to the Iceland Ocean Cluster organisation and their 100% Fish Project, whose mission is "to inspire the seafood industry and seafood communities to utilise more of each fish, increase the value of each fish landed, support new business opportunities, increase employment and decrease waste."

Strengths of this approach that could be drawn on in Aotearoa New Zealand's efforts to use more of the fish include:

- **Taking a bottom-up approach to accelerate innovation.** The private-sector initiative operates an accelerator to support start-ups in the seafood industry. There are over 70 companies in the programme and a large group of entrepreneurs starting companies to capitalise on fish waste. The Iceland Ocean Cluster invests in these companies and also brings other investors in.
- **Welcoming ideas from within and outside the fisheries industry.** Though the network is mostly focused on start-ups, the cluster also supports innovation from incumbent companies in the fishing industry. This is important because although many of the innovative products have come from newcomers to the industry, it is difficult to realise some of the ideas without existing fisheries expertise and industry connections (den Hollander and Thorsteinsson, 2020).
- **Incubating good ideas and offering a physical meeting space.** Bringing people together to support their initiatives provides networking and learning opportunities, knowledge spill over and economies of scale to reduce the risk of failure (den Hollander and Thorsteinsson, 2020). The benefit of sharing space is shown by 70% of the companies who are part of the cluster having collaborated together. It is especially helpful to connect the entrepreneurs new to the industry with the experienced fisheries companies to share insights and overcome hurdles.

- **Focusing on local value add in fishing communities.** To restore opportunities to smaller fishing towns, some of the new innovations are in technology development for fish utilisation that would allow processors to operate on smaller scales, e.g. through modular systems, which could help to revive more remote fishing communities.
- **Expanding networks beyond borders.** The team developed an Ocean Cluster Network, which includes several clusters in the US, Canada and Norway, to strengthen innovation and utilisation of fish by-products so that products can be developed through collaboration within the network. There is plenty of opportunity to share lessons and collaborate, all while preserving the unique value propositions and commercially sensitive information inherent to each company, and several such projects are already underway.

Although some companies in Aotearoa New Zealand are taking steps in this direction, the wider seafood industry would benefit from transforming thinking around by-products, moving away from seeing by-products as waste to seeing them as a rich resource from which we can draw value. We could learn from programmes such as the Bioresource Processing Alliance. This could make the seafood industry become even more productive to the broader economy and aligns with the Government's vision in its economic plan of moving from volume to value (New Zealand Government, 2019b). Using the whole fish requires product innovation in the versatile use of the fish by-products and process innovation in harvesting raw materials. Technological developments related to by-products from wild fisheries are relevant to aquaculture and vice versa.

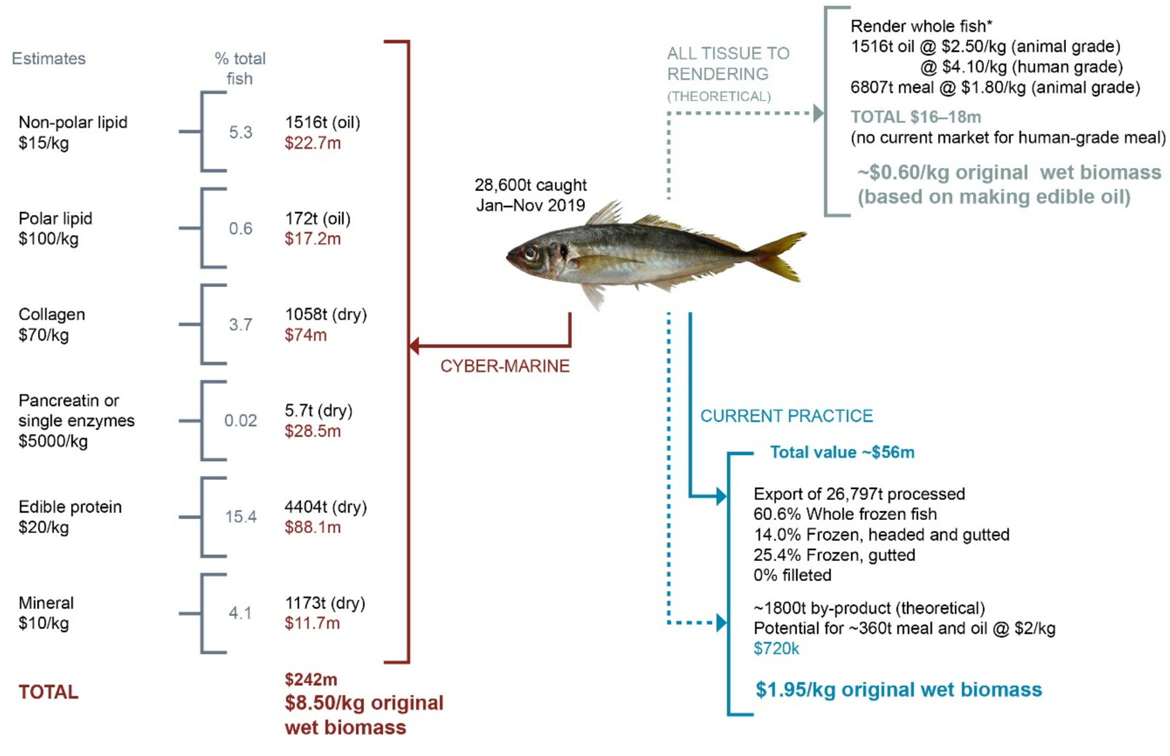

Figure 161: Potential to increase the value of jack mackerel through the refined use of by-products to be of higher value. Image credit: Plant & Food Research.

Recognising that using more of our catch is not only positive for fisheries sustainability but also has significant economic potential, Aotearoa New Zealand should take a focused approach to accelerating opportunities in this sector. A local, context-specific approach will be necessary, but we can look to Iceland for inspiration and experience. The Iceland Ocean Cluster is part of a broader suite of related initiatives that contribute to a thriving by-products industry in the country. These include an annual international one-day conference, Fish Waste For Profit, aimed at companies involved in the commercial fishing, aquaculture and processing sector, and Ocean Excellence – a one-stop-shop consulting firm to help fishing companies develop solutions to use 100% of the fish.

6.7.1 MOVING UP THE VALUE CHAIN

The approach that leads to the highest value will depend on the species of fish and the established market. Efficacy and profitability need to be balanced. A few species are sold as whole fish as this generates the highest value. For other species, the highest value product may be the primary product (e.g. fillets or collagen) with the rest of the fish processed into secondary products. Currently, there is general under-valorisation more than under-utilisation. Ultimately, the goal is for companies to develop a cascade of products for each species that can generate more value than they otherwise get by selling the fish whole, or generating low-value by-products.

Pharmaceutical, nutraceutical and cosmetic applications of fish by-products

Pharmaceutical uses of fish by-products include biotechnology, nutraceuticals and cosmetics. Several projects funded by Seafood Innovations Ltd relate to development of such products. There has also been considerable investment by the Ministry of Business, Innovation and Employment and its predecessors in projects through the Bioresource Processing Alliance and in projects funded by industry. These types of products require a high level of sorting and processing to pharmaceutical quality standards, but this leads to a high level of value-add (Secretariat of the Pacific Community, 2014).

There are numerous medical and surgical applications from fish by-products in development. For example, squalene from shark liver is used as an adjuvant in vaccine delivery. One example in development by is the use of a crystallin protein found in the fish eye lens in ophthalmic surgeries (e.g. as a glue rather than sutures) or treatments (e.g. to treat corneal disease). Researchers at Otago University have used the sugar chitosan from squid pens to develop a gel to prevent surgical adhesions.

The nutraceutical market is also ripe for applications from fish by-products and Aotearoa New Zealand companies are already selling and developing nutraceutical and cosmetic products. It is important that these are scientifically validated.

Nutritional supplements and value-added food products from fish by-products

Nutritional supplements and food products require a high level of sorting and quality control to meet food-grade quality standards. Some products require mass transformation while others need to be sorted into the individual product. The value-add can range from moderate to high, and there is a moderate market capacity for these products. The potential for use of fish by-products in food fortification is influenced by nutritional value, bioavailability of nutrients, texture and smell, religious restrictions and regulatory requirements, but there are still challenges regarding safety and interaction with other ingredients and some technical concerns remain (Nawaz *et al.*, 2020).

Using fish by-products in agriculture, animal feed and energy generation

For fish by-products that cannot be processed into higher-value products in the pharmaceutical and nutritional markets, there are lower value but larger market capacity options that include animal feed (agriculture and aquaculture), biofuels, bio-stimulants and fertilisers. The quality standards for these applications are less strict and products generated require less sorting.

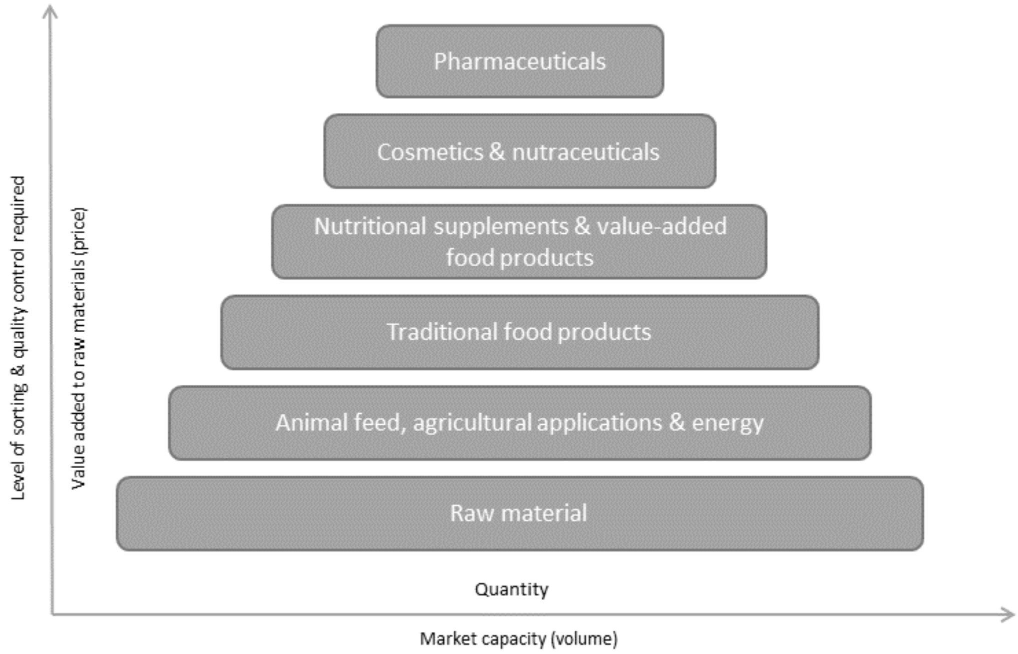

Figure 162: Demonstration of the relationship between value add and quantity available for different categories of fish by-products.

6.7.1.1 EXAMPLES OF APPLICATIONS FOR FISH BY-PRODUCTS.

A number of companies in Aotearoa New Zealand are already manufacturing high-value products from fish. Products include squalene from shark livers; fish oil for health supplements; marine collagen from fish skin for cosmetics and heath supplements; and shark cartilage as a health food supplement. It is important that such product development is validated by scientific studies on efficacy and focused on secondary product streams in existing harvests.

Figure 163: Fish offcuts at Lee Fish are saved and used as fishmeal in a variety of products.

Table 17: Examples of a range of high-value fish by-products.

Body part	Composition and products of potential	Examples of application
Skin	Collagen and gelatin	Wound care e.g. Kerecis (Iceland). Collagen cosmetics and supplements e.g. various products from Copalis (France); see 6.7.2: case study: High quality marine collagen from Aotearoa New Zealand (Sanford Ltd and Revolution Fibres). Fish leather e.g. Nordic Fish Leather (Iceland).
Bone	Cartilage calcium Collagen and gelatin Minerals	Calcium/bone supplement e.g. United Fisheries' Nutri Zing (NZ).
Muscle/red fish meat	Protein isolates – bioactive compounds e.g. carotenoids	Supplements e.g. BioBalance Astaxanthin from algae (NZ).
Liver	Omega-3 oils	Canned cod liver e.g. Ajtel (Iceland). Oils, capsules and supplements e.g. LYSI (Iceland) and Dropi (Iceland). Squalene from shark livers (skincare products and as an adjuvant in vaccine manufacture) e.g. Seadragon Marine Oils Ltd (NZ) produce squalene from shark livers. At least six NZ companies are making fish oils.
Viscera	Enzymes e.g. Trypsin High oil content (Salmon)	Spray to protect against common cold e.g. ColdZyme (Iceland).
Crustacea shell	Chitosan	Medical gel and spray e.g. Primex's ChitoCare (Iceland). Dietary supplements e.g. Genis (Iceland). Pharmaceutical-grade health supplements e.g. New Zealand Coastal Seafoods (NZ) capsules from green shell mussels.
Swim bladder/maw	Collagen	Wet, dried or powder e.g. New Zealand Coastal Seafood's Ling Maw (see 6.7.3: case study: Trade limitations hindering the sale of a high-value fish by-product). Isinglass, fining agent.

Body part	Composition and products of potential	Examples of application
Scales	Collagen and gelatin	Bioplastic (UK).
Fins	Collagen and gelatin	
Blood	Nutrients, small protein molecules and iron	
Heads	High oil content (salmon)	Oils, capsules, supplements.
Mixed (i.e. offal)		Fertiliser e.g. United Fisheries' Bio Marinus (see 6.7.4: case study: Fish waste to address myriad environmental issues). Fish meal e.g. several companies export fish meal to China.
Shark cartilage	Chondroitin sulfate	Powders for health supplements e.g. Waitaki Biosciences (NZ).
Mussels		Mussel power e.g. Enzaq (NZ, owned by Sanford) produce mussel powder and are expanding the production site. Mussel oils e.g. Aroma Ltd (NZ).

6.7.1.2 CHALLENGES AND OPPORTUNITIES

There is huge potential for large generators of fish processing by-products to extract more value. However, there are numerous challenges to overcome in order to process the whole fish into marketable products, with even greater challenges for developing high-value products. Some barriers are logistical, while others technical or social.

A significant challenge for Aotearoa New Zealand's industry is having over 100 commercial species with different potentially valuable components that cannot be processed in the same manner as each other due to variable tissue mixtures depending on the market for other uses (e.g. skins for collagen, or heads for rock lobster bait or food; fish that may not be filleted so there is no economic means to separate tissues; potential species and quality variability in response to water temperature changes). In addition, our current marine products processing infrastructure designed for manufacture of single products has no flexibility and often destroys one component when recovering another. Making our challenges into unique opportunities requires knowing exactly what is in any raw material in real time, then using this information to direct processing, choosing from a suite of integrated technologies to maximise raw material use and product value.

A culture change is also needed to shift thinking from volume to value, which has been a long-term strategy across primary industries and a long-stated government goal. Further analysis of this is outside the scope of this report but analysis to understand why we are not moving faster up the value chain could be beneficial in the context of commercial fisheries. Policy could encourage innovation and reduce these barriers so Aotearoa New Zealand's industry as a whole can lead in this space, while ensuring that higher value by-products do not impact food security.

One industry representative articulated the opportunities and barriers clearly when they said, “We are sitting on a goldmine, but we don’t know how to tackle it.”

“We are sitting on a goldmine, but we don’t know how to tackle it.”

Key ways to streamline commercialisation of fish by-products include:

- **Improving knowledge of demand and opportunities for supply.** The industry’s understanding of the consumer could be improved via better access to market data to inform investment, entrepreneurship and innovation. Connecting this market knowledge with what we know about the species, location and volume of by-products generated by our fisheries companies could help to identify opportunities to extract high-value products for which there is consumer demand. At the same time, developing species-specific understanding of potential proteins of interest via chemical compositional analysis is important to develop novel products which can also be high value.
- **Addressing issues in processing systems and supply chains.** Streamlining processes for higher value products could help to overcome some of the cumbersome aspects of by-product processing or remove logistical inefficiencies that make it unprofitable. This may mean improving aspects related to storage on vessels, split processing operations, or gaps in supply and processing chains, though these are generally thought to be of a high standard in our industry. Vertical integration of fishing and processing in Iceland has helped streamlined processes there and the WaSeaBi project in the EU aims to address these issues.
- **Planning and support to establish infrastructure.** Most commercial fisheries companies are capital constrained and the cost of establishing infrastructure and manufacturing processes can hinder product development. Many by-product project proposals have stalled due to high capital costs. Collaboration between companies or processors to establish economies of scale would be one step to help address this problem. Alternatively, different companies each specialising in key products or different parts of the supply chain and offering contract manufacturing to the others could address this challenge.
- **Improving access to technical expertise and applied science.** Many of the higher value products such as those with pharmaceutical applications require technical expertise. This is an area where great potential may remain untapped unless people within the industry become better connected to researchers with technical expertise to fulfil this development (see 6.7.2: case study: High quality marine collagen from Aotearoa New Zealand). Some applications may call for the business to lead the research themselves, which requires more flexibility in contracts and research funding models as well as a research industry that is able to provide applied research as a service.
- **Making it easier to do clinical trials:** Clinical regulatory requirements can be a challenge to meet, both financially and logistically, but developing a clinically proven ingredient means a higher and more guaranteed income from the product. Funded or subsidised clinical research would remove the barrier that many companies face in making a high-value medical product from a fish by-product.
- **Supporting networks and connection.** As discussed in section 6.3: How we fish, facilitating connections between fisheries stakeholders is important in innovating for a more sustainable future. The Iceland Ocean Cluster and Canada’s Ocean Assets stakeholder database are examples of ways to do this with a specific focus on using the whole fish. The Bioresource Processing Alliance could be drawn on to support this.

Some challenges for by-product processing that are unique to wild fisheries (as opposed to aquaculture) include having to manage supply issues where there are short fishing seasons with large landings, rather than a constant supply year-round.

The Food and Beverage Manufacturing Industry Transformation Plan, currently in early development, may help to address some of these issues.

6.7.2 CASE STUDY: HIGH QUALITY MARINE COLLAGEN FROM AOTEAROA NEW ZEALAND

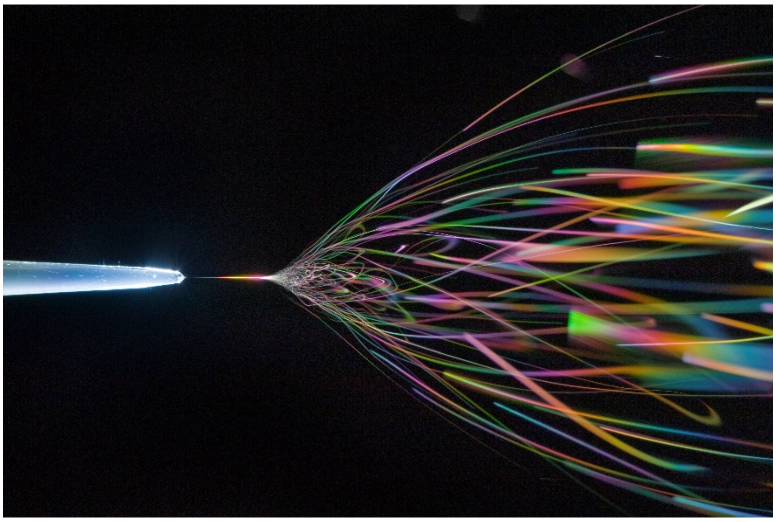

Figure 164: Electrospinning nanofibers from hoki skin. Image credit: Plant & Food Research/Robert Lamberts.

One product that has garnered increasing attention in the past two decades is collagen. Low-cost by-products such as fish skin and scales can be converted into collagen-based products, which have high added value potential for use in various health-related sectors, such as food, medicine, pharmaceuticals and cosmetics, and low environmental impact (Salvatore *et al.*, 2020). The marine collagen market is estimated to reach US$1,040 million by 2026. In addition to fish, jellyfish and sponges also have high levels of collagen which can feed the same market for 'marine collagen'. Methods are well established to extract collagen, with variations to address differences for the part of the fish (e.g. scale vs bone) and species-specific differences. Compared to collagen derived from bovine and porcine sources, marine collagen is considered safer, because it is less likely to trigger an immune response or transfer disease, and is free from religious concerns (Salvatore *et al.*, 2020; Lim *et al.*, 2019). Another benefit is the bioavailability, as collagen from aquatic sources currently employed in healthcare and food sectors is predominantly type I collagen, mostly derived from fish scales and skin. Type II collagen can be obtained from fish cartilage (e.g. shark cartilage), while type IV collagen can be extracted from marine sponges and some jellyfish (Salvatore *et al.*, 2020). Marine collagens also typically have a lower melting temperature, which makes them easier to digest.

When Sanford first began to look beyond commodity fisheries products to more premium products, they saw a gap in the market. There was unmet demand for collagen, specifically high-quality sustainable collagen products. Because collagen is an abundant protein found throughout fish, the company had good supply from their various fisheries. Deciding on the source and specific products was the first challenge.

The company contacted Aotearoa New Zealand's CRIs in search of expertise, which led them to connect with researchers at Plant & Food Research who had developed the novel extraction methods and processing technologies to extract collagen from hoki skin. Sanford had quota for hoki. This spawned the use of a single waste stream from a single species to make premium collagen products.

The first product came about through collaboration with Revolution Fibres and a technique called electrospinning. This technique transformed the skin into nanofibre 500 times thinner than human hair, which could be made into high-value collagen beauty products that are instantly absorbed into human skin. The novel product is a dissolvable cosmetic collagen patch made from hoki skin called actiVLayr.

The next product soon to reach the market is a cosmeceutical hydrolysed collagen product which is both odourless and flavourless.

The key considerations in the product development process that ensured a high value for these collagen products were:

1. **Medical approval.** It takes a significant investment in clinical research to meet regulatory requirements for clinical claims but being able to make the claims means that products will be able to be marketed as speciality high-value products and businesses will be able to charge more.
2. **Single source.** Extracting collagen only from the skin of a single species is easier to market as a pure product which draws a higher value. This is strengthened by being fished from Aotearoa New Zealand’s waters which are viewed as pristine in many overseas markets.
3. **Sustainability credentials.** From a marketing perspective, hoki was suitable as being MSC-certified and QMS-managed gave credibility to sustainability claims.

Using hoki skins to create high-value collagen products aligned with Sanford’s goal to make premium products out of commodities in a sustainable way. Sanford’s experience shines a light on some of the hurdles faced in developing high-value products and how to overcome these. The broader fisheries industry in Aotearoa New Zealand could learn from these experiences to expand the premium products offered from our fisheries industry.

6.7.3 CASE STUDY: TRADE LIMITATIONS HINDERING THE SALE OF A HIGH-VALUE FISH BY-PRODUCT

New Zealand Coastal Seafoods are a marine biotech company built on the 'tail to tip' ethos. Recently they have begun to expand their suite of fisheries by-products to include nutraceuticals made from mussel powder, seaweed extracts and more. That expansion is the silver lining of a trade issue that has limited their sale of their original product, ling maw.

Ling maw is the swim bladder of the fish, which is considered by some Chinese people to be one of the four traditional delicacies of the sea due to its high nutritional content. Over the years, New Zealand Coastal Seafoods has developed a unique production process that involves cold-curing the product rather than heating it. Freezing the ling at sea within six hours of being caught contributes to its desired properties including low water content, longer lifetime, maintained flavour and integrity in its structure when cooked.

Maw is in high demand, which draws a high value for the product. That high value has driven unsustainable fishing internationally and currently all fish maw is blacklisted for export into China because of sustainability concerns. Ironically, export of whole ling into China is allowed from Aotearoa New Zealand as ling are considered to be sustainably fished here.

New Zealand Coastal Seafoods has invested in food processing technology and there is demand for their product in China, but trade limitations are disrupting the $100-120 million industry. Their experience demonstrates the importance of market access for our commercial fishing industry. Overseas market access requirements, including standards, assurances and traceability, are surmountable hurdles, but where trade limitations come in the government is required to step in.

Figure 165: Ling caught off the Northland coast. Image credit: Norman Holtzhausen/Wikimedia (CC BY-SA 3.0).

6.7.4 CASE STUDY: FISH WASTE TO ADDRESS MYRIAD ENVIRONMENTAL ISSUES

The fisheries industry wants to reduce waste and generate more value from by-products. The agricultural industry wants to maintain high productivity and minimise nitrogen losses. Local company United Fisheries has developed a liquid fertiliser from fish offal that could help both industries achieve these goals by turning the low-value fish waste stream into a value-added product that improves pasture and reduces nitrate leaching.

Using seafood as silage is not new. There is an evidence base to support the general benefits of using of fish waste as fertiliser, but studies are needed to evaluate the impacts of a particular product in a specific application.

The Bio Marinus product developed by United Fisheries is a fish liquid fertiliser which is currently on the Aotearoa New Zealand market. Fish offal is channelled through a screw conveyor to a digester tank where it is heated to 65°C and hydrolysed by plant enzymes to turn it into a liquid state. After enzymatically hydrolysing overnight, a filtering step ensures that the liquid will flow smoothly through hoses and sprayers. A common organic acid is added to stabilise the protein and oil rich liquid fertiliser before it is cooled to 20°C and decanted into containers.

Early small-scale studies undertaken through a project with Lincoln University and jointly funded by Seafood Innovations Ltd demonstrated benefits of the fertiliser. The findings included no ill effects on cows when used as feed or fertiliser (Gibbs, 2015b), the ability to use less nitrogen in standard fertilisers when combined with Bio Marinus (Carey and Jiang, 2011, 2012), improved pasture quality (Carey and Jiang, 2011, 2012) and enriched Omega-3 content in lamb meat (Gibbs, 2015a).

These findings suggest multiple value-add opportunities for Bio Marinus. For example, in the US Omega-3-enriched beef is sold as premium, healthy meat and there may be a similar opportunity here. Better quality milk could add value to our milk products, and reduction in nitrate run-off has potential positive implications for climate change and water quality, both of which could draw a higher value.

In addition to the preliminary research results, the company reports that farmer feedback has alluded to further benefits of using the fertiliser but these are yet to be backed up by scientific evidence.

In order to realise the added value of Bio Marinus' benefits, the encouraging early results and feedback need to be backed up with evidence from larger scale studies. United Fisheries has proposed such studies in collaboration with Manaaki Whenua.

In order to realise the added value of these benefits, the encouraging early results and feedback need to be backed up with larger scale studies.

This example highlights that there may be untapped value in our fisheries by-products because of barriers to undertaking research. Companies need reputable studies and robust evidence to make the claims associated with higher-value products. Making sure we have a responsive research system that companies can access to support product development within their operating budgets is crucial to maximising the value from our commercial fisheries.

There may be untapped value in our fisheries by-products because of barriers to undertaking research.

6.7.5 IMPROVING TRACEABILITY TO ADD A PREMIUM TO PRODUCTS

Traceability allows food to be tracked through all stages of its production, including processing and distribution. It is primarily used to facilitate food safety and quality assurance and is a cost of doing business internationally, but traceability can also increase transparency and build confidence in the sustainability of the product. This adds a premium, which customers will pay for (see 6.7.7: case study: How a commitment to transparency and traceability has generated a premium product).

Widespread use of traceability systems that demonstrate social and environmental sustainability of commercial catch could help to reinforce best practice in the industry and send a message to consumers about the sustainability of that fishery, adding value in a commercial market. Companies that have fished legally and sustainably can prove this via traceability systems and set a precedent for making this information open and accessible while shining a light on illegal fishing and fraudulent labelling of seafood products. However, findings that significant illegal trade is ongoing in the Atlantic bluefin tuna fishery despite mandated catch documentation suggest that current systems need to become more watertight (Hosch, 2019).

There are different ways of measuring and reporting seafood production, processing and distribution, and additional methods to verify claims and identify false information. Catch documentation schemes are used to record and certify details of fish capture and processing, with the documentation accompanying the product through the supply chain. Records, where kept, were traditionally paper-based but traceability software now supports electronic data transmission from point of harvest to point of sale (or part of supply chain) via interoperable software e.g. barcodes, RFID tags and QR codes. Analytical methods and instruments to support traceability can be used to verify or falsify claims in a traceability system (but alone do not provide traceability). Systems can also be set up to alert users when data anomalies suggest irregularities or if companies are known to have expired certifications or are blacklisted on IUU database. Technological advances are likely to change these processes (see 6.7.8: case study: Blockchain supply chain traceability project). As technologies improve, such as in EM, these can be combined to facilitate traceability systems that allow retailers to present a complete and transparent origin story for each fish (van Helmond *et al.*, 2020).

Government requirements for traceability, private sector sustainability commitments, and a greater interest in supply chain transparency because of legal and social risks are some of the factors driving seafood traceability systems to expand beyond food safety and inventory management (Lewis and Boyle, 2017). Traceability systems used for compliance purposes could be built on for traceability that supports sustainable fisheries management (Hosch and Blaha, 2017). These may need to be adapted when the objective of the system is to share information with the consumer in order to add a market premium, to ensure the information provided meets consumers' needs (Rodriguez-Salvador and Dopico, 2020). How these systems impact the fishery depend on their legal or voluntary framework. For example, restrictions from an individual country or region around what fish can be imported only control what enters the end market, not what comes out of the fishery (i.e. the fish could be sold elsewhere). In contrast, a multilateral catch documentation scheme, backed by international law via RFMO, controls what is fished and monitors it throughout the supply chain.

In Aotearoa New Zealand, it is already a legislated requirement for seafood producers to track information (OpenSeas, 2019) and import markets have their own requirements that our seafood industry needs to meet. For example, fish and fishery products caught and processed outside the EU have to comply with the EU's eCERT framework in order for their import to be authorised.

The first global standards were established by the Global Dialogue on Seafood Traceability in 2017 and these could be implemented by the Aotearoa New Zealand seafood industry. There are also calls for a global, secure, interoperable support system for seafood traceability, but that faces many challenges such as technological and financial constraints, language barriers and regulatory differences (Hardt *et al.*, 2017). In the meantime, voluntary approaches, country specific approaches and government-to-government agreements are likely to be where progress is made.

6.7.5.1 LABELLING MAY HELP PROTECT THREATENED SPECIES

Detailed labelling of seafood products has the potential to protect threatened marine species. A recent Australian study highlighted that over 90 endangered marine species can be legally caught in commercial fisheries across the world, many of which are importers into Australia. By the time the fish has been processed, exported and sold (with minimal details on the label), the consumer can be unaware of the plight of the catch (Roberson *et al.,* 2020).

Figure 166: Accurate seafood labelling is important to protect threatened species and improve consumer trust.

The researchers suggest four key elements that should be included to accurately label seafood:

- the species – bigeye tuna, not "tuna",
- where it was caught – Queensland, not just "wild caught",
- how it was caught – pole-and-line, not just "dolphin-safe", and
- the company responsible for the fishing.

There also need to be mechanisms to monitor compliance and traceability of seafood. Using genetic sequencing to match a fish or fish product to a species, population or individual could support sustainable fishing by preventing food fraud and protecting vulnerable species (Ogden, 2008; Martinsohn *et al.*, 2018). It could be used throughout the supply chain to stop practices such as product mislabelling. So far this is only used sporadically in fisheries (e.g. through FishTrace, FISH-BOL, FishPopTrace), despite suggestion that costs are lower than values of confiscated catches and fines (Martinsohn *et al.*, 2018).

Implementing regulations and improving transparency across the global seafood supply chain will require national and international policy action. Awareness from seafood consumers, which has led to positive industry change in the past, will be critical to further improvements (Roberson *et al.*, 2020).

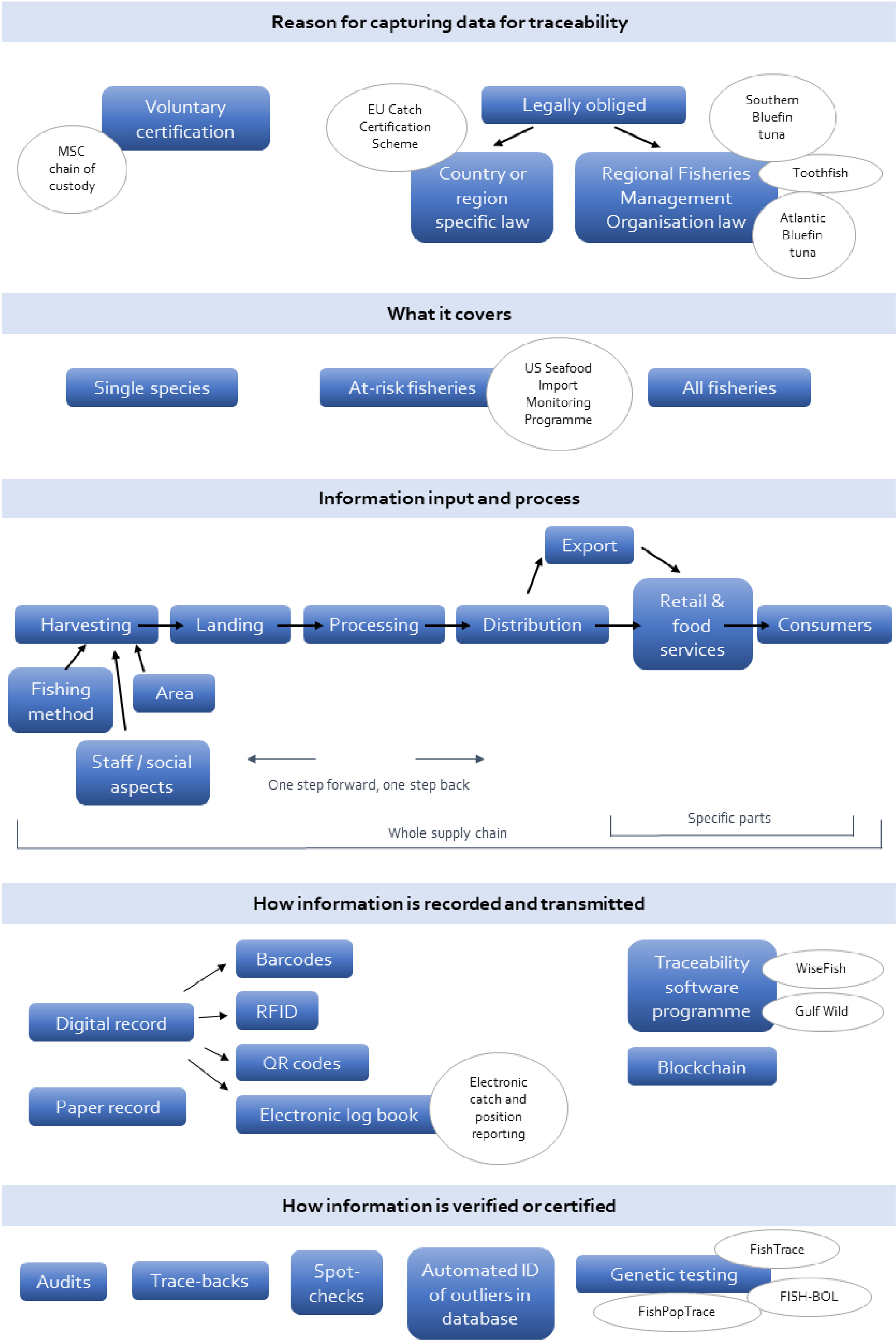

Figure 167: The different features of traceability systems that are available. Examples are shown in grey circles.

6.7.5.2 SUSTAINABILITY SCHEMES PROVIDE A WAY TO BENCHMARK AND IMPROVE FISHING PRACTICES

One way to encourage improvements in fisheries sustainability is to set a benchmark for sustainable practices through accreditation or certification schemes, many of which come with an associated eco-label. With rising community expectations around the transparency and accountability of fisheries management, these types of schemes can help to assure people that products are sustainable. These rising expectations will also mean that certification needs to be credible with respect to protection, bycatch mitigation and gear impacts.

Some retailers may limit the products they will stock to only include those that have met sustainability standards. This means achieving certification gives that particular fishery market access. Where retailers don't restrict the products they will stock, individuals may still choose to buy a particular product because it has an eco-label. The idea is that the positive economic impacts[225] that come with being certified will encourage more fisheries to improve their practices to meet certification standards, which will in turn lift sustainability practices throughout the industry. Additional benefits include greater social acceptance of the industry and improved governance processes (van Putten *et al.*, 2020).

Private standards may be set internally by the individual organisation (first-party scheme), by an industry association for their members (second party), or by an independent organisation (third party). Over 30 third-party schemes already exist globally and many Aotearoa New Zealand fisheries companies engage with such programmes. Large numbers of schemes can sometimes create market confusion and can risk accusations of falsely representing a product to be more environmentally sound than it is. On the public side, some governments have supported the establishment of regional or national schemes, including France and Iceland, who have both based their eco-label on FAO guidelines (Washington and Ababouch, 2011).

There are several important points regarding the application of sustainability schemes in fisheries management.

- **Sustainability schemes are a way to set best-practice expectations.** These schemes provide a way to make clear the expectations for sustainable fisheries management and support the industry to not only meet these but to continually improve their practices. Open and transparent certification processes and eco-labelling can maintain social license for fisheries, influence community perceptions of fisheries management, enhance public confidence in the sector and address concerns about the sustainability of fishing. Measuring the proportion of Aotearoa New Zealand's fisheries that are accredited to a sustainability scheme could be a useful indicator of progress towards sustainability of our fisheries over time (Pinkerton, 2010). However, sustainability schemes may not be comprehensive in setting best practice – standards can be potentially set too low or may not address impacts of fishing methods such as trawling and dredging.
- **Measuring sustainability requires a solid evidence base.** Data and knowledge about fisheries stock status and wider ecosystem impacts are needed to assess whether a fishery is sustainable. The majority of fisheries will have enough data to inform the process but some, in particular small-scale fisheries, may be limited by this. Continued improvements in data collection and innovations to make fishing practices more sustainable will be key to making sure all fisheries can be assessed and pass certification (as discussed in section 6.2.2: Data-driven knowledge is the cornerstone of effective and sustainable fisheries management).
- **The voluntary nature of schemes may limit engagement.** Many local fisheries companies are already engaged with sustainability schemes, but there are barriers which prevent others getting involved while it

[225] Price premiums are reported in studies are around 10-15%, for example, 11% price premium in Baltic Sea cod fishery (Blomquist *et al.*, 2020).

is not considered essential for market access or is not government-mandated. For smaller-scale fisheries, financial or organisational barriers may be the reason for not engaging.

- **Government assistance can make these schemes more accessible.** To address the financial barrier that may prevent some fishers being assessed, the government can provide financial assistance to companies to get their products certified. In Aotearoa New Zealand, this already occurs for the MSC scheme via the Environmental Certification Fund (Lee and Viswanathan, 2019). The government can also fund baseline studies that benefit many fishers, for example in Western Australia the state government funded independent third-party assessment taking a bioregional approach to assess a number of different fisheries in a region at once (Bellchambers *et al.*, 2016).
- **Mandatory accreditation could even the playing field.** As suggested by Telesetsky (2016), a government scheme that indicates basic compliance with sustainability practices (akin to a 'warrant of sustainability') could set a benchmark and shape norms in the industry. Consistency among Aotearoa New Zealand's seafood industry could strengthen the credibility of the whole industry, particularly on the international market. Iceland have taken a similar approach, developing a 'country of origin' eco-label based on the fact they believe they are viewed as a responsible fisheries country and wanted a way to verify this. A 'statement of responsible fisheries in Iceland' was co-developed by government and industry and all products have to undergo independent certification based on this statement to use the label. Maintaining independence in the assessment is important and having certification against a trusted, independent and transparent standard may also reduce the burden of responding to stock assessment information requests. Unless a mandatory programme is supported by the government, similar barriers to uptake from smaller players may occur.
- **Demand for certified sustainable products is likely to increase.** For now, it's important for the Aotearoa New Zealand fisheries brand to be seen as sustainable and Fisheries New Zealand could play an important role in assisting the local industry to achieve certification across the board (Fisheries New Zealand, 2018a). In the future, not meeting sustainability criteria may prohibit overseas market access, so it's important for our fisheries exporters to stay ahead of these demands by achieving certification for globally recognised schemes.
- **It's important to strike a balance between consistency and monopolisation:** Having similar standards is beneficial to know that the same stringency is applied across different products and may be helpful for people to be able to compare products. However, if one scheme takes over there is a chance that what constitutes 'sustainability' will be monopolised. This means any limitations, disadvantages or perverse incentives associated with that scheme will become widespread (Hadjimichael and Hegland, 2016).

Sustainability schemes are likely to play an important role in continuing to challenge Aotearoa New Zealand's fisheries industry to improve their management practices. Achieving and maintaining certification of established but evolving standards can be used alongside government-driven management initiatives to achieve sustainable fisheries management.

Sustainability schemes must be credible to achieve these goals. Some fisheries that have been certified to schemes have received criticism for not adequately addressing fisheries impacts (Jacquet *et al.*, 2010; Christian *et al.*, 2013). These concerns can include bycatch and fisheries being certified that have not been scientifically assessed in decades, particularly in fisheries where fish are reportedly increasingly difficult to catch and fishers have not been reaching the TAC limits. For some fisheries, the level of investment needed can be very large. This issue is particularly pertinent for small, inshore fisheries which have significant data gaps that would need to be filled as a result of limited research spending allocation due to their small size.

6.7.6 CASE STUDY: THE MARINE STEWARDSHIP COUNCIL

Founded in 1996 by the World Wildlife Fund and Unilever, the MSC is a global voluntary certification scheme. The scheme is widely used and recognised, with an estimated 15% of global fish catch MSC-certified (Bellchambers *et al.*, 2016; Roheim and Zhang, 2018). There are two separate standards that work together. The Fishery Standard relates to sustainability of wild-capture fisheries. The Chain-of-Custody Standard relates to traceability and requires everyone in the supply chain to meet the standard to use the eco-label. Conditional certification can be achieved if a fishery is near the threshold and develops an action plan to make the improvements needed.

Achieving MSC certification means that the way a particular fishery is fished meets the evidence-based standards of sustainability, developed by scientists, the fishing industry and conservation groups, which factor in the sustainability of the stock, ecosystem impacts and effective governance. The assessors determine whether the standards are met by looking at quantitative and qualitative evidence, rather than requiring specific tools or approaches to be used. However, MSC certification is not universally accepted as 'sustainable'.[226] Some concerns relating to MSC certification include that it can be achieved in fisheries that use damaging fishing techniques, such as bottom trawling, which may mislead consumers about the impacts of the fishing effort to harvest the fish. In particular, the certification of some orange roughy stocks has been controversial given the use of bottom trawling in this fishery (which causes harm to habitats and ecosystems e.g. corals and sponges, see 5.3.4: case study: Orange roughy stock health).

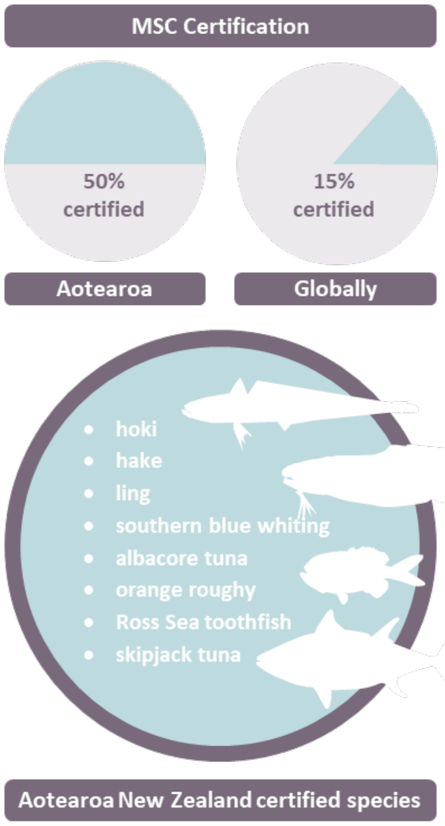

Figure 168: Percentage of fished volume certified by MSC and the species of certified stocks for Aotearoa New Zealand.

Half of the volume of Aotearoa New Zealand's wild-caught fish are certified to this sustainability scheme, with much higher rates for deepwater fisheries compared to inshore fisheries. In total, there are eight species (across 18 stocks) that are certified to MSC standards in Aotearoa New Zealand: hoki, hake, ling, southern blue whiting, albacore tuna, orange roughy, Antarctic (Ross Sea) toothfish, and skipjack tuna/aku[227]. However, hake – an MSC-certified species – recently fell below its soft limit in HAK7 (Fisheries New Zealand, 2019g), demonstrating that certification does not necessarily preclude issues with stock sustainability.

A strength of the MSC standards is that fisheries have to maintain certification, not just achieve it once. Ongoing improvements in fishing sustainability are key to gaining and maintaining certification, which can include approaches such as establishing new harvest strategies, developing measures to minimise bycatch, mitigating fishing impacts on vulnerable species, habitats and ecosystems, and changing governance or policy practices. In addition to annual audits to make sure standards are continuing to be met, recertification has

[226] See 'Review of the MSC standard – claim and reality'; Make Stewardship Count; 'Critical changes needed to improve the MSC Standard'
[227] *Katsuwonus pelamis.*

to be achieved every five years. In that time, the standards will have evolved to reflect improved knowledge and understanding about the wider impacts of fisheries, making sure that the bar for sustainable practice continues to be raised. Going forward, efforts to include or increase the weight of certain criteria such as social standards and climate change impacts of the fishing practices may help to make the standard more holistic (Hadjimichael and Hegland, 2016).

The independent and transparent assessment and verification is another strength of the MSC. Being independent helps to build trust with consumers and retailers. The process also allows for people or organisations to object to the certification of particular fishery. However, the level of scrutiny an assessment receives depends on the local context and in places where there are limited financial resources or NGO presence these processes may be less effective (Hadjimichael and Hegland, 2016).

Because of the need to maintain certification, changes liked those experienced in hake could lead to the stock losing its certification. A lack of available data, which is a significant issue for some of Aotearoa New Zealand's fisheries may also be a barrier to achieving or renewing certification. These issues need to be considered in the context of MSC providing market access to international markets.

6.7.7 CASE STUDY: HOW A COMMITMENT TO TRANSPARENCY AND TRACEABILITY HAS GENERATED A PREMIUM PRODUCT

A small fishing company in Murihiku Southland, Gravity Fishing, has such high demand for their premium product with 100% traceability and transparency that the owner is supporting other fishers around the country to establish similar business models to help meet demand.

Fishing. Image credit: Gravity Fishing.

The owner, Nate Smith, has sustainability firmly entrenched his business model. He was recently awarded the Emerging Leader Award at the New Zealand Seafood Sustainability Awards. The drive for sustainability comes from Nate's observation that fish stocks were declining in the waters around Rakiura Stewart Island where he had fished for years.

Acting on his concerns about how fishing methods and the amount of fish being taken were negatively impacting his local environment, Nate flipped the usual commercial fishing model on its head. Aspects of his approach that could help other businesses add a premium to their sustainably caught seafood products include:

- **Catching only what is wanted.** Rather than fishing as much as possible and finding a market afterwards, Gravity Fishing's business is based on a catch-to-order system. The crew tells their mailing list what Nate expects to catch, based on where he's going fishing, and then takes orders and fishes only that amount. The fish-to-order system means that no fish is wasted.
- **Using a precise and minimal impact fishing method.** Concerns about fishing impact drove Nate to strip back the fishing process to the most basic method. The crew changed their fishing method to use a traditional hook and line technique, modernised by the electronic jigging technology. Based on the number of fish the crew want to catch (from the orders made before departure), they will put a specific number of hooks on the line. The jigging technology recognises when fish are on the line and within less than a minute they are brought to the surface. The fast catch coupled with using the Japanese method ikijime to kill the fish quickly maintains the fish at a very high quality. The method also allows the fishers to cause minimal impact to the seafloor and have limited or no bycatch.
- **Keeping the supply chain short.** The business model keeps things local and cuts out the middleman. As well as fishing, the crew do the processing and packaging of their fish. Initially Gravity Fishing fished-to-order for people around Aotearoa New Zealand and overseas, but as a further commitment to sustainability (by reducing transport and packaging needs), the business now limits supply to those where delivery is nearby.
- **Selling the whole fish.** Rather than processing the fish to fillets, Gravity Fishing sell the fish whole to people they supply, mainly restaurants. This eliminates the need for them to deal with fish waste or establish markets for by-products and gives people the chance to use other parts of the fish in food products.
- **Letting people see for themselves.** Gravity Fishing is very open about its processes, documenting details online and regularly updating social media. But for the ultimate transparency, the crew offers an experience for people to go out on a fishing trip to learn exactly how the fish gets from the ocean to their plate.

Together, limiting catch, selling the whole fish, having a short supply chain and being open about processes so customers are confident in the sustainability of the product, allows Gravity Fishing to charge a significant premium. Selling the fish for around six times as much as was charged previously enables the business to catch the equivalent times fewer fish, helping stocks to replenish.

A key part of being able to replicate Gravity Fishing's model among other small, local fishers nationwide is ensuring that small independent fishers have access to quota. Access to a quota package of mixed species has the potential to transform his and similar businesses.

Gravity Fishing's experience shows that having complete transparency which allows customers to see the responsible fishing approaches used to catch the fish they buy adds significant value to the catch. Sustainably caught fish with 100% traceability and transparency is viewed as a premium product.

6.7.8 CASE STUDY: BLOCKCHAIN SUPPLY CHAIN TRACEABILITY PROJECT

The Pacific Islands' tuna industry has faced issues relating to illegal fishing and human rights abuses because of crew working conditions and safety. Enabling full traceability and strengthening transparency in the supply chain is seen as a key way to address these issues. A collaborative project between WWF in Australia, Fiji and New Zealand, tech innovator ConsenSys, communications technology implementer TraSeable, and tuna fishing and processing company Sea Quest Fiji seeks to address this issue using a blockchain traceability system to establish 'Bait-to-plate transparency' (WWF New Zealand, 2018).

Blockchain is a digital ledger, originally used in digital currencies, which provides a tamper-proof record of information via a shared database. Applying this to a fisheries traceability system means that details about where and when the fish was caught, which vessel it was caught by and what fishing method was used can be accessed by people throughout the supply chain, including customers at the point of purchase.

Blockchain has been trialled in a few fisheries: yellowfin tuna[228] and skipjack tuna in South-east Asia,[229] Fiji and Pacific Islands,[230] and Patagonian toothfish/Chilean sea bass[231] in the subantarctic.[232] Its application in the Pacific Islands tuna industry is a significant development compared to the current system where tracking is undertaken using paper records (or not at all) and information is not available to people when they buy fish (Visser and Hanich, 2018). The hope is that the technology will help to prevent IUU fishing and provide a market premium for sustainably caught fish, which is clearly demonstrated by the transparent supply chain.

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The technology relies on an RFID tag being fixed to the fish when it is landed. It will register automatically at various points on the vessel, dock and processing facility. At the processing facility, the products receive a QR code (or potentially near field communication or NFC device). The QR code is used to track the product to the retailer and the consumer can scan the code with their smartphone app to show the history of the fish and how it got to their plate. Making information easily accessible to the consumer, where it adds value to their decision making but does not overload them, will be key to the successful implementation of the system (Montecchi *et al.*, 2019).

There are a range of benefits from implementing a traceability system, including promoting sustainably, adding a premium to products, exposing human rights issues and improving work conditions for fishers, and supporting product recalls where needed. Using blockchain as the technological solution for the system helps to guarantee the record is not tampered with. By tracking the fish from the moment it's caught, blockchain would make it very difficult for any illegal or unreported tuna to enter the market. However, it is important to note that while blockchain can provide chain-of-custody information, it is not insurmountable to mislead people using the system and the effectiveness will depend on how closely users check for inconsistencies (Baird, 2018). So far, around six companies are using the system but implementation has faced hurdles across the supply chain.

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[228] *Thunnus albacares.*
[229] See 'From shore to plate: Tracking tuna on the blockchain' and 'Tracking Tuna from Catch to Customer'
[230] See 'Blockchain Food Traceability' and 'Pacifical wild tuna'
[231] *Dissostichus eleginoides.*
[232] 'We create traceability & transparency technology'; 'Austral fisheries case study'

Further work aims to address these hurdles by dealing with patchy internet access, supporting the move from paper records by providing tablets, ensuring tags are durable in rough conditions, and growing buy-in within the industry to accept this increased level of transparency and traceability.

It is important to note that while blockchain can provide chain-of-custody information, it is not insurmountable to mislead people using the system and the effectiveness will depend on how closely users check for inconsistencies.

Figure 170: TraSeable QR code label. Image credit: WWF/Netflix.

PART 7: VISION: IMAGINING A DIFFERENT FUTURE – FISHING IN AOTEAROA IN 2040

When the panel that the Office of the Prime Minister's Chief Science Advisor reported on our Rethinking Plastics Project, we began with a vision from our panel in which we imagined a different future.[233] This proved helpful to capture how a new future might look if our recommendations were accepted. People were ready to imagine a different future because there was a social and cultural licence for change. For this project, there has been a very different mood, with little consensus on the extent of the need for change, and an understanding that change would be dependent on many factors, only one of which is the role that science might play.

Nevertheless, to end this report, we present an imagined future – not a prediction – but a provocation to envisage a different way of harvesting from our oceans, which draws on some of the exciting research ideas presented in part 6.

To end this report, we present an imagined future – not a prediction – but a provocation to envisage a different way of harvesting from our oceans, which draws on some of the exciting research ideas.

[233] https://www.pmcsa.ac.nz/topics/rethinking-plastics/our-vision-rethinking-plastics/

In a future Aotearoa, Amelia and Nikau are showing Amelia's grandad what they have done with his old trawler. The old girl looked the same as ever sitting on the wharf, so sitting in the galley with a cup of tea, grandad doesn't really see what all the fuss is about. They are heading out to catch snapper, just like they did twenty years ago, although the best fishing spots have shifted as the oceans have warmed, and the range of spots you are allowed to fish in keeps changing, to keep up with the moving fisheries.

The solar panels on the roof are the first clue that something has changed, and there are a lot more screens in the wheelhouse too. Amelia wanders in to show him how they all work after they drop the net. It's not actually a net to be honest, but it's still called a net in the same way that in 2020 we still 'dialled' a number on a smartphone screen – an affectionate nod to outdated technology. The 'net' no longer drags along the seabed, as computer technology ensures the fishing equipment gently glides through the water just above the bottom, keeping intact precious shellfish, sponge and coral beds with an acoustic tickler available for coaxing bottom dwellers towards the surface for those catching scampi and prawns.

The boat has slowed and is moving gently at the speed of a swimming snapper. The screens light up and the old wheelhouse develops a new vibe. Grandad watches with delight as live snapper enter the net and keep swimming calmly, while smaller fish dart in and then out, completely unharmed. Slowly but surely, the net starts to fill, almost exclusively with snapper. A second screen shows a catalogue of individual fish, all annotated with individual markings. Fishal recogition™ is a patented AI technology which can identify individual fish that are perfect for the very high-end premium fish market. Amelia has used the nickname function so that some of her favourites light up. FR2897, Daisy, is highlighted on the screen, confusing and delighting grandad in equal measure. The algorithm can identify the fish by the pattern of spots on its scales, and reports that this is the third time that Daisy has been located. This time she is the perfect size for the premium export harvest category, and will be harvested rather than left in the sea to mature further.

On a third screen, the numbers are being crunched. The fish have been filmed from multiple angles and are being ID'd, sized, counted and virtually weighed. Cameras under boats have proved much more popular than the ones on the deck, and the old privacy issues of the 2020s are forgotten as the fully automated electronic monitoring leaves the fishers themselves free from observation. Data is livestreamed to the central data hub and automatically processed before heading to the regulator for compliance purposes.

It is very rare that there are any breaches of fishing regulations these days, because the technology acts as a safeguard to fishing over quota, and selectivity is so high that bycatch is negligible and is recorded swimming away. In any case, most local management plans have set catch limits lower than quota limits to protect the marine ecosystems. The central data hub also enables electronic monitoring of the live bycatch; this is aggregated across fishing vessels to ensure commercial sensitivity is respected. This has led to a paradigm shift in environmental monitoring, with a deep understanding of ecosystem health at all trophic levels informing the detailed dynamic three-dimensional models of marine ecosystems.

Finally, on screen four, specific data for this vessel arrives back, copied to head office for commercial intelligence. The fish-to-order delivery times are estimated for the high-end restaurants at home and overseas; Daisy is heading to Sydney. And the local wharf sales, building on early Ministry for Primary Industries pilot schemes and implemented nationally as part of the 'Affordable Healthy Food Initiative' across Aotearoa's primary sector in 2025, are calculated for sale at local prices on return. These attract a government subsidy and a large crowd of locals. The robot-harvested scallops are a particular favourite.

Grandad is grudgingly impressed, but lurches into genuine excitement when screen five flashes an alarm. There is a large pod of dolphins nearby. The restoration of marine ecosystems is starting to lead to increasing challenges in avoiding the growing population of marine mammals. NewNetTech™ and the evolution of underwater bait-setting systems for longlines have completely solved the heartbreaking capture of seabirds from the old days, but there are still challenges with dolphins and sea lions that need manual intervention. Nikau runs into the wheelhouse to respond to the alarm. The OOApp™ had predicted that the dolphins were in another part of the gulf, but there was a 10% chance they would encounter some today in this top snapper spot. Happily the dolphins have not yet entered the net, so there is no need to release the snapper. Nikau turns up the volume on the precisely tuned acoustic pinger, and grandad swears he sees the dolphins scowl as they turn away. The catch is saved, and they all stand on the deck watching as the dolphins head off.

Amelia explains that the central fisheries data hub is not just collecting data from nets. It also collects detailed information on the seafloor, aggregated appropriately so that researchers have full and ready access without jeopardising commercially valuable information. The majority of our seabed has now been mapped and we know where our most vulnerable and important habitats are. While the seafloor and all seamounts are now protected from the harms of bottom trawling, which was phased out ahead of target in 2035, many are still in the process of recovering and the decades-long process of seamount restoration has begun as a priority research area in which Aotearoa leads the world.

Extensive marine coastal habitats are protected and we know much more about the creatures that live there. From the Far North right down to Rakiura Stewart Island we are starting to see the return of majestic native kelp forests along our coastlines. Divers can swim among the large snapper and tarakihi that dart through these complex underwater forests. There are also numerous crevices full of large rock lobsters. Our thriving coastal areas help repopulate commercial fisheries both inshore and deeper at sea.

The Strategic Ocean Action Plan launched by the new Oceans and Fisheries Minister with Te Ohu Kaimoana and the Iwi Leader's Forum in 2022 represented a true Treaty partnership to care for the oceans. The QMS has evolved to better serve our fisheries system and the environment, while affirming the rights afforded by the Treaty of Waitangi. The agreed principles underlying the action plan brought congruence to the regulatory system across the fisheries and marine protection legislation, helped to coordinate specific localised management plans, and led to a shared sense of purpose to protect the oceans as a healthy environment with an abundance of fish nurtured by management at the appropriate spatial scale. The stalemate between those wanting to protect the ocean and those wanting to fish was finally broken during the process of community building that preceded the plan, and the agreed comprehensive network of areas protected by nuanced rāhui, informed at a local scale by local knowledge and mātauranga Māori, has allowed many of our marine habitats to recover and flourish.

The integrated fisheries research platform 'Ko moana tenei', which began in 2023, has increased our understanding of the basic biology of commercial species, food webs and ecosystems and means we have much greater confidence in the sustainability of our systems. The online dashboard has made it far easier to navigate the wealth of information and tunnel down into details of interest. Establishing ecological indicators back in the 2020s made a huge difference and ongoing refinement means that our ecosystem models are continually improving and have fewer assumptions every year. It's now routine that research surveys use trawl gear that skims over the bottom without contact, deploy autonomous vehicles to satellite tag fish underwater, use cameras to monitor benthic habitat, and collect genetic and biochemical data to feed into annual stock assessments.

This year will be the first that the new traffic light stock assessment system has completed its cycle for every commercially fished stock. And now that there's full transparency around commercial and non-commercial catch data, stock assessments and the decision-making process for reviewing stock status and catch allowance, the public are confident in the sustainability of fishing that takes place in Aotearoa. Community and local knowledge feeds more directly into decision making alongside industry data, at both a local and national level and communication is a two-way street. Not surprisingly, lots of our best ideas about new approaches to fishing have come from fishers, including the new ropeless acoustic pop-up pots that are used to harvest a now thriving rock lobster population, supported by scientific monitoring.

With the new Innovations Cluster and stronger relationships in the sector, it became much easier for fishers to engage in the research system and develop their ideas, with streamlined resourcing and minimal form filling. The annual showcase means these ideas spread far and wide. As Amelia and Nikau head to shore, an excited researcher contacts the boat – she was automatically alerted that one of the tagged fishes her team has been following is on board and wants a biopsy to check its DNA to inform genetic studies on the diversity of the stock and biochemical studies to confirm which nursery it had come from. She can also sample the seawater that has been automatically collected for eDNA giving a reliable and active measure of ocean biodiversity, which stabilised in 2030. They arrange to meet back at the wharf where the locals are already gathering for a fresh feed. Parallel innovations have taken place in the deep sea fishing sector, with multi-party ocean monitoring platforms supporting government and industry research, and innovations in fishing gear transforming the selectivity, efficiency and yield, while minimising damage to the seafloor.

There is one more piece of the puzzle to share with grandad. Many of the fish are now sold whole, and those that are filleted fetch nearly as high a price per fish. This too is a result of the research efforts to extract maximum value from the whole fish. Pure bioactives, fish oils, feedstock for cellular agritech and even fish leather are now manufactured and exported, often from the filleting factory sites themselves, to maximise the yield of the valuable marine-derived produce by processing while still fresh. The speed and responsiveness of our commercial fisheries has moved the industry to near-zero waste.

And then its home for a feed. We all have confidence in where and how our fresh fish caught, with a quick scan on an app telling the story of where and how your kaimoana was caught. Kaitiakitanga became part of an increased social environmental consciousness during the 2020s and means pollution has reduced through changes in materials used, our recycling abilities, and community initiatives that aim to clean up our environment.

Even though our population has increased, we have a better understanding of how land-based activities can be controlled to reduce the impact on oceans and have implemented many changes to reduce these impacts. These advances were made through the 2022 Oceans Strategic Action Plan which engendered greater cross-sector communication, relationships, and the acknowledgement of funding needs for cross-sectoral issues. In many areas previously impacted by land-based activities, ecosystems are recovering (like the return of subtidal seagrass and mussel beds) – some naturally and others with rehabilitative help.

While climate change continues to impact on our ecosystems, the ocean observing system established in 2022 has provided the vital information we've needed to understand the changing oceans and enable us to strengthen the resilience of many of our ecosystems to better withstand changes in ocean acidification, extreme weather events, and other issues current and future. The drive for community science in the marine space led to many recreational fishers and other non-commercial vessels adding sensors to their boats and collecting data for this system. We have already decreased the carbon footprint of our fisheries by moving to cleaner and more energy efficient means of fishing, along with our targeted technologies like the smart net and minimal biofuel waste.

Commercial fishing in Aotearoa is seen as word-leading and the Oceans and Fisheries Minister, along with all New Zealanders, is justly proud of the huge advances we have made in managing our ecosystems and fisheries in a way that benefits everyone. As well as providing affordable healthy kai for our communities, the reputation of our practices and our products around the globe, and the enormous growth in demand for seafood, has grown the industry to be a ten billion dollar contributor to GDP. Fishing is a sought-after career for our school leavers. We have led the use of sustainable practices in our trade agreements and the Comprehensive and Progressive Trans-Pacific Partnership (CPTPP) won an award from the World Sustainable Trade Organisation (WSTO) for its contribution towards international marine restoration as part of sustainable trade. Aotearoa is still on a mission to improve our knowledge and our systems, with commercial fisheries and scientists working together with the wider community to ensure that our industry and environment continue to thrive using ever more innovative tools and practices.

GLOSSARY

7.1 TE REO MĀORI TERMS

The translations are described based on the Māori Dictionary, and as they are used in this report. Other sources are noted in footnotes.

Māori	English
hapū	kinship group, clan, subtribe
īnanga/īnaka	whitebait, juvenile freshwater fish of several species
iwi	tribe
kaimoana	seafood
Kāti Hauirapa	a hapū from the Waikōuaiti area of Otago
kaitiaki	guardian
kaitiakitanga	guardianship and conservation or protection; managing the environment based on a Māori worldview
kaumātua	elder, a person of status within the whānau
kaupapa Māori	Māori approach, ideology, topic or principles
ki uta ki tai	from the mountains to the sea
kōhanga	nursery, birthplace
(te) korowai	the name of a group of marine guardians in Kaikōura
mahinga kai/mahika kai	food-gathering place, natural resources
mana	prestige, authority
mana whenua	power associated with possession and occupation of tribal land
manaakitanga	hospitality, kindness, generosity
mātaitai reserve	recognise and provide for traditional fishing through local management. They allow customary and recreational fishing but usually don't allow commercial fishing; areas closed to commercial fishing that may also restrict recreational and customary fishing
mātauranga Māori	the body of knowledge originating from Māori ancestors, including the Māori worldview and perspectives, Māori creativity, and cultural practices
mauri	life force, vital essence
(te) moana	(the) ocean
rāhui	a temporary closure or prohibition; in the fisheries context, this generally involves restricting use of a fisheries area

Māori	English
rangatahi	younger generation, youth
rangatira	chief, supervisor
rangatiratanga	chieftainship, the right to exercise self-determination and sovereignty
rohe	district, region, area
rohe moana	customary fishing area of tangata whenua
Tai Timu Tai Pari	Sea Change
taiāpure	local fisheries that are significant for food, spiritual, or cultural reasons; managed by local communities, which may have additional fishing rules
Tangaroa	the Māori god of the sea and fish; also the name of one of NIWA's research vessels
tangata whenua	local people, people born of the whenua
taonga (species)	treasure; a native species of special cultural significance to Māori
tauiwi	non-Māori, foreigner, colonist
te ao Māori	the Māori worldview
te hā o Tangaroa kia ora ai tāua	the breath of Tangaroa sustains us
Te Moutere o Motiti	Motiti Island
Te Ohu Kaimoana	a statutory organisation dedicated to future advancement of Māori interests in the marine environment; this term is defined in the Māori Fisheries Act 2004 and the Fisheries Act 1996
Te Wahipounamu	a World Heritage site incorporating four national parks including Fiordland National Park
tiaki	protect, conserve, look after
tikanga	correct procedure, custom, protocol, the customary system of values and practices that have developed over time and are deeply embedded in the social context
tūpuna/tīpuna	ancestors
wāhi taonga	places of sacred or extreme importance to Māori
wāhi tapu[234]	a place sacred to Māori in the traditional, spiritual, religious, ritual, or mythological sense
wairua	spirit
waka	canoe

[234] Heritage New Zealand Pouhere Taonga Act 2014

Māori	English
whānau	family
whanaungatanga	relationship, kinship, sense of family connection forged through shared experiences

7.2 TECHNICAL TERMS & ABBREVIATIONS

Since this is a report on commercial fishing, where applicable, we have used the Fisheries New Zealand definition for technical terms and abbreviations in this glossary. We note that there are other definitions of many terms and discuss this for some key terms above.

Term	Meaning	Also called
abundance	the amount of something as measured by number of individuals	
ACE	annual catch entitlement; an entitlement to harvest a quantity of fish, aquatic life, seaweed or other stock, taken in accordance with a fishing permit and any conditions and limitations imposed by or under the Fisheries Act 1996	annual catch entitlement
AEBAR	aquatic environment and biodiversity annual review; a review produced each year by Fisheries New Zealand that presents scientific information on the effects of fishing on the environment, marine biodiversity, and aquatic environments	aquatic environment and biodiversity annual review
AFMA	Australian Fisheries Management Authority	
AI	artificial intelligence	
AIS	automatic ship identification system	
annual catch entitlement	an entitlement to harvest a quantity of fish, aquatic life, seaweed or other stock, taken in accordance with a fishing permit and any conditions and limitations imposed by or under the Fisheries Act 1996	ACE
ANZBS	*Aotearoa New Zealand Biodiversity Strategy*	*Te Mana o Te Taiao*
AOS	acoustic-optical system	
aquaculture	the farming of fish or shellfish	
aquatic environment and biodiversity annual review	a review produced each year by Fisheries New Zealand that presents scientific information on the effects of fishing on the environment, marine biodiversity, and aquatic environments	AEBAR
B	biomass; the size of the stock in units of weight; often, biomass refers to only one part of the stock (e.g. spawning biomass, recruited biomass or vulnerable biomass, the latter two of which are essentially equivalent)	biomass

Term	Meaning	Also called
B_0	unfished biomass; the theoretical carrying capacity of the recruited or vulnerable biomass of a fish stock. In some cases, it refers to the average biomass of the stock in the years before fishing started more generally, it is the average over recent years of the biomass that theoretically would have occurred if the stock had never been fished B_0 is often estimated from stock modelling and various percentages of it (e.g. 40% B_0) are used as biological reference points to assess the relative status of a stock	original biomass, unfished biomass
B_{MSY}	the average stock biomass that results from taking an average catch of maximum sustainable yield under various types of harvest strategies often expressed in terms of spawning biomass, but may also be expressed as recruited or vulnerable biomass B_{MSY} is a common fisheries management target	
ballast	water taken in to a tank in the hull of vessels for stability	
bathymetry	the measurement of depth	
benthic	pertaining to the bottom of the ocean or the seafloor	
benthic protection area	any area established by the Fisheries (Benthic Protection Areas) Regulations 2007 as being a BPA	BPA
BERL	Business and Economic Research Ltd	
biodiversity	the variety and diversity of all life on land, in freshwater and in the sea, including the places where they live it pertains to the variety of *different* species present, the variability of ecosystems themselves and diversity *within* species	biological diversity
biofouling	the accumulation of microorganisms, plants, algae, or small animals on surfaces such as pipes or vessel hulls	
biogenic	produced by living organisms e.g. a coral reef is a biogenic structure	
biological diversity	the variety and diversity of all life on land, in freshwater and in the sea, including the places where they live it pertains to the variety of *different* species present, the variability of ecosystems themselves and diversity *within* species	biodiversity

Term	Meaning	Also called
biomass	the size of the stock in units of weight; often, biomass refers to only one part of the stock (e.g. spawning biomass, recruited biomass or vulnerable biomass, the latter two of which are essentially equivalent)	B
blue economy	a term that is sometimes used to capture a holistic approach to managing human use of the oceans, including biological, social and economic dimensions	ocean economy, marine economy
BOMEC	benthic-optimised marine environment classification	
BPA	any area established by the Fisheries (Benthic Protection Areas) Regulations 2007 as being a BPA	benthic protection area
BRUVS	baited remote underwater video station	
bryozoan	a family of aquatic invertebrate animals that form colonies	
bycatch	species not targeted by a fishery but caught incidentally during fishing operations	non-target species
calcareous	composed of calcium carbonate	
cartilaginous	made of cartilage, i.e. the skeletons of sharks	
CASAL	a fish stock assessment model	
catch per unit effort	the quantity of fish caught with one standard unit of fishing effort e.g. the number of fish taken per 1,000 hooks per day; or the weight of fish taken per hour of trawling CPUE is often assumed to be an abundance index a declining CPUE may mean that more effort e.g. metres of net set and/or length of soak time, is required to catch a given volume of fish; this in turn may indicate that a fish stock has declined (although other factors can also influence rates of CPUE, particularly the method used to catch the fish)	CPUE
catchability	catchability is the proportion of fish that are caught by a defined unit of fishing effort	
catchment	area of land in which rainfall drains towards a common watercourse, stream, river, lake or estuary	
CBD	Convention on Biological Diversity	
CCSBT	Commission for Conservation of Southern Bluefin Tuna	
cetacean	aquatic mammals including dolphins, whales and porpoises	

Term	Meaning	Also called
chemoautotroph	organism that produces organic molecules by fixation of carbon dioxide, using energy derived from the oxidation of inorganic substances such as iron	
chimaera	a family of cartilaginous fish	ghost sharks
chondrichthyans	the family of cartilaginous fish including sharks, rays and ghost sharks	
CNN	convolutional neural network; a deep neural network inspired by the human vision system often used for image analysis	convolutional neural network
cod-end	the end of a trawl net which retains the catch and the part of the net where the most size selection takes place	
commercial fishing	taking fish, aquatic life, or seaweed in circumstances where a fishing permit is required; this term is defined in the Fisheries Act 1996	
convolutional neural network	a deep neural network inspired by the human vision system often used for image analysis	CNN
CPR	continuous plankton recorder	
CPUE	the quantity of fish caught with one standard unit of fishing effort e.g. the number of fish taken per 1,000 hooks per day; or the weight of fish taken per hour of trawling CPUE is often assumed to be an abundance index a declining CPUE may mean that more effort e.g. metres of net set and/or length of soak time, is required to catch a given volume of fish; this in turn may indicate that a fish stock has declined (although other factors can also influence rates of CPUE, particularly the method used to catch the fish)	catch per unit effort
CRI	Crown Research Institute; crown-owned companies that carry out scientific research	
CSIRO	Commonwealth Scientific and Industrial Research Organisation; Australia's national science agency, similar to New Zealand's CRIs	

Term	Meaning	Also called
customary fishing	the traditional rights confirmed by the Treaty of Waitangi and the Treaty of Waitangi (Fisheries Claims) Settlement Act 1992, being the taking of fish, aquatic life, or seaweed or managing of fisheries resources, for a purpose authorised by Tangata Kaitiaki / Tiaki, to the extent that such purpose is consistent with Tikanga Māori and is neither commercial in any way nor for monetary gain or trade this term is defined in the Fisheries (Kaimoana Customary Fishing) Regulations 1998	
demersal	pertaining to the seafloor and deep water column affected by the seafloor	
discards	any fish or other organisms that are landed but subsequently returned to the ocean	
DOC	Department of Conservation	
dredging	a fishing method where a steel net (a dredge) is towed along the seafloor by a vessel and scrapes up all the shellfish living there	
DTIS	deep towed imaging system	
EAFM	ecosystem approach to fisheries management; fisheries management that moves beyond single-species measures to incorporate wider ecosystem effects. Also called ecosystem-based fisheries management (EBFM); this differs from ecosystem-based management (EBM) which refers to management of the ocean more broadly – not just fisheries.	ecosystem approach to fisheries management, EBFM, ecosystem-based fisheries management
EBFM	ecosystem-based fisheries management; fisheries management that moves beyond single-species measures to incorporate wider ecosystem effects; also called ecosystem approach to fisheries management (EAFM); this differs from ecosystem-based management (EBM) which refers to management of the ocean more broadly – not just fisheries.	ecosystem-based fisheries management, EAFM, ecosystem approach to fisheries management
EBM	ecosystem-based management; using a holistic approach to management of the whole ocean taking into account the ecosystems	ecosystem-based management
ecosystem	an area where plants, animals, and other organisms, as well as weather and landscape, interact as a system	

Term	Meaning	Also called
ecosystem approach to fisheries management	EAFM; fisheries management that moves beyond single-species measures to incorporate wider ecosystem effects; also called ecosystem-based fisheries management (EBFM); this differs from ecosystem-based management (EBM) which refers to management of the ocean more broadly – not just fisheries	EAFM, EBFM, ecosystem-based fisheries management
ecosystem-based fisheries management	EBFM; fisheries management that moves beyond single-species measures to incorporate wider ecosystem effects, also called ecosystem approach to fisheries management (EAFM); this differs from ecosystem-based management (EBM) which refers to management of the ocean more broadly – not just fisheries	EBFM, ecosystem approach to fisheries management, EAFM
ecosystem-based management	EBM; using a holistic approach to management of the whole ocean taking into account the ecosystems	EBM
ecosystem thinking	a holistic perspective that moves beyond single-species measures to consider the whole ecosystem and its interconnections, including biodiversity	
echogram	the 2D output from an echosounder	
echosounder	a device that uses sound and echoes to detect organisms underwater	
eDNA	environmental DNA	
EEZ	Exclusive Economic Zone; a maritime zone over which the coastal state has sovereign rights over the exploration and use of marine resources usually, a state's EEZ extends to a distance of 200 nautical miles (nm) (approx. 370 km) out from its coast, except where resulting points would be closer to another country Aotearoa New Zealand has a 200 nm EEZ that was declared in 1978; the EEZ formally extends from the territorial sea at 12 nm (from the coastline) to 200 nm; this term is defined in the territorial sea and Exclusive Zone Act 1977	Exclusive Economic Zone
EM	electronic monitoring	
EPA	Environment Protection Authority	
epigenetics	the study of changes in gene expression (active vs inactive genes) rather than the underlying DNA sequence	
ER	electronic reporting	
ERA	ecosystem risk assessment	

Term	Meaning	Also called
ESP3	open-source software to process large hydro-acoustic datasets	
ESR	New Zealand's Institute of Environmental Science and Research; a CRI	
Exclusive Economic Zone	Exclusive Economic Zone; a maritime zone over which the coastal state has sovereign rights over the exploration and use of marine resources usually, a state's EEZ extends to a distance of 200 nautical miles (nm) (approx. 370 km) out from its coast, except where resulting points would be closer to another country Aotearoa New Zealand has a 200 nm EEZ that was declared in 1978; the EEZ formally extends from the territorial sea at 12 nm (from the coastline) to 200 nm; this term is defined in the territorial sea and Exclusive Zone Act 1977	EEZ
eutrophic	overly enriched with nutrients and/or minerals, resulting in excessive plant and algal growth (e.g. an algal bloom) and corresponding depletion in oxygen levels that may kill other organisms living in the water such as fish	
EwE	Ecopath with Ecoism; a type of ecosystem model	
FAD	fish aggregating device	
FAO	Food and Agriculture Organization, part of the United Nations	
finfish	a bony, jawless or cartilaginous fish with fins, as opposed to shellfish	
FINZ	Fisheries Inshore New Zealand	
fish stock	in this report, a stock or fish stock usually describes a management unit of a species as defined by Fisheries New Zealand; a stock may be a discrete biological unit, with little to no reproductive mixing with other stocks of the same species in other cases, there may be migration or mixing between stocks	stock
Fisheries New Zealand	the government agency that regulates fishing in Aotearoa New Zealand, part of the Ministry for Primary Industries	FNZ

Term	Meaning	Also called
Fisheries Settlement 1992	the Treaty of Waitangi (Fisheries Claims) Settlement Act became law in late 1992, and gave effect to the Deed of Settlement, signed in September 1992 this deed (1) settled Māori claims to commercial fishing; (2) clarified Māori rights to customary or non-commercial fishing; and (3) discharged the Crown's obligations in respect of Māori commercial fishing interests under the Treaty of Waitangi	Treaty of Waitangi (Fisheries Claims) Settlement Act 1992; Māori Fisheries Settlement 1992
Fishery Management Area	Fishery Management Area; the New Zealand 200 nautical mile EEZ is divided into 10 areas, each known as a Fishery Management Area FMAs are based on likely stock boundaries as well as administrative considerations; the standard FMAs are the basis of QMAs for most fish stocks; this term is defined in the Fisheries Act 1996	FMA
FishServe	a subsidiary of Seafood New Zealand that provides administrative services to the Aotearoa New Zealand commercial fishing industry	
FMA	Fishery Management Area; the New Zealand 200 nm EEZ is divided into 10 areas, each known as a Fishery Management Area FMAs are based on likely stock boundaries as well as administrative considerations; the standard FMAs are the basis of QMAs for most fish stocks; this term is defined in the Fisheries Act 1996	Fishery Management Area
FNZ	Fisheries New Zealand, the government agency that regulates fishing in Aotearoa New Zealand, part of the Ministry for Primary Industries	Fisheries New Zealand
Gazette	the *New Zealand Gazette* is the official government newspaper, published weekly; regulations are notified in the *Gazette* after they are made but before they come into force	
ghost gear	abandoned, lost or discarded fishing gear	
ghost shark	a family of cartilaginous fish	chimaera
gillnet	vertical panels of netting held in place by regularly spaced floats and weights, catches sea life by entanglement	
GIS	geographical information system; an organised collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information a GIS can combine relational databases with spatial interpretation and outputs often in form of maps	

Term	Meaning	Also called
GPR	geospatial position reporting	
GPS	global positioning system	
habitat	the place or environment that provides everything an organism needs to live and grow	
hard limit	biomass limit below which fisheries should be considered for closure	
HMS	highly migratory species	
HPSFM	habitats of particular significance to fisheries management	
hydroacoustic	the study and application of sound in water	
ikijime	a humane method of quickly killing fish originating in Japan, where a spike is quickly inserted just behind the fish's eye	
individual transferable quota	a property right that represents the quota owners' share of a fishery; ITQs can be bought or sold there are 100 million shares in each fish stock; the number of shares owned determines the amount of ACE generated each fishing year	ITQ
IOC	intergovernmental oceanographic commission	
ITQ	a property right that represents the quota owners' share of a fishery; ITQs can be bought or sold there are 100 million shares in each fish stock; the number of shares owned determines the amount of ACE generated each fishing year	individual transferable quota
IUCN	International Union for Conservation of Nature	
IUU	illegal, unreported and unregulated (of fishing)	
jigging	using a line with multiple baits, moving it up and down vertically to attract target species	
lacustrine	related to lakes	
landing	an amount of fish (or other marine life) harvested from the sea and brought onshore	
LAWA	Land Air Water Aotearoa	

Term	Meaning	Also called
LINZ	Land Information New Zealand	
longlining	using a very long fishing line with shorter lines and baited hooks every few feet	
machine learning	an application of AI where algorithms learn and improve from experience, rather than being explicitly programmed	
Māori Fisheries Settlement 1992	the Treaty of Waitangi (Fisheries Claims) Settlement Act became law in late 1992, and gave effect to the Deed of Settlement, signed in September 1992 this deed (1) settled Māori claims to commercial fishing; (2) clarified Māori rights to customary or non-commercial fishing; and (3) discharged the Crown's obligations in respect of Māori commercial fishing interests under the Treaty of Waitangi	Fisheries Settlement 1992; Treaty of Waitangi (Fisheries Claims) Settlement Act 1992
marine economy	a term that is sometimes used to capture a holistic approach to managing human use of the oceans, including biological, social and economic dimensions	blue economy, ocean economy
marine protected area	an area of the marine environment especially dedicated to, or achieving, through adequate protection, the maintenance and/or recovery of biodiversity at the habitat and ecosystem level in a healthy functioning state	MPA
marine reserve	marine reserves are specified areas of the sea and foreshore that are managed to preserve them in their natural state for scientific study or other purposes marine reserves may be established in areas that contain underwater scenery, natural features or marine life, of such distinctive quality, or so typical, or beautiful, or unique, that their continued preservation is in the national interest; within a marine reserve, all marine life is protected and fishing and the removal or disturbance of any living or non-living marine resource is prohibited, except as necessary for permitted monitoring or research; this includes dredging, dumping or discharging any matter or building structures	
marine trophic index	a measure of the mean trophic level of fish caught	
maw	swim bladder	

Term	Meaning	Also called
maximum sustainable yield	MSY, the largest long-term average catch or yield that can be taken from a stock under prevailing ecological and environmental conditions; it is the maximum use that a renewable resource can sustain without impairing its renewability through natural growth and reproduction For most quota management stocks, the total allowable catch is set at a level that either moves the stock towards, or maintains the stock at or above a biomass level that can support the maximum sustainable yield (section 13 of the Fisheries Act 1996);this term is defined in the Fisheries Act 1996	MSY
MBIE	Ministry of Business, Innovation and Employment	
MEC	marine environment classification	
mesopelagic	inhabiting the intermediate depths of the sea around 200-1,000 m	
MfE	Ministry for the Environment	
MICE	models of intermediate complexity; a type of ecosystem model	
microchemical	analytical chemistry for studying small samples	
micronekton	group or organisms intermediate in size between zooplankton and nekton; consists mainly of crustaceans, small cephalopods and small fishes	
MPA	marine protected area; an area of the marine environment especially dedicated to, or achieving, through adequate protection, the maintenance and/or recovery of biodiversity at the habitat and ecosystem level in a healthy functioning state	marine protected area
MPI	Ministry for Primary Industries	
MSC	Marine Stewardship Council	

Term	Meaning	Also called
MSY	MSY, maximum sustainable yield, is the largest long-term average catch or yield that can be taken from a stock under prevailing ecological and environmental conditions; it is the maximum use that a renewable resource can sustain without impairing its renewability through natural growth and reproduction for most quota management stocks, the total allowable catch is set at a level that either moves the stock towards, or maintains the stock at or above a biomass level that can support the maximum sustainable yield (section 13 of the Fisheries Act 1996); this term is defined in the Fisheries Act 1996	maximum sustainable yield
neural network	a type of machine learning system inspired by the structure of a human brain	
NGS	next-generation sequencing	
NIWA	National Institute of Water and Atmospheric Research; a CRI that carries out a large amount of fisheries research under contract to MPI	
NOAA	National Oceanic Atmospheric Administration (US)	
nominal stock	stocks that represent less than one percent of catch	
non-target species	species that are unintentionally caught or not routinely assessed for fisheries management	bycatch
nutraceutical	a substance that is a food or derived from food that provides medical or health benefits including the prevention and treatment of disease	
observer	a person placed onboard a fishing vessel to independently confirm catch and record a range of information such as bycatch species	
observer effect	observed trips do not represent unobserved trips as the presence of an observer changes fisher behaviour	
ocean economy	a term that is sometimes used to capture a holistic approach to managing human use of the oceans, including biological, social and economic dimensions	blue economy, marine economy
OIA	Official Information Act	
olfactory	related to the sense of smell	
oligotrophic	water bodies characterised by nutrient deficiency that can support few forms of life	

Term	Meaning	Also called
OOS/GOOS	Ocean Observing System; Global Ocean Observing System	
OPMCSA	Office of the Prime Minister's Chief Science Advisor	
original biomass	B_0; the theoretical carrying capacity of the recruited or vulnerable biomass of a fish stock; in some cases, it refers to the average biomass of the stock in the years before fishing started More generally, it is the average over recent years of the biomass that theoretically would have occurred if the stock had never been fished. B_0 is often estimated from stock modelling and various percentages of it (e.g. 40% B_0) are used as biological reference points to assess the relative status of a stock	B_0, unfished biomass
otolith	part of the inner ear of fish important for balance and hearing; this grows from the centre out in a series of daily rings and seasonal bands or growth zones; otoliths can be used to identify the age of fish	
PCE	Parliamentary Commissioner for the Environment	
pelagic	pertaining to the open ocean; neither close to the shore nor near to the seafloor	
phylodynamics	the study of population dynamics and evolutionary processes as it relates to the relationships between organisms of different species	
phytoplankton	microscopic marine algae	
pinger	an active sound emitter used to deter bycatch from net entanglement	
pinniped	family of semi-aquatic marine mammals including seals and sea lions	

Term	Meaning	Also called
plenary	Fisheries New Zealand holds fisheries assessment working groups throughout the year to discuss and review stock assessments; the working group meetings are open to the public, and include researchers, FNZ staff, commercial, customary, recreational and environmental stakeholders every year in May 'plenary sessions' are held to assess the fisheries managed within the QMS, as well as other important fisheries in the New Zealand EEZ, and to discuss various matters that pertain to fishery assessment a plenary report is then released by 31 May that summarises the conclusions and recommendations from the meetings of the Fishery Assessment Working Groups held during the previous months, as well as the Fishery Assessment Plenary session	
polyp	an individual belonging to the *Cnidaria* family which includes coral-forming organisms and sea anemones	
potting	a method of catching some marine species such as crayfish where a pot-like trap attached to a long rope is baited, dropped in the water and retrieved later; once entered, the target marine organism can't escape	trapping
protected species	(a) any marine wildlife as defined in section 2 of the Wildlife Act 1953 that is absolutely protected under section 3 of that Act; (b) any marine mammal as defined in section 2(1) of the Marine Mammals Protection Act 1978; this term is defined in the Fisheries Act 1996	
PVC	polyvinyl chloride; a type of plastic	
QMA	species within the QMS are managed by QMAs; QMAs are geographic areas within the EEZ the standard fishery management areas are the basis of quota management areas for most fish stocks	Quota Management Area
QMS	the QMS controls the overall catches for virtually all the main fish stocks found within Aotearoa New Zealand's 200 nautical mile EEZ	Quota Management System
quota	quota is a right which allows people to own a share of the 100 million shares available for a particular species in a defined area ownership of quota generates an annual catch entitlement to catch that stock; within the commercial catch limit, access is determined by ownership of ACE and the possession of a fishing permit	

Term	Meaning	Also called
Quota Management Area	species within the QMS are managed by QMAs; QMAs are geographic areas within the EEZ the standard fishery management areas are the basis of quota management areas for most fish stocks	QMA
Quota Management System	the QMS controls the overall catches for virtually all the main fish stocks found within Aotearoa New Zealand's 200 nautical mile EEZ	QMS
recruitment	the addition of new individuals to the fished component of a stock; this is determined by the size and age at which fish are first caught	
RFID	radio-frequency identification	
RFMO	regional fisheries management organisation	
rhodolith	calcareous nodules formed by marine algae found on the seafloor	
RMA	Resource Management Act 1991	
ROV	remotely operated vehicle	
SDG	sustainable development goal	
seamount	a geological formation rising from the seafloor that does not reach the sea surface – essentially, an underwater mountain	
sediment	particles or clumps of soil, sand, clay, silt or other matter suspended in water	
SEFRA	spatially explicit fisheries risk assessment	
seine/seining	a fishing method using a net that hangs vertically and encircles a school of fish	
SFFF	sustainable food and fibre futures	
ShiPCC	sea-going high-performance computing cluster	
SIL	Seafood Innovations Ltd	
SLED	sea lion exclusion device	
SNP	single nucleotide polymorphism; a variation at a single site in a DNA sequence	
SNP-ChIP	a microarray to measure genetic variation	
soft limit	a biomass limit below which the requirement for a formal, time-constrained rebuilding plan is triggered	
spat	shellfish larvae attached to a surface	

Term	Meaning	Also called
spawning	the production or depositing of large quantities of eggs in water	
spawning biomass	the total weight of sexually mature fish in a stock that spawn in a given year	
SPM	spatial population model	
SSIF	strategic science investment fund	
SST	satellite surface temperature	
stock	in this report, a stock or fish stock usually describes a management unit of a species as defined by Fisheries New Zealand; a stock may be a discrete biological unit, with little to no reproductive mixing with other stocks of the same species in other cases, there may be migration or mixing between stocks	fish stock
stock assessment	the application of statistical and mathematical tools to relevant data in order to obtain a quantitative understanding of the status of the stock relative to defined benchmarks or reference points (e.g. B_{MSY}) the results may include (1) an estimate of the current biomass relative to biomass targets; (2) an estimate of current and recent exploitation rates relative to optimum exploitation rates; (3) a determination of changes in the biomass of fish stocks in response to fishing; and/or (4) to the extent possible, a prediction of future trends in stock biomass stock assessments are based on (1) surveys; (2) knowledge of the habitat requirements, life history, and behaviour of the species; (3) likely environmental impacts on stocks; and (4) catch and effort statistics	
stock structure	(1) The geographical boundaries of the stocks assumed for assessment and management purposes (e.g. albacore tuna may be assumed to be comprised of two separate stocks in the North Pacific and South Pacific). (2) The boundaries that define self-contained populations in a genetic sense. (3) Known, inferred or assumed patterns of residence and migration for stocks that mix with one another	
sustainability / sustainable use	In this report, **sustainability** or **sustainable use** usually refers to sustainability as defined in the Fisheries Act 1996 – that is, (a) maintaining the potential of fisheries resources to meet the reasonably foreseeable needs of future generations, and (b) avoiding, remedying or mitigating any adverse effects of fishing on the	

Term	Meaning	Also called
	aquatic environment. Sometimes, we use a narrower definition referring to the long-term maintenance of a single fish stock without considering the wider ecosystem impacts. At other times, we use a broader meaning of sustainability that encompasses ecological and social factors, including but not limited to biodiversity (genetic, species and ecosystem diversity), environmental and ecosystem impacts.	
TAC	total quantity of each fish stock that can be taken by commercial, customary Māori interests, recreational fishery interests and other sources of fishing-related mortality, to ensure sustainability of that fishery in a given period, usually a year; this term is defined in the Fisheries Act 1996	total allowable catch
TACC	total quantity of each fish stock that the commercial fishing industry can catch in a given year; the TACC is a portion of the TAC that is set after allowances have been made for customary and recreational fishing, and for other sources of fishing-related mortality; this term is defined in the Fisheries Act 1996	total allowable commercial catch
telson	the last segment in the abdomen or terminal appendage to the abdomen found in crustaceans such as rock lobsters	
tipping point	a point at which an ecosystem makes an abrupt shift between different states, driven by environmental change	
tori line	a type of bird-scaring fishing line with coloured streamers that is deployed behind a longline fishing vessel to deter seabirds from accessing baited hooks	
total allowable catch	total quantity of each fish stock that can be taken by commercial, customary Māori interests, recreational fishery interests and other sources of fishing-related mortality, to ensure sustainability of that fishery in a given period, usually a year; this term is defined in the Fisheries Act 1996	TAC
total allowable commercial catch	total quantity of each fish stock that the commercial fishing industry can catch in a given year; the TACC is a portion of the TAC that is set after allowances have been made for customary and recreational fishing, and for other sources of fishing-related mortality; this term is defined in the Fisheries Act 1996	TACC

Term	Meaning	Also called
trapping	a method of catching some marine species such as crayfish where a pot-like trap attached to a long rope is baited, dropped in the water and retrieved later; once entered, the target marine organism can't escape	potting
trawling	a fishing method where a net is dragged through the water behind a vessel	
Treaty of Waitangi (Fisheries Claims) Settlement Act 1992	the Treaty of Waitangi (Fisheries Claims) Settlement Act became law in late 1992, and gave effect to the Deed of Settlement, signed in September 1992 this deed (1) settled Māori claims to commercial fishing; (2) clarified Māori rights to customary or non-commercial fishing; and (3) discharged the Crown's obligations in respect of Māori commercial fishing interests under the Treaty of Waitangi	Fisheries Settlement 1992; Māori Fisheries Settlement 1992
trolling	a fishing method using a line, sometimes with multiple lures, and dragging it horizontally through the water to simulate prey movement	
trophic cascade	flow of changes in an ecosystem and relative abundance of prey species, triggered by the removal or addition of a top predator	
trophic level	the position an organism occupies in a food web	
turbidity	a measure of the murkiness of water due to the presence of suspended particles	
UAV	unmanned aerial vehicle	
UBA	underwater breathing apparatus	
UNCLOS	United Nations Convention on the Law of the Sea	
UNEP	United Nations Environment Programme	
unfished biomass	B_0; the theoretical carrying capacity of the recruited or vulnerable biomass of a fish stock; in some cases, it refers to the average biomass of the stock in the years before fishing started More generally, it is the average over recent years of the biomass that theoretically would have occurred if the stock had never been fished. B_0 is often estimated from stock modelling and various percentages of it (e.g. 40% B_0) are used as biological reference points to assess the relative status of a stock	B_0, original biomass
UNFSA	United Nations Fish Stocks Agreement	
UNGA	United Nations General Assembly	

Term	Meaning	Also called
UTF	underwater topographical feature	
VIAME	video and image analytics for marine environments	
VME	vulnerable marine ecosystem; a marine ecosystem is classified as 'vulnerable' based on the characteristics that it possesses, such as uniqueness or rarity; functional significance of the habitat; fragility; life-history traits of component species that make recovery difficult; and structural complexity' examples are seamounts and deepwater coral forests.	vulnerable marine ecosystem
vulnerable marine ecosystem	vulnerable marine ecosystem; a marine ecosystem is classified as 'vulnerable' based on the characteristics that it possesses, such as uniqueness or rarity; functional significance of the habitat; fragility; life-history traits of component species that make recovery difficult; and structural complexity' examples are seamounts and deepwater coral forests.	VME
WCPFC	Western and Central Pacific Fisheries Commission	
WGS	whole genome sequencing	
WWF	World Wildlife Fund	
xenophyophore	single-celled organisms that live on the seafloor, extracting minerals from their surroundings to construct an exoskeleton	

Ka pū te ruha, ka hao te rangatahi

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