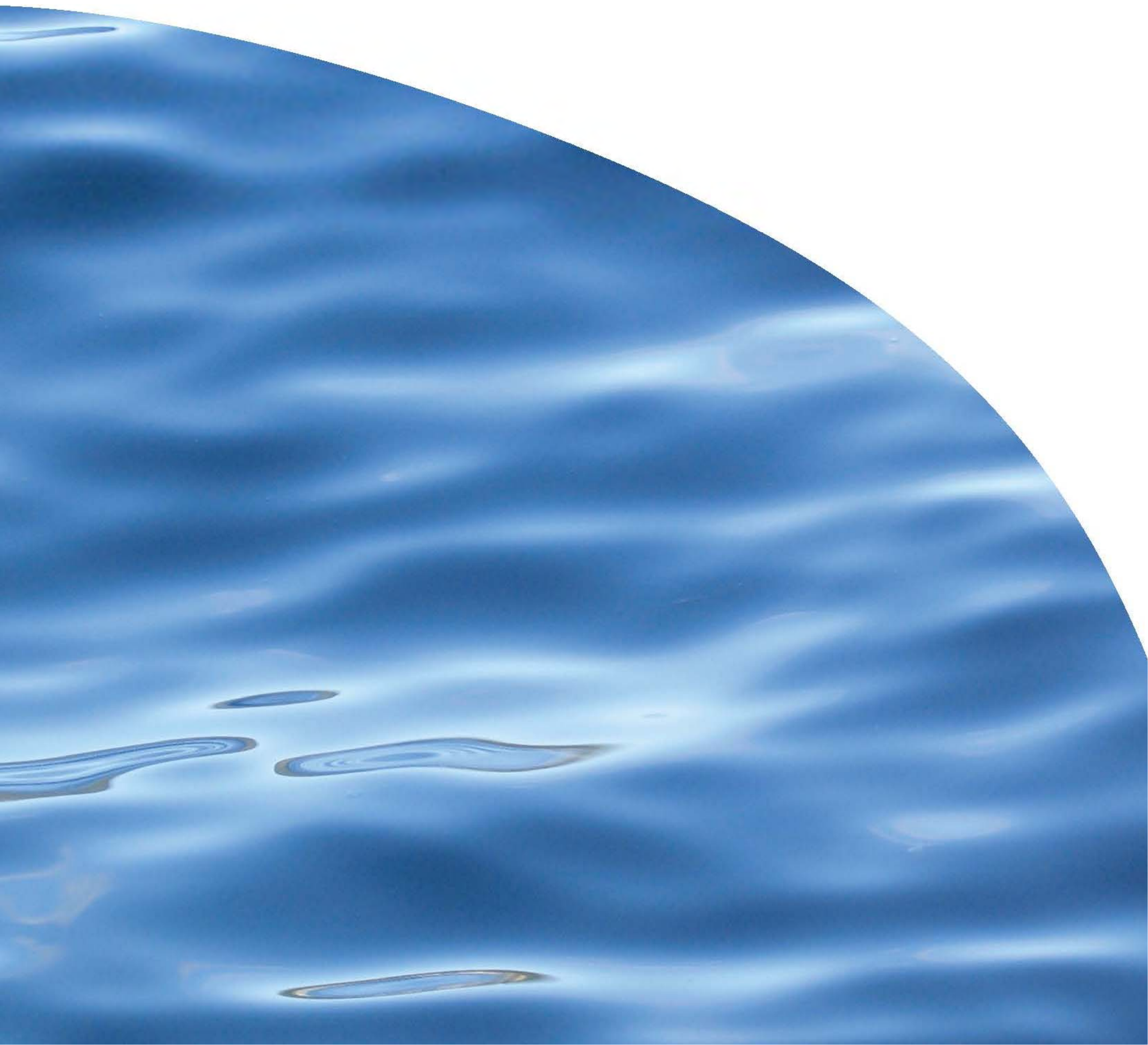
REPORT NO. 2481

NEW ZEALAND MARINE FARM MONITORING WORKSHOP: 12 DECEMBER 2013



NEW ZEALAND MARINE FARM MONITORING WORKSHOP: 12 DECEMBER 2013

DAVID TAYLOR[1], NIGEL KEELEY[1], STEPHANIE HOPKINS[2], HAMISH WILSON[2]

[1] CAWTHRON INSTITUTE

[2] MINISTRY FOR PRIMARY INDUSTRIES

Prepared for Marlborough District Council / MSI Envirolink

CAWTHRON INSTITUTE
98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand
Ph. +64 3 548 2319 | Fax. +64 3 546 9464
www.cawthron.org.nz

REVIEWED BY:
Natasha Berkett

APPROVED FOR RELEASE BY:
Rowan Strickland

ISSUE DATE: 3 April 2014

RECOMMENDED CITATION: Taylor DI, Keeley N, Hopkins S, Wilson H 2014. New Zealand Marine Farm Monitoring Workshop: 12 December 2013. Prepared for Marlborough District Council / Envirolink. Cawthron Report No. 2481. 13 p. plus appendices

1. BACKGROUND

Cawthron Institute (Cawthron) was approached by Marlborough District Council (MDC) to coordinate a Marine Farm Monitoring Workshop, which would build on the Best Practice Management (BPM) Workshop for Salmon Farming and help direct development of regional monitoring standards for salmon farming in the Marlborough Sounds. The workshop was funded by an Envirolink medium advice grant (1463-MLDC93) and included 44 participants spanning 21 national and international organisations. The organisations represented included those from the aquaculture industry, local community interest groups, education providers, resource management consultants, science providers, regional councils and central government (See Section 5 for a full list of participants). The inaugural New Zealand Marine Farm Monitoring Workshop was held at the Cawthron Institute on 12 December 2013.

This report summarises the outcomes and recommendations from the New Zealand Marine Farm Monitoring workshop, and provides an overview of the proceedings. Copies of the presentations from the workshop are also attached.

Overall project aim:

Provide advice and recommendations on existing and future marine farm monitoring practices in the Marlborough Sounds and other marine farming areas.

Objectives:

1. Compare NZ monitoring practices to those in Tasmania and Scotland to identify existing monitoring techniques that could be adapted or applied in NZ.
2. Describe / present existing monitoring practices and identify to what extent these address or fail to address current consent requirements.
3. Determine what the underpinning goals for monitoring should be and what changes are needed, if any.
4. Identify potential ways to reduce cost and increase speed of both field methods and reporting, so that management response times can be improved.
5. Identify new / potential technologies or methods that might be viable for monitoring and what research might be required surrounding these.

2. OUTCOMES AND RECOMMENDATIONS

Objective 1:

Compare NZ monitoring practices to those in Tasmania and Scotland to identify existing monitoring techniques that could be adapted or applied in NZ.

Outcome:

Kenny Black (Scottish Association for Marine Science, SAMS) detailed the methods used internationally to monitor the effects of salmon farming on the environment but stressed that while some were more rigorous than others, none were perfect. All focussed on benthic effects and most were aimed at maintaining a functioning biological community under the farms (Figure 1). Sulphides were used in some cases, but mostly in conjunction with benthic infauna assessments, and these might prove useful once further research had calibrated them to local environments.

State	Sulphide	Benthos	Neither
New Brunswick	X		
BC	X	X	
Chile		X	
Ireland		X	
UK		X	
Norway			X
Washington		X	
Maine	X	X	
NZ	X	X	

Figure 1. Monitoring of sulphides and benthos (benthic infauna) in the main global salmon farm regions (States).

He advised against monitoring that does not provide useful information (*e.g.* spot measurement of water column properties when these vary too much temporally and spatially to be informative). His final suggestion was that a local panel would be best to agree on a combination of national and international monitoring methods to address NZ requirements.

Richard Ford (Ministry for Primary Industries, MPI) detailed the NZ Government’s Aquaculture Strategy and 5-year Action Plan. He noted that several other marine monitoring initiatives are underway including Environmental Domain Plan, Marine Environmental Monitoring Programmes (MEMP), Ministry for the Environment (MFE) indicators, and National Scale Environmental Standards, which should be considered when developing monitoring techniques. The Aquaculture Planning Fund (APF) is also providing councils with funding to target monitoring in the marine environment; examples include MDC hydrodynamic and ecological modelling, and the Waikato

Regional Council's (WRC) monitoring guidance for aquaculture. A key output from MPI has been the Aquaculture Ecological Effects Guidance package (literature review and overview available at www.mpi.govt.nz). A risk screening tool and a decision makers' dashboard are soon to be released. This work provides a good basis to further develop consistent approaches to monitoring the effects of aquaculture on the marine environment.

Hilke Giles (Waikato Regional Council, WRC) presented an overview of their Aquaculture Planning Fund (APF) project to develop best management practice guidance for aquaculture monitoring. A draft guidance document is due June 2014. Workshops with stakeholders are planned May–August 2014. The aim is to combine State of Environment (SOE) monitoring and resource consent monitoring to maintain, or improve overall health of the marine environment and place aquaculture into context with other stressors. The project's main goals are:

- Integration of SOE and consent monitoring
- Fit for purpose
- Consistency
- Cost effectiveness
- Collaboration
- Transparency

Catriona MacLeod (University of Tasmania) provided an overview of outcomes from the Marlborough salmon farming BPM workshop held earlier in the week. She stressed the importance of building flexibility into monitoring and standards as improvements will be made over time. The ability to build research themes as standards are being developed is seen as a great opportunity. The BPM workshop built trust and relationships, and provided a framework of engagement for discussions. Clarity of science was achieved — it is clear what we know and what we don't know. The next step is to use this information to help set the monitoring goals.

Recommendations:

1. Through targeted working groups, develop monitoring techniques and standards for the Marlborough region based on nationally and internationally accepted methods.
2. Establish two targeted working groups to address the priority areas identified in the workshop: 'Benthic Zone Monitoring and Standards' and 'Integrated Cumulative Effects Monitoring Approaches' (see Objective 3 below).
3. Consider applying a wider monitoring framework to Marlborough Sounds (e.g. a monitoring framework is being developed for WRC that may be adapted for use in the Marlborough Sounds).

Objective 2:
Describe / present existing monitoring practices and identify to what extent these address or fail to address current consent requirements.

Outcome:
Presentations by **Nigel Keeley** and **Chris Cornelisen** (Cawthron), and **Craig Depree** and **Niall Broekhuizen** (NIWA) outlined existing farm-scale and water body-scale monitoring practices in the Marlborough Sounds and discussed how monitoring standards would provide greater certainty and flexibility for councils and marine farm consent holders. The inconsistencies and complexities of monitoring requirements in existing salmon farm consents was highlighted. Monitoring requirements have developed as the science of monitoring has progressed, and older consents often do not reflect current knowledge or methods. Development of monitoring standards would allow greater flexibility to incorporate new monitoring methods over time, and would bring consistency in monitoring requirements across consents. They would also potentially enable the integration of consent based monitoring with State of the Environment type monitoring.

Recommendation:

1. Development of consistent monitoring standards to allow for more simplified and flexible consent conditions — these should be progressed through targeted working group(s).

Objective 3:
Determine what the underpinning goals for monitoring should be and what changes are needed, if any.

Outcome:
Through a **group exercise at the workshop**, participants recognised four priority areas for marine farm monitoring discussion:

1. Standards (flexibility / response) / ecological consequences
2. Integrated monitoring approaches (SOE, cumulative, consent)/ baselines and scale (farm, water body, national)
3. Cost-effective monitoring (relevant, purposeful)
4. Communicating information.

Using a prioritisation exercise, ‘Benthic Zone Monitoring and Standards’ and ‘Integrated Cumulative Effects Monitoring Approaches’ were identified as having the highest priority for discussion at the workshop. However, there was general consensus that although ‘Communication’ was a lower priority for immediate discussion it was already an integral part of the workshop, and was vital to building community understanding and acceptance of aquaculture going forward.

The workshop discussion of the priority issue 'Benthic Zone Monitoring and Standards' made the following key points:

- Important to link monitoring with environmental effects but recognise it is scale dependant: farm / water body / national.
- Guidance / standards are needed to define and monitor acceptable zones of effect beneath salmon farms (benthic) for low and high water flow sites.
- Setting acceptable zones of effects is challenging in high flow sites as there is a larger footprint but the effects are less intense.
- Establish national level guidance / standards (ensuring consistency and a 'bottom-line' of acceptable effects) but still have the ability to develop regional approaches.

The workshop discussion of the priority issue 'Integrated Cumulative Effects Monitoring Approaches' made the following key points:

- Integration of council SOE (baseline) and consent (farm level) monitoring; is a collaborative approach to gathering long-term environmental data required?
- Need guidance / consistency on how to do baseline monitoring, *e.g.* number of sites, frequency *etc*.
- National coordination and sharing of data is important — utilise the large amount of existing monitoring results and data being collected.

Recommendations:

1. A working group including members of MDC, Cawthron, NIWA, NZKS, MPI and SAG is to be formed to develop goals and standards for salmon farm benthic zone monitoring and standards (initially for the Marlborough Sounds). Dr Nigel Keeley (Cawthron) has been delegated the task of leading the Monitoring and Standards working group.
2. MDC to consider adapting and applying an integrated cumulative effects monitoring framework to Marlborough Sounds (e.g. the WRC monitoring framework, which is under development, may be applicable to the Marlborough Sounds).

Objectives 4 and 5:

Identify potential ways to reduce cost and increase speed of both field methods and reporting, so that management response times can be improved.

Identify new / potential technologies or methods that might be viable for monitoring and what research might be required surrounding these.

Outcome:

A talk by **Susie Wood** (Cawthron), showed how next generation sequencing tools have the potential to make marine farm monitoring more cost effective and responsive. **Craig Depree** (NIWA) presented research into the use of diver operated micro-probes to measure pore-water sulphides. **Niall Broekhuizen** (NIWA) discussed research that could be used to predict mussel productivity in the Marlborough Sounds. **Chris Cornelisen** (Cawthron) presented research by Lincoln Mackenzie into new ways to predict Harmful Algal Blooms in the Marlborough Sounds.

Recommendations:

1. Use monitoring standards to reduce complexity of consent conditions and improve flexibility and timing of management response.
2. Continue to support investment into the development of new monitoring technologies.
3. Ensure flexibility is built into monitoring practices and standards, so that new and more cost-effective methods can be used as they are developed.

2. WORKSHOP AGENDA

When: Thursday 12 December 2013, 08:50–17:00 hrs

Venue: Cawthron Institute, Halifax Street East, Nelson 7010

Title: Future-focused marine farm monitoring: increased responsiveness, lower costs and greater social licence for aquaculture in New Zealand.

Table 1. Marine farm monitoring workshop timetable.

Time	**Activity**	**Participant(s)**
08:50–09:00	Arrival and coffee	All participants
09:00–09:15	Welcome	Charlie Eason, CEO Cawthron
09:15–09:30	**Introduction**: Purpose and aims for the day	Dave Taylor, Cawthron
09:30–10:50	**Talks:**	
	• International salmon farm monitoring methods	Kenny Black, SAMS
	• Ecological guidance package for aquaculture: implications for monitoring	Richard Ford, Ministry for Primary Industries
	• Monitoring environmental effects of marine farms in the Waikato region	Hilke Giles, Waikato Regional Council
	• Overview of outcomes from BPM workshop	Catriona Macleod, UTas
10:50–11:10	**Group Exercise 1 and morning tea:** Generate ideas about the question: *"What are the 2-3 key issues or areas you see as priorities with marine farm monitoring"* Participants will write issues on post-it notes to place on the white-board provided.	All participants
11:10–12:20	**Talks: Existing and future tools for marine farm monitoring**	
	• From porewater sampling to profile imaging - past experiences and future directions for benthic impact monitoring around salmon farms	Craig Depree, NIWA
	• The ecology of benthic enrichment — the value of present and future indicators	Nigel Keeley, Cawthron
	• Next generation tools for cost-effective environmental monitoring of finfish farms	Susie Wood / Xavier Pochon, Cawthron
12:20–13:00	**Lunch**	
13:00–13:10	**Group Exercise 2: Prioritisation exercise** Each person will identify their top three priorities for themes / categories using 3 dots. This will give focus to the afternoon discussions.	All participants
13:10–13:50	**Talks: Ecosystem monitoring and cumulative effects**	
	• Monitoring the water column in the coastal marine zone to detect effect and infer cause	Niall Broekhuizen, NIWA
	• Aquaculture and cumulative effects the big picture	Chris Cornelisen, Cawthron
13:50–15:00	**Group discussion:** Priorities	All participants

Time	Activity	Participant(s)
15:00–15:20	**Afternoon tea**	
15:20–16:30	**Group discussion:** Priorities *continued* Set goals and action points, identify research needs	All participants
16:30–17:00	Wrap up, next steps and close.	Dave Taylor, Cawthron

3. WORKSHOP PRESENTATIONS

A PDF version of each of the presentations at the marine farm monitoring workshop has been attached in Section 6.

4. WORKSHOP GROUP EXERCISE RESULTS — PRIORITISING ISSUES FOR MARINE FARM MONITORING

One of the objectives of the workshop was to determine priorities for marine farm monitoring using a group exercise process.

A list of all of the issues identified by the workshop participants under each of four general headings can be found below (NB. 1a and 2a were later merged with the primary headings). NB: These bullet points represent **individual views** of workshop attendees.

It is also important to note that the monitoring and standards working group for NZKS BPM guidelines will likely address a number of issues that were raised in the Marlborough Sounds context.

1) Standards (flexibility/response) (38 priority dots)

- Clarity required as to what the issues are and what is an acceptable level of effect
- Changing goalposts over time
- Timeliness in getting information/tools
- Balance between prescriptive and outcomes — what needs to be defined and what left to management practices
- Measure parameters in a standardised way to allow reporting across regions and nationally
- Minimum effective controls *vs* 'best practice' — what level is necessary to make any impact consistent with accepted standards

- Time lag between collecting data and management responses
- Remaining viable in a global market
- Clearly identifying environmental factors that are necessary to determine environmental impacts rather than reasons to satisfy social carrying capacity
- What is best practice now? What will it look like in the future?
- How to encourage flexibility to improve / adapt monitoring programme or adapt farm operations to be responsive to monitoring results
- Purpose focussed; cost effective, response time; flexibility
- Dealing with the 'unexpected'
- Common benthic standards (not variable)
- Standards for prevention of lice and disease
- What is the end use? If exceeded, what is the real consequence, will the world end?
- Proportionality of response
- Timeframe for industry response
- Consistency/standards?

1a) Ecological consequences (4 priority dots)

- Linking of monitoring with real environmental effect — a certain number does not equal damage
- Setting clear idea as to what the risk being addressed is
- Data not perfect therefore don't farm?
- Tighter coupling between variables measured and environmental effects
- Ensuring monitoring results are put in context: an ES = 6 under a low flow farm may not constitute an environmental disaster
- Need someone to collate existing environmental data for aquaculture regions → what is available, who owns it etc. Such a dataset should be freely available for all to use
- What fraction of seabed can be impacted without changing regional water quality and system dynamics unacceptably? How does this interrelate to acceptable local intensity?
- How does acceptable level of change relate to alternative uses / expectations of water body and sediments?

2) Integrated monitoring approaches (SOE, cumulative, consent) (32 priority dots)

- Need to utilise existing monitoring networks
- Linking catchment monitoring and regulation with marine farm monitoring

- Putting the results into the wider perspective
- Are farm monitoring requirements being increasingly driven by councils' need to have SOE monitoring?
- Overall nitrogen budget of natural environment; anthropogenic contribution to N levels; anthropogenic impact of N levels on biodiversity
- National Environmental Standard (NES) needs to be relevant / adaptable to context
- Cost / capacity / mandate from regional councils to monitor SOE
- Placing individual consents well within the larger spatial context
- National coordination of SOE data collection sites
- Holistic
- Big picture- ecosystem change
- Proving cause-effect especially with multiple pressures
- Monitoring cost to be spread across all those who impact the environment
- Consistency in terms, methodology, analysis, frequency
- Cause: effects — linking activity to effects
- Cumulative effects in wider coastal area
- Reporting / transparency
- How to predict carrying capacity (nutrients) effectively
- Cumulative effects
- Putting finfish nutrient input into the context of every other anthropogenic input
- How to ensure aquaculture is not penalised by other users
- Place of finfish farming in all anthropogenic nitrogen fluxes; do natural nitrogen levels curtail intensity of anthropogenic fluxes
- Estimating carrying capacity
- Setting levels of acceptable change
- Wider scale effects
- Portion out those effects that are linked to other inputs
- Biofouling and pest incursion from other vectors/ not aquaculture
- Monitoring certainty, appropriate scale for type of aquaculture, techniques are appropriate for purpose
- Economy of scale, farms not the only investment
- Monitoring that reflects aquaculture's % impact on the environment
- Dealing with existing consents and redundant monitoring

2a) Baselines and scale (farm, water body, national) (8 priority dots)

- Baseline monitoring and farming can be conducted / started together? 2-year gap?
- Increase baseline monitoring
- Baseline water quality data to enable assessment of change
- Water column measurements at appropriate spatial and temporal resolution
- Taking history or not taking history into account
- Different hydrodynamic modelling techniques to predict water column carrying capacity — can they be consistent?
- Lack of fundamental research on sediment/water column nutrient fluxes, biogeochemistry rate measurements, fate of water column nutrients from fish farms
- Level of detail re: methods, frequency, calibration, stats analysis of monitoring data
- What are plausible natural time-scales of recovery?
- What are acceptable time scales for initiation (by farmer) of response to a breach?

3) Cost effective monitoring (relevant, purposeful) (17 priority dots)

- Funding? Across sectors, across agencies, within sectors
- Cost-effective monitoring
- Cost — there must be more cost-effective options
- Relevance
- A clear separation must be between 'user' and 'public / shared' cost
- Lack of consistency between parties
- Cost, relevance, what's really necessary to monitor farm compliance? is the rest just nice to know?
- Clarity and relevance of data, and what it means
- Relevant monitoring, relevant reactions
- Clear idea of what the monitoring is being used for — is it for the sake of monitoring?
- Achievable
- Data sharing

4) Communicating information (6 priority dots)

- Clearly communicating to other groups what the farm's monitoring results are
- Transparency and communication

- Public understanding of monitoring results. Public not to be alarmed when there is no significant effect.
- Open access to data

5. LIST OF PARTICIPANTS

Organisation	Name	Contact
Scottish Association for Marine Science	Kenny Black	kenny.black@sams.ac.uk
University of Tasmania	Catriona Macleod	Catriona.Macleod@utas.edu.au
NZ King Salmon	Mark Gillard	Mark.Gillard@kingsalmon.co.nz
	Grant Lovell	Grant.Lovell@kingsalmon.co.nz
	Grant Rosewarne	Grant.rosewarne@kingsalmon.co.nz
	Mark Preece	Mark.preece@kingsalmon.co.nz
	Karen Mant	Karen.mant@kingsalmon.co.nz
NIWA	Niall Broekhuizen	Niall.Broekhuizen@niwa.co.nz
	Don Morrisey	Don.Morrisey@niwa.co.nz
	Ken Grange	Ken.grange@niwa.co.nz
	Craig Depree	Craig.Depree@niwa.co.nz
Ministry for Primary Industries	Richard Ford	Richard.Ford@mpi.govt.nz
	Hamish Wilson	Hamish.Wilson@mpi.govt.nz
	Mat Bartholomew	Mat.bartholomew@mpi.govt.nz
	Stephanie Hopkins	Stephanie.hopkins@mpi.govt.nz
Marlborough District Council	Steve Urlich	Steve.Urlich@marlborough.govt.nz
	Alan Johnson	Alan.Johnson@marlborough.govt.nz
	Bruno Brosnan	Bruno.brosnan@marlborough.govt.nz
KPF	Bob Nicolle	BBN@unitedfisheries.co.nz
Department of Conservation	Andrew Baxter	abaxter@doc.govt.nz
Aquaculture Direct	Graeme Coates	Graeme@aquaculturedirect.co.nz
Cawthron Institute	Charles Eason	Charles.Eason@cawthron.org.nz
	Dave Taylor	Dave.Taylor@cawthron.org.nz
	Chris Cornelisen	Chris.Cornelisen@cawthron.org.nz
	Lincoln Mackenzie	Lincoln.Mackenzie@cawthron.org.nz
	Grant Hopkins	Grant.Hopkins@cawthron.org.nz
	Paul Gillespie	paul.gillespie@cawthron.org.nz
	Nigel Keeley	Nigel.Keeley@cawthron.org.nz
	Susie Wood	Susie.Wood@cawthron.org.nz
	Fiona Gower	fiona.gower@cawthron.org.nz
	Emma Newcombe	emma.newcombe@cawthron.org.nz
Sounds Advisory Group	Rob Schuckard	rschckrd@xtra.co.nz
	Eric Jorgensen	oceanbayfarm@hotmail.com
Aquaculture New Zealand	Colin Johnston	Colin.johnston@aquaculture.org.nz
Sanford Group Limited	Ted Culley	tculley@sanford.co.nz
Environment Southland	Nick Ward	nick.ward@es.govt.nz
Ngai Tahu Seafoods	Merv Whipp	Merv.whipp@ngaitahu.iwi.nz
NMIT	Charmaine Gallagher	Charmaine.Gallagher@nmit.ac.nz

Organisation	Name	Contact
PALMS Ltd	Ron Sutherland	palmsltd@xtra.co.nz
Waikato Regional Council	Hilke Giles	Hilke.Giles@waikatoregion.govt.nz
Tasman District Council	Rosalind Squire	Rosalind.Squire@tasman.govt.nz
	Rob Smith	Rob.Smith@tasman.govt.nz
Aquatic Sciences	Mark James	markj@aquaticsciences.co.nz

6. PRESENTATIONS FROM THE MFM WORKSHOP

Below are copies of these workshop presentations by the following contributors:

- Eason (Cawthron): Welcome to the marine farm monitoring workshop
- Taylor (Cawthron): Workshop introduction and aims
- Black (SAMS): Regulation of salmon farming in different states
- Ford (MPI): Marine Farm Monitoring
- Giles (WRC): Monitoring effects of marine farms in Waikato
- Depree (NIWA): Porewater to profile imaging
- Keeley (Cawthron): The ecology of benthic enrichment
- Wood and Pochon (Cawthron): Next generation tools for monitoring
- Broekhuizen (NIWA): Nelson monitoring workshop
- Cornelisen (Cawthron): MDC monitoring workshop

MARINE FARM WORKSHOP AT THE CAWTHRON INSTITUTE

CHARLES EASON, CHIEF EXECUTIVE | 12 DECEMBER 2013

OVERVIEW AND RESEARCH CAPABILITY

- 197 employees
  - 73 Coastal & Freshwater
  - 33 Aquaculture
  - 71 Analytical Services
  - 20 Support
- NZ's largest independent research institute
- Established by Thomas Cawthron Trust in 1919
- Solutions focused-nimble
- Partner with industries, research groups and communities

CAWTHRON INSTITUTE


AQUACULTURE
SUPPORTING THE DEVELOPMENT OF
SUSTAINABLE AQUACULTURE

GROWTH IN CAPACITY

spatNZ

nmit
Nelson Marlborough Institute of Technology

KONO
Pure taste of New Zealand

Pacific Marine Farms

Ministry for Primary Industries
Manatū Ahu Matua

CAWTHRON
INSTITUTE

GROWTH IN CAPABILITY

Selective breeding
Genetics
Molecular biology
Cryopreservation
Spat production
Optimised algae production
Animal health
Industry scale-up
Novel farming technologies
Coastal and marine ecology
Marine farm planning & monitoring
Modelling, invertebrate ecology
Understanding marine toxins
LCMS
Safety and influencing international regulations

Cawthron and collaborators

Sustainable Growth

CAWTHRON INSTITUTE

RESOURCE MANAGEMENT

PROVIDING KNOWLEDGE FOR SUSTAINABLE MANAGEMENT OF OUR NATURAL RESOURCES

Capabilities:

- Ecohydraulics
- Periphyton ecology
- Macroinvertebrate ecology
- Fish ecology
- Water quality
- River health indicators
- Marine ecology
- Taxonomy
- Surveys and mapping

RESOURCE MANAGEMENT FOR:-

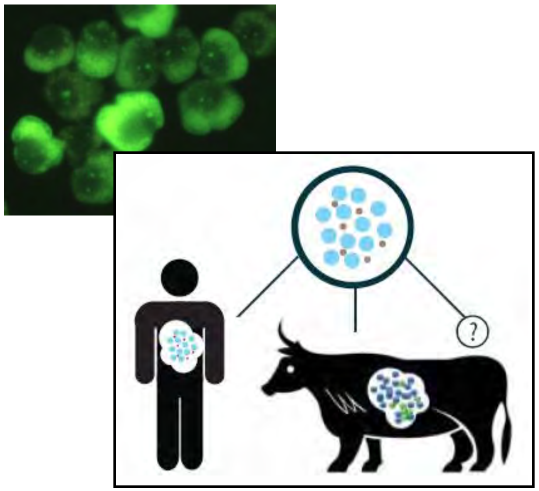
- Hydro-electric
- Water supply
- Sewage treatment
- Irrigation
- Local and central government
- EPA hearings
- Ports
- Aquaculture
- Biosecurity
- Oil and gas

Underpinned by aquatic ecosystem research and knowledge

CAWTHRON INSTITUTE

ENVIRONMENTAL MONITORING TOOLS

Ecological & Molecular

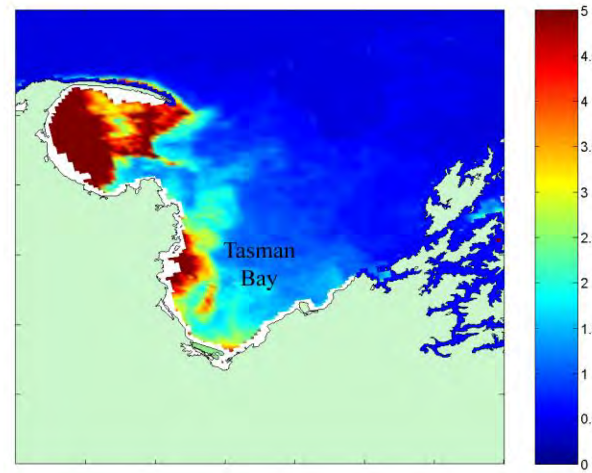


- Microbial Source Tracking
- Harmful algae and toxins
- Cyanobacteria
- Bio-invasive species
- Bethnics
- Future indicators
- New generation tools

Buoys

- Real time observation
- Web access-Open datasets
- Long-term SOE monitoring

Satellite Imagery



- River plumes
- Suspended sediments
- Chlorophyll

CAWTHRON INSTITUTE

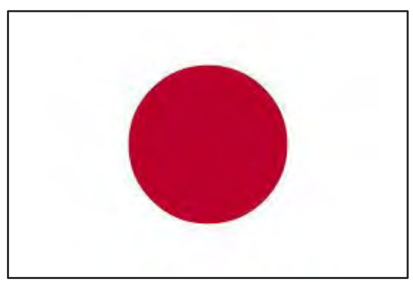
http://www.cawthron.org.nz/coastal-freshwater-resources/tascam.php

SEAFOOD – SAFETY

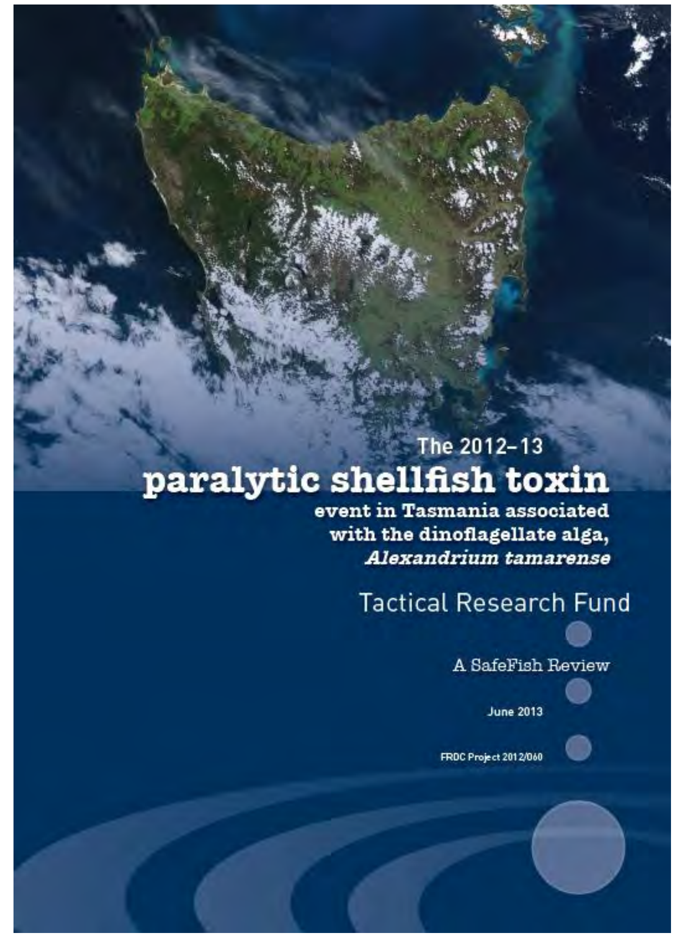
Capability	Taxonomy, genetics, algae bloom ecology; LCMS ‘McNabb method’; sensible regulatory limits; phytoplankton monitoring
Focus	Low-risk contaminants off regulated list; proactive research/ready for new organisms / toxins / emergency response; influence international panels

CAWTHRON
INSTITUTE

FOOD SAFETY - SEAFOOD



$23m AUD



CAWTHRON INSTITUTE

FOOD SAFETY AND QUALITY

PROTECTING NEW ZEALAND'S PREMIUM STATUS IN INTERNATIONAL MARKETS

SUMMARY

- One of the largest applied marine research providers
- Freshwater and marine research-convergence of skills
- Partnerings with NIWA, MPI and experts in private industry + international collaborators
- Provides strength required to deal with major issues and environmental concerns
- Help provide solutions for industry and communities

CAWTHRON
INSTITUTE

CAWTHRON AQUACULTURE PARK TENANTS

KONO
Pure taste of New Zealand

Pacific Marine Farms

spatNZ

nmit
Nelson Marlborough Institute of Technology

CAWTHRON COLLABORATORS

Plant & Food RESEARCH
RANGAHAU AHUMĀRA KAI

Ministry for Primary Industries
Manatū Ahu Matua

NIWA
Taihoro Nukurangi

ESR

agresearch

UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo
NEW ZEALAND

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

AUT
UNIVERSITY
AUCKLAND, NEW ZEALAND

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

CAWTHRON
INSTITUTE

www.cawthron.org.nz

CAWTHRON
INSTITUTE

Marine Farm Monitoring Workshop: Purpose and Aims

Dave Taylor

Team Leader – Coastal Aquaculture Solutions

Coastal and Freshwater Group, Cawthron Institute

mon·i·tor *v.*

To do something rather than nothing – **Monitor for monitoring's sake**

To collect heaps of data that go nowhere – **Inappropriate**

To produce reports that sit on a shelf - **Overly complicated**

To pour money into Davy Jones' Locker – **Costly**

mon·i·tor *v.*

To systematically track **- To a plan, for a purpose**

To test or sample at an appropriate frequency **- Appropriate**

To keep a close watch over **- Cost effective**

To guide, to direct **– Communication, Build Trust**

Where do your issues lie with marine farm monitoring?

What are we really concerned about?
Given the environmental consequence, do we need it?
Will it really help us understand something better, manage better, reduce concern, and build trust?

If **yes,** then we have a **purpose**

Purpose driven monitoring – but need **appropriate** standards

What are appropriate **Environmental Quality Standards** for marine farming (today just salmon farming)?

Where do your issues lie with marine farm monitoring?

Monitoring plan:

Scale	- A) Farm, B) Water body, C) National
Environment	- Benthic, water-column, etc.
Method	- Consistent, Robust, - Appropriate to detect effect - Future proofed but backwards compatible
Frequency	- Appropriate to check against standard - Cost-effective
Reporting	- Consistent - Timely - Easily understood - Cost-effective - Provides directions for future

Where do your issues lie with marine farm monitoring?

Action points

- Tiered / Stepwise
- Appropriate to environmental consequence
- Realistic for industry and ecological timeframes

Aims for today

1) Identify your issues with monitoring

2) Prioritise your issues for the afternoon discussion

All issues will be captured – can't address everything today

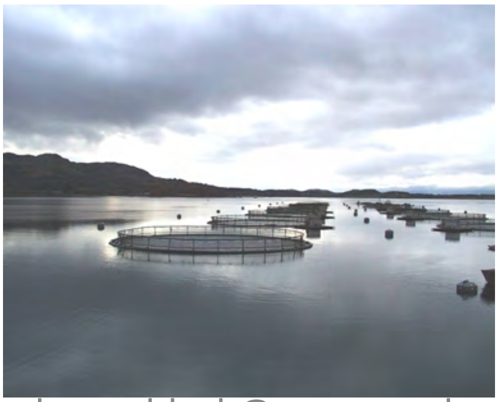
- Specific Issues Working Groups – will be formed
- February 2014 – 2nd Marlborough Sounds Salmon Farm BPM workshop

Monitoring is useless without <u>clear</u> reasons for the monitoring and the <u>objectives</u> that it will satisfy.

Unless individual monitoring projects fit into a <u>wider strategic framework</u>, the results are unlikely to be used and the environmental understanding will be lost.

The design of a monitoring programme must therefore have regard to the final use of the data <u>before</u> monitoring starts.

Regulation of salmon farming in different states



kenny.black@sams.ac.uk

Wilson AM, Magill SH, Black KD (eds) (2009) Review of environmental impact assessment and monitoring in salmon aquaculture., pp 455-535. FAO, Rome

TABLE 1
Salmonid aquaculture activities and their environmental impacts

Farming activity	Source of impact	Potential environmental impact	Environmental risk
Discharge of particulate and dissolved nutrients	Waste feed Faecal matter Excretory products	Organic enrichment of sediments	Sediments underlying cages become anoxic and changes in benthic assemblage
		Nutrient enrichment of water column	Eutrophication
Discharge of chemicals	Medicines Anti-foulants	Eco-toxicity	Loss of sensitive species
Interactions with wild fish populations	Escapes	Genetic dilution of wild stock	Decrease in genetic diversity, fitness
	Disease and parasite transference	Diseased wild stock	Decrease in health, increase in mortality

Source: adapted from Scottish Executive, 2002.

New Brunswick

TABLE 3
Classification of marine finfish aquaculture sites by sediment sulphide concentrations, as applied in New Brunswick

Site Classification		Sediment sulphide concentration	Responsive management decision framework	
Oxic	Oxic A	0 – 750 µM	Tier 1 monitoring**	Adhere to Operational Best Management Practices*
	Oxic B	750 – 1500 µM		
Hypoxic	Hypoxic A	1500 – 3000 µM	Tier 1 monitoring**	Adhere to Operational Best Management Practices, including appropriate Adjustments to the practices*
	Hypoxic B	3000 – 4500 µM	Tier 1, 2 monitoring**	Adhere to Operational Best Management practices, including appropriate Additional measures*
	Hypoxic C	4500 – 6000 µM	Tier 1,2,3 monitoring**	Adhere to Further enhanced Operational Best Management Practices*
Anoxic	Anoxic	> 6000 µM	Tier 1,2,3 monitoring**	Response measures to be decided in consultation with ASERC.

* Refer to Environmental Management Program for the Marine Finfish Cage Aquaculture Industry in New Brunswick (NBDENV, 2006a).
**See SOP (NBDENV, 2006b)

New Brunswick

TABLE 4

Components of the annual monitoring program conducted in New Brunswick, as detailed in the *Standard Operating Practices for the Environmental Monitoring of the Marine Finfish Cage Aquaculture Industry in New Brunswick*, (NBDENV, 2006b)

Monitoring component		Methodology	Determinand
Video survey		To be carried out along transects where appropriate Collection of all diver collected cores to be recorded Sea floor observation at each end of transects1	Seafloor observations as follows; Approximate sediment thickness; sediment colour; sediment consistency; surface consolidation; gas bubbles; % Beggiatoa coverage; presence of feed and faeces; macrofauna/flora; presence of detritus and fouling organisms.
Sediment samples	< 30.5 m depth	Cores to be collected by diver Minimum disturbance to cores is desirable. Clear cores 30 cm x 5 cm. Cores to be pushed into a depth of 10 cm	**Redox** Redox potential to be determined within the top 2 cm for each core or grab sample1 **Sulphide** A 5 ml subsample from the top 2 cm (after redox analysis) for sulphide determination1
	> 30.5 m depth	Gravity corer for silt and clay sediments Heavy grab for other sediments Three cores or grabs per sample location	

* Full details provided in SOP. SOP also gives details of any deviations from the details provided (i.e. differences between monitoring tiers). References to full technical documents are available from NBDENV.

BC

TABLE 5

Sampling methodology employed in British Columbia, Canada, as detailed by Protocols for Marine Environmental Monitoring (MWLA)

Determinand	Sampling equipment	Sampling location	Spatial scale	Replicates
Baseline monitoring				
Class abundance and richness of megafauna	transect	Across entire site Reference stations*	Length /width of site At least 100 m long	Enough to identify biophysical characteristics to 50 m resolution two at each station (One transect should run perpendicular to the shore)
Class abundance and richness of macrofauna	quadrat	Across entire site Reference stations	1 x 1 m (nine 33 x 33 cm sections) as above	Enough to represent each substratum Five at each station
S^{2-}, E_h, TVS or TOC, SGS, Cu or Zn,	Petit-Ponar, Ponar, Smith-MacIntyre, van Veen grab	All stations	Any size	Three grabs per sediment type for each probable footprint. Minimum five grabs if only one sediment type present
Species richness and abundance of infauna and epifauna	Smith-MacIntyre, van Veen grab	All stations	0.1 m^2	Three grabs per sediment type for each probable footprint. Minimum five grabs if only one sediment type present
Operational monitoring				
S=, E_h,	Petit-Ponar, Ponar, Smith-MacIntyre, van Veen grab	All stations – perimeter of cage array, 30 m from 0 m station, perimeter of tenure and reference stations. Transect should be parallel to prevailing current	Any size	Three grabs at all stations. If mean S^{2-} value is above 1300 µM additional two grabs should be obtained from that station for S^{2-} and Eh.
TVS or TOC, Cu or Zn,	See as for S^{2-}	Only stations at perimeter of cage array and reference station	Any size	Three grabs at each station located at perimeter of cage array and at each reference station
SGS	See as for S^{2-}	Only stations at perimeter of cage array and reference station	Any size	One grab at each station located at perimeter of cage array and at each reference station
Family richness and abundance of infauna and epifauna	Smith-MacIntyre, van Veen grab	All stations	0.1 m^2	five grabs at each station. Three at each reference station

* Reference stations for Baseline Monitoring – should be 0.5 - 2.0 km from facility and must be 0.5 km apart. The mean depth at the reference station should be within 20 percent of the mean depth of the tenure. Characteristic and influences at the reference stations should be similar to that of the tenure

BC

Operators in BC are required to carry out routine monitoring at all sampling stations within 30 days of peak finfish biomass for each production cycle.

In cases where the cage array has been relocated within the production cycle, the vacated site must be monitored within 30 days of the relocation.

If free sulphide concentration is found to exceed specified levels the operator must repeat sulphide monitoring and undertake sediment biological sampling.

Chile

TABLE 6

Methodologies to be applied to Preliminary Site Descriptions and Environmental Information in Chile, as directed by Resolution 404/2003

Determinand		Sampling equipment		Sampling Stations	Replicas/ timings	Notes
Current		Acoustic Doppler current profiler		To be measured 1 m from the seafloor in the middle of the farm site.	Readings every 5 mins for at least 4 days	
				Water column divided into ten layers, speed and current to be measured in each	Readings every 5 mins for an entire tidal cycle (at least)	
Bathymetry	Cat 1 & 2	Lead line		Depth to be measured at each vertex of a 25 m x 25 m grid over the site		Bathymetric profile to be drawn with 10 m isobaths. To be presented along with a site plan.
	Cat 3,4 & 5	Continuous echo sounder		Entire area of site should be measured		
Visual registry	PSD	Diver operated digital recording, or be ROV		Two transects, running from furthest vertexes of site and passing through mid point	Minimum of ten minute recording for each transect	VHS format. Should describe sediment, presence of micro-organisms, presence of gas bubbles
	EI			Visual register of sedimentation area. 2, 100 m perpendicular transects. Should be under cage array with maximum biomass.		
Sediment granulometry		Sediment samples obtained using a grab with 0.1 m² bite	130 g, top 3 cm	**PSD**. The licensed operating area should be divided into quadrants of 1 hectare (100 m x 100 m). Each vertex is deemed to be a sampling station **EI**. At least three stations within area of sedimentation, with maximum biomass levels should be sampled. In addition to this two reference stations should be sampled.	No replicates required for **PSD** Resolution 404/2003 states 3 replicas at each sampling and reference station for the EI	Detailed methodology provided in resolution 404/2003
Organic matter content			100 g, top 3 cm			
Benthic macrofauna			1.0 mm sieve			ID to family or species level. Each species or family to be weighed.
Redox and pH		From grab or corer	Top 3 cm			pH probe temperature compensated
Dissolved oxygen	PSD	In situ, ex situ (from water sampler)		Centre of site — To be determined every 5 m, from 10 m to 1 m above seafloor	To be carried out once for **PSD**, then every two months during production.	Concentration and saturation to be determined
	EI			Beneath two cages		

PSD – Preliminary Site Description, EI – annual Environmental Information

Ireland

TABLE 7
Irish environmental monitoring methodology

Area of Impact		Sampling Location	Determinand	Methods employed	EQS	Frequency
Sea Lice*		Presence of ovigerous sea lice on farmed fish in cages	Number of lice per fish	Visual quantitative count. 30 fish sampled form 2 cages, one selected at random, one inspected each time	2 ovigerous lice per fish, (June-February). 0.3-0.5 ovigerous lice per fish (March-May)	14 times a year. Fortnightly during March, April and May.
		Presence of mobile lice in cage	Number of mobile lice in cage	Visual quantitative count.	When numbers are high even if there are no ovigerous females present.	
Water Column		Sampling stations along a transect agreed by the Marine Institute in accordance with Single Bay Management and CLAMS plans. All stations are logged using Differential Geographic Positioning System with an accuracy of +/-0.5m	Temperature Ammonia Nitrite mg/l Nitrate Phosphate Salinity	Samples are collected from water directly beside the cages at the surface, mid-depth and 1m above the sea bed.		Monthly during December to March each year. Report submitted to DCMNR by 30 April each year
Benthic	Level 1	Numerous stations directly under the cages, at the edge of the cages, along two transects at right angles to each other at +/-10m, +/-20m, +/-50m and +/-100m and a control site at least 500m distant from the cages.	Presence of bacterial mats, feed pellets, litter, gas bubbles, anoxic areas, fauna, macro-algae, sediment colour and texture	Video and/or underwater photography. Observational survey by divers.	Yes	Annually, during peak biomass or within 30 days after end of harvesting a year class. Report submitted to the DCMNR by end November each year.
	Level 2		Level 1+ redox	In addition to the above a minimum of 3 redox measurements are taken at each station using a platinum electrode.	Yes	
	Level 3		Level 2 + macro-fauna	Biological samples taken by grab or core, sieved through 1mm sieve. Specimens identified to species level, number of species and abundance recorded.	Yes	

* www.marine.ie/NR/rdonlyres/0210E4CE-F4AA-47F2-8D51-EFEA10A4C4E8/0/MonitoringProtocol3.pdf

Ireland

TABLE 8
Level of benthic monitoring to be carried out at salmon farms in Ireland depending on mean current speed and annual production (McMahon, 2000)

Production (tonnes)	Mean current speed (cm s^{-1})		
	<0.1	<0.5	>10
0 - 499	Level 1	Level 1	Level 1
500 – 999	Level 2	Level 1	Level 1
>1 000	Level 3	Level 3	Level 2

UK

TABLE 20
Sea bed monitoring sample analysis, United Kingdom

Determinand	Methodology
Visual	Qualitative assessment. Colour: black brown, etc Consistency: sand, mud, etc Texture: soft, firm, etc. Presence of feed pellets and/or Beggiatoa
Redox	Two profiles are taken per sample at 1 cm intervals immediately on collection using a portable redox meter.
Organic Carbon	Samples are taken from 50ml of the top 2 cm of the sample. Procedure in Allen et al. (1974) is recommended for analysis.
Particle Size Analysis	Samples of 100 ml are taken from the top 20 cm and analysed by dry sieving or laser granulometry.
Benthic infauna	Grab samples are washed through a 1 mm sieve and preserved in buffered formalin. Fauna are identified to the lowest taxon possible and the data presented as a species abundance matrix e.g. Shannon-Weiner

UK

TABLE 21
Sediment quality criteria and action levels*, United Kingdom

Component	Determinand	Action Level within AZE		Action level outside AZE
Benthos	Number of Taxa	Less than 2 polychaete taxa present		Must be at least 50% of reference station value
Benthos	Number of Taxa	Two or more replicates with no taxa present		
Benthos	Abundance	Organic enrichment polychaetes present in abnormally low densities.		Organic enrichment polychaetes must not exceed 200% of reference station value.
Benthos	Shannon-Weiner Diversity	N/A		Must be at least 60% of reference station value.
Benthos	Infaunal Trophic Index	N/A		Must be at least 50% of reference station value.
Sea Bed	*Beggiatoa*	N/A		Mats present
Sea bed	Feed pellets	Accumulations of pellets		Pellets present
Sediment	Teflubenzuron	10.0 mg/kg dry wt/5 cm core applied as a average in the AZE.		2.0 µg/kg dry wt/5 cm core
Sediment	Copper	*Probable effects* 270 mg/kg dry sediment	*Possible effects* 108 mg/kg dry sediment	34 mg/kg dry sediment
Sediment	Zinc	*Probable effects* 410 mg/kg dry sediment	*Possible effects* 270 mg/kg dry sediment	150 mg/kg dry sediment
Sediment	Free sulphide	4800mg kg^{-1} (dry wt)		3200 mg kg^{-1} (dry wt)
Sediment	Organic carbon	9%		
Sediment	Redox potential	Values lower than -150 mV (as a depth profile average) or values lower than -125 mV (in surface sediments 0 – 3 cm).		
Sediment	Loss on ignition	27%		

* www.sepa.org.uk/pdf/guidance/fish_farm_manual/annex/A.pdf

Norway

TABLE 14
Norwegian environmental monitoring methodology

Zone	Determinand**		Methods employed	EQS		Frequency		Investigator
B Local and intermediate	Presence of macro infauna		Quantitative assessment of sediment for presence or absence of macro infauna after 1mm sieve.	Yes.** Presence=0 Absence=1 Mean sample score - ≤0.5 EC 1-3 >0.5 EC 4		The frequency of the complete B investigation:		
						DEX1	Every second year	
	pH and redox		Electrodes inserted directly into sediment immediately after sampling in grabs Measurements are taken at 1cm depth.	Yes*** Mean score ≤1=EC1, <1≤2=EC2 <2 ≤ 3=EC3, > 3=EC4		DEX2	Every year	
						DEX3	Twice a year Spring and Autumn)	
	Sensory Sediment variables. Due to the subjective nature of these variables their scores are combined and combined EQS applied	Colour	Subjective visual assessment of sediment samples	No. Light grey, brown=0 Dk brown, black=2	Combined scores giving EC. Mean score as for pH and redox			External consultant
		Odour and consistency	Subjective olfactory assessment of sediment samples	No No smell=0 Slight smell=2 Strong smell=4				
		Gas ebullition	Quantitative assessment of sediment for presence or absence of gas bubbles	No Absent=0 Present=4				
		Sludge layer thickness	Top layer of overlying sludge measured through transparent core.	No 0-2cm=0, 2-4cm=1 4=6cm=2 6-8cm=3 >8cm=4				
C Intermediate and regional	Quantitative and qualitative assessment of benthic fauna		According to NS9423, NS9410 and the Norwegian Pollution Control Authority	Yes. EQS are set according to NS9410 and by the Norwegian Pollution Control Authority.		At the discretion of the local authority.		Expert consultant
	Organic content of sediment							
	Particle size of sediment							
	Sensory sediment variables as in B investigation							
	Oxygen content of the water column							

* DEX = Degree of Exploitation, **Environmental Condition where EC 1-3 = acceptable conditions, EC4= unacceptable conditions. *** Based on a scoring system detailed in Hansen *et al.* (2001)
** In this report determinand is defined as a constituent or property of the environment which is determined through measurement or analysis

Washington State

TABLE 23
Details of sampling protocol for environmental assessment of salmon aquaculture in Washington State, the United States of America. (SAIC guidelines, Weston 1986)

	Aim	Location and timing of sampling	Number of samples and replicates, where applicable	Analysis/ Notes
Bathymetric Surveys SCS*	*To characterise the bathymetry of the proposed site (area within 300 ft of the cage perimeter)*			
Hydrographic Surveys SCS and AM*	Current velocity and direction **AM**	Centre of cages – near surface (6 feet) and mid-depth	Measurements over 1 complete tidal cycle. Minimum of ten evenly spaced measurements at each depth. Mean current speed is determined as arithmetic average of the ten measurements	Not during spring or neap tides. During the report weather conditions should be noted. During **AM** single current measurement 20 ft down current of the cages
	Drogue tracking – *to estimate the potential fate of particulate material and the potential for eddy circulation*	2 drogues to be released from centre of site. One is set at 6 feet, one at mid-depth	Drogue trajectory should be followed for a minimum of 8 hrs	
	Vertical hydrographic profile – *to evaluate intensity of water stratification*	Centre of proposed site. Measurements should be made at 1, 10, 20, 30 and then 30 ft intervals to a maximum depth of 3 ft above sea floor		Where possible any existing information on the site should be provided
Diver/Visual Surveys SCS and AM	Applies to sites where the depth is under the cages or within 300 ft of the site is less than 75 ft. *To determine the presence of habitats of special significance (HAS).* *To estimate the extent of solid accumulation (AM only)*	**Site Characterisation Survey**		
		Exact location and number of transects should be established on consultation with State officials.	Where most of the area is less than 75 feet, 3-5 transects of 200 ft long	Surveys should establish details on substrate type, presence of Beggiatoa mats and presence/density of any HAS
		Annual Monitoring		
		4 transects, at least 200 ft long, starting from the centre of each side of the cage array.		Depth and extent of solid accumulation at 20 ft intervals along the transect. Presence and density of Beggiatoa mats and any HAS
Benthic Infauna BS* and AM		Stations should be established on a transect down current of the cages. Stations set at cage perimeter and at distances of 20, 50, 100 and 200 ft	Diver cores with area at least 0.01 m^2, or grab/box corer with area of at least 0.1 m^2. Samples should be sieved at 1.0 mm	All organisms should be identified to lowest taxonomic level, species where possible
Sediment Chemistry BS and AM		See location for benthic infauna	3 replicate diver cores, or 3 replicate grab samples	Analysis –TOC, T Kjeldahl N, particle size distribution. Eh discontinuity. Cores to 2 in.
Water Quality AM	*In order to document the effect of culture activity on dissolved oxygen and nutrient on the water column*	Should be conducted in July-September annually, within the hour of slack tide. 3 stations – 100 ft up current of cages, 20 ft and 100ft down current of cages	3 replicates at each station, at a depth midway between surface and bottom of cage nets	Analysis – dissolved oxygen, temperature, salinity, pH, ammonia, nitrite/nitrate, concentration of unionised ammonia. Loading estimates for ammonia and nitrite/ nitrate

* SCS – Site Characterisation Survey, BS – Baseline monitoring, AM – Annual Monitoring.

Maine

TABLE 25

Near-field, far-field and reference station water quality monitoring requirements, sediment and benthic monitoring and video survey requirements for the State of Maine finfish cage annual monitoring, Maine United States of America

Determinand	Location/Timing	Monitoring Level I	Monitoring Level II	Methods/Notes
Sediment and benthic monitoring – to be carried out at same time as video monitoring, along the same transect as described for video monitoring				
Redox potential (mV)	(i) Minimum of four stations along the transect – two on either side of the cage array (ii) One location 30 m away on either side of the cages, one location within the mixing zone (iii) At each location a minimum of three samples taken perpendicular to transect spaced at distances reflecting and within the lateral extent of greatest benthic impact (iv) If grab samples used for sediment analysis sub-samples, no more than ¼ should be removed	Apr-May and Aug-Oct		Cores of top 3 cm
Sulfide (uM)				
Anoxic sediment, gas formation and Beggiatoa				
Azoic conditions (per 0.1 square m)		1/5yrs in Aug/Oct as minimum		May also be required if warning levels are exceeded. . Single cores 4 inches or greater in diameter and inserted to resistance or 15 cm. Depth of core shall be reported. Samples sieved through 1.0 mm sieve. Taxa measurements to include presence, absolute and relative abundance and Shannon-Weiner Diversity Index
Infauna (per 0.1 square m)				
Sediment grain size (%)		When taxa measured		
TOC (mg/g)				
Copper – total metal (mg/kg dry wgt)		1/2yrs		Cores must be of top 2 cm. Should be measured when fish biomass is at maximum
Zinc – total metal (mg/kg dry wgt)				
Medications used (µg/kg dry wgt)		Within 1mth of use		Tests should include analysis for primary metabolites

Comparison

State	Sulphide	Benthos	Neither
New Brunswick	X		
BC	X	X	
Chile		X	
Ireland		X	
UK		X	
Norway			X
Washington		X	
Maine	X	X	
NZ	X	X	

Ministry for Primary Industries
Manatū Ahu Matua

Marine Farm Monitoring

Rich Ford

12 December 2013

Growing and Protecting New Zealand

www.mpi.govt.nz

What the presentation will cover

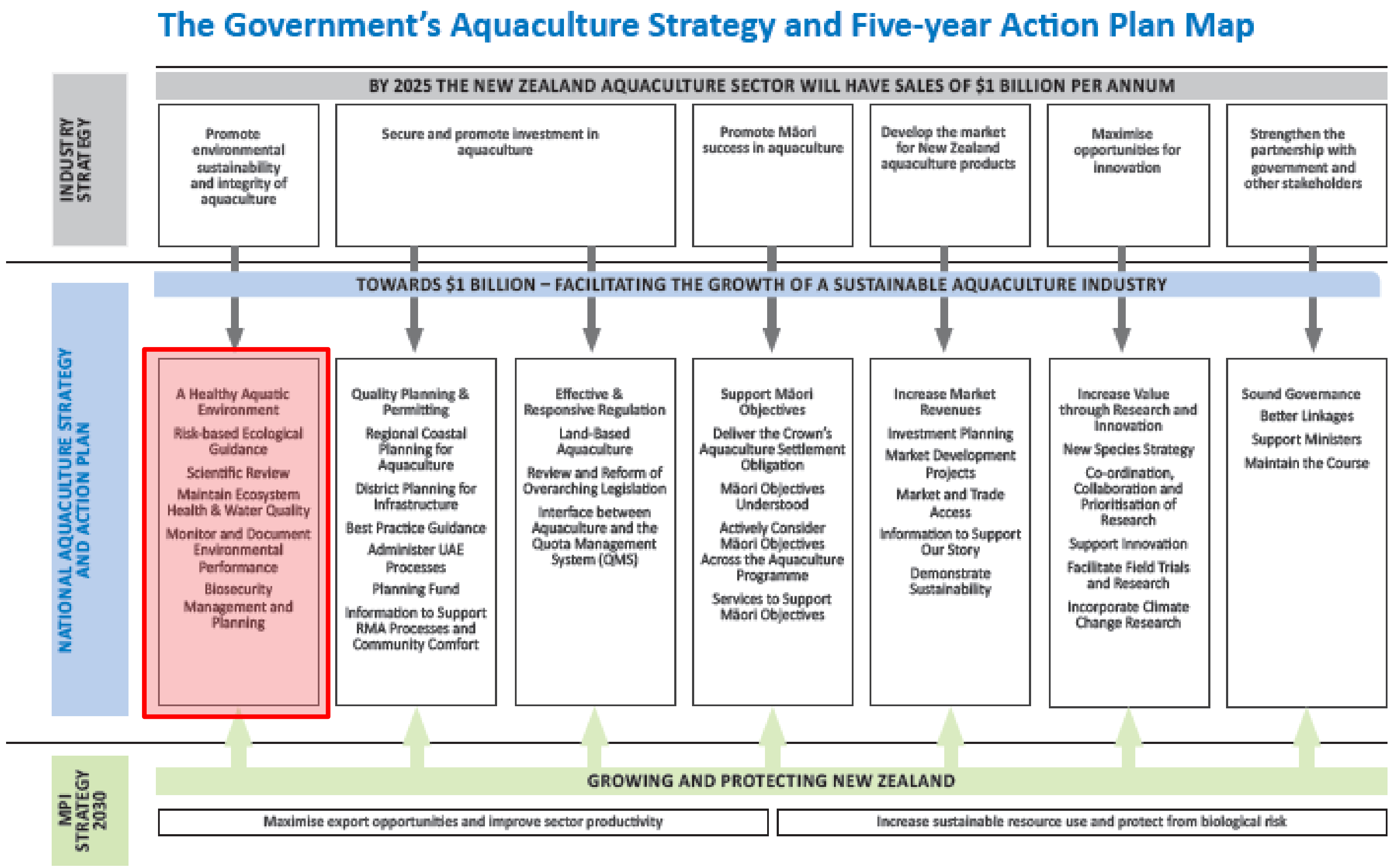
1. Big Picture: Govt’s aquaculture strategy

   + Other Govt work on monitoring

2. Work underway on aquaculture monitoring
3. Ecological Guidance Package to support monitoring
4. Our next steps

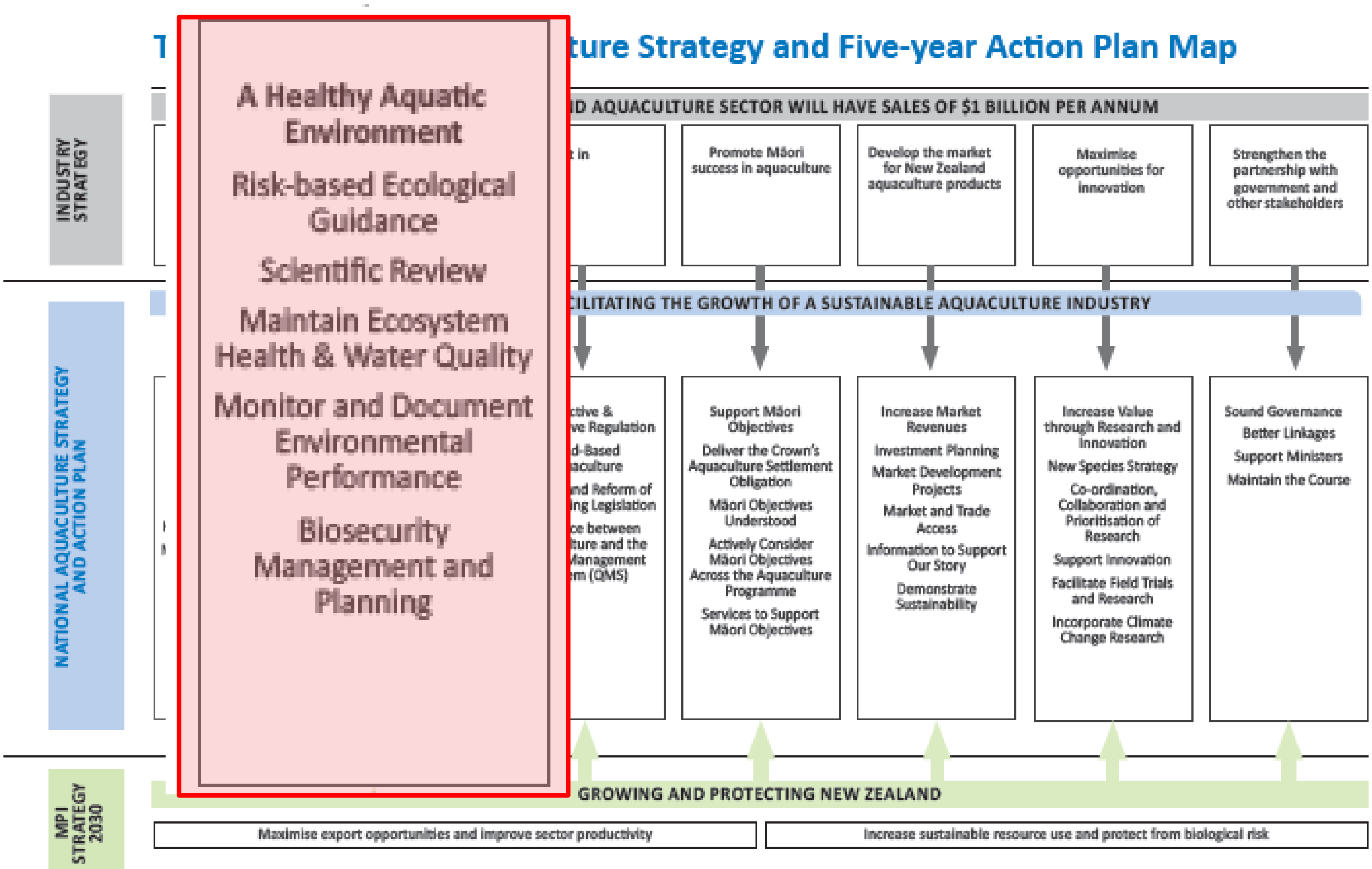


Big Picture: Support for Aquaculture



www.aquaculture.govt.nz

A Healthy Aquatic Environment



www.aquaculture.govt.nz

Big Picture: Other Govt work on monitoring

1. Environment Domain Plan
    - Produced in 2013 by Statistics NZ with MfE and DoC
    - Looks at what statistical information is available and whether this information answers the big questions about the state of our environment
2. Marine Environment Monitoring Programme MEMP
    - Collaborative project initiated by MPI in 2010
    - Aim is to design a national MEMP to track long term changes in marine environment
        - Online inventory (meta-database) of existing datasets (136!)
        - Review, identify gaps → design national MEMP
    - Draft report complete and under review in MPI

Big Picture: Other Govt work on monitoring

3. National Environmental Standards, etc.
4. MFE's indicators programme
   - Aim to improve environmental reporting
   - Environmental Reporting Bill currently being drafted
   - Five domains: air, climate and atmosphere, land, freshwater, marine and including biodiversity and ecosystems across all domains
   - Next step for marine domain: work with central government, CRIs and local authorities on indicator selection (early 2014)
5. Regional Council SOE monitoring
   - Monitoring is required under RMA (SOE and consent)
   - Rich source of publicly available marine monitoring information.

- **Coordination between these streams is important**

Work underway on aquaculture monitoring

- 3 relevant projects currently underway
- Funded by Aquaculture Planning Fund (MPI)
  1) Marine Management Model (Waikato)
  2) Marlb. Sounds hydrodynamic and ecological modelling
  3) Aquaculture monitoring guidance (Waikato)

- Good timing to start this discussion
- Work towards consistent approaches to monitoring & reporting environmental performance

Aquaculture Ecological Guidance – Background

- Why is it needed?
  - There is **uncertainty** in terms of ecological effects
  - **Misinformation**
  - There is **variability** in terms of the amount of science provided or requested with each consent.
  - **No consensus on the science, or national guidance on how apply it.**

- Aquaculture planning needs to be underpinned by science-based information on ecological effects

Aim of Ecological Guidance Package

To develop risk-based ecological impact assessment guidance to support nationally consistent RMA aquaculture decisions

- To provide credible, up-to-date scientific information on the ecological effects of marine-based aquaculture, and
- To identify risks, uncertainty, management and mitigation
- A broad audience of potential users
  - Regional Councils
  - Applicants
  - Public
  - Science Providers

What is the Ecological Guidance Package?

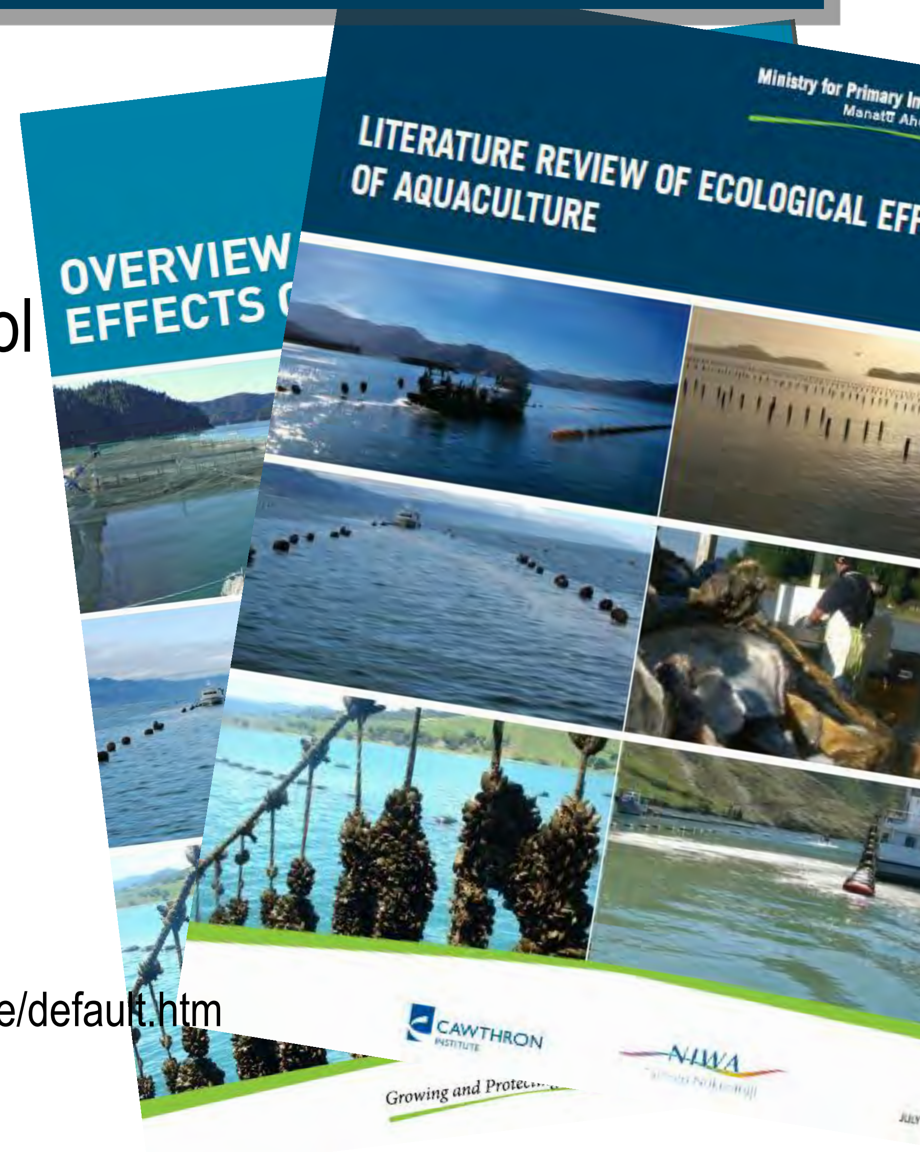
1: Literature Review

2: Overview of Ecological Effects

3: Aquaculture Risk Screening Tool

4: Decision-makers' Dashboard

- 1 & 2 available now
- 3 & 4 in development
- Web-based to enable updates



http://www.fish.govt.nz/en-nz/Commercial/Aquaculture/default.htm

1. Literature Review - Scope

- To compile and summarise the known and potential effects of marine-based aquaculture in NZ.
- Scope presently limited to salmon, hapuku, kingfish, mussels, oysters, *Undaria* and sea cucumbers.
- A document collaboratively authored by MPI, NIWA and Cawthron utilising 16 different authors or reviewers.

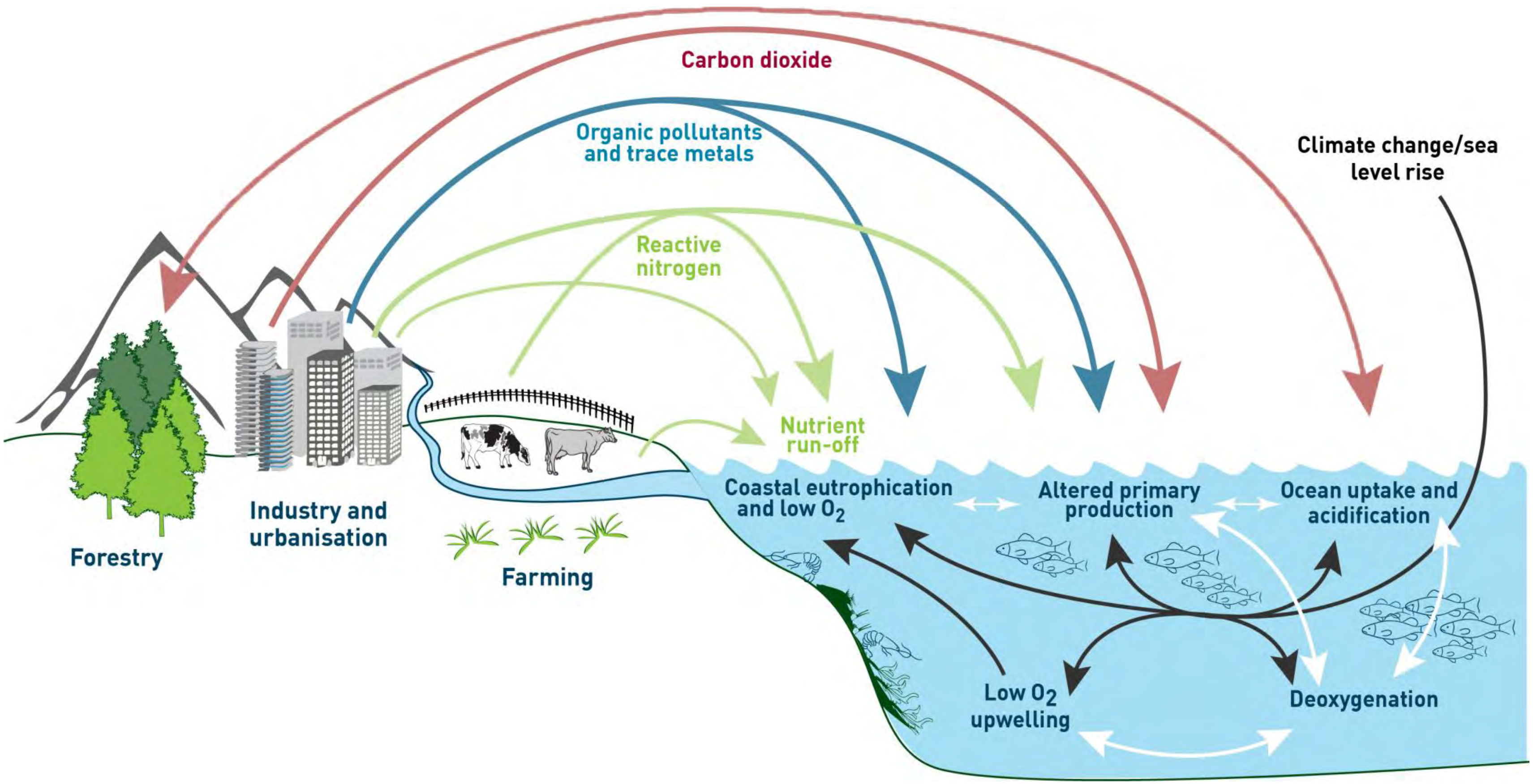



1. Literature Review - Chapters

- Introduction
- Water column
- Seabed
- Marine mammals
- Wildfish
- Seabirds
- Biosecurity
- Escapees
- Genetic modification
- Additives
- Hydrodynamics
- Cumulative Effects

- Finfish, shellfish and lower trophic species covered
- Management and mitigation
- knowledge gaps

1. Cumulative effects
- Aquaculture risks don't occur in isolation

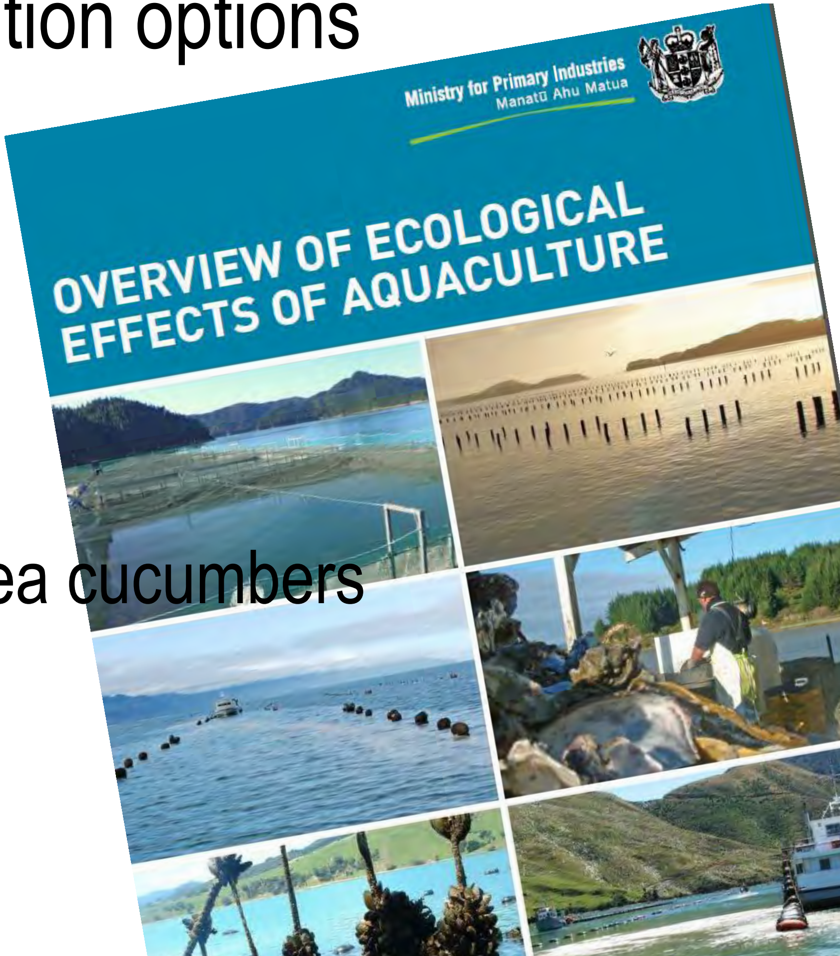


2. Overview of Ecological Effects

A summary of key messages & significance of effects with management and mitigation options

Chapters:

- Introduction
- Effects of finfish aquaculture
- Effects of shellfish aquaculture
- Effects of farming *Undaria* and sea cucumbers
- Cumulative effects
- Monitoring



3. Aquaculture Risk Screening Tool

- An initial screening tool to flag the potential ecological risks of an aquaculture proposal
- Based on site-specific information
- Interactive survey format
- Evolved from Risk Assessment Workshop in February 2012
- A draft tool to be refined with stakeholder input

3. Aquaculture Risk Screening Tool

Attributes and Criteria are the basis of the Tool:

Example: Attributes and Criteria for the seabed effects of mussel farming

Attribute	**Potential extent of adverse effect**				
	Insignificant (1)	**Minor (2)**	**Moderate (3)**	**Major (4)**	**Unacceptable (5)**
Site depth (m)	n/a	>35m	20-35m	<20m	n/a
Site current speed ($cm.s^{-1}$)	n/a	>15 $cm.s^{-1}$	8.5 to 15 $cm.s^{-1}$	less than 8.5 $cm.s^{-1}$	n/a
Stocking density of the farm	n/a	<1000 spat or <150 juveniles per m of rope	1000-5000 spat or 150-200 juveniles per m of rope	>5000 spat or >200 juveniles per m of rope	n/a

3. Aquaculture Risk Screening Tool - example

Seabed Effects

Attribute	Criteria Score	Mitigation and management options	Notes
1. Site depth	Less than 20 metres	**For mussel farming:** Careful site selection - avoid enrichment-sensitive biota and habitats, is there a deeper site available? Altering feed capacities, optimising feed management and matching farm placement and design to site, monitoring and adaptive management. Refer MPI (2013) Chapter 3 Benthic Effects.	$(Notes)
2. Current Speed	Between 8.5 and 15 cm.s-1	**Careful site selection** - avoid enrichment-sensitive biota and habitats, is there a well flushed site available? Altering feed capacities, optimising feed management and matching farm placement and design to site, monitoring and adaptive management. Refer MPI (2013) Chapter 3 Benthic Effects.	$(Notes)
3. Farming Intensity	Greater than 5000 spat or 200 juveniles per m of rope	Reducing stocking densities, best management practices to minimise drop-off, monitoring effects of enrichment, biodeposits and drop-off of shell debris/biofouling. Refer MPI (2013) Chapter 3 Benthic Effects.	$(Notes)

For each category of potential ecological effect, attributes are presented that describe characteristics or environmental factors that influence the level of ecological effect.

Users of the tool identify where the proposed farm scores for each attribute, which is assigned a score based on its scale of effect.

Management and mitigation options are provided for each attribute, linked to the scale of effect. Other information is also provided where relevant.

4. Decision-makers' Dashboard

- To help prioritise potential effects that are more likely to be higher risk
- Use in conjunction with the Aquaculture Risk Screening Tool for a specific proposal

4. Decision-makers' Dashboard

Key to table

Symbol	
	Effect potentially of high relative significance
	Effect potentially of medium relative significance
	Effect potentially of low relative significance
	Specific information about finfish (salmon, kingfish, hāpuku)
	Specific information about shellfish (oysters and mussels)
	Specific information about seaweeds and sea cucumbers
	Key knowledge gaps

•Indicates where higher risks may potentially fall

Cumulative effects
Biosecurity risks
Water column effects (finfish)

= Larger spatial scale, cumulative, or potentially irreversible consequences

- Assumes appropriate site selection
- Based on Relative Importance Weighting exercise by expert panel

Repeated themes of the Ecological Guidance Package

- Many ecological effects minor, well managed and of low ecological consequence
- **Careful site selection** is crucial
- Potential effects with large spatial scale, cumulative or irreversible → generally higher risk
- **Best management practices** to deal with factors like biosecurity risks, minimising entanglements, escapees
- Uncertainty in some cases best managed by setting precautionary limits and **adaptively managing**
- Ecosystem-wide management focus

Closing questions and next steps

- What are the priorities?
- Key issues?
- What is the best way forward?

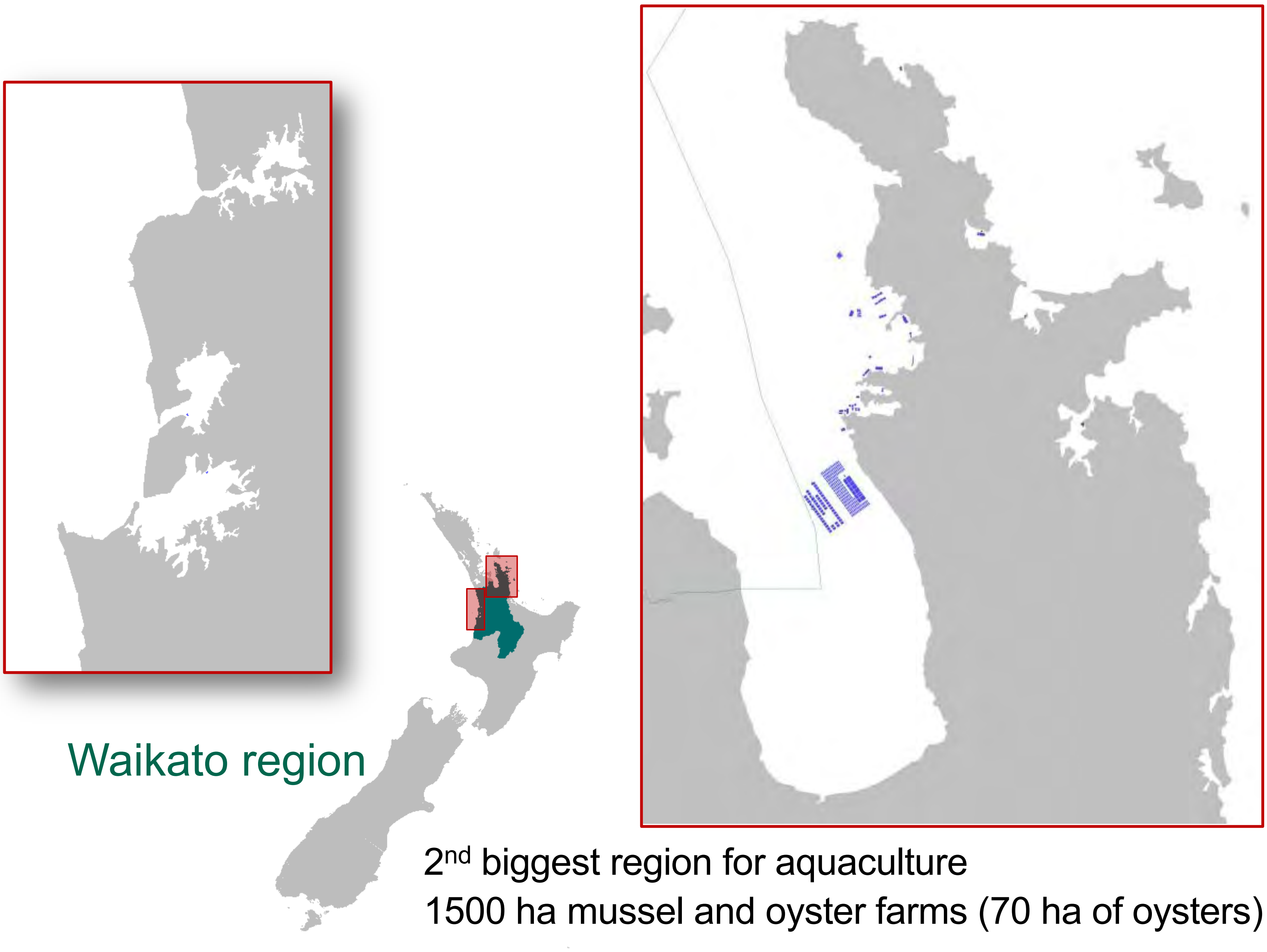
- Aquaculture monitoring is an MPI priority for 2014 (part of social licence and building on ecological guidance package)
- A technical working group to develop indicators of aquatic health and monitoring approaches planned for 2014

Monitoring ecological effects of marine farms in the Waikato region

Hilke Giles

Barrie Forrest, Chris Cornelisen, Nigel Keeley (Cawthron Institute)

Brett Beamsley (MetOcean Solutions Ltd)

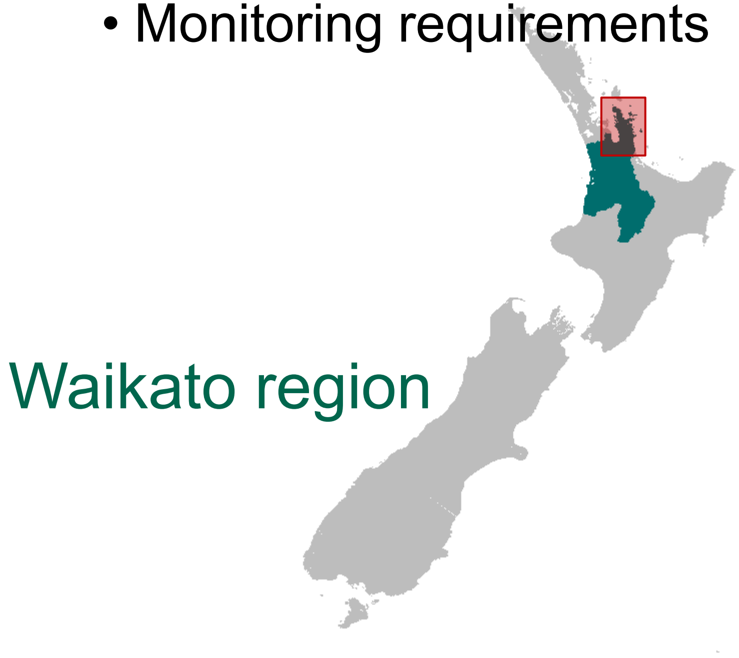


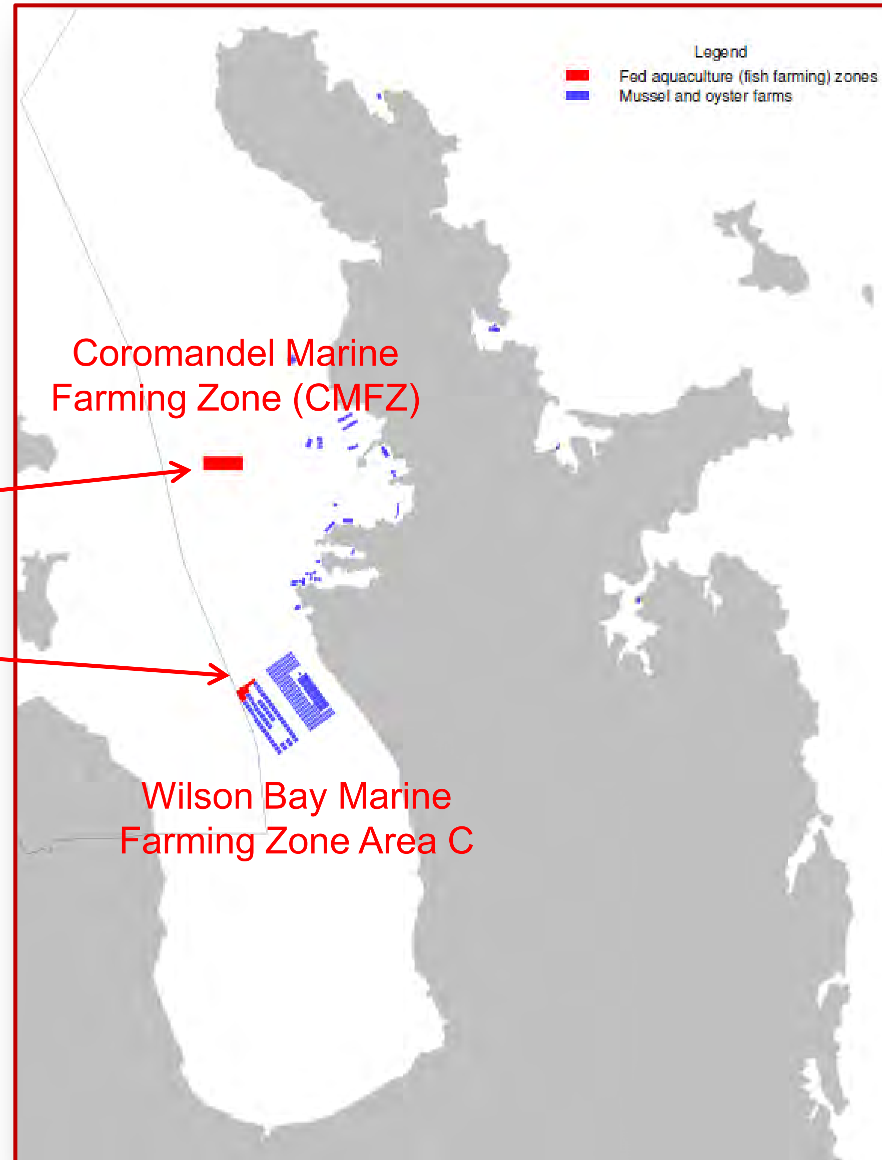
Waikato region

2nd biggest region for aquaculture
1500 ha mussel and oyster farms (70 ha of oysters)

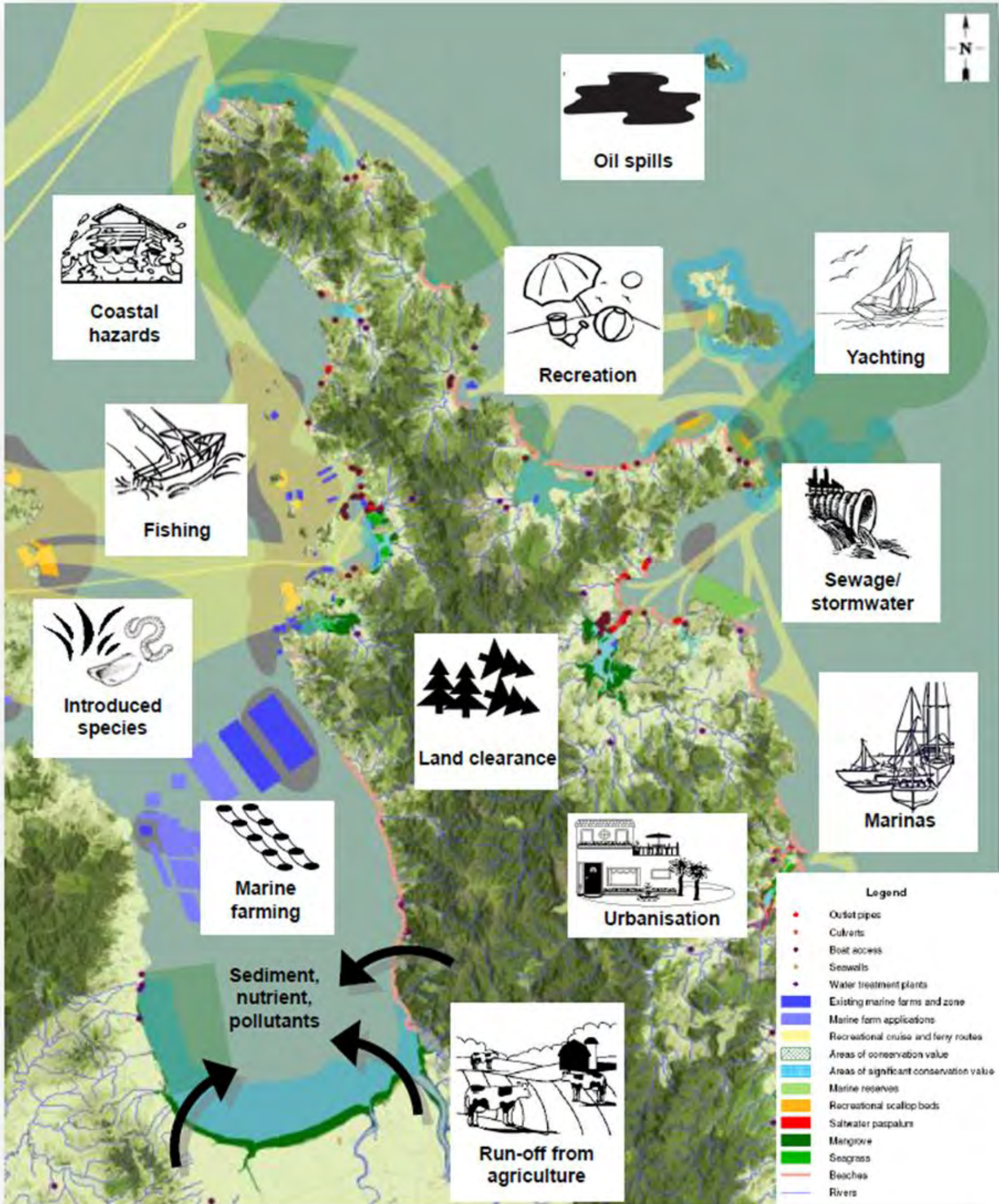
2011 Aquaculture Law Reforms

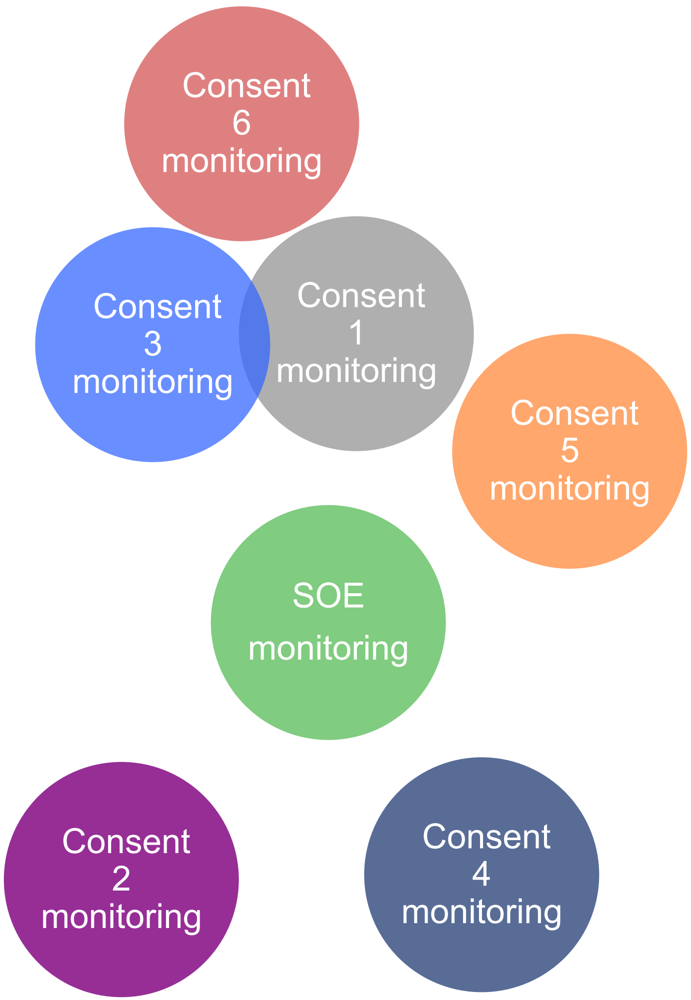
- Changes to WRC Coastal Plan
- Allows species diversification
- 2 fish farming zones
- Restrictions in Plan:
  - >20 m water depth
  - Nitrogen discharge limits:
    - 800 t/y CMFZ (+ feed discharge)
    - 300 t/y Wilson Bay
  - Monitoring requirements



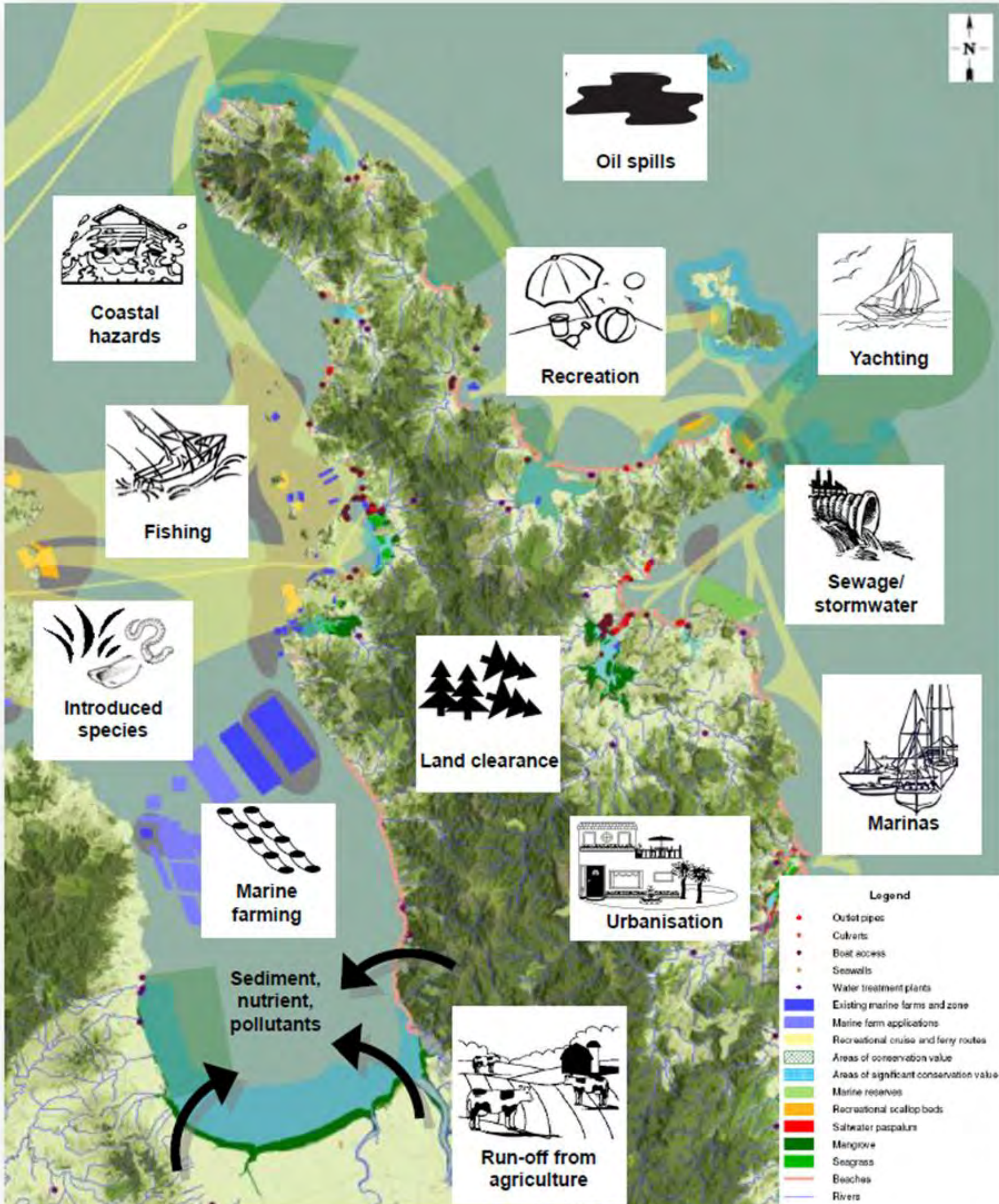


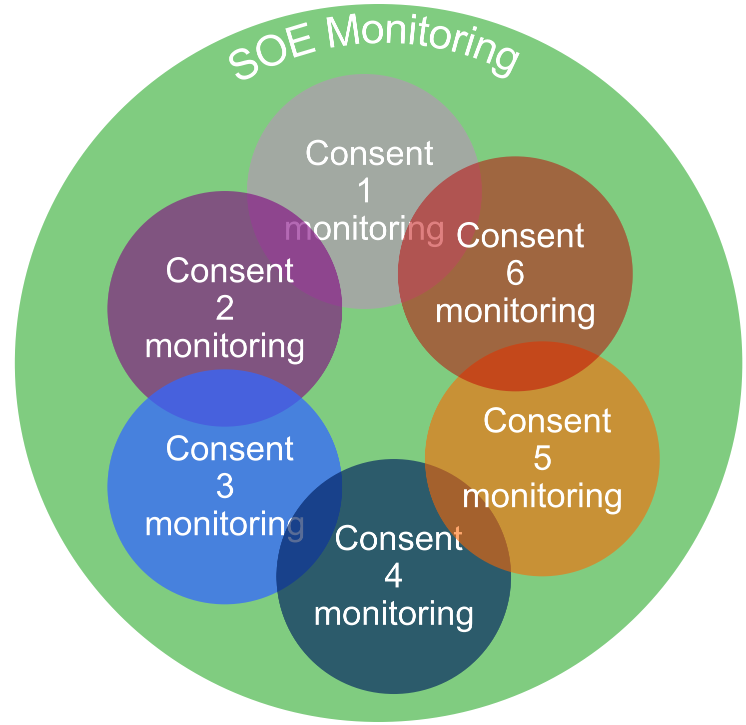
Monitoring now





Monitoring in the future





Project: Framework for regional environmental monitoring

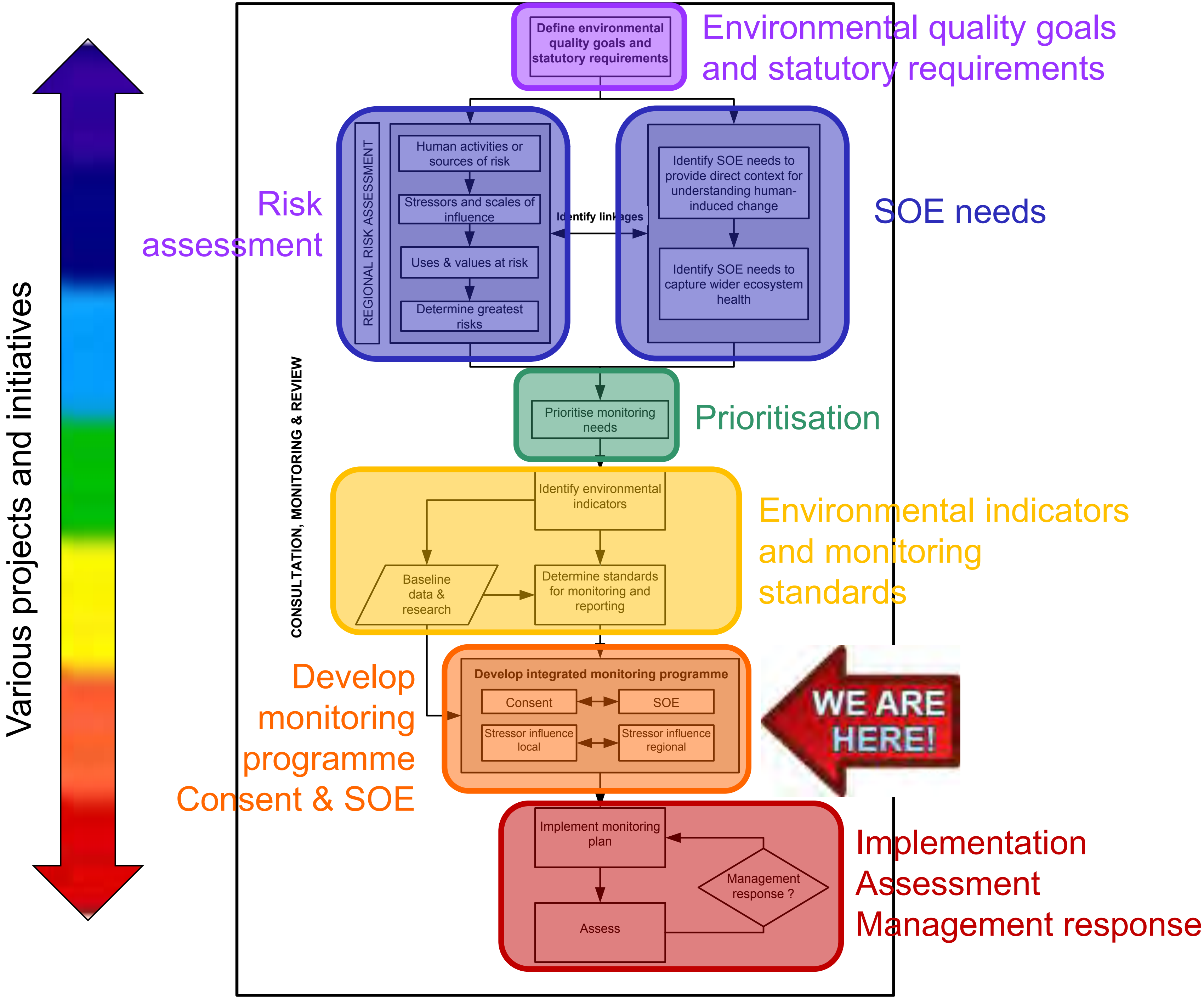
Case study 1: Aquaculture

Project: Framework for regional environmental monitoring

- Acknowledge current approach to SOE and consent monitoring needs improvements
- New framework principles
  - Integration of SOE and consent monitoring
  - Fit-for-purpose
  - Consistency
  - Cost-effectiveness
  - Cooperation / alignment of interests
  - Transparency / certainty
- Cumulative effects

Project: Framework for regional environmental monitoring (contd.)

- Case study 1: Aquaculture
- Objectives
  - Manage environmental change associated with fish farming and increase in shellfish farming
  - Integrate SOE and consent monitoring
  - Provide industry with clear guidance on monitoring and reporting requirements


Various projects and initiatives
Environmental quality goals and statutory requirements
Define environmental quality goals and statutory requirements
Risk assessment
REGIONAL RISK ASSESSMENT
Human activities or sources of risk
Stressors and scales of influence
Uses & values at risk
Determine greatest risks
Identify linkages
Identify SOE needs to provide direct context for understanding human-induced change
Identify SOE needs to capture wider ecosystem health
SOE needs
CONSULTATION, MONITORING & REVIEW
Prioritise monitoring needs
Prioritisation
Identify environmental indicators
Baseline data & research
Determine standards for monitoring and reporting
Environmental indicators and monitoring standards
Develop monitoring programme Consent & SOE
Develop integrated monitoring programme
Consent
SOE
Stressor influence local
Stressor influence regional
WE ARE HERE!
Implement monitoring plan
Management response ?
Assess
Implementation Assessment Management response

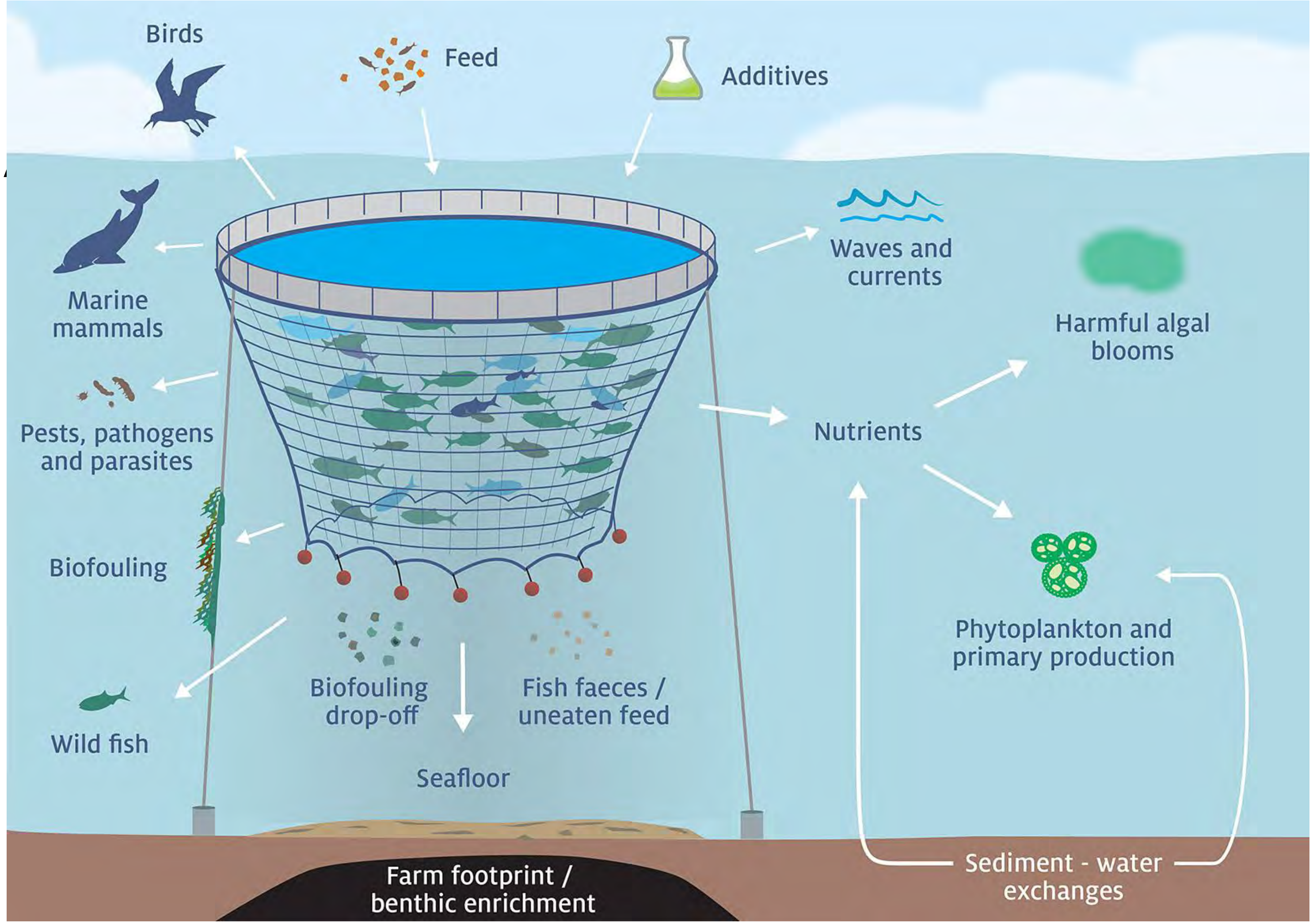
Approach for consent monitoring

1. Identify key ecological issues (finfish, mussel, oyster)

2.

3.

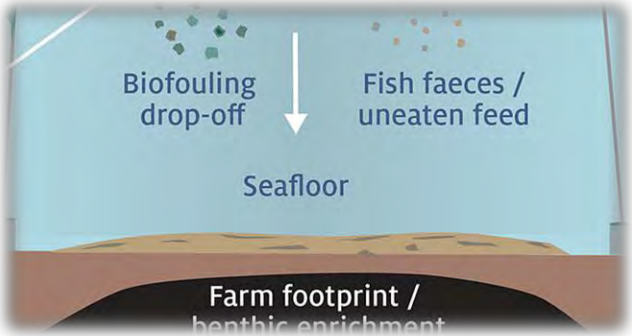
4.



Approach for consent monitoring

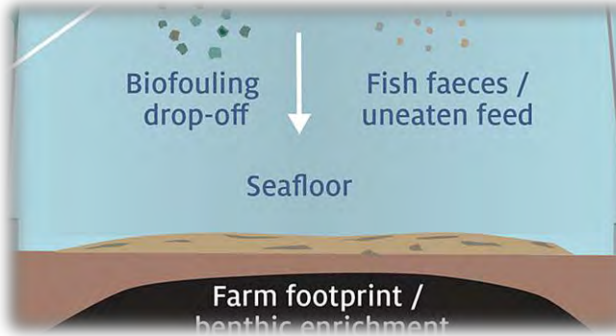
1. Identify key ecological issues (finfish, mussel, oyster)
2. Risk assessment
3. Appropriate approach for each issue
   - Site selection
   - Mitigation
     - Irrespective of known/perceived risks
     - Best Management Practices
   - Record keeping and reporting
   - Monitoring
     - If possible environmental standards and adaptive management
4. Identify SOE needs/gaps
   - Contextual information
   - Reference data
   - Cumulative effects

Example: Benthic effects



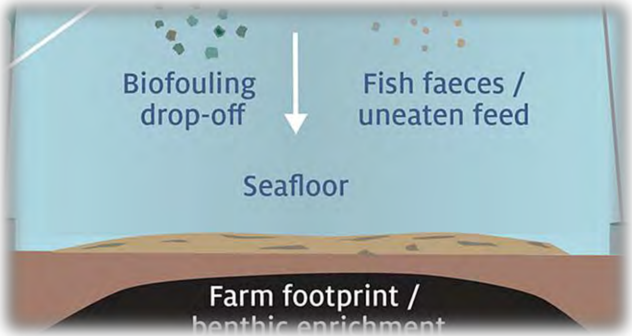
- Well understood
- Type of effect similar for different types of aquaculture
- Proposed approach
  - Site selection
  - Best Management Practices
  - Record keeping and reporting (e.g. stocking densities, feeding rates)
  - Monitoring using benthic enrichment indicator
  - Support monitoring with modelling
  - Identify SOE needs

Example: Benthic effects



- Project tasks
  - Assess suitability of benthic enrichment indicator for Waikato region
  - Baseline indicator values
  - Acceptable maximum indicator levels
  - Same approach/standards for different species?
  - Trigger levels? Adaptive management?
  - Learn from NZKS experience
  - Collate Best Management Practices (industry COPs)
  - Involve council planning and consenting staff
  - Use of models to support monitoring

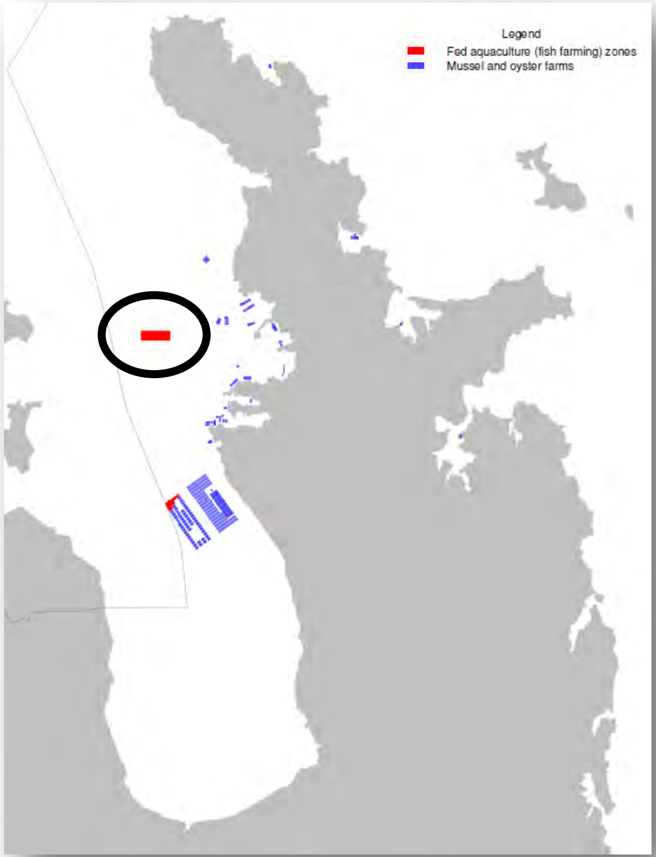
Example: Benthic effects

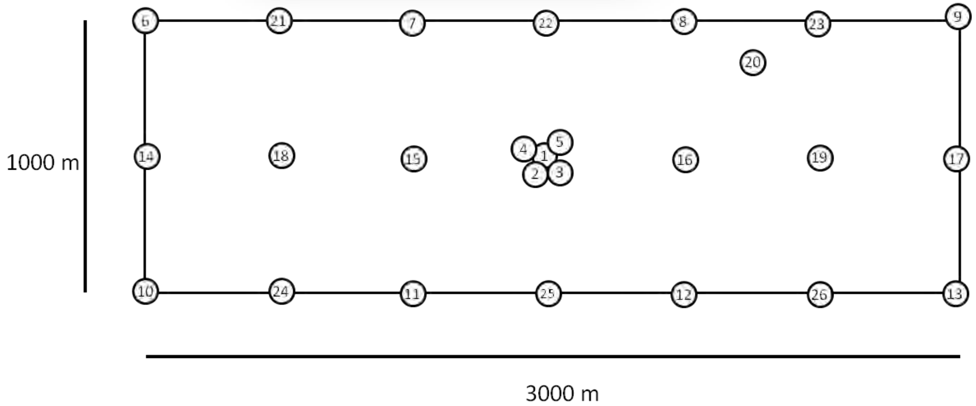


- Project tasks
  - Assess suitability of benthic enrichment indicator for Waikato region
  - Baseline indicator values
  - Acceptable maximum indicator levels
  - Same approach/standards for different species?
  - Trigger levels? Adaptive management?
  - Learn from NZKS experience
  - Collate Best Management Practices (industry COPs)
  - Involve council planning and consenting staff
  - Use of models to support monitoring

Example: Benthic effects (contd.)

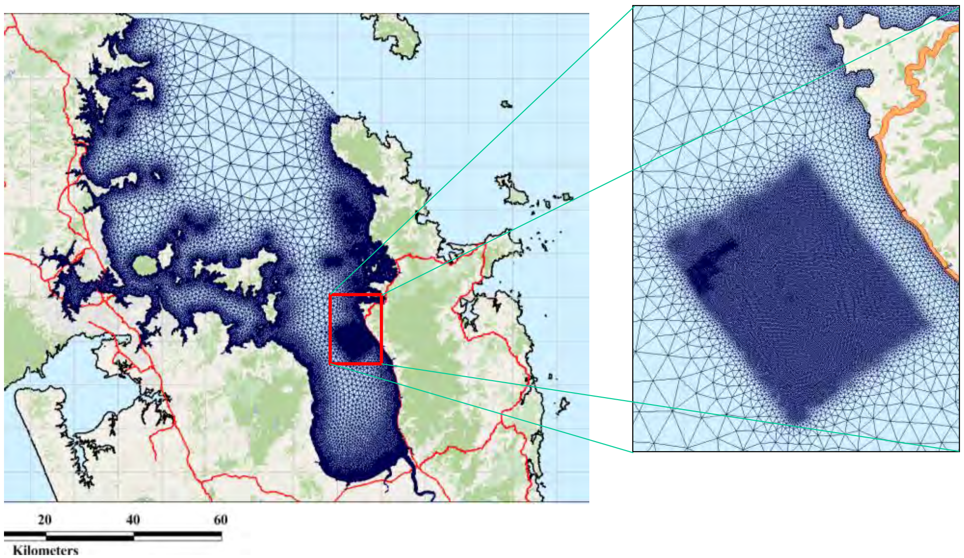
- Project task Baseline indicator values





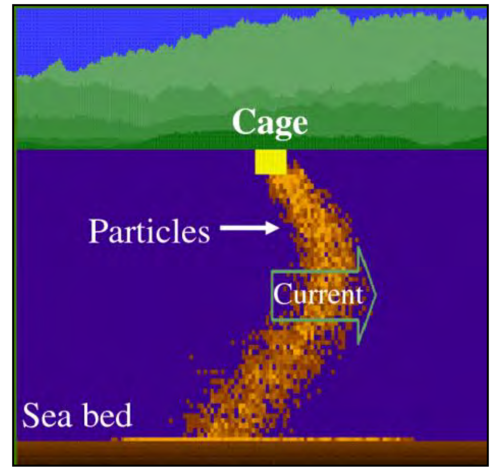
Example: Benthic effects (contd.)

- Project task Use of models to support monitoring



Hydrodynamic model

+



Farm footprint model

+ more

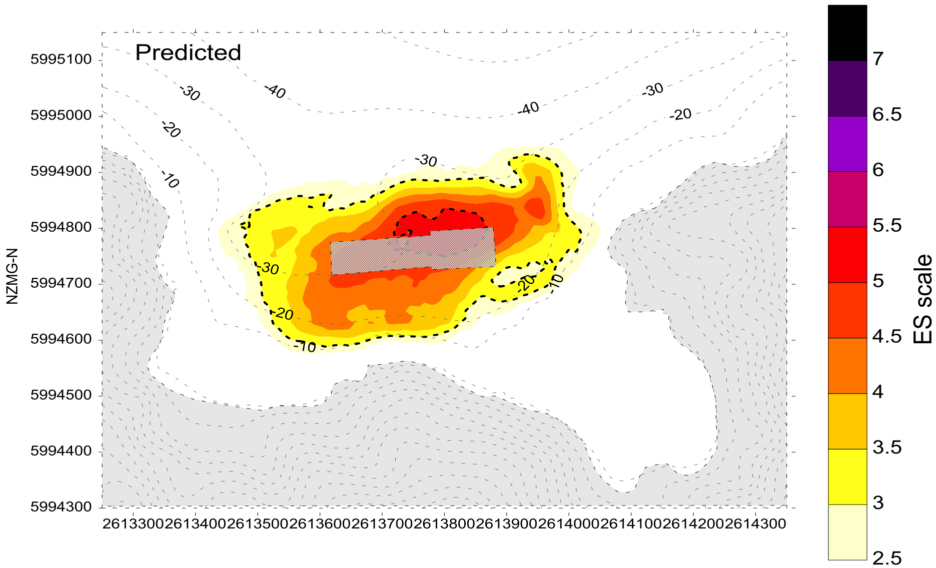
= Waikato Regional Council
Marine Management Model

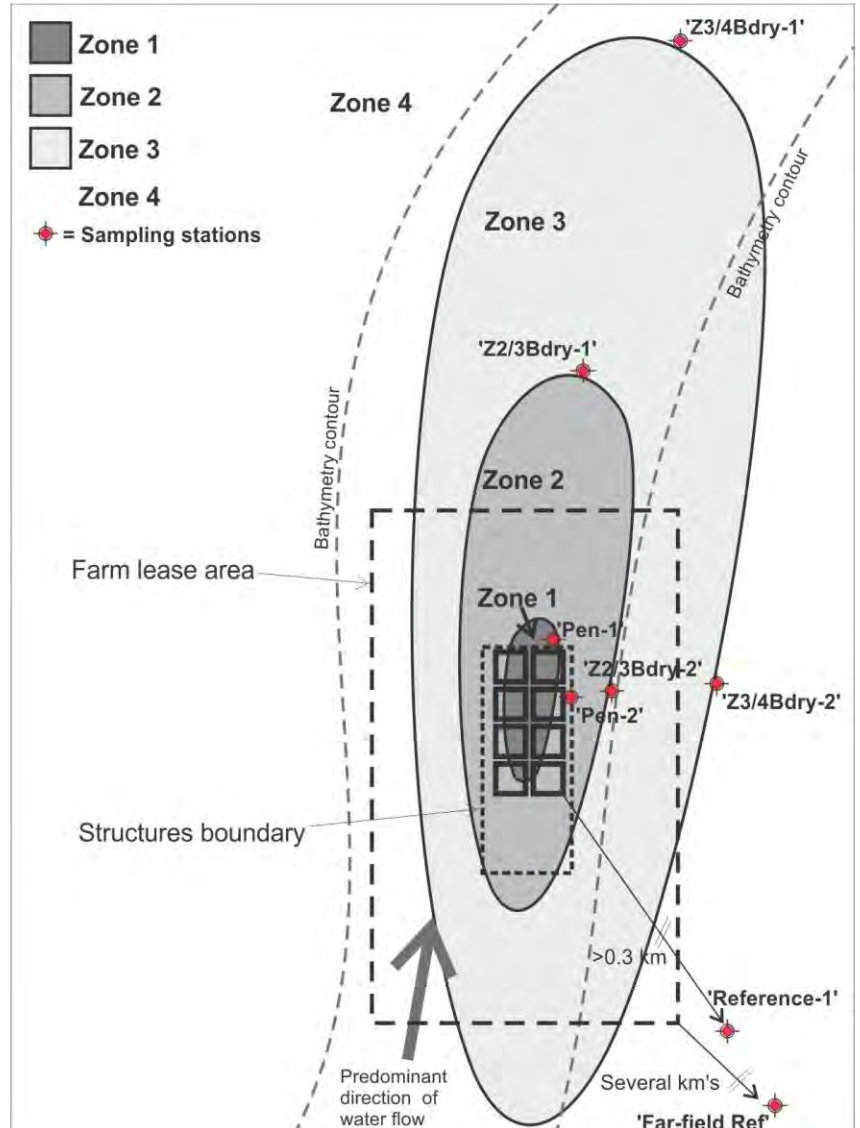
Free to the public

Aligned to consent requirements

Example: Benthic effects (contd.)

- Project task Use of models to support monitoring (contd.)





Images courtesy of Nigel Keeley

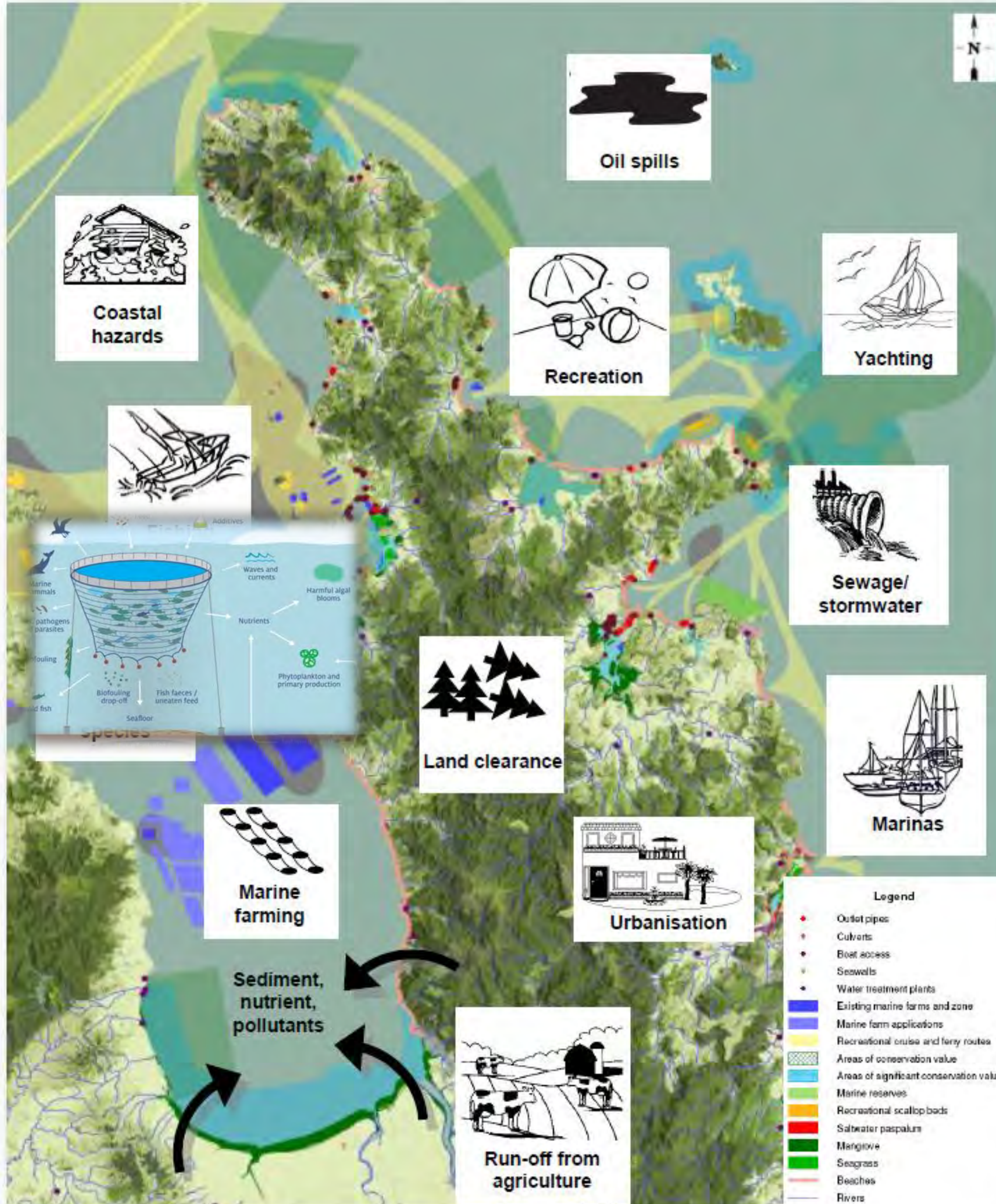
Example: Benthic effects (contd.)

- Project task Collate Best Management Practices (industry COPs)

Management goal	BMP	Monitoring and reporting	Sector
Minimise seabed impacts	• Maintain stocking densities at a level that can meet standards for seabed impacts stipulated by WRC.	• Maintain records of farm stocking densities and times of stock additions and harvesting, and report to WRC annually or as requested.	F
	• Implement practices to minimise feed wastage, which may include: ○ Developing feed management plans and on-going assessment of feed management ○ Ensuring that feeds are formulated for the species, life-stage, environment and feeding system used. ○ Monitoring of feed consumption. ○ Securing feed storage and delivery systems to prevent catastrophic loss. ○ Monitoring waste feed on seabed.	• Maintain records of quantities of feed used, and waste feed on seabed, and report to WRC annually or as requested.	F
	• Maintain a minimum space of 5 m between nets and the seabed, to promote adequate flushing of farm wastes.	• None required.	F
	• Appropriate storage, land-based disposal, of garbage and inorganic solid waste.	• None required.	All

Example: Marine mammals

- Risk depends on overlap of aquaculture site and marine mammal habitats
- Type of effect similar for different types of aquaculture
- Proposed approach
  - Focus on site selection
  - Best Management Practices
  - Record keeping and reporting
- Project tasks
  - Best Management Practices
  - Record keeping and reporting requirements
- Recommendations
  - WRC to encourage and support specific research into effects
  - Gather baseline data and identify critical habitats


N
Oil spills
Coastal hazards
Recreation
Yachting
Sewage/ stormwater
Additives
Waves and currents
Harmful algal blooms
Nutrients
Phytoplankton and primary production
Biofouling drop-off
Fish faeces / uneaten feed
Seafloor
Land clearance
Marinas
Marine farming
Urbanisation
Sediment, nutrient, pollutants
Run-off from agriculture
Legend
Outlet pipes
Culverts
Boat access
Seawalls
Water treatment plants
Existing marine farms and zone
Marine farm applications
Recreational cruise and ferry routes
Areas of conservation value
Areas of significant conservation value
Marine reserves
Recreational scallop beds
Saltwater paspalum
Mangrove
Seagrass
Beaches
Rivers

Next steps

- Draft guidance document completed by June 2014
- May-August 2014: Contact aquaculture industry
- Workshops/meetings with stakeholders to
  - present draft guidance document
  - listen to feedback
  - work out solutions
  - incorporate suggestions as much as possible
  - ensure final approach has wide support
- Timing: flexible

Open to conversations at any time

Acknowledgements

Ministry for Primary Industries
Manatū Ahu Matua

Aquaculture Planning Fund

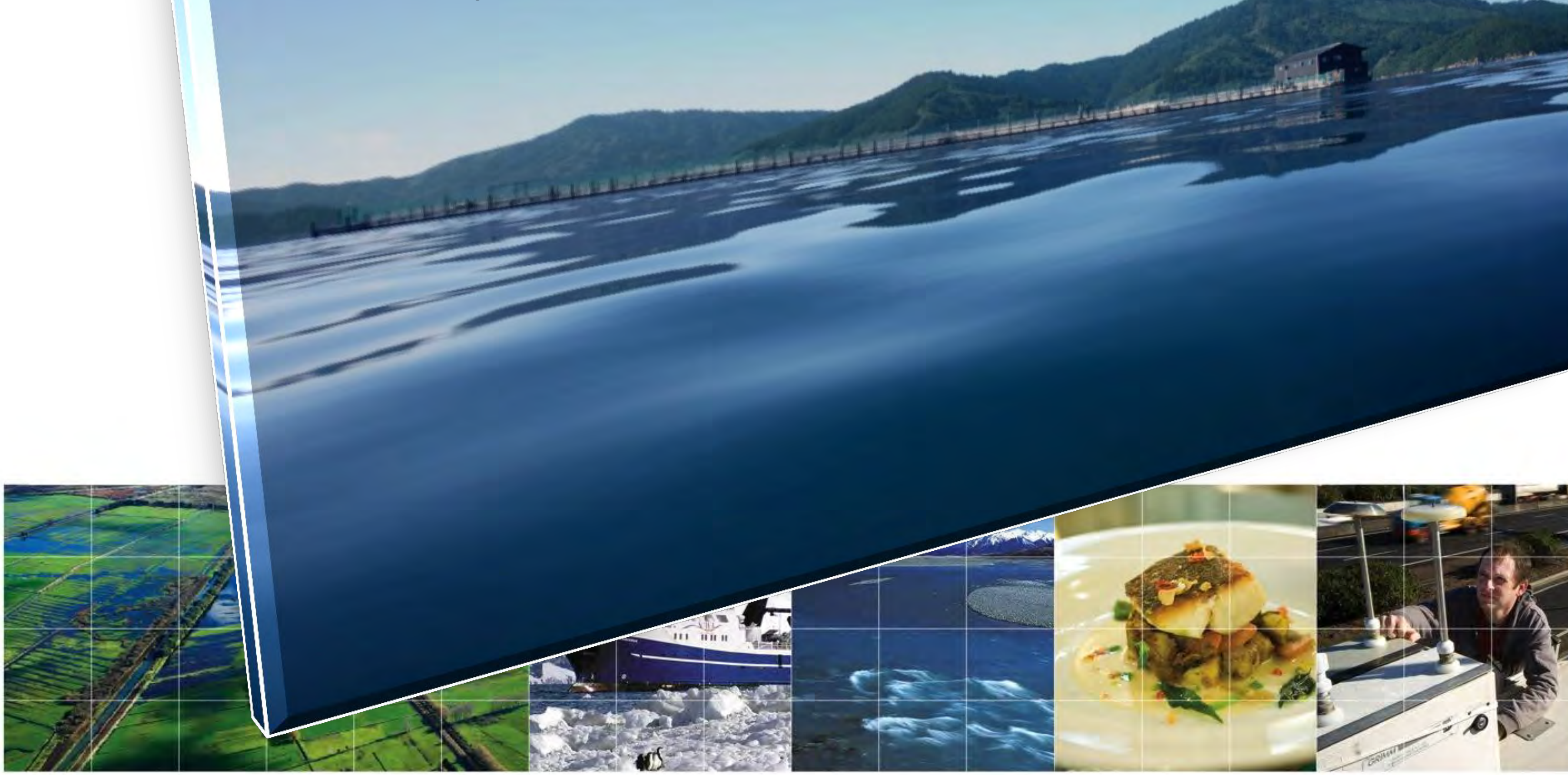
CAWTHRON

METOCEAN SOLUTIONS LTD

NIWA
Taihoro Nukurangi

From porewater to profiling:

experiences and future directions for monitoring benthic impacts around salmon farms



NIWA – Sustainable Aquaculture Programme

- project: *stressors, transport and sinks*
  - comprised of three themes, one of which is:
- *"the fate of crop-induced stressors / contaminants once they have been delivered into the environment"*

- benthic effects of organic matter (OM) deposition from fish farming

- understanding of biogeochemical processes under farms
- characterisation of OM loading rates to seafloor around farm

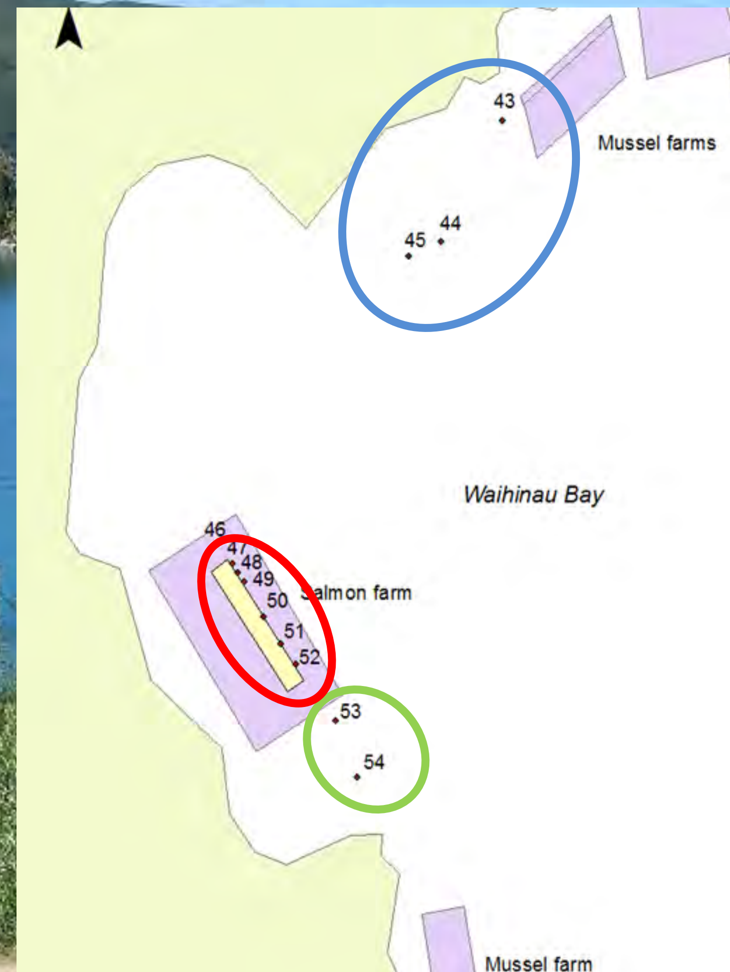
- 'case study' → Waihinau Bay

Talk outline

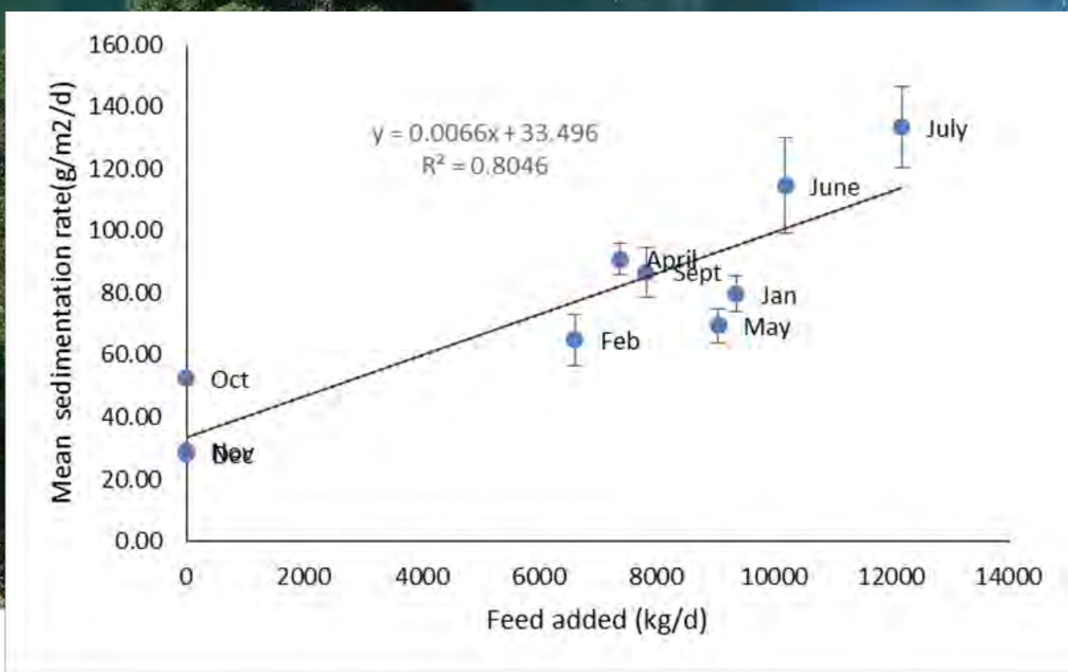
- overview of 2013 benthic work at Waihinau
  - sediment trapping
  - biogeochemistry (5 months after fallowing)
  - SPI overview (v.brief)
- Future biogeochemical work
- Comments / questions regarding current monitoring

Waihinau Bay – Sediment trapping

- traps deployed for 4 to 9 days
  - 2m above sea bed
- Jan, Feb, Apr, May, Jun, Jul, Oct, Nov, Dec
- 12 sites: 3 ref, 6 farm, 3 ‘near field’

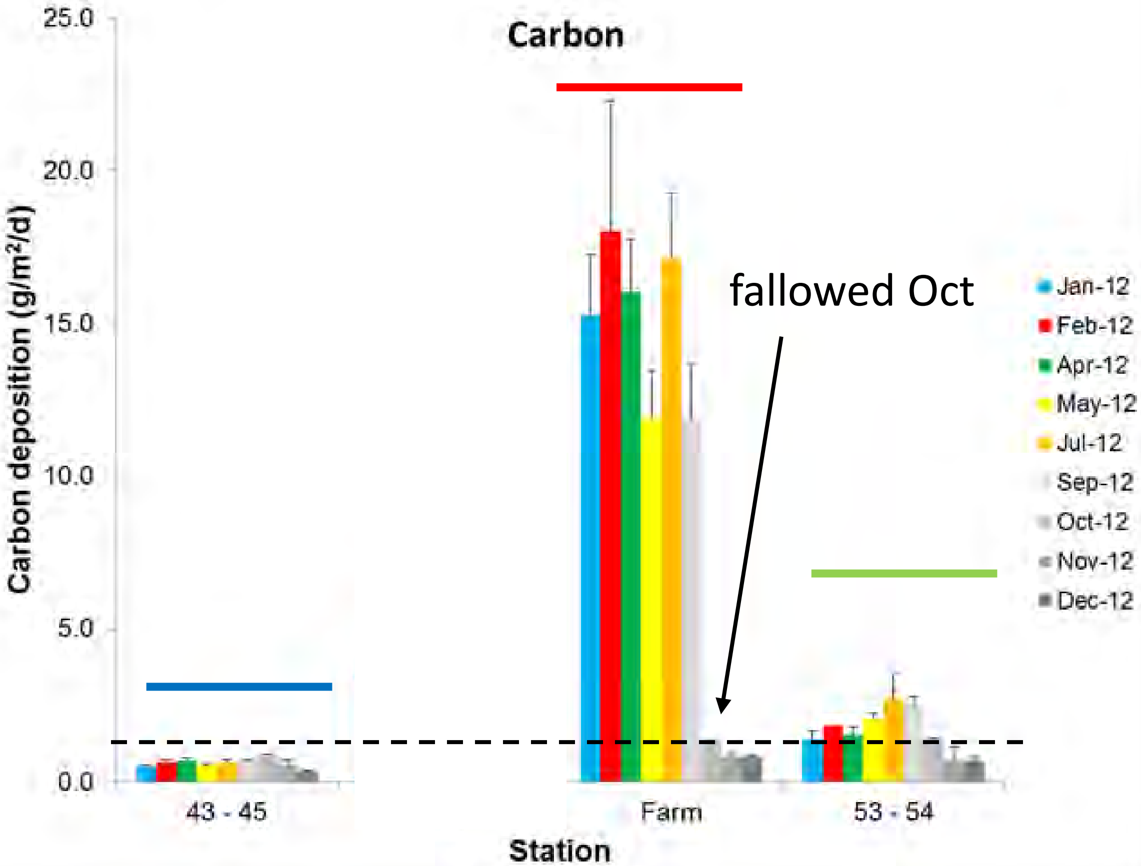


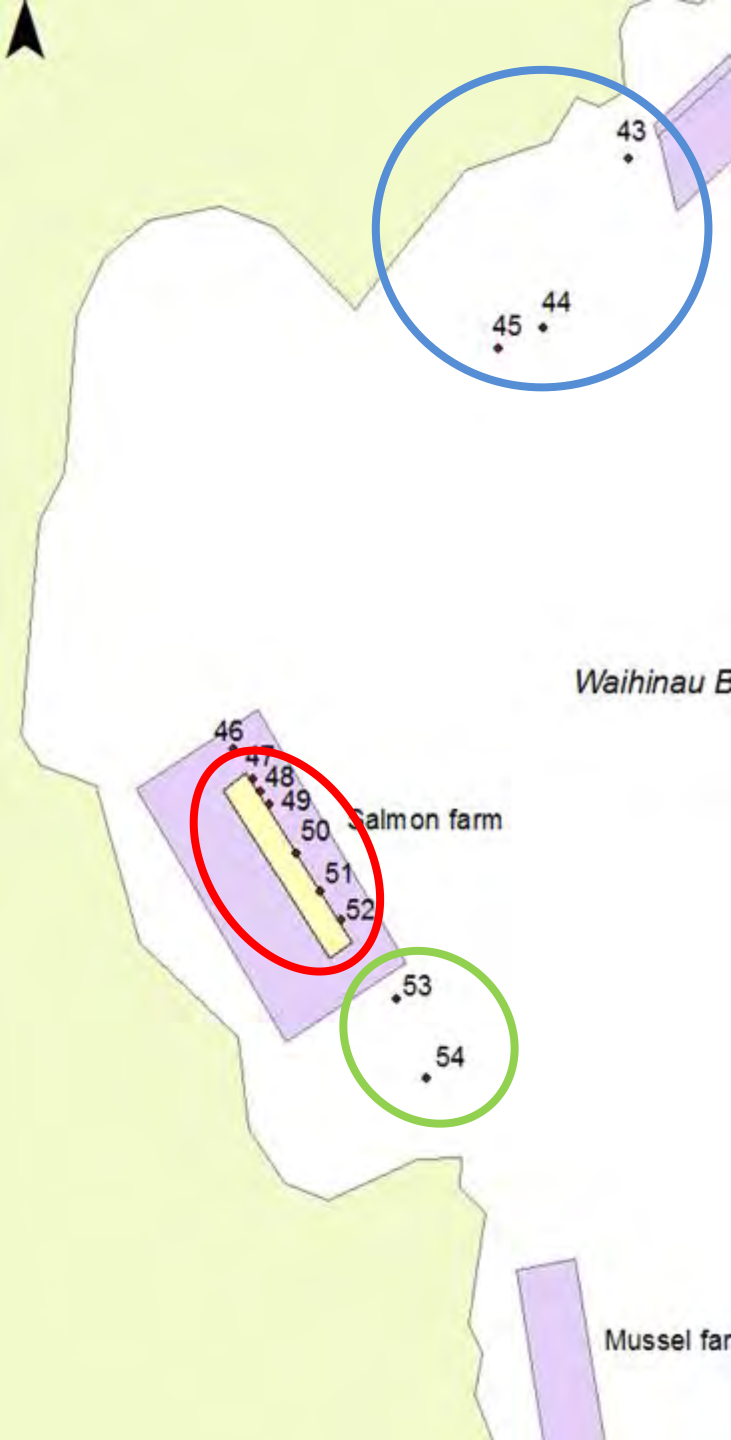
- good correlation with feed inputs



Sedimentation rates

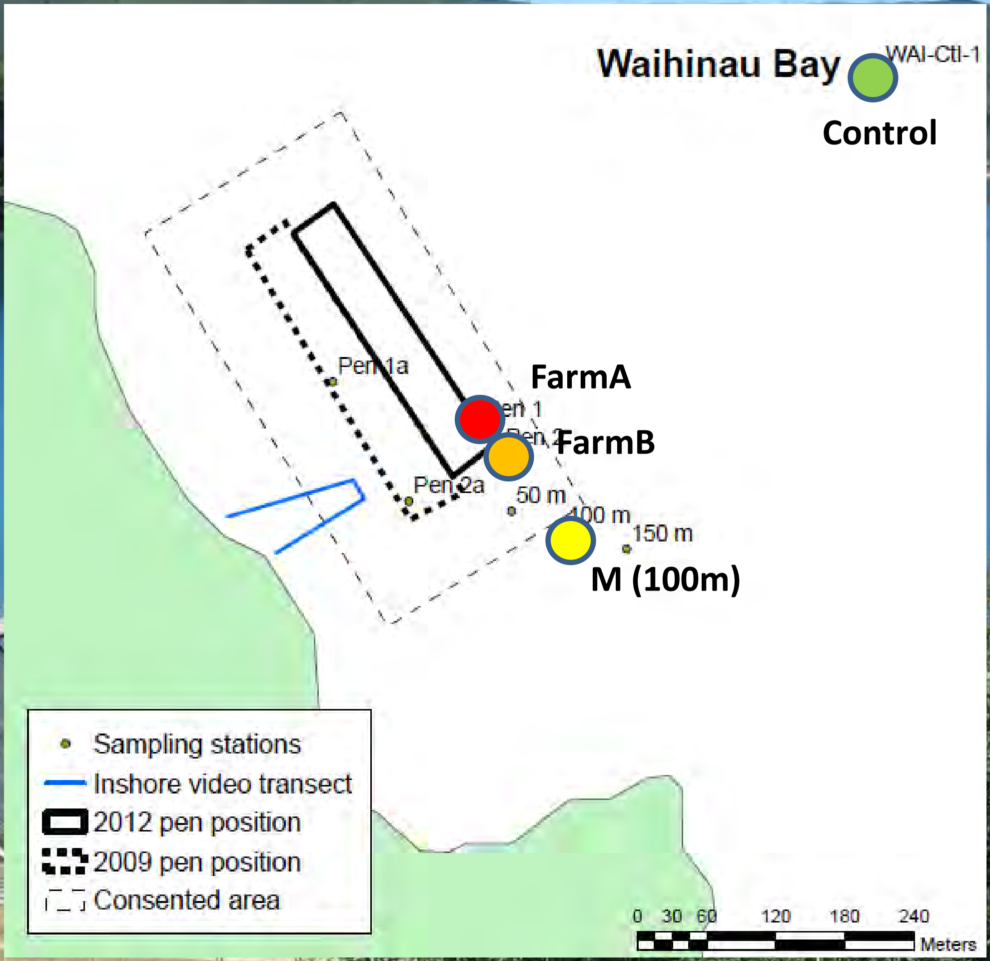
- OC sedimentation rate (g C/m^2/day)
  - control: 0.6 farm: 12-18 near: <3
- <u>17 to 36</u>-fold higher rates at farm sites
- <5 g C/m^2/d suggested 'threshold'
- C loading at Waihinau ~3-fold higher





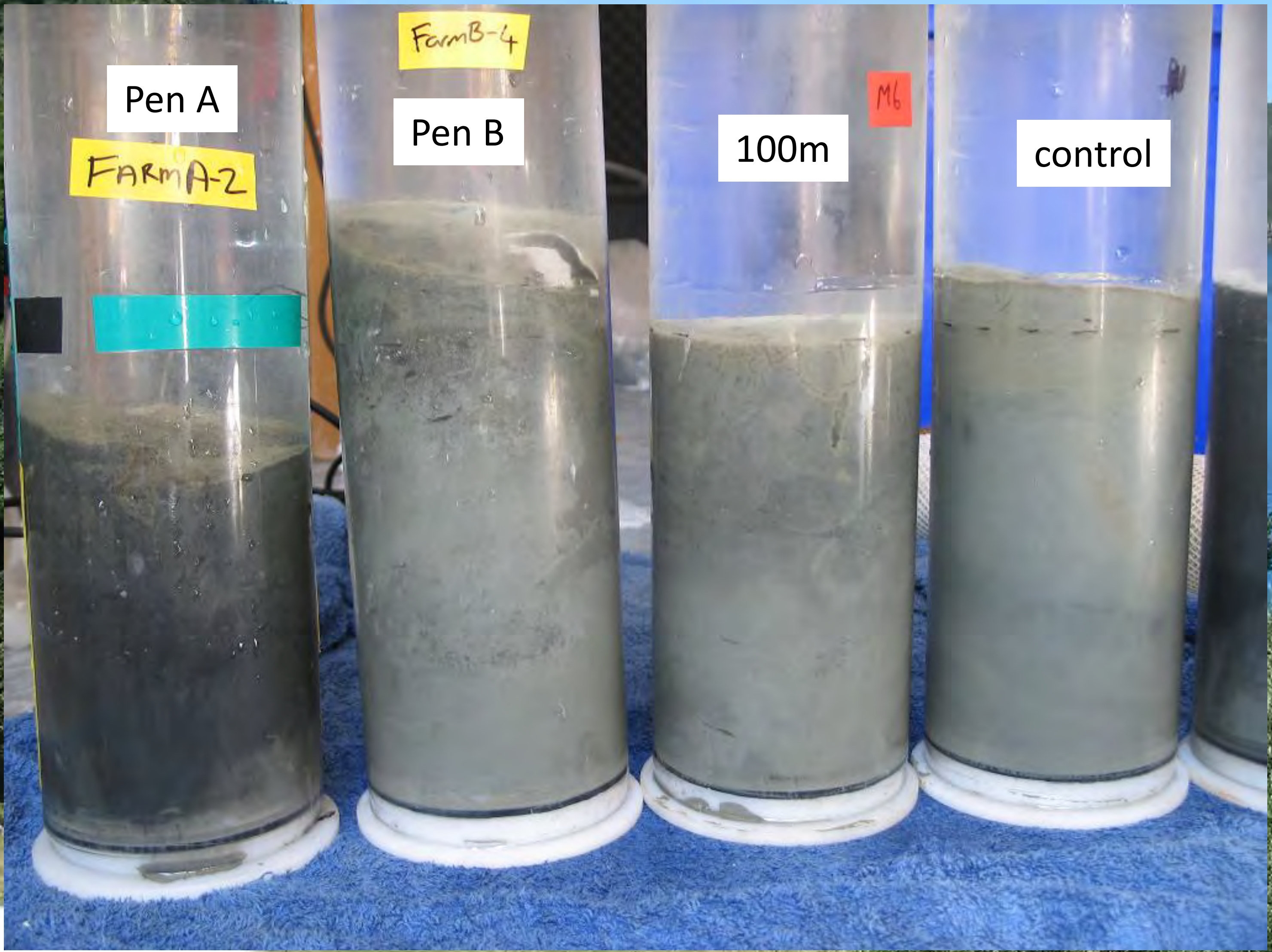
Waihinau Bay – biogeochemistry (March 2013)

- fallowed 2010 and 2011
- resumed Nov 2011 (different site)
- fallowed Oct 6 2012 (5 months)



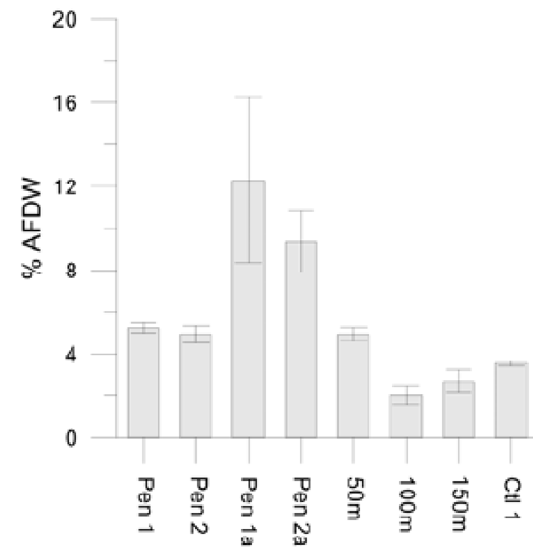
Waihinau Bay – biogeochemistry (March 2013)

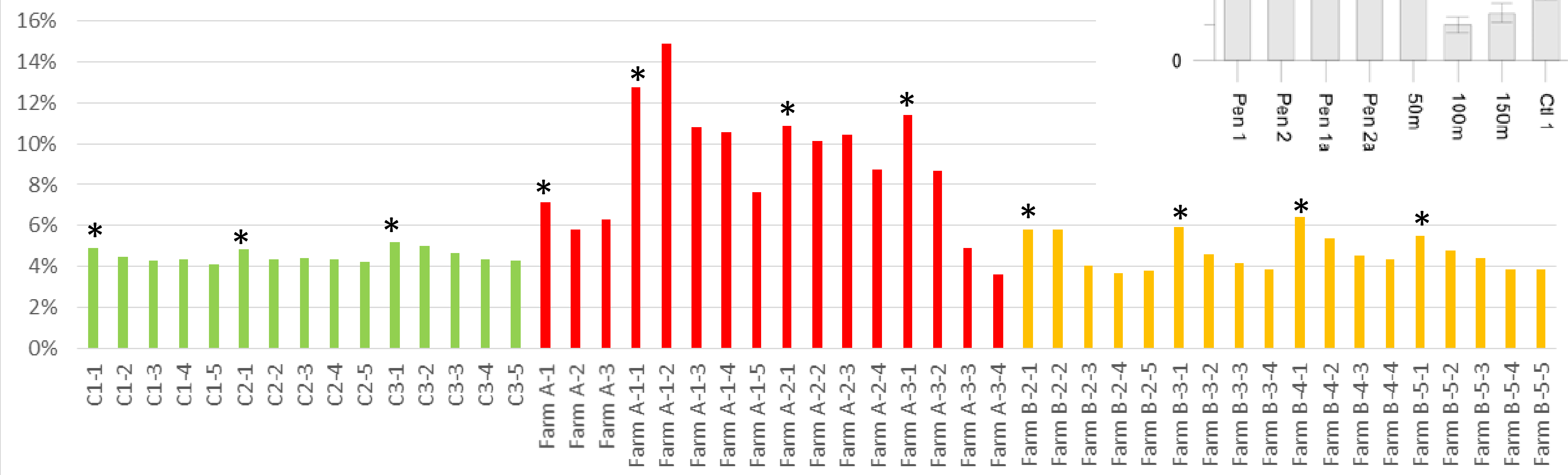
- dive collected cores
- incubations/porewater/solid phase analyses



Organic enrichment

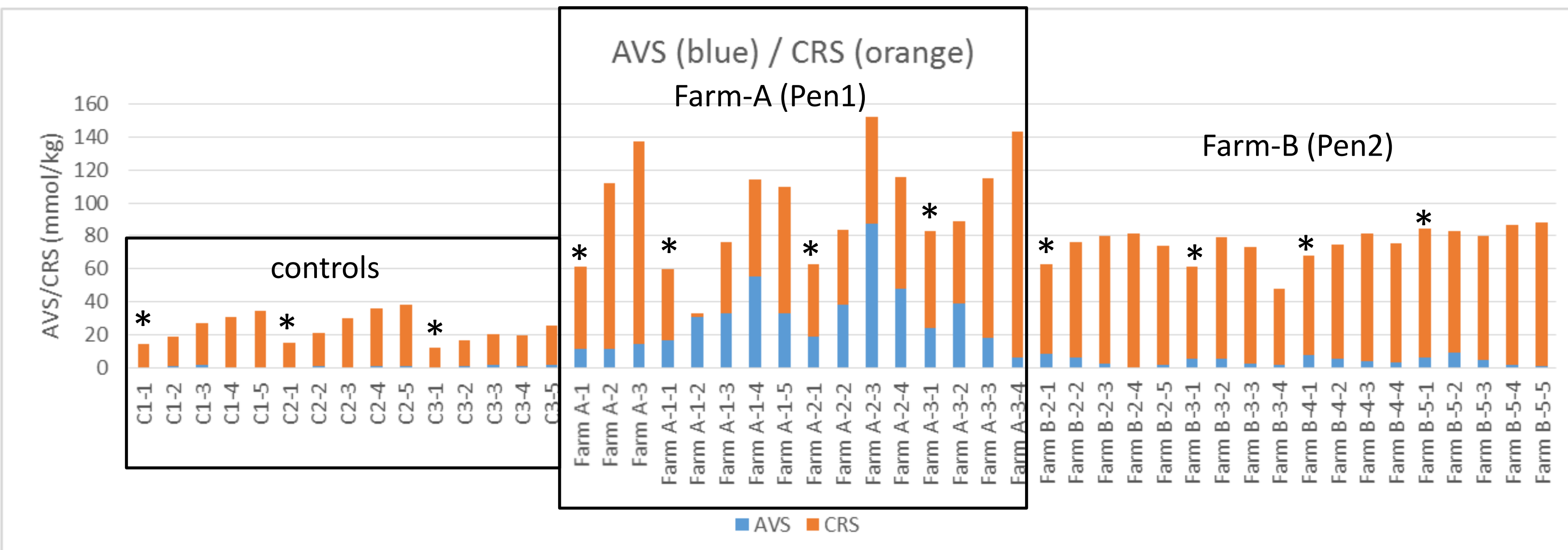
- OC: controls <1 % OC; Pen1 ~4% OC; Pen2 ~2%
  - Pen2 close to control in subsurface layers
- OM: controls = 4-5%; Pen1 = 10-12%; Pen2 = 5-6%
- Pen1 (2013) similar to Pen1a (2012) ?
- significant enrichment after 5 months





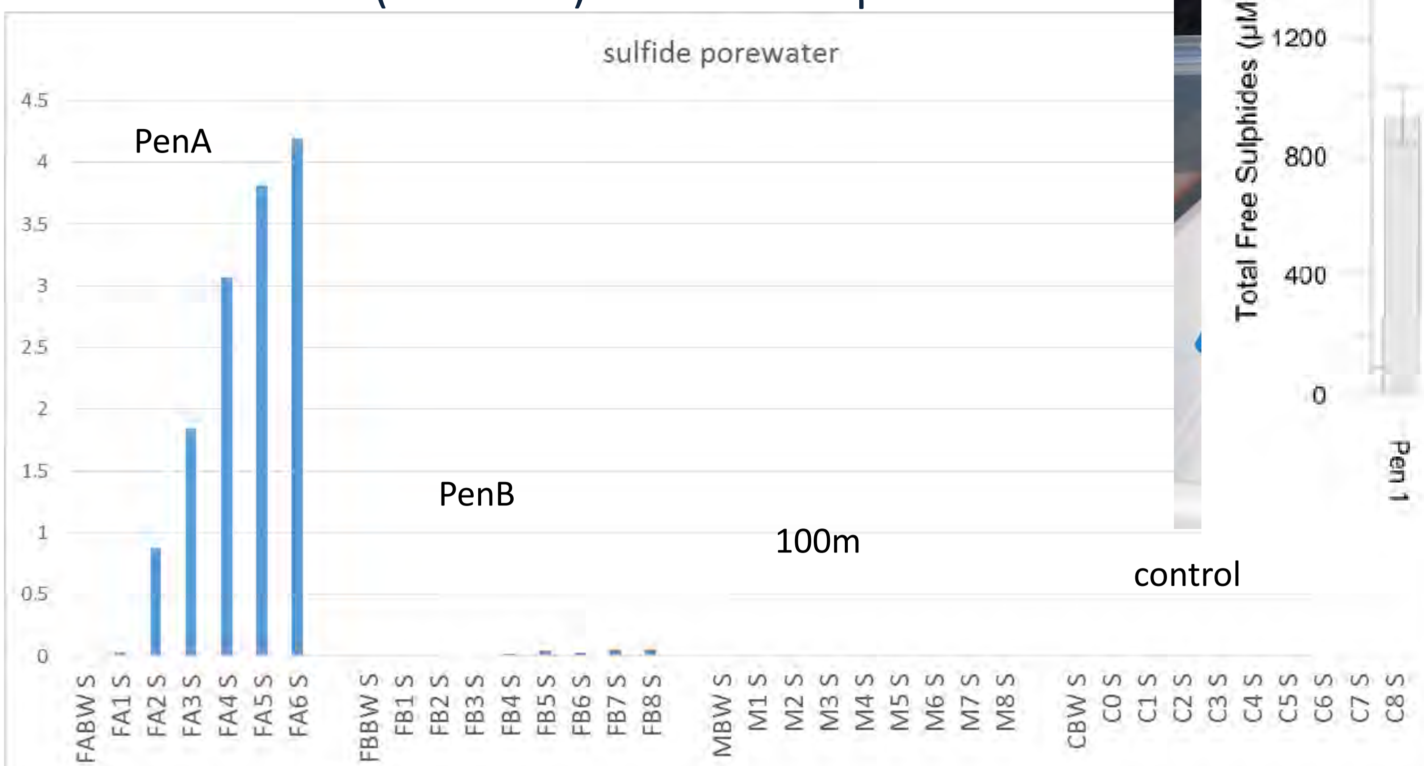
Sediment sulfide pools (CRS/AVS)

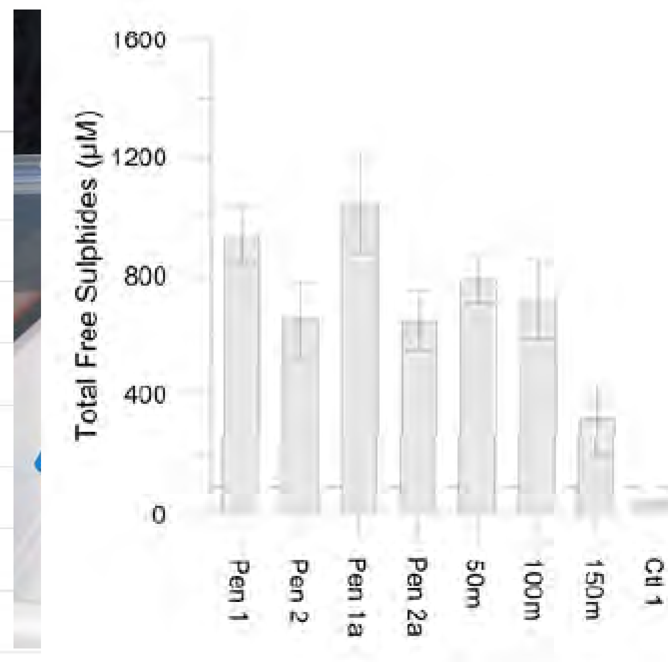
- AVS = iron monosulfides (FeS) via Fe^{2+} + sulfide
- CRS = more stable pyrite forms (FeS_2)
- 5 month fallowing still labile pool of sediment sulphides at Pen1
- interesting but no point unless looking at sulfur/iron cycling



Porewater sulfide

- after 5 months fallowing…
- porewater sulfide at PenA site still very high (up to 4,000 µM)
  - porewater NH_4 also high (1,000 µM)
- Comparison with sediment sulfide via ISE (SAOB) method
  - Pen1 sites (0-20mm) = 4,000-5,000 µM sulfide (ISE)
  - Pen2 sites (0-20mm) = 600 to 1,000 µM
  - Controls (0-20mm) = 40 to 100 µM

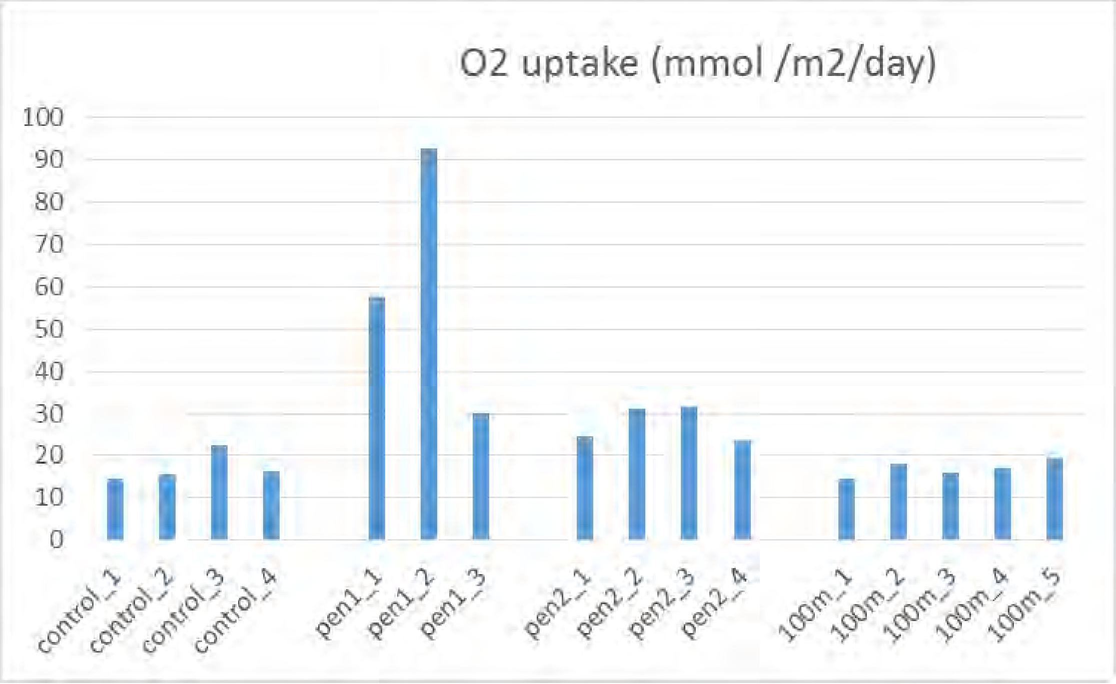




NIWA
Taihoro Nukurangi

Sediment incubations (O_2 uptake)

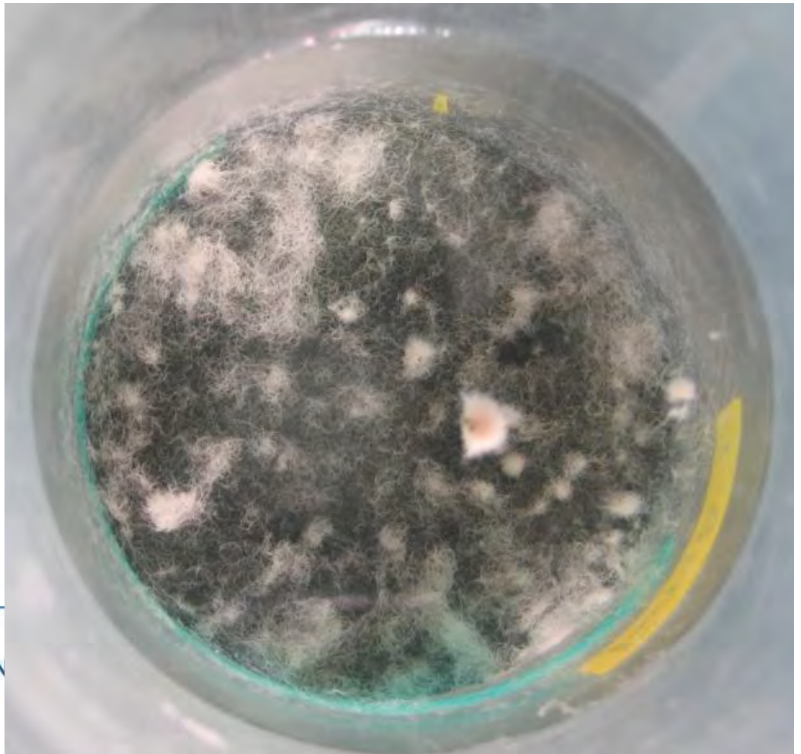
- Pen1 up to 90 mmol $O_2/m^2/d$ (median 58 mmol)
- 6x higher than control site
- Pen2 site O_2 consumption was twice that of the control (28 vs 16 mmol O_2/m2/d)
- max. rate equates to around 1 g $C/m^2/d$
- expect higher rates at impacted sites
  - refractory carbon
  - malfunctioning benthic processes
  - difficult to tell – 1 measurement
  - no supporting macrofaunal data



Summary

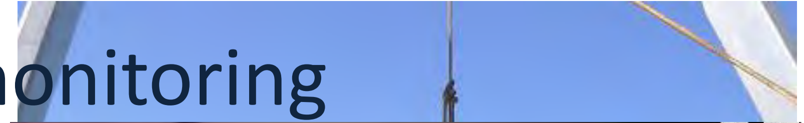
- After 5 months fallowing, Pen A is still a very anoxic sediment characterised by –ve redox (-150 mV), high sulfide, high NH4, and some *beggiatoa*
- Challenge for NZKS may be relatively high annual production maintained at each farm
- other countries harvest every 2 or 3 years (NB) – single age class

- Back of the envelope calc.
- NB – 24,000 tonnes (~50ish farms)
- average farm 1,620 t
- annual 3-yearly average = 540 t?
- NZKS (7500t/5) = 1,500 t annually?

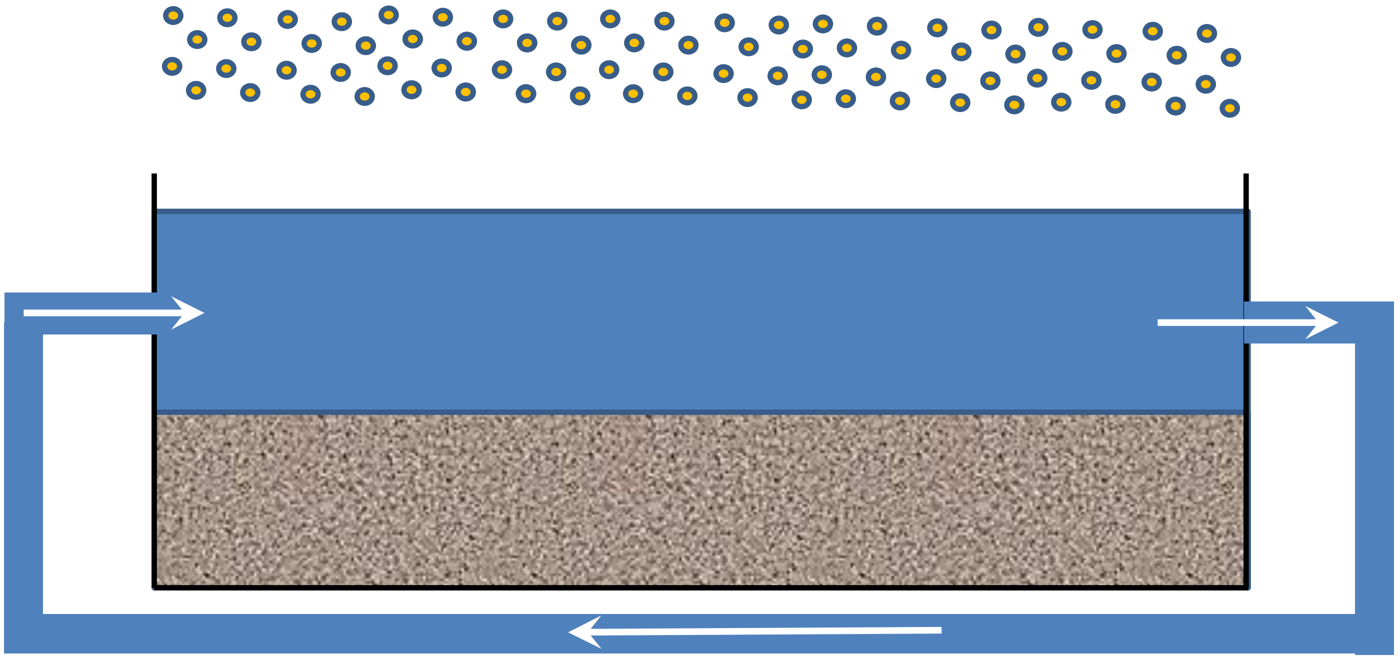


SPI application for benthic monitoring

- my experience….
- promised a lot but delivered little
- Some issues
  - limit of depth deployment
  - unreliability
  - boat requirements for deployment
  - Issues with penetration (shell hash)
  - used as a proxy for chemistry rather than biology?



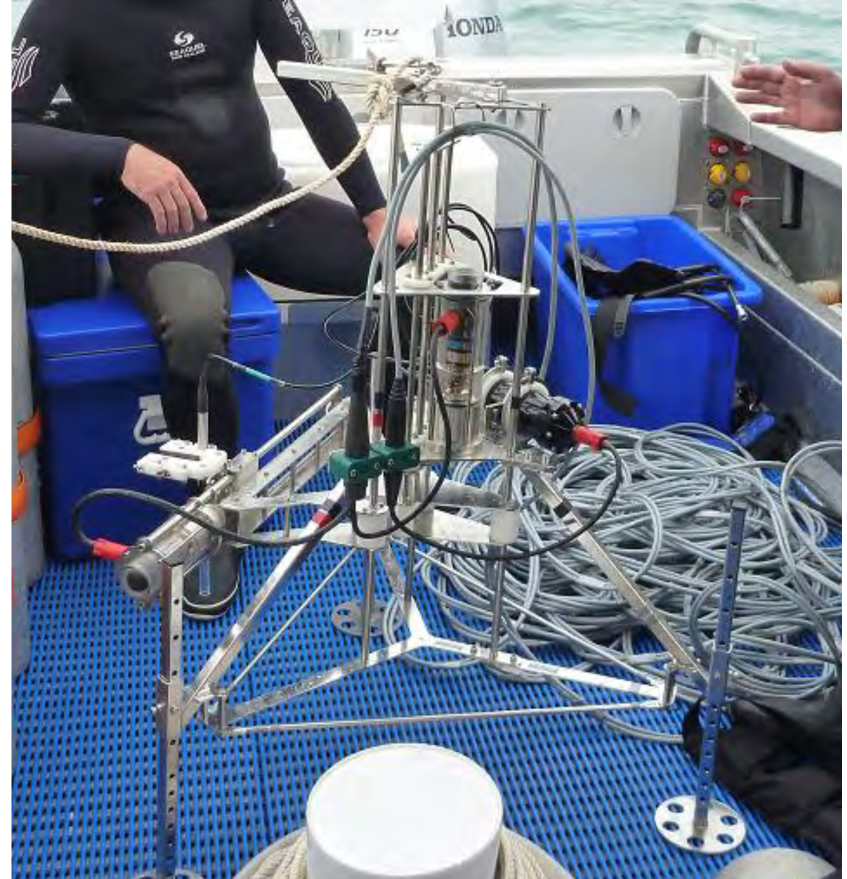
This year - Chambers: continuous OM loading expt

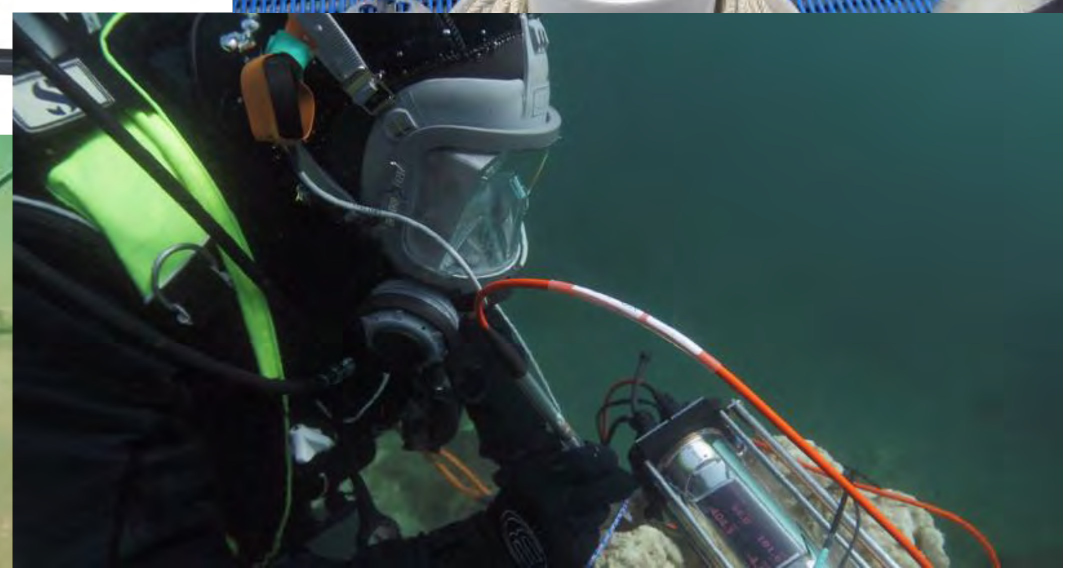


- allow more frequent monitoring over ‘enrichment’ cycle
- focus on carbon and nitrogen budgets for the system
- how does benthic OM metabolism respond to high carbon loadings?
  - trajectory of enrichment (linear or evidence of malfunctioning?)
- how does benthic metabolism of OM of enriched respond to fallowing?
  - ‘recovery trajectory’

Future research toys

- in-situ measurement of sulfide /redox/pH





REPORT NO. 2080

ASSESSMENT OF ENRICHMENT STAGE AND COMPLIANCE FOR SALMON FARMS - 2011

enhancing the benefits of New Zealand's natural resources

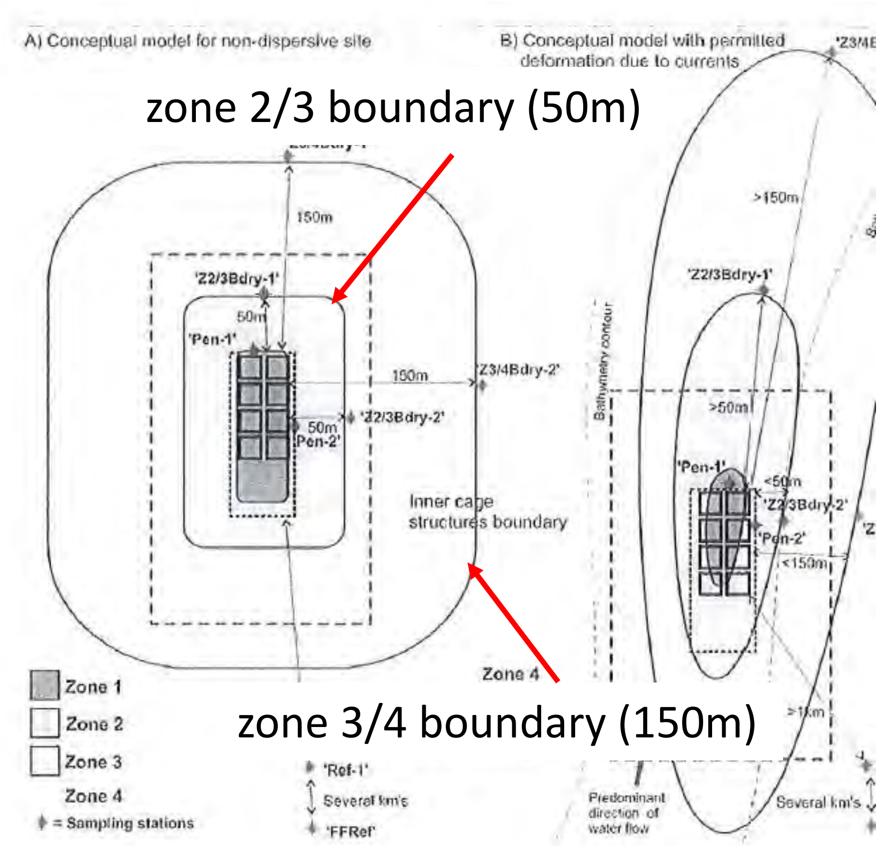
NIWA
Taihoro Nukurangi

Comments/questions on current monitoring (1)

- zones concept appears a little ambiguous
  - diagram shows 4 zones (1 being under pens)
  - 'zone table' only includes 3 zones
- zone 2/3 in table is 150m; in diagram it is 50m

Spatial Zone	Spatial extent	Equivalent ES 2010 AMP
1	Beneath the pens and out to 50 m from their outside edge	5 or less ES 6 is permitted but undesirable*
2	From 50 to 150 m from the outside edge of the pens	3.5 or less
3	Beyond 150 m from the outside edge of the pens	2.5 or less** (1.5 or less)
All zones	These conditions are not permitted beneath any NZKS farm	7

enhancing the



Comments/questions on current monitoring (2)

- ES spatial zones vs boundaries
  - Pen out to 50m - 'zone 1' - ES 5 or less
  - 50 to 150m – 'zone 2' - ES 3.5 or less
  - if boundary monitoring, then ambiguity which zone applies?
    → 50m distance is arguably zone 1 & 2
  - should state something like: *"zone 1 is characterised by a gradient of ES5 (or less) at 0m to ES3.5 at 50m"*
  - Similarly – *"zone 2 is characterised by an enrichment gradient of ES3.5 at 50m to ES2.5 at 150m"*

Spatial Zone	Spatial extent	Equivalent ES 2010 AMP
1	Beneath the pens and out to 50 m from their outside edge	5 or less ES 6 is permitted but undesirable*
2	From 50 to 150 m from the outside edge of the pens	3.5 or less
3	Beyond 150 m from the outside edge of the pens	2.5 or less** (1.5 or less)
All zones	These conditions are not permitted beneath any NZKS farm	7

Comments/questions on current monitoring

- ES system appear complex relative to other systems
- ES value can be calculated from OM/chemistry/biology
  - so why are biological and chemical parameters always measured?
- have large data base - ES/parameter correlations etc
- scope to use chemistry as proxy for ES?
  - lower cost ('Tier' monitoring system)
  - compliant sites assessed by 'zone 1' chemistry (tier 1)
  - non-compliance = increasing monitoring effort via high 'tiers'
  - greater opportunity for responsive adaptive management?
    - (New Brunswick: Tier 2 occurs within 20 days of Tier 1 sulfide exceedance)
- like other countries, Tier 1 monitoring could focus on sampling sites where impacts are greatest
  - *no exceedance at cage (near field) then unlikely to be effect further afield*
- scope to use Canadian system = classification based on [S^{2-}]?
  - could correlate chemistry/OM to biological index like AMBI?
  - → which are already correlated to ES score (fig 9 #1872)
  - correlate sediment [S2-] with AMBI – validate Canadian-type sulfide limits

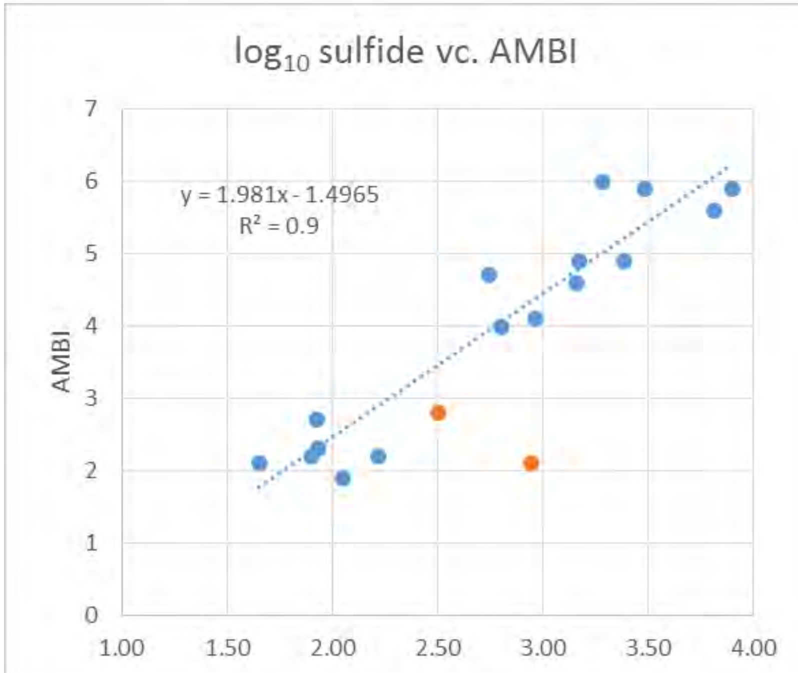
New Brunswick: EMP (example of S^{2-} based 'oxic' system)

- Site classification and management response

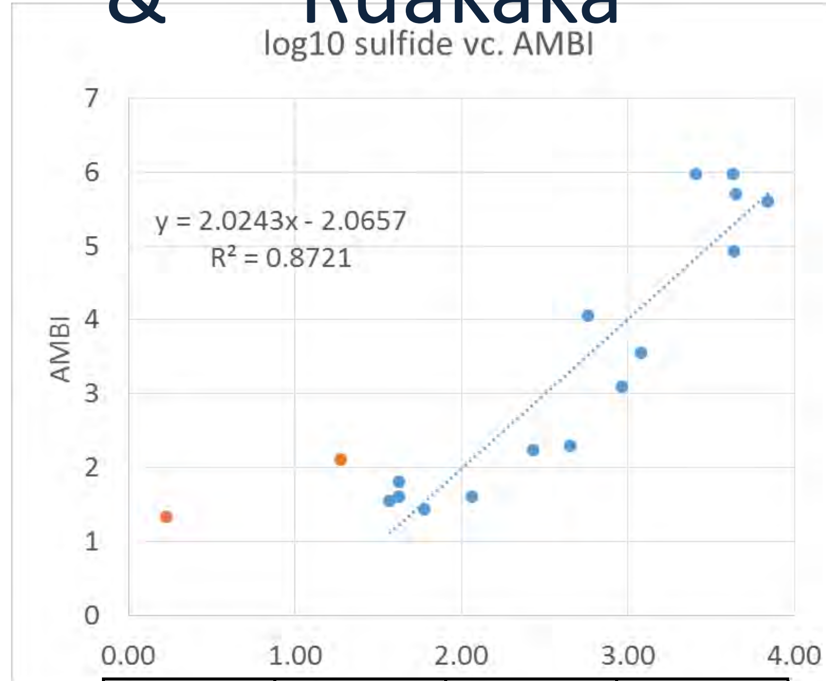
Site Classification	Sediment Condition	Responsive Management Decision Framework	
		TIERED EEM	**Site Management Response**
Oxic A	**Sulfide < 750 µM**	TIER 1 EEM (See SOP)	*Refer to Operational Best Management Practices* as defined in the Section 3.1
Oxic B	**Sulfide = 750 to 1499 µM**		
Hypoxic A	**Sulfide = 1500 to 2999 µM**	TIER 1 EEM (See SOP)	Refer to Section 3.2.2 including the Adjustments to the Operational *Best Management Practices.*
Hypoxic B	**Sulfide = 3000 to 4499 µM**	TIER 1, 2 EEM (See SOP)	Refer to Section 3.2.3 including the Additional *Operational Best Management Practices.*
Hypoxic C	**Sulfide = 4500 to 5999 µM**	TIER 1,2,3 EEM (See SOP)	Refer to Section 3.2.4 including the Further enhanced Operational *Best Management Practices.*
Anoxic	**Sulfide ≥ 6000 µM**	TIER 1,2,3 EEM (See SOP)	Further response measures will be decided upon in consultation with the Site Management Committee as defined in Section 3.2.5

- Reference site and baseline measurements indicate {S^{2-}} <300 µM

Quick look at: Te Pangu & Ruakaka



ES	AMBI	logS	[S]
1	3.1	2.3	210
2	3.8	2.7	474
3	4.6	3.1	1,200
4	5.3	3.4	2,708
5	>5.3	>3.4	>2,700



ES	ambi	logS	[S]
1	2.5	2.3	180
2	3.1	2.6	356
3	3.8	2.9	790
4	4.4	3.2	1,564
5	5	3.5	3,094
6	5.7	3.8	6,861

- Largely consistent with <750, 1500, 3000 and 6000 µM of NB/NS
  - Potential for simplified sulfide-based site classification (Tier 1)?

Acknowledgements

- funding
  - MBIE / Envirolink
- monitoring data
  - NZKS and Cawthron
- NIWA data
  - Don Morrisey, Sue Clearwater, Dan Cairney, Stephen Brown

Thank you