Unifying variables to quantify benthic enrichment – the value of present and future indicators

Nigel Keeley

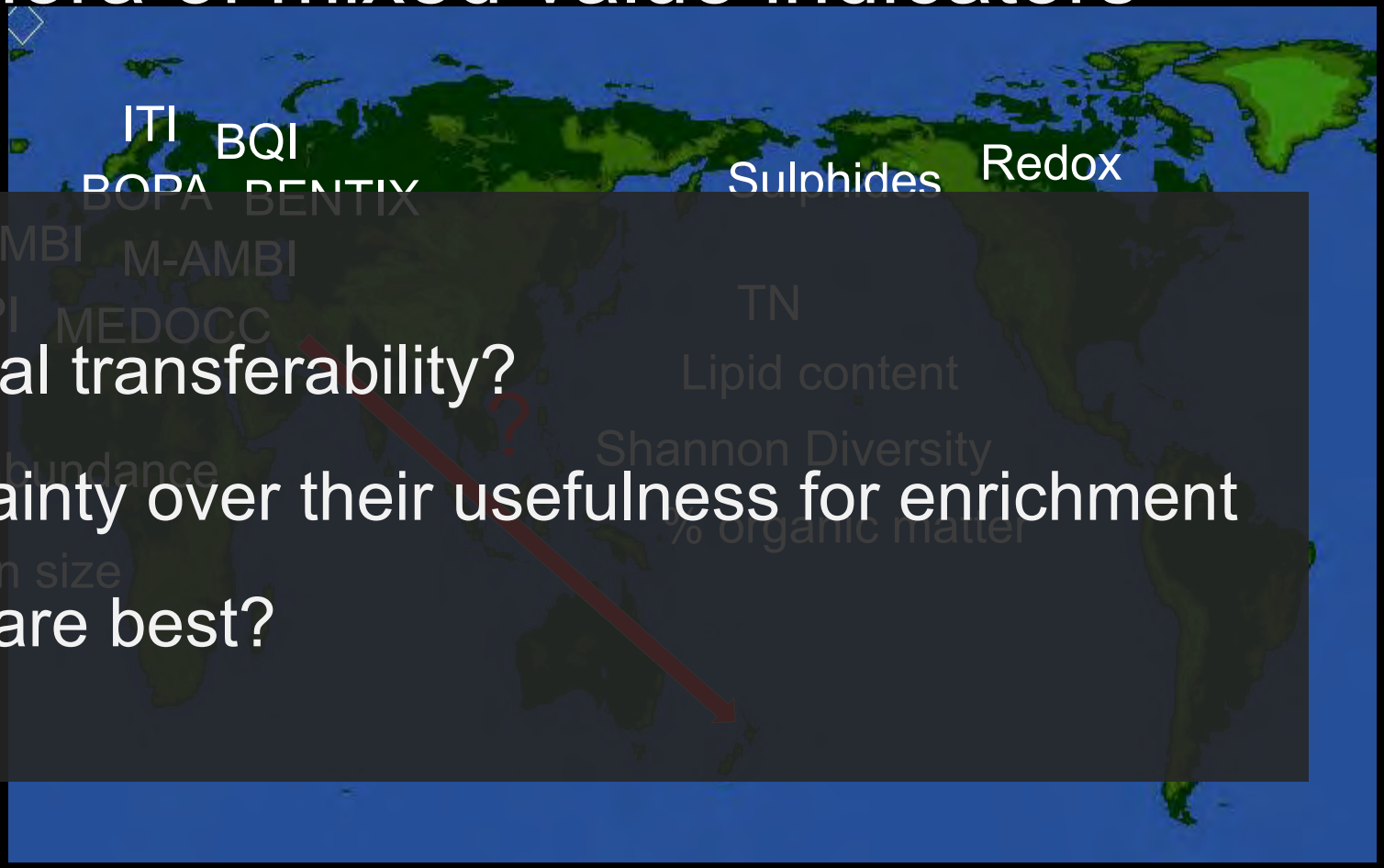
(Cawthron Institute & IMAS QMS, University of Tasmania)

Primary supervisors: Catriona Macleod (IMAS & University of Tasmania, Aus.)

& Barrie Forrest (Cawthron)

Secondary supervisors: Christine Crawford (IMAS, UTas), Mark Gibbs (CSIRO), Chris Cromey (Sailing the world)

A: Plethora of mixed value indicators



- Regional transferability?
- Uncertainty over their usefulness for enrichment
- Which are best?

Indicator	Result	Units
Total abundance =	153	Individuals/core
No species =	22	Taxa/core
Shannon Diversity =	1.36	Index
Pielou's J'	0.62	Index
% Organic matter =	6.8	% w/w
Total free sulphides =	490	µM

→ ?

- All indicators have their limitations
- Requires expert opinion / subjective interpretation ---> Different assessments from different people
- No single variable that incorporates biological and chemical information

B: Relating words to numbers

Existing NZKS low flow farm standards:

Zone	Spatial extent	Description and 'bottom line'
1	**Beneath the cages and out to 50 m** from their outside edge	Sediments become highly impacted and **contain low species diversity, dominated by opportunistic taxa** (e.g. polychaetes, nematodes). It is expected that **a gradient will exist** within this zone, with **higher impacts present directly beneath the cages.**
2	**From 50m to 150m** from the outside edge of the cages	A transitional zone between zones 1 and 3. Within this zone, some enrichment and enhancement of opportunistic species may occur, however **species diversity remains high with no displacement of functional groups. It is expected that a gradient will also exist within this zone.**
3	**Beyond 150 m** from the outside edge of the cages	**Normal conditions** (i.e. background or control conditions).
All zones	These conditions are **not permitted** beneath any NZKS farm	**Sediments that are anoxic and azoic** (i.e. no life present) will not be permitted.

Unclear, open to interpretation

How much higher? Over how much area?

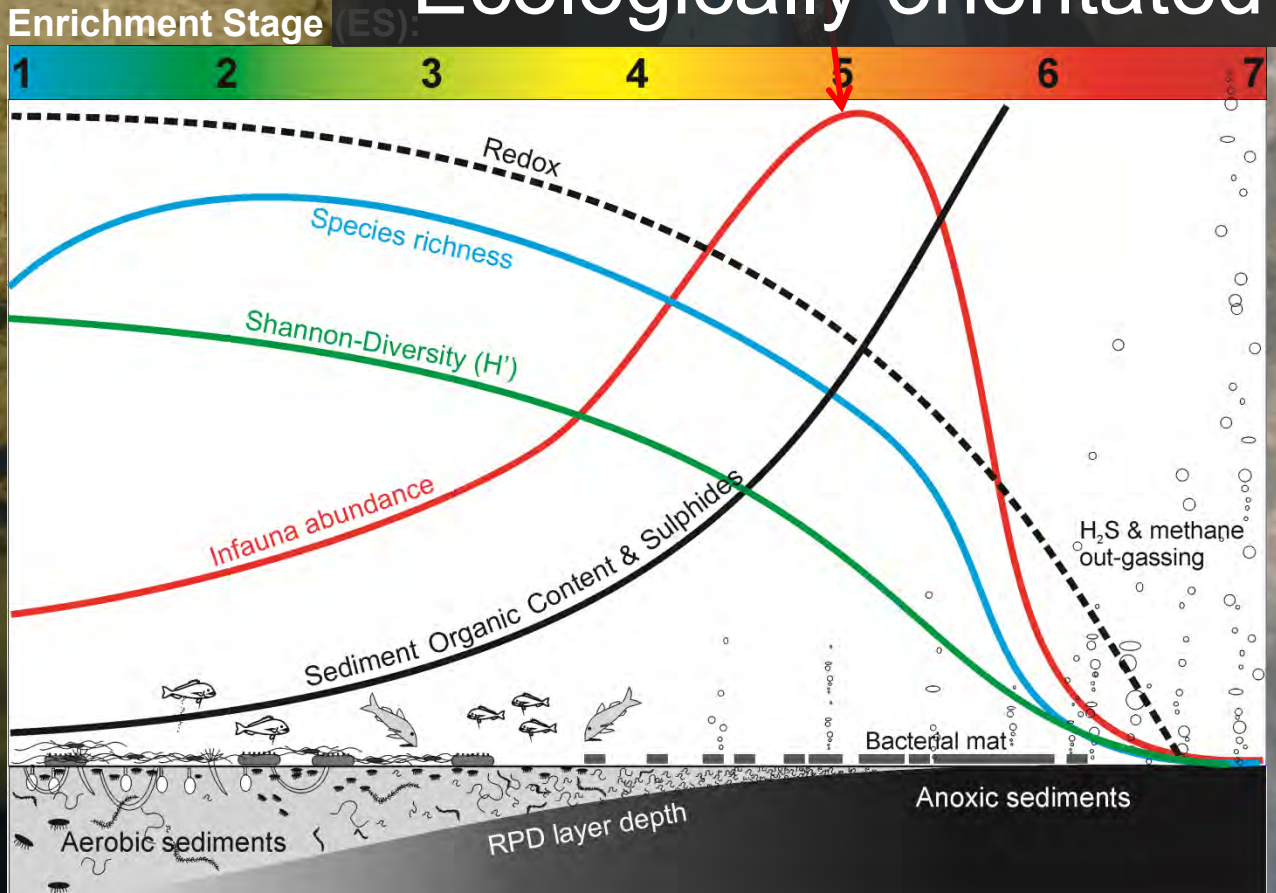
Unclear, open to interpretation

The only <u>prohibited</u> condition is strict anoxia / azoic conditions. Near impossible state.

The problem → **The ES variable** → Characterising taxa for biotic indices → sp… → Using relationships derive ES → Points of contention

- Established
- Bounded
- Universal
- Ecologically orientated

Pristine/ natural



Anoxic/ azoic

Unify variables & information through process of 'best professional judgment' (BPJ)

See: Teixeira et al. 2010. MPB 60, 589-600

Give narrative criteria & data to experts

↓

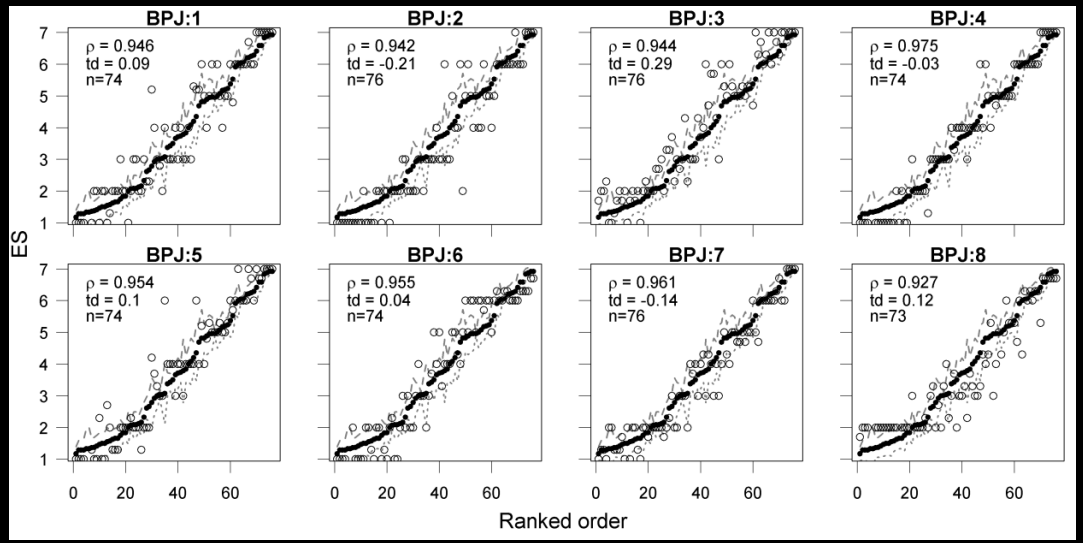
Evaluate & 'classify' environmental data (~ scaled & ranked)

↓

Determine average ES (bounded continuous variable, 1-7)

↓

Use as common gradient to compare variables

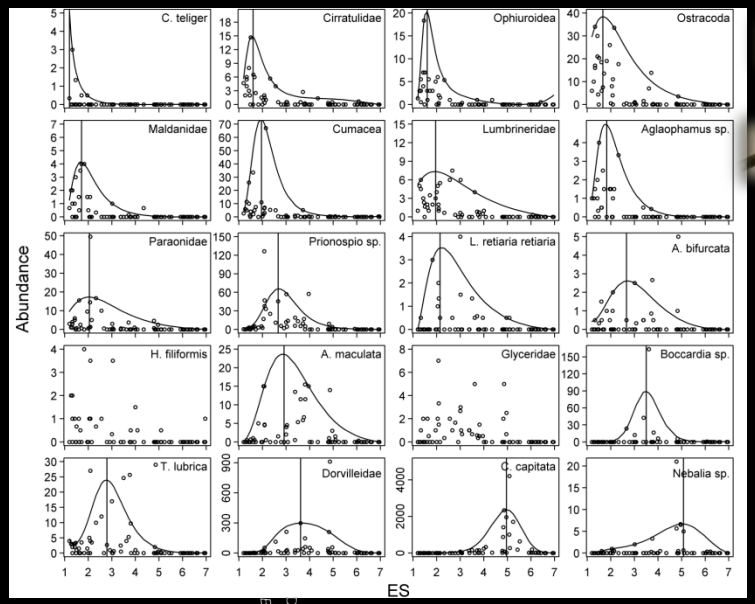


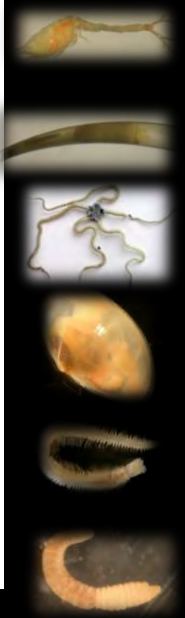
-Look for biases
-Compare among 'experts'
-Check validity of approach

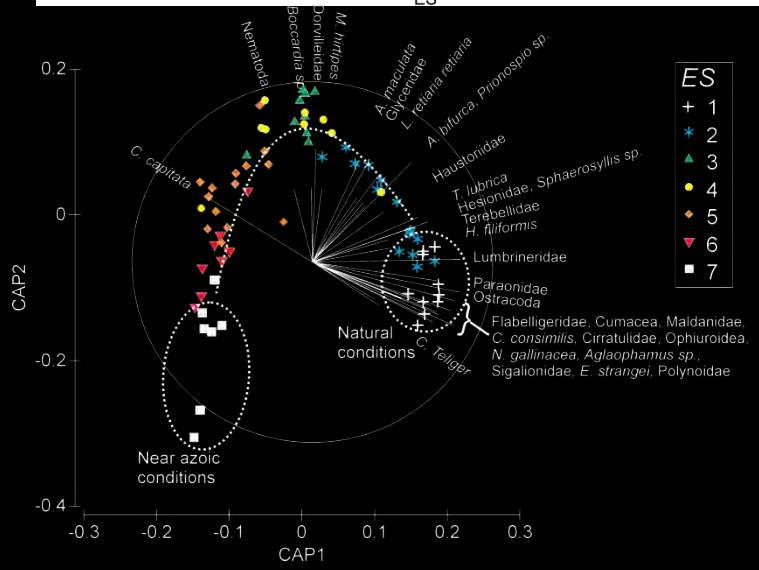
See: Keeley et al. 2012
Ecological Indicators 12: 154-166

Used ES via BPJ to classify taxa in to Ecological Groups for use in biotic indices,

e.g. AMBI (Borja et al. 2000)







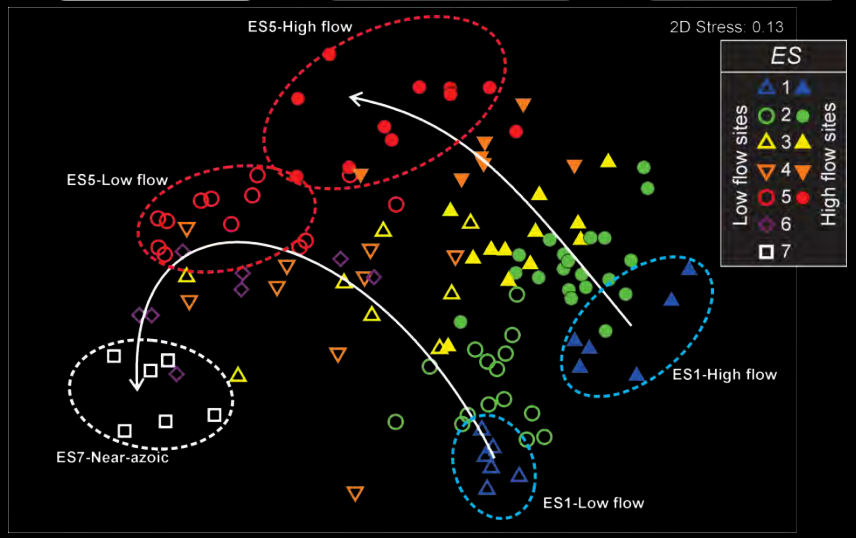
See: Keeley et al. 2012 Ecological Indicators 12: 154-166

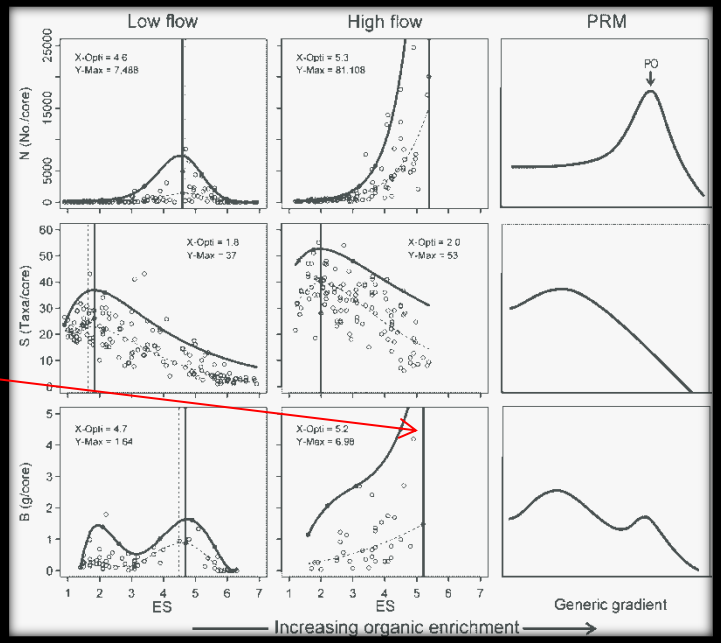
Able to contrast enrichment responses at high and low flow sites

High flow characteristically different

Peak abundances extreme

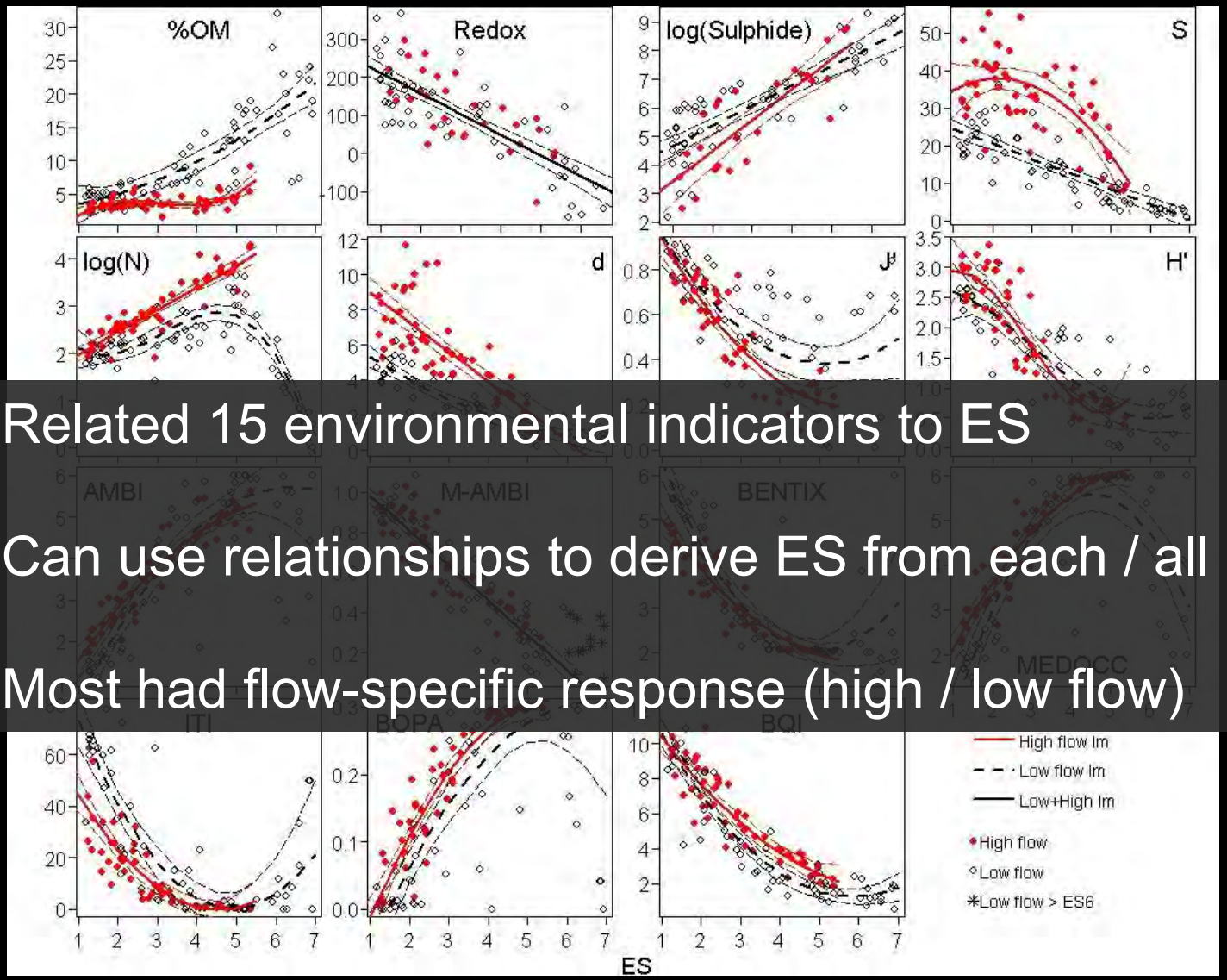
ES>5 rare





See: Keeley et al. 2013 MPB 66: 105-116.

The problem → The ES variable → Characterising taxa for biotic indices → Flow specificity → **Find best indicators** → Using relationships to derive ES → Points of contention



-Related 15 environmental indicators to ES

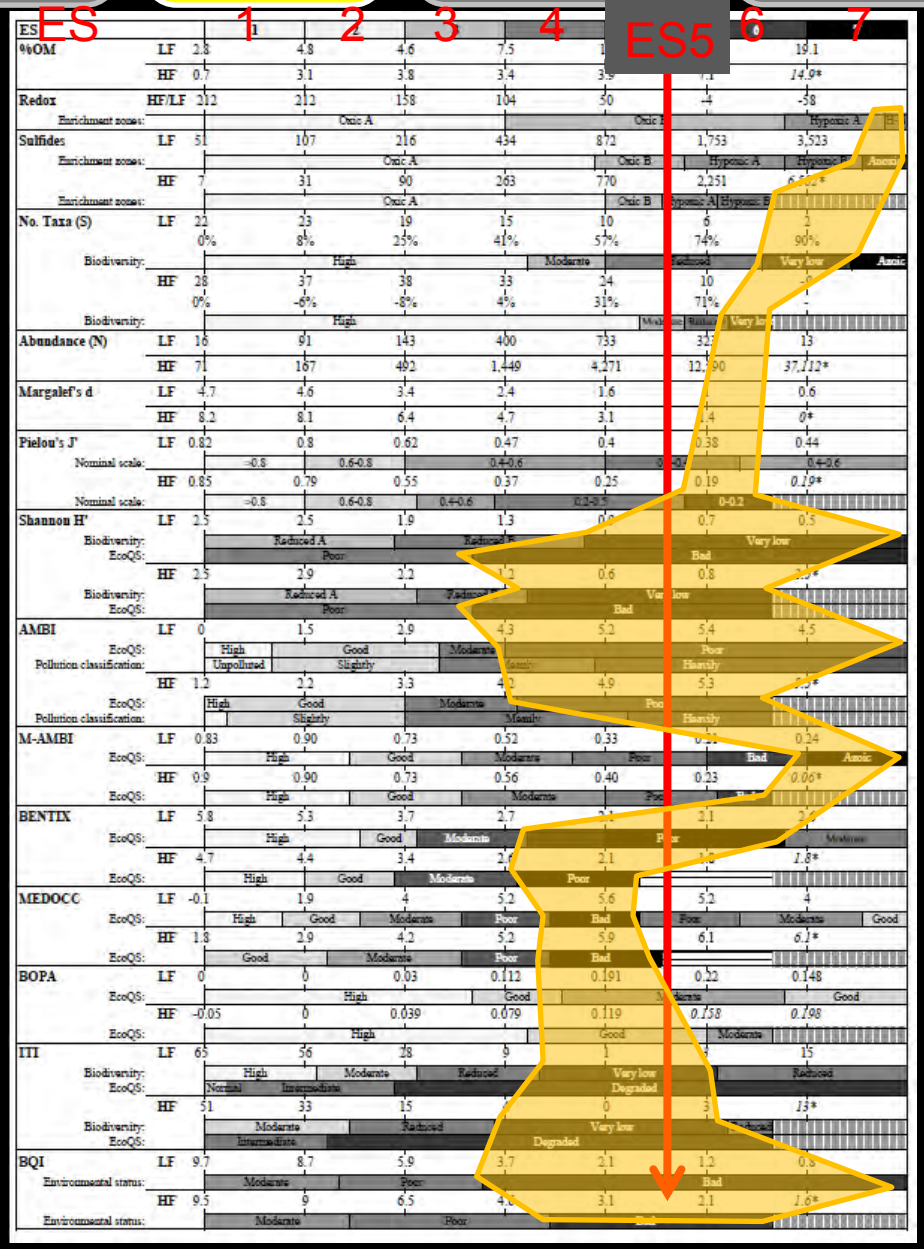
-Can use relationships to derive ES from each / all

-Most had flow-specific response (high / low flow)

Keeley et al. 2012 Ecological Indicators 23: 453-466

Inconsistency between ecological quality status indicated, both:

- Among indicators/ indices
- Within indicators, between flow regimes



Keeley et al. 2012 Ecological Indicators 23: 453-466

The problem → The ES variable → Characterising taxa for biotic indices → Flow specificity → **Find best indicators** → Using relationships to derive ES → Points of contention

Selected for variables that:

1. Correlate well with ES
2. Are versatile
3. Are meaningful & established
4. Give complimentary information
5. Are cost effective

Ranking of indicators according to fit:

	Low Flow				High Flow				Invasive	
	Poly.	Adj.	Overall	Flow	Poly.	Adj.	Overall	Flow	Poly.	Adj.
Variable	order	R2	rank	rank	order	R2	rank	rank	order	R2
BQI	2	0.9097	1	**1**	2	0.8307	7	**5**	-	-
M-AMBI	3	0.8325	6	**2**	1	0.8501	4	**3**	1	0.8195
Log(N)	3	0.744	11	**3**	1	0.824	10	**8**	-	-
d	2	0.7371	12	**4**	1	0.6261	24	**11**	-	-
AMBI	3	0.732	13	**5**	2	0.8774	3	**2**	-	-
H'	2	0.7212	14	**6**	3	0.8292	8	**6**	-	-
BENTIX	2	0.7199	15	**7**	2	0.8469	5	**4**	-	-
S	1	0.6937	17	**8**	2	0.4386	28	**14**	-	-
ITI	2	0.6868	18	**9**	2	0.7093	16	**9**	-	-
log(S^{2-})	1	0.6807	19	**10**	1	[illegible]	[illegible]	[illegible]	-	-
%OM	3	0.6712	21	**11**	3	0.3518	30	**15**	-	-
MEDOCC	2	0.6492	22	**12**	2	[illegible]	[illegible]	[illegible]	-	-
Redox	1	0.6453	23	**13**	1	0.4956	26	**12**	1	0.6098
BOPA	3	0.5479	25	**14**	1	[illegible]	[illegible]	[illegible]	-	-
J'	2	0.43	29	**15**	2	0.8265	9	**7**	-	-

Recommended:

-Macrofauna (N, S, AMBI, M-AMBI, BQI)

-Sediment chemistry (S^{2-} > redox)

-%OM – informative, but poor predictor

Keeley et al. 2012 Ecological Indicators 23: 453-466

The problem → The ES variable → Characterising taxa for biotic indices → Flow specificity → Find best indicators → **Using relationships to derive ES** → Points of contention

Select low / high flow

SITE INFORMATION							
Flow environment:	LF						
Farm/site:	Farm-X						
Station:		Cage1	Cage2	50m A	50m B	Control A	Control B
	TOM	9.4	17.3	9	8.2	4.9	5.4
	Redox	-32	-2.3	-51	15	166	187
	Sulphides	3486	3215	1312	957	42	42
	Abundance	5645	5278	177	234	43	80
	No. Taxa	10	4	13	21	20	20
	Richness	1.04	0.35	2.32	3.67	5.05	4.34
	SWDI	0.10	0.01	1.46	2.41	2.69	2.39
	AMBI	5.98	6.00	3.54	3.38	1.46	1.68
	M-AMBI	0.14	0.05	0.52	0.76	0.91	0.86
	BQI	1.84	1.22	3.02	4.74	9.31	10.46
	ES equivalents						
	TOM	4.01	5.82	3.88	3.62	1.5	1.5
	Redox	4.42	4.15	4.59	3.99	2.64	2.45
	Sulphides	5.31	5.18	3.91	3.52	1.04	1.04
	Abundance	5.78	5.72	2.82	3.06	1.62	2.15
	No. Taxa	4	5.67	3.34	2.18	2.28	2.28
	Richness	5.08	6.07	3.56	2.4	1.68	1.99
	SWDI	6.04	6.19	3.71	2.07	1.59	2.12
	AMBI	5.01	5.03	3.2	3.07	1.64	1.8
	M-AMBI	5.89	6.37	3.85	2.58	1.75	2.04
	BQI	5.07	5.72	3.96	2.72	1.43	1.58
Weighting		Cage1	Cage2	50m A	50m B	Control A	Control B
0.1	Organic loading	4.01	5.82	3.88	3.62	1.5	1.5
0.2	Sediment chemistry	4.87	4.67	4.25	3.76	1.84	1.75
0.7	Infauna composition	5.27	5.82	3.49	2.58	1.71	1.99
	Overall ES:	5.06	5.59	3.68	2.92	1.72	1.89

Raw data input

ES equivalents (using empirical relationships)

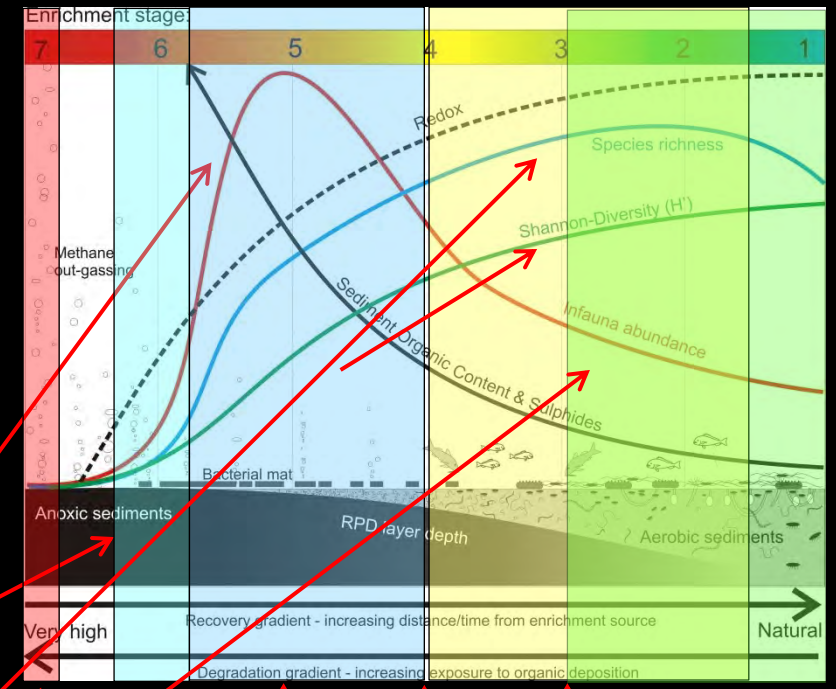
Overall ES

The problem → The ES variable → Characterising taxa for biotic indices → Flow specificity → Find best indicators → **Using relationships to derive ES** → Points of contention

Back to the problem…

-Have tool to be more definitive
-But surpassed accuracy of EQS

Zone	Spatial extent	Description and 'bottom line'
1	**Beneath the cages and out to 50 m** from their outside edge	Sediments become highly impacted and **contain low species diversity, dominated by opportunistic taxa** (e.g. polychaetes, nematodes). It is expected that **a gradient will exist** within this zone, with **higher impacts present directly beneath the cages.**
2	**From 50 m to 150 m** from the outside edge of the cages	A transitional zone between zones 1 and 3. Within this zone, some enrichment and enhancement of opportunistic species may occur, however **species diversity remains high with no displacement of functional groups. It is expected that a gradient will also exist within this zone.**
3	**Beyond 150 m** from the outside edge of the cages	Normal conditions (i.e. background or control conditions).
All zones	These conditions are **not permitted** beneath any NZKS farm	**Sediments that are anoxic and azoic** (i.e. no life present) will not be permitted.



ES≤5

ES≤6? ?

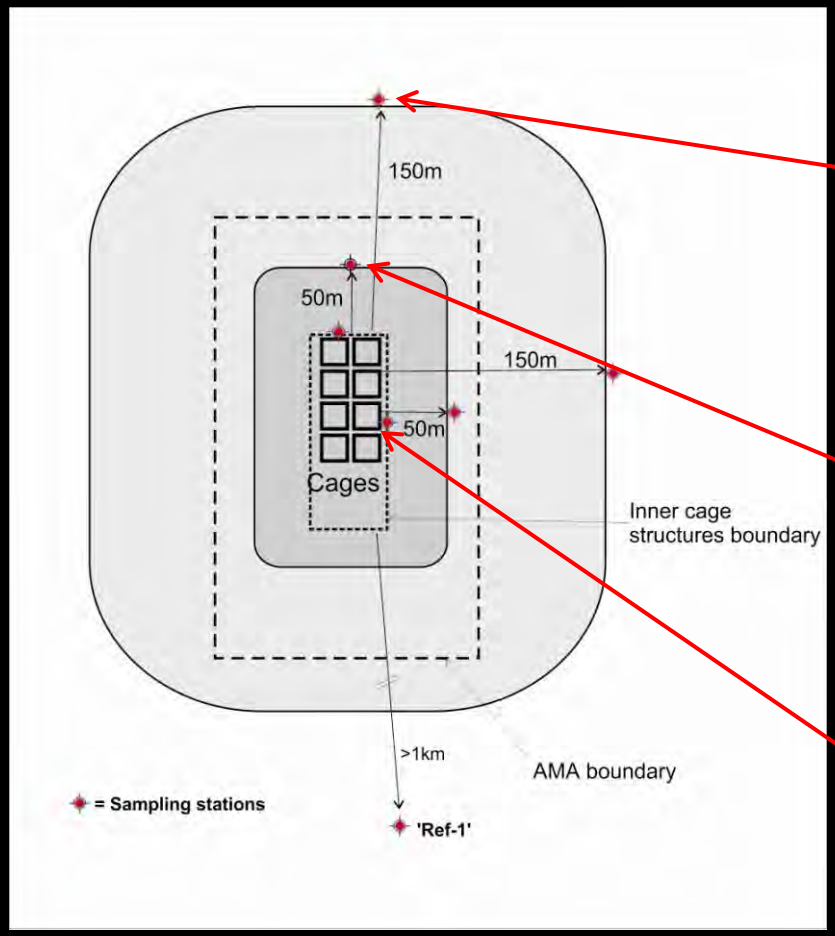
ES ≤ 3.5-4 50m

ES≤3 150m
+comparable to Ref

The problem → The ES variable → Characterising taxa for biotic indices → Flow specificity → Find best indicators → Using relationships to derive ES → Points of contention

1. Where to monitor?

-worst case, spatial extent, or both?



150m and beyond (Zone 3-4 Bdry)

- Delineates true outer extent of effects
- 'Natural' conditions expected
- 'Zone of reasonable mixing' RMA Section 70/107

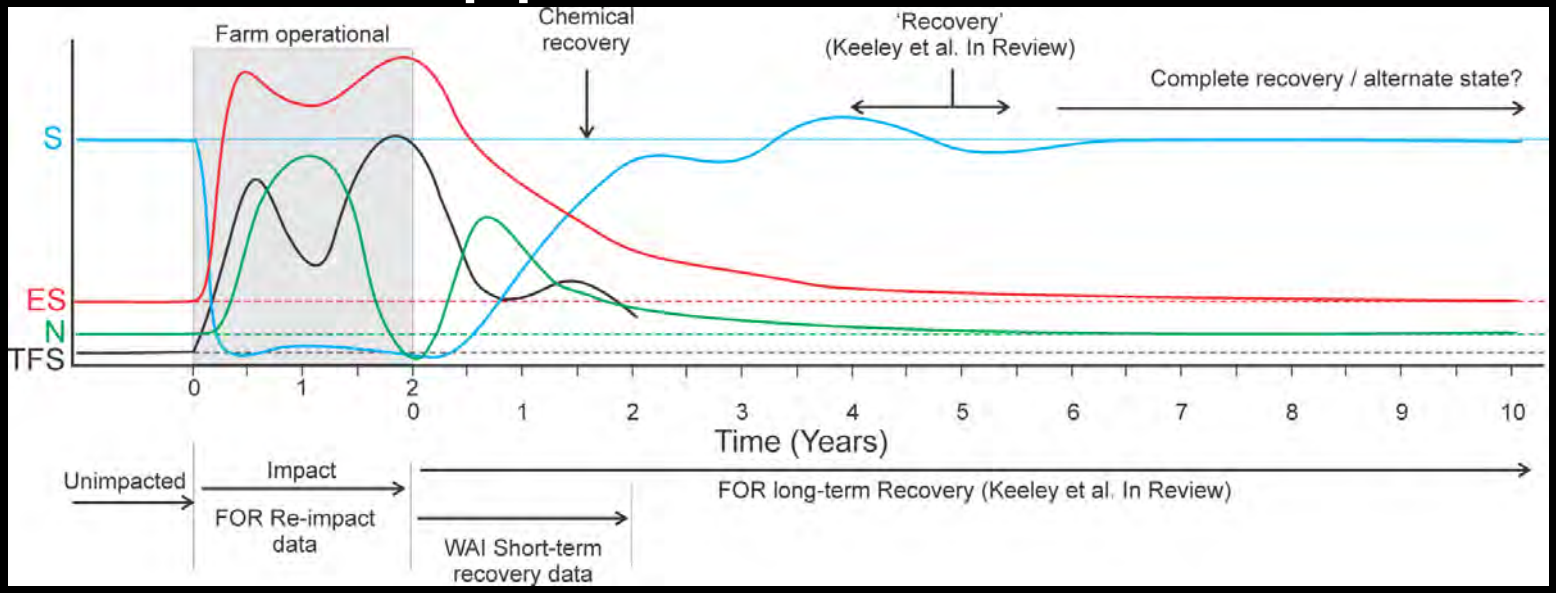
50m to 150m (Zone 2-3 Bdry)

- Delineates extent of 'highly impacted' area
- Consistent with 'AZE' (international acceptable zone of effects, i.e. 30m-50m)

At / beneath Cages (Zone 1-2 Bdry)

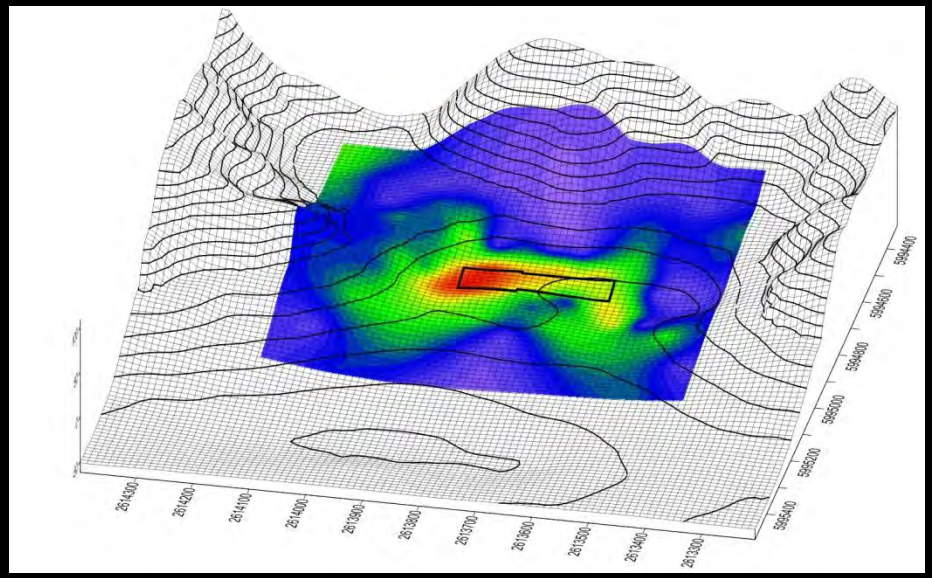
- Monitor worst case scenario
- Goal of maintaining functional / productive macrofauna
- Can avoid accumulative state
- Permanent occupation - sustainability

2. What happens ES>5 – low flow?

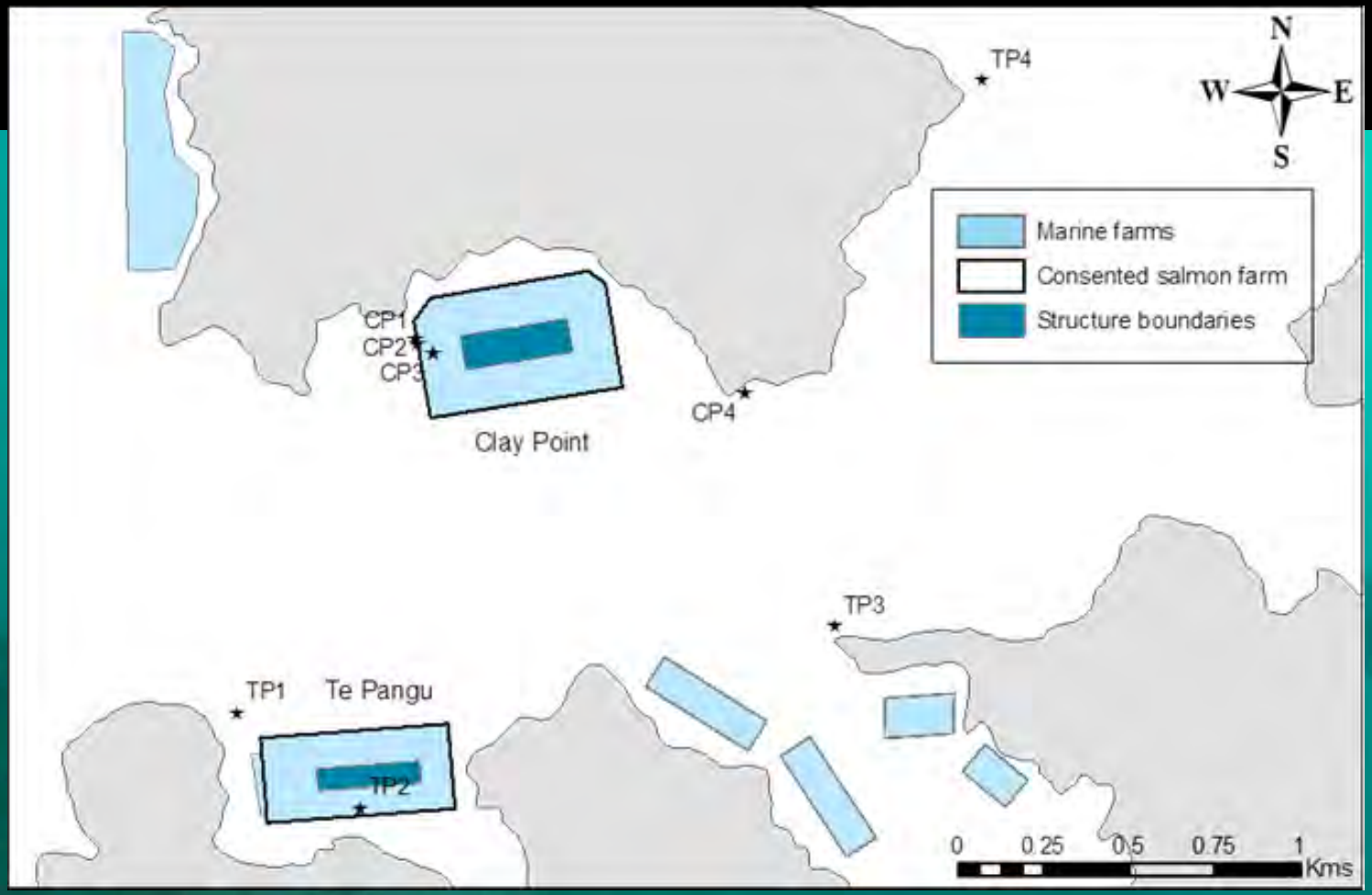


- The local seabed effects are reversible
- Wider ecological consequences not evident
- ES6-7 difficult to avoid – relatively low production levels
- Time spent in a accumulative phase prolongs recovery – by ~1 year?
- Production issues & risk of 'souring' a site

3. What happens ES>5 – high flow?



- Larger footprint (2 to 4 times – out to ~300-600m)
- More diffuse footprint – minimal organic accumulation (ES>5 rare)
- Can sustain high production levels = larger discharges to ecosystem
- Reversibility not studied, but assumed more rapid
- Reef communities 100-200m away remain unaffected


N
W
E
S
TP4
Marine farms
Consented salmon farm
Structure boundaries
CP1
CP2
CP3
CP4
Clay Point
TP3
TP1
Te Pangu
TP2
0
0.25
0.5
0.75
1
Kms

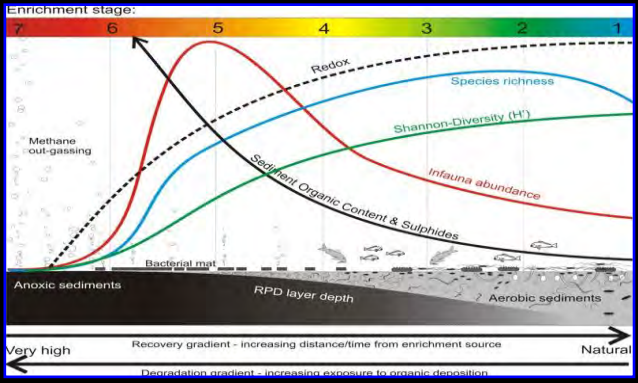

Marine farms
Consented salmon farm
Structure boundaries
Clay Point
Te Pangu

Summary & future directions

- Developed a quantitative way to unify indicators and characterise effects
- ES is a conceptual approach, but quantifiable and underpinned by established, robust indicators
  - Flexible - can add / replace cheaper, better indicators once proven
  - Other potential applications
- Greater understanding and improved ability to measure of effects
- Highlighted need to determine appropriate standards for marine farming

Acknowledgements:
-Internally funded by Cawthron Institute
-Support from:
University of Tasmania
New Zealand King Salmon Company Ltd
-PhD supervisors: Catriona Macleod, Barrie Forrest, Christine Crawford, Chris Cromey, Mark Gibbs.

Development of a high-throughput molecular tool for rapid and cost-effective environmental monitoring of finfish farms



XAVIER POCHON[1], JAN PAWLOWSKI[2], NIGEL KEELEY[1], **SUSIE WOOD[1]**

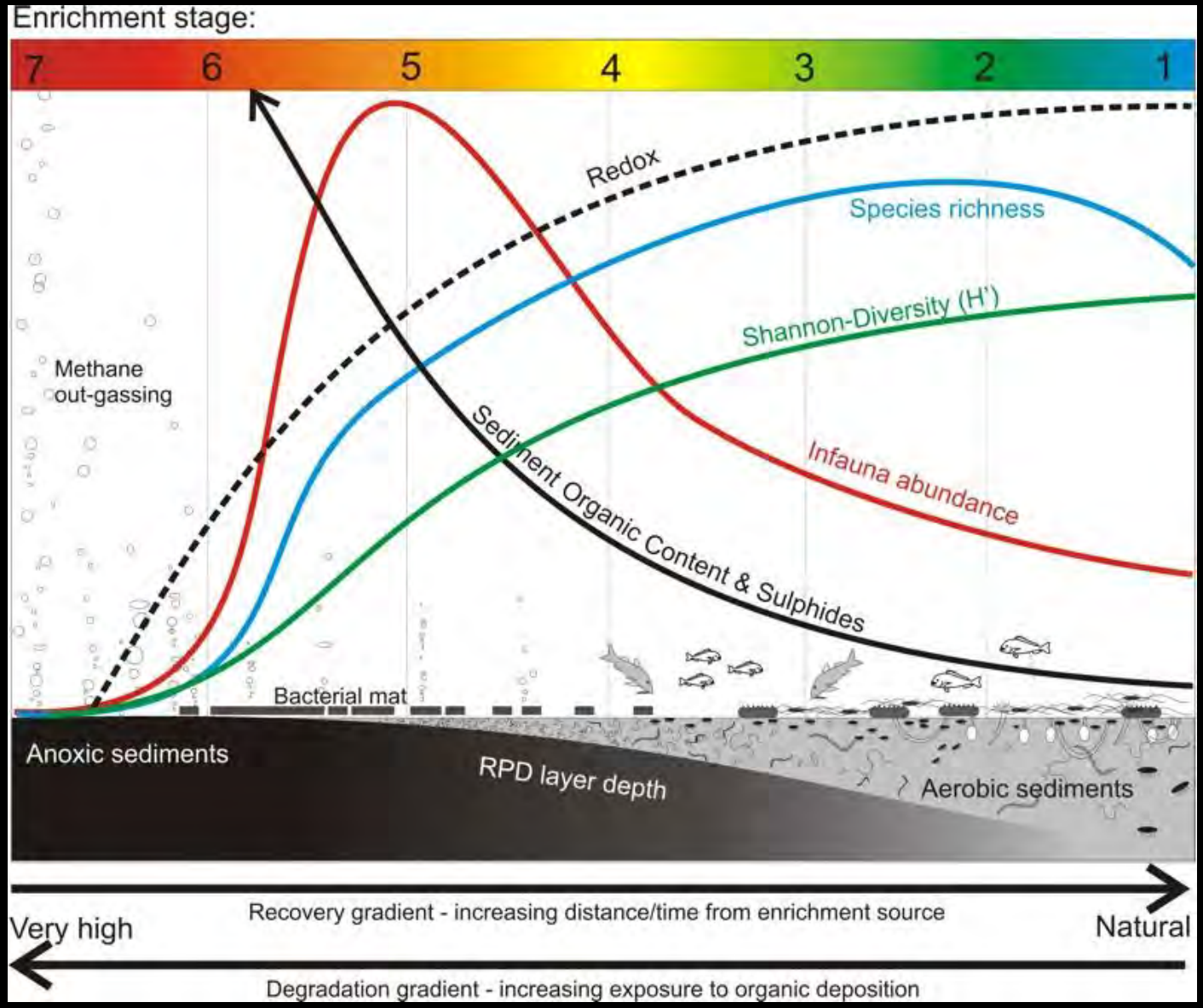
1. Cawthron Institute, 98 Halifax St East, Nelson, New Zealand
2. University of Geneva, Geneva, Switzerland

CAWTHRON INSTITUTE

Ministry of Business, Innovation & Employment

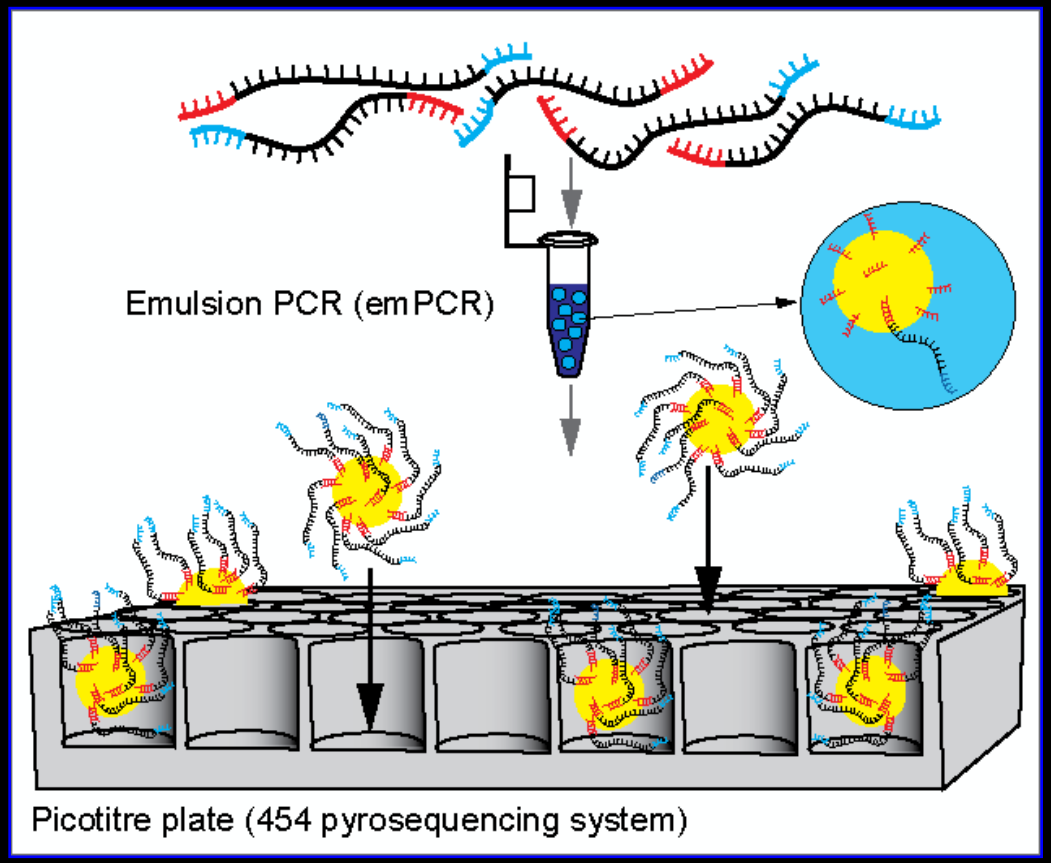
UNIVERSITÉ DE GENÈVE

Biomonitoring



Labor intensive, expensive, and slow turnaround

Next-Generation Sequencing



- High-throughput
- Parallelize sequencing
- <Millions of reads at once
- Low-cost sequencing
- Multiplex capability
- Multiple species detection (Metabarcoding)

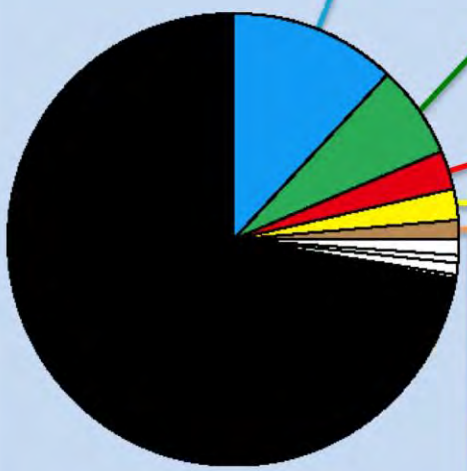
Mass sequencing

Stripped Science

by Viktor S. Poór

```
3415b_allogromiid_WE  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGAATTGTTTTT--CTTTTAAAA----------------------
3416a_allogromiid_WE  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGAATTGTTTTT--CTTTTAAAA----------------------
3416b_allogromiid_WE  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGAATTGTTTTT--CTTTTAAAA----------------------
3541_Saccammina.spha  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGTTTTGTTTCTTTTTTATTTTTTTAAATTAGA------------
3530_Saccammina.spha  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGTTTTGTTTCTTTTTTATTTTTTTAAATTAGA------------
3529_Saccammina.spha  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGTTTTGTTTCTTTTTTATTTTTTTAAATTAGA------------
2656_Rhabdammina.dis  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGAATTGCTTTTTTTTTTTAATNATTTTTTTATTTTAAAATAAAAA
2655_Rhabdammina.dis  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGAATTGCTTTTTTTTTTATT--ATTTTTTTATTTWAAAATAAAAA
4724.1_H.indivisa_SV  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGAATTTTTTTT-ATTTTTTTATAAAA----------------
4643.2_H.indivisa_SV  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGAATTTTTTT--ATTTTCTTATAAAA----------------
4643.1_H.indivisa_SV  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGAATTTTTTTTTATTTTTTTATAAAA----------------
4645.1_H.indivisa_SV  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGAATTTTTTTT-ATTTTTTTATAAAA----------------
4645.2_H.indivisa_SV  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGAATTTTTTTT-ATTTTTTTATAAAA----------------
4859.1_H.indivisa_SV  GGGTCCGGACACACTGAGGATTGACAGGCAATC---ATGTGAATTTTTTTT-ATTTTCTTATAAAA----------------
2357_Cylindrogullmia  GGGTCCGGACACACTGAGGATTGACAGGCAACA---ACGCAGACTTTTTAAA--------------------------------
2356_C.alba_Tjärno    GGGTCCGGACACACTGAGGATTGACAGGCAACA---ACGCAGACTTTTTAAA--------------------------------
3999_C.alba_DML       GGGTCCGGACACACTGAGGATTGACAGGCAACA---ACGCAGACTTTTTAAA--------------------------------
4000_C.alba_DML       GGGTCCGGACACACTGAGGATTGACAGGCAACA---ACGCAGACTTTTTAAA--------------------------------
4010_C.alba_DML       GGGTCCGGACACACTGAGGATTGACAGGCAACA---ACGCAGACTTTTTAAA--------------------------------
4729_C.alba_SV        GGGTCCGGACACACTGAGGATTGACAGGCAACA---ATGCAGGCAGACTATTTTTAGTCA------------------------
4682_C.alba_SV        GGGTCCGGACACACTGAGGATTGACAGGCAACA---ATGCAGGCAGACTATTTTTAGTCA------------------------
4634_C.alba_SV        GGGTCCGGACACACTGAGGATTGACAGGCAACA---ATGCAGGCAGACTATTTTTAGTCA------------------------
4639_C.alba_SV        GGGTCCGGACACACTGAGGATTGACAGGCAACA---ATGCAGGCAGACTATTTTTAGTCA------------------------
4613_C.alba_SV        GGGTCCGGACACACTGAGGATTGACAGGCAACA---ATGCAGGCAGACTATTTTTAGTCA------------------------
5062.5_Cylindrogullm  GGGTCCGGACACACTGAGGATTGACAGGCAACA---ATGCAGGCAGACTATTTTTAGTCA------------------------
4894.1_Cylindrogullm  GGGTCCGGACACACTGAGGATTGACAGGCAACC---ATGGGTTTGTTGCGCCGCCGAACTCGCGTTT------------------
4894.2_Cylindrogullm  GGGTCCGGACACACTGAGGATTGACAGGCAACC---ATGGGTTTGTTGCGCCGCCGAACTCGCGTTT------------------
7896_Lagenammina.are  GGGTCCGGACACACTGAGGATTGACAGGCAACC---ATGCAGTGTTTTAATTTAACTATTATTA----------------------
7898_Lagenammina.are  GGGTCCGGACACACTGAGGATTGACAGGCAACC---ATGCAGTGTTTTAATTTAACTATTATTA----------------------
5226_Leptammina_WED   GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGCTAACAGTTTCTTTTTTTTT--------------------------
5174b_Leptammina_WED  GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGCTAACAGTTTCTTTTTTTTT--------------------------
5174a_Leptammina_WED  GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGCTAACAGTTTCTTTTTTTTT--------------------------
3352a-_Leptammina_WE  GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGCTAACAGTTTCTTTTTTTTT--------------------------
3352b_Leptammina_WED  GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGCTAACAGTTTCTTTTTTT----------------------------
3353a--_Leptammina_W  GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGCTAACAGTGTCTTTTTTTTTT-------------------------
3353b_Leptammina_WED  GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGCTAACAGTGTCTTTTTTTTTT-------------------------
3356a_Leptammina_WED  GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGTGCTTTGTAACTTTTTTTT----------------------------
3356b_Leptammina_WED  GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGTGCTTTGTAACTTTTTTTT----------------------------
3357a_Leptammina_WED  GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGTGCTTTGTAACTTTTTTT-----------------------------
3357b_Leptammina_WED  GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGTGCTTTGTAACTTTTTTT-----------------------------
3360a_Leptammina_WED  GGGTCCGGACACATTGAGGATTGACAGGCAATT---ATTGTGCTTTGTAACTTTTTTT-----------------------------
3360b_Leptammina_WED  GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGTGCTTTGTAACTTTTTTT-----------------------------
10541-6_Spiculosipho  GGGTCCGGACACACTGAGGATTGACGGGCAATT---ATTGCTTTTGAGTTTTTTTTTTTTTTTT--------------------
10542-14_Spiculosiph  GGGTCCGGACACACTGAGGATTGACAGGCAATT---ATTGCTTTTGAGTTTTTTTTTTTTTTTT--------------------
```

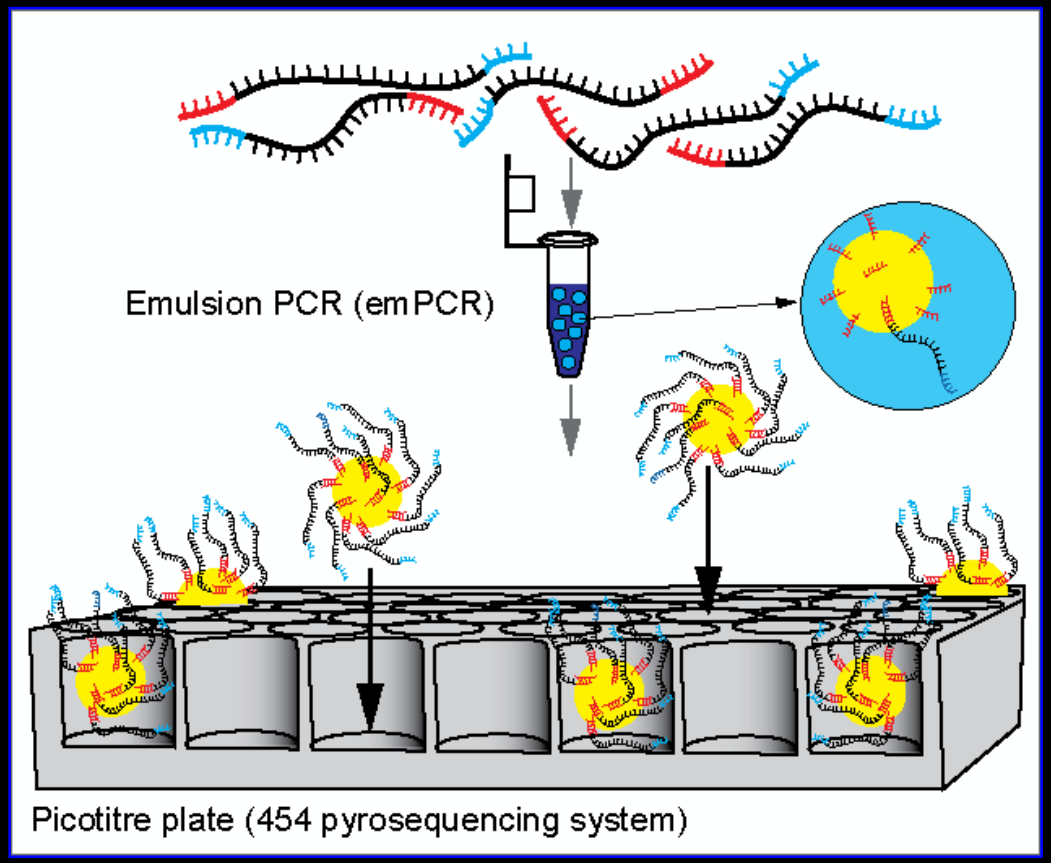
Biodiversity in Tasman Bay Water



31 Families	36 Genera	42 Species
Anthessiidae	Anthessius	*Anthessius* sp.
Balanidae	Elminius	*Elminius modestus*
Calanidae	Limnocalanus	*Limnocalanus macrurus*
Euterpinidae	Euterpina	*Euterpina acutifrons*
Oithonidae	Oithona	*Oithona sp.*
Peltidiidae	Alteuthellopsis	*Alteuthellopsis* sp.
Sididae	Penilia	*Penilia avirostris*
Bodotriidae	Vaunthompsonia	*Vaunthampsonia minor*
Ceratiaceae	Neoceratium	*Ceratium fusus*
Dinophysiaceae	Ceratium	*Ceratium tenue*
Gonyaulacaceae	Dinophysis	*Ceratium furca*
Oxytoxaceae	Gonyaulax	*Dinophysis* sp.
Peridiniaceae	Alexandrium	*Gonyaulax spinifera*
Podolampaceae	Thecadinium	*Gonyaulax polygramma*
Prorocentraceae	Gotoius	*Alexandrium affine*
	Protoperidinium	*Alexandrium margaelefii*
	Scrippsiella	*Thecadinium dragescoi*
	Roscoffia	*Gotoius excentricus*
	Prorocentrum	*Protoperidinium crassipes*
		Protoperidinium elegans
		Protoperidinium punctulatum
		Scrippsiella trochoidea
		Roscoffia capitata
		Prorocentrum donghaiense
		Prorocentrum micans
Amphibolidae	Amphibola	*Amphibola crenata*
Veneridae	Venus	*Venus verrucosa*
Hiatellidae	Hiatella	*Hiatella arctica*
Limidae	Limaria	*Limaria hians*
Mesodesmatidae	Paphies	*Paphies subtriangulata*
Myidae	Mya	*Mya truncata*
Mytilidae	Perna	*Perna* sp.
Semelidae	Abra	*Abra alba*
Siphonariidae	Kerguelenella	*Kerguelenella lateralis*
Veneridae	Austrovenus	*Austrovenus stutchburyi*
	Chamelea	*Chamelea gallina*
Asteriidae	Asterias	*Asterias* sp.
Spionidae	Aurospio	*Aurospio dibranchiata*
Hesionidae	Ophiodromus	*Ophiodromus flexuosus*
Opheliidae	Ophelina	*Ophelina acuminata*
Sigalionidae	Neoleanira	*Neoleanira tetragona*
Sabellidae	Sabella	*Sabella* sp.

Arthropoda | Dinoflagellata | Mollusca | Echinodermata | Annelida

Next-Generation Sequencing



- High-throughput
- Parallelize sequencing
- <Millions of reads at once
- Low-cost sequencing
- Multiplex capability
- Multiple species detection (Metabarcoding)

Foraminifera for Finfish Monitoring

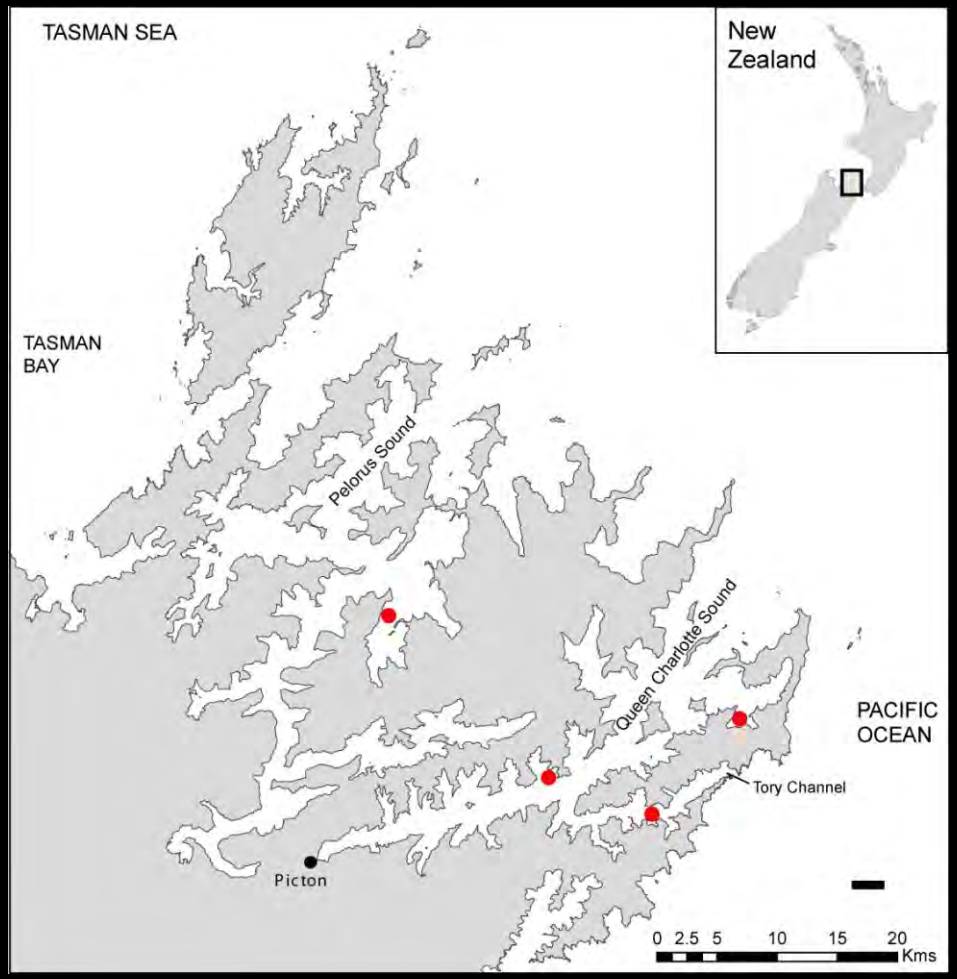
- Abundant
- Highly responsive to pollution
- Specific markers/probes available
- Foraminiferal community index (FCI)
- Reduce analysis costs & turnaround time

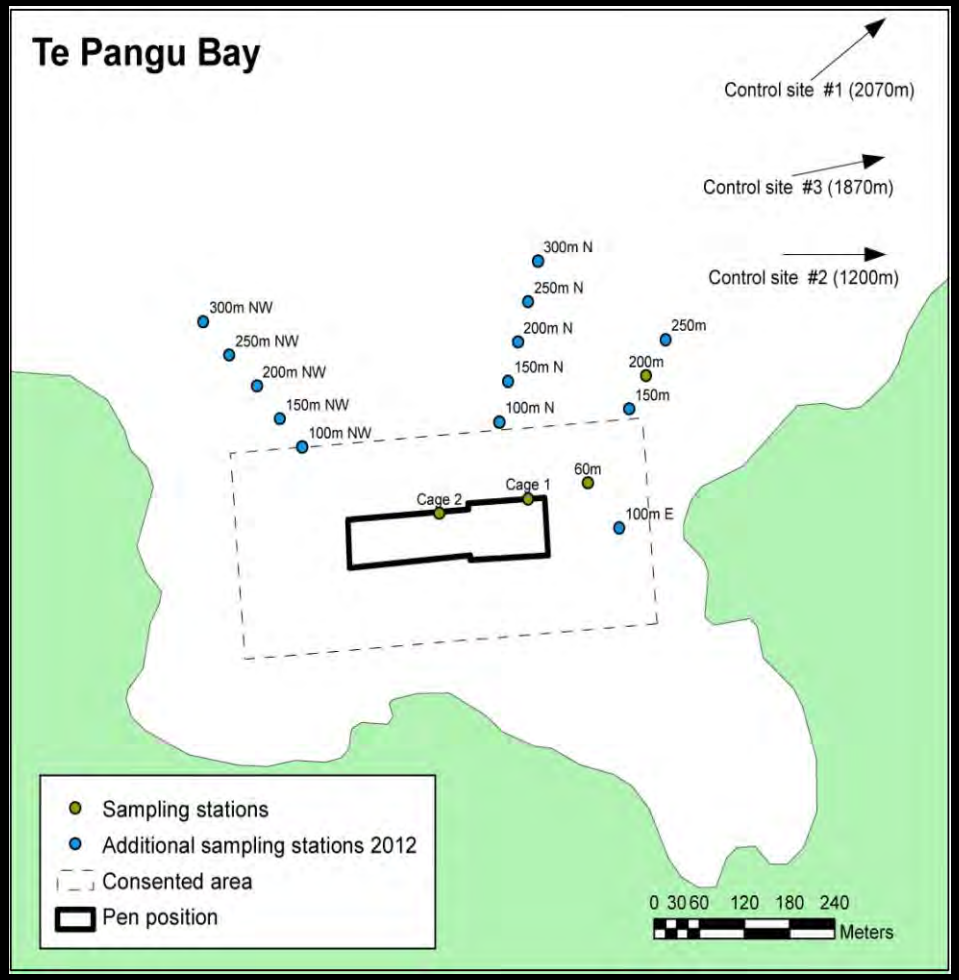
Funding - Smart Idea – MBIE project

Title: Development of a high-throughput molecular tool for rapid and cost-effective environmental monitoring of finfish farms.

Start date and finish date: 01/10/2012-30/09/2014

Sampling





- 4 salmon farms in Marlborough Sounds
- Low-flow and high-flow sites

- Collection of samples across gradients
- Triplicate sampling

Research Plan

SAMPLING
Nov'12

Forams ID

Core sediment

Genetic ID
Jan'13

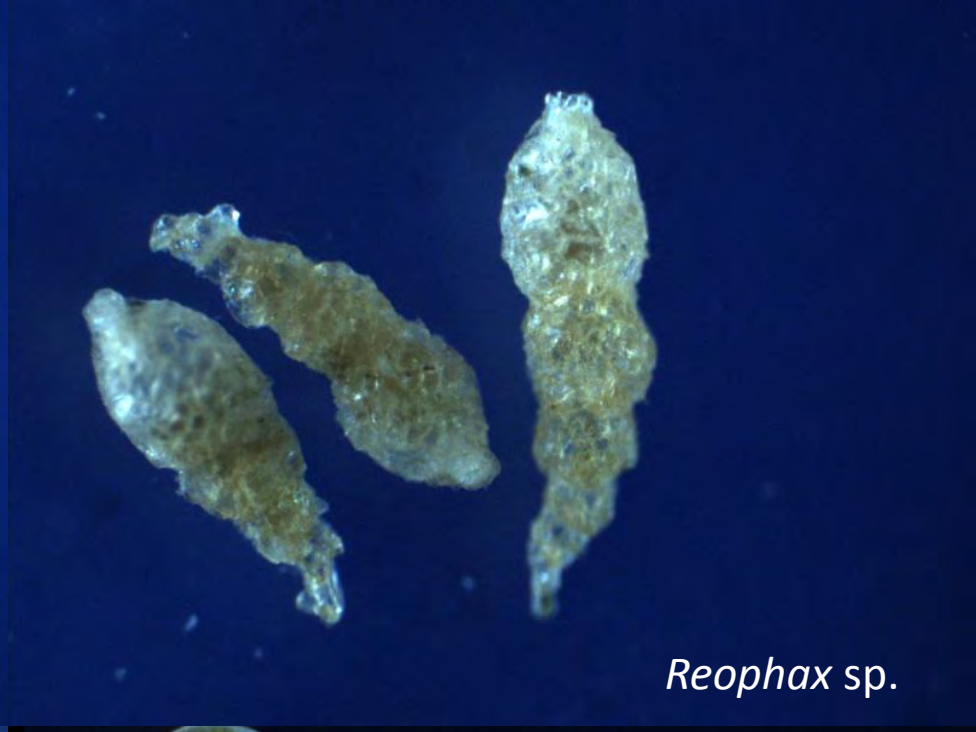
Database
Mar'13

foramBARCODING
Molecular Database of Foraminifera

http://forambarcoding.unige.ch/

Contributed sequences for ~50 NZ species


Notorotalia sp.


Reophax sp.


Rosalina sp.


Nonionella sp.

Hirudinea sp.

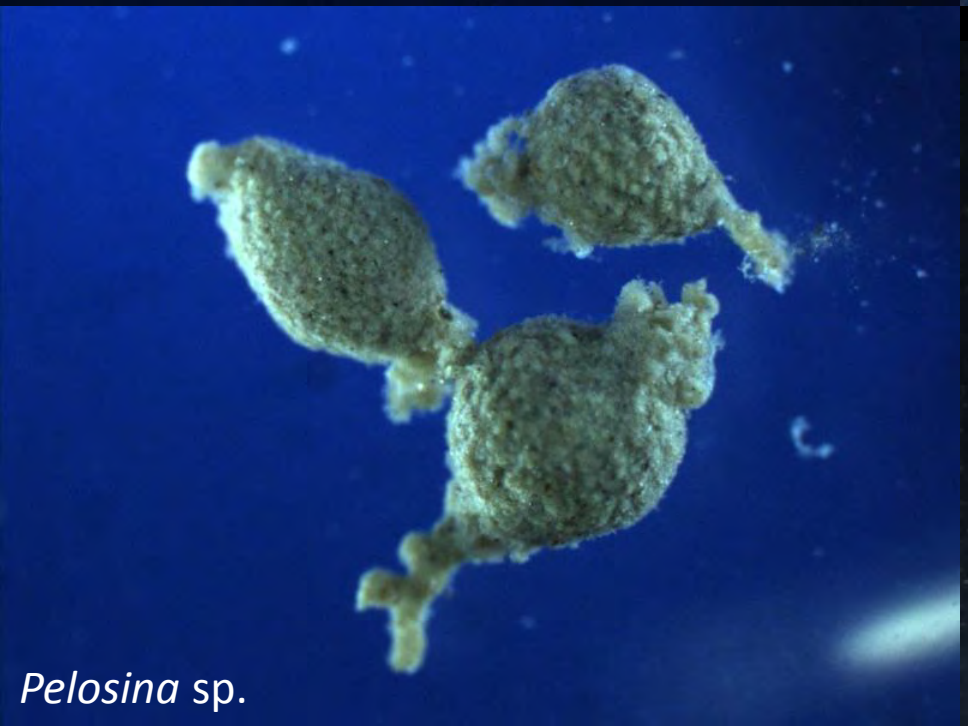
Bathysiphon sp.

Leptohyalis sp.

Hyperammina sp.


Psammophaga sp.


Crithionina hispida


Pelosina sp.


Pelosina sp.

Research Plan

SAMPLING

Forams ID

Core sediment

Genetic ID

Database

DNA / RNA extract

Mar'13

NGS

Jun'13

FCI

Nov'13

foramBARCODING

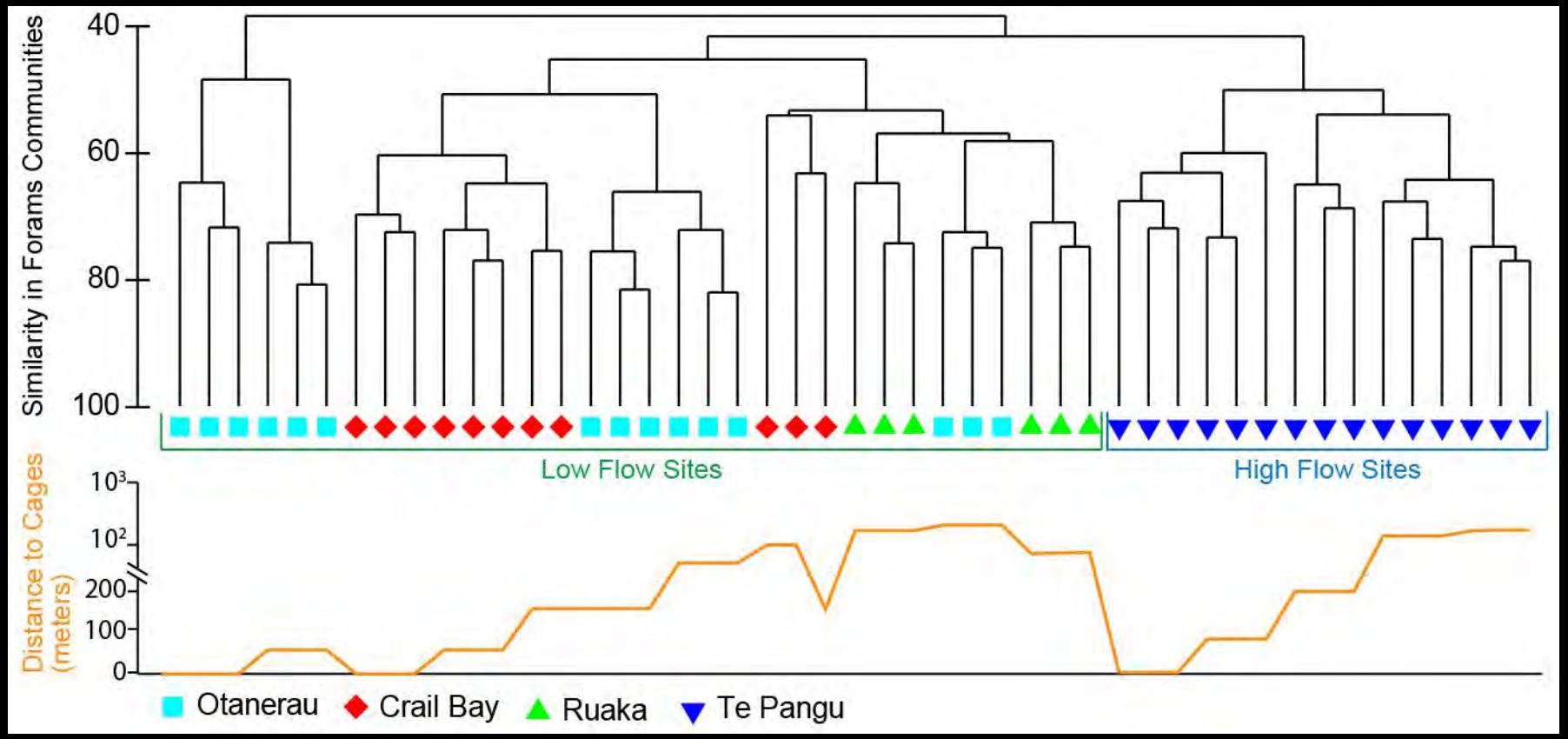
Molecular Database of Foraminifera

http://forambarcoding.unige.ch/

NGS Data – 120 Samples

NGS OUTPUT DATA	
Number of reads	7.7 Million
Number of reads after QC	2.6 Million (21k per sample)
Foram classes / orders / families / species	3 / 5 / 43 / 150

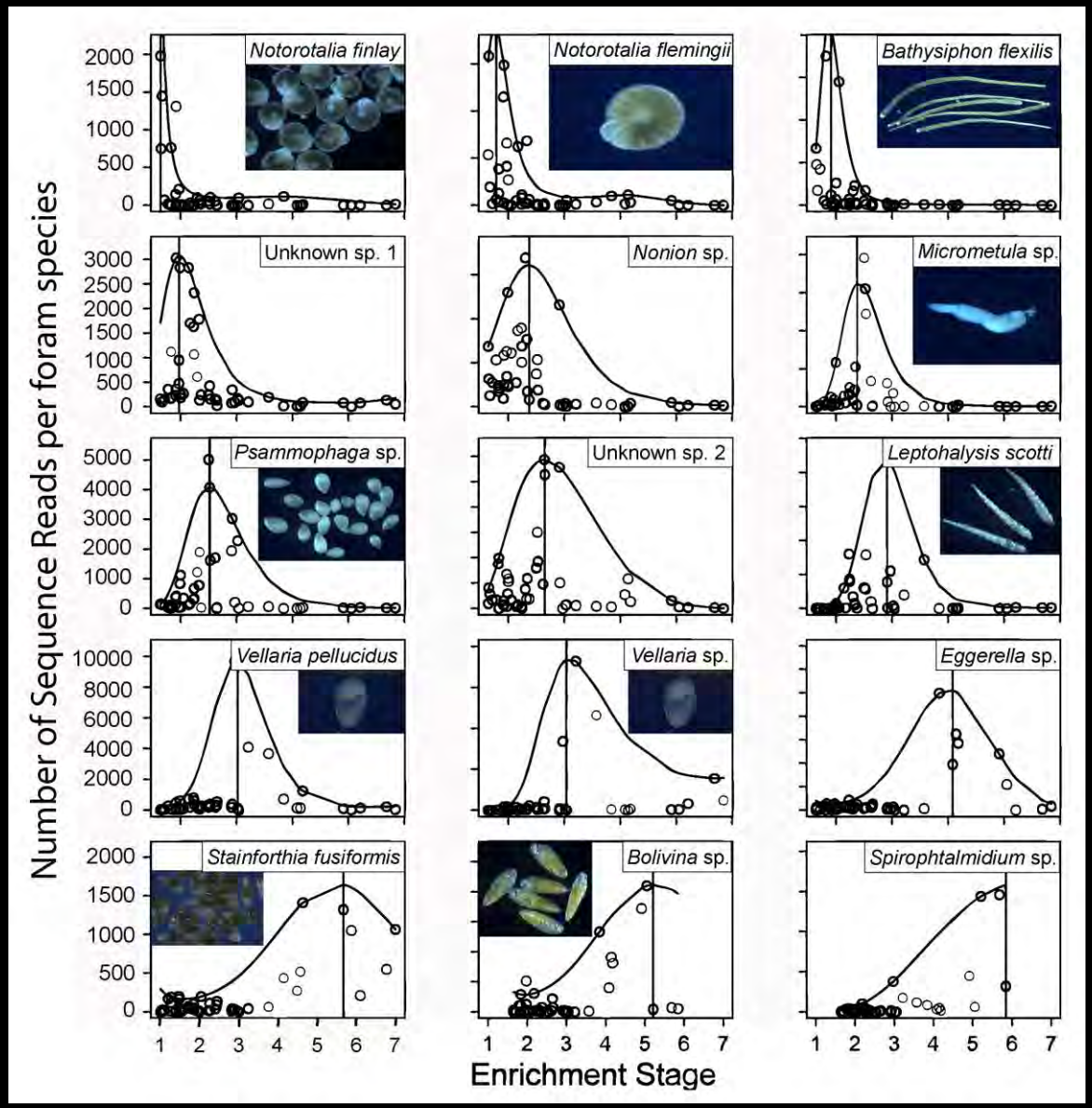
Community Structure



Foraminiferal communities are:

a) Very distinct between High and Low flow sites
b) Relatively unique within each farm
c) Well-partitioned by distance to cage

Abundance-ES Plots

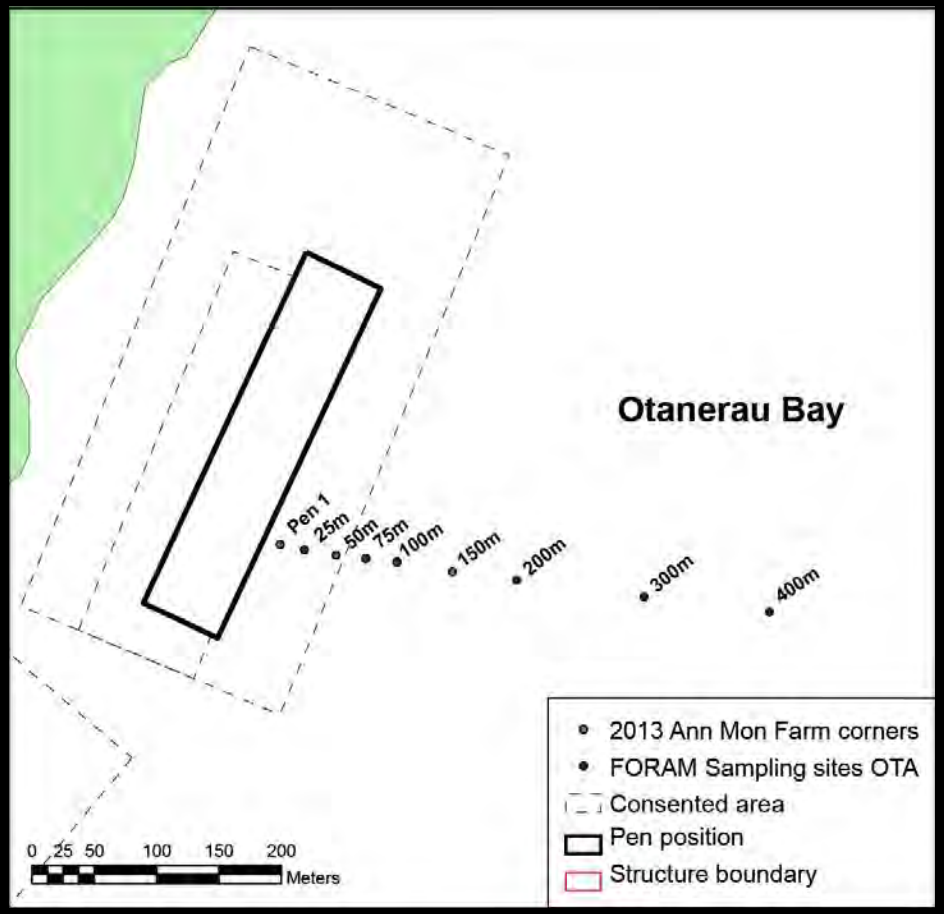


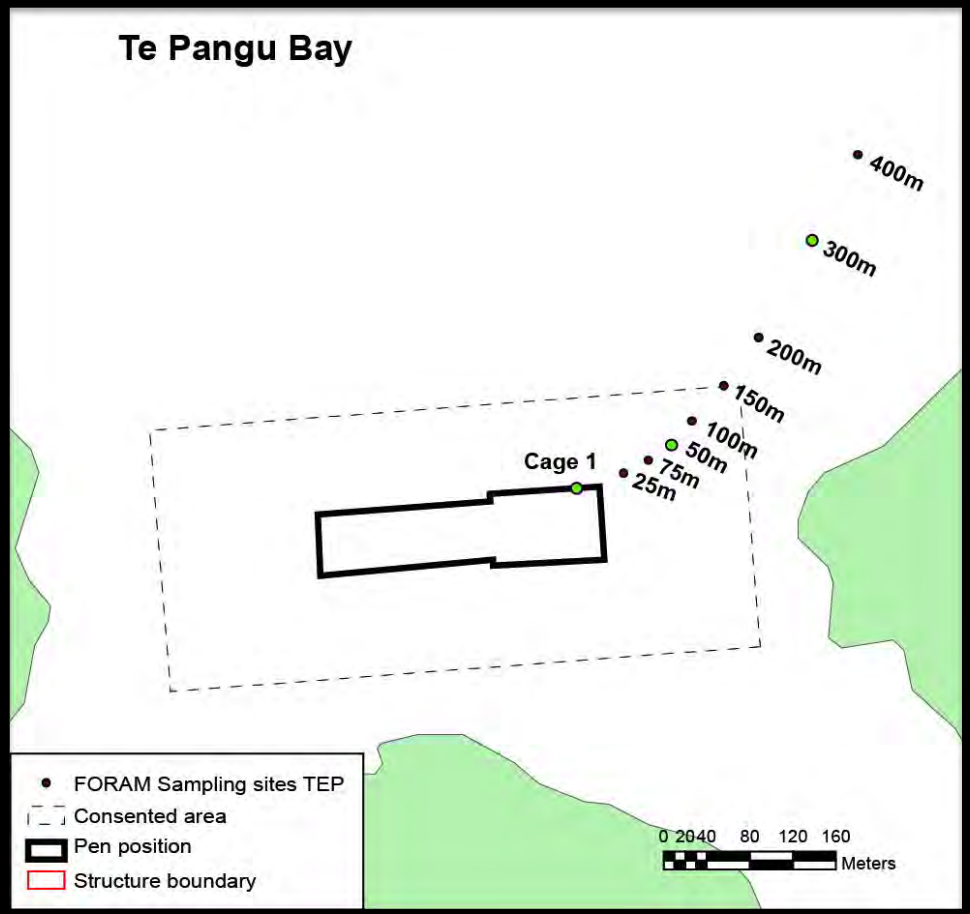
15 Key Bioindicator forams species identified:

From most sensitive (top left) to most opportunistic (bottom right).

Data will be used to generate the FCI

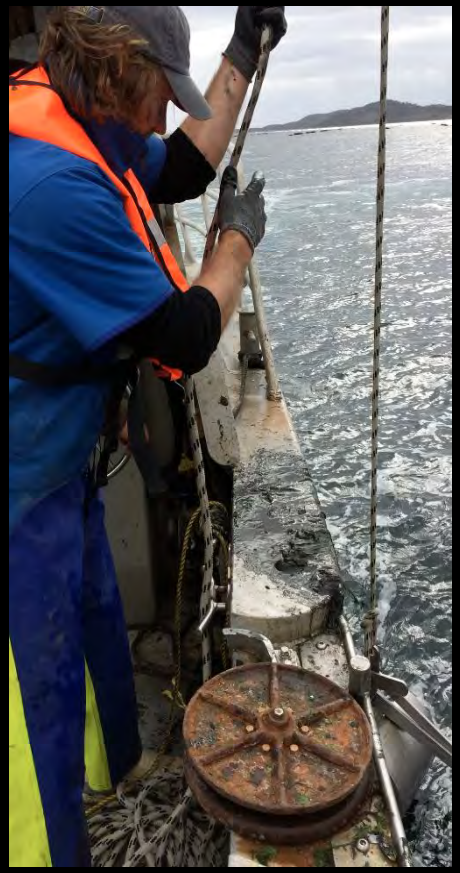
2013 Sampling





- Fine-scale community change between high and low flow environments
- Yearly comparison

2013 Sampling



- Test the tool in another NZ location

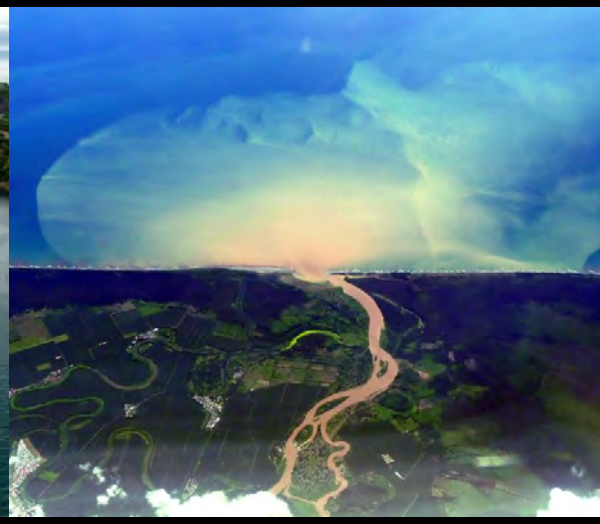
Summary

- Accurate / simultaneous detection >100 samples
- Tremendous potential for cost-effective monitoring
- Small sample size = faster collection
- Current research:
  a) Streamline analysis, b) Generate FCI
- Re-bid smart idea for Phase 2 (April 2014)

Future Potential

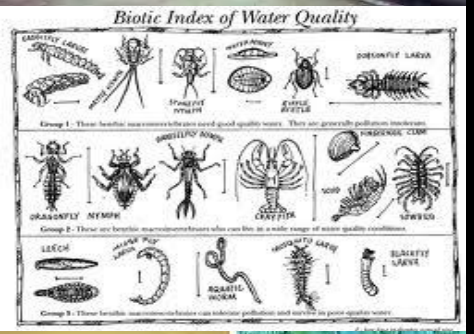
- Apply to other marine environmental monitoring and biodiversity assessments
    - Mining industry
    - Estuary health
    - Impact of point discharges
    - Toxic marine algae



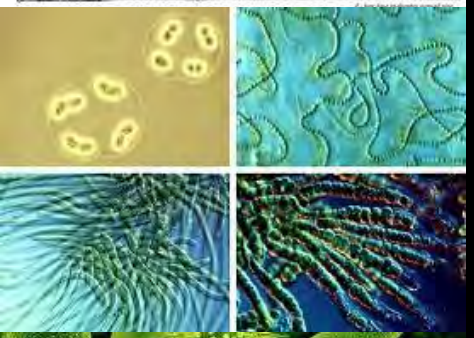


Other NGS Applications

Marine biosecurity - Biofouling communities



Macroinvertebrate Communities - Measure river health



Cyanobacterial Communities in lakes

Bacterial Communities in aquaculture larvae

Acknowledgments

New Zealand King Salmon
Sanford Limited

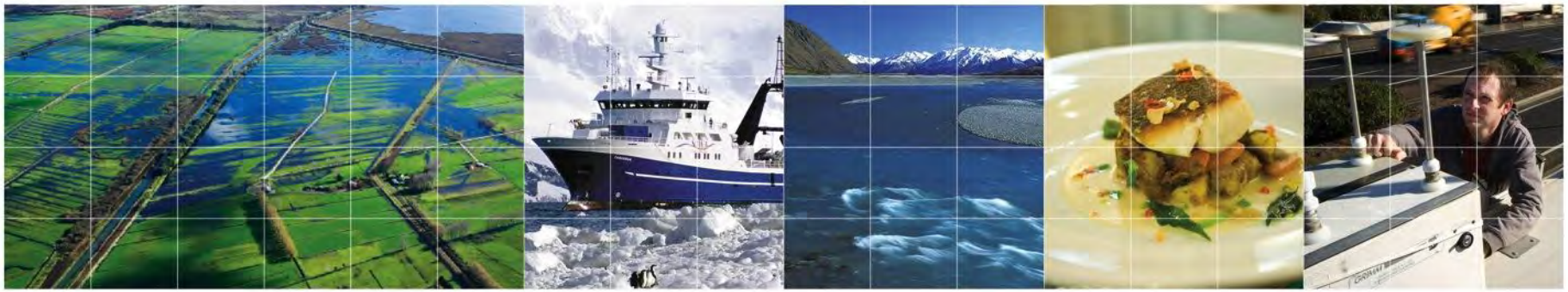
Maria Holzmann (University of Geneva)
Franck Lejzerowicz (University of Geneva)
Philippe Esling (University Paris VI)
Colomban de Vargas (CNRS, Roscoff, France)
Jonathan Drew (University of Otago)
Reid Forrest (Cawthron)

CAWTHRON INSTITUTE
Ministry of Business, Innovation & Employment
UNIVERSITÉ DE GENÈVE

Monitoring the water column in the coastal marine zone to detect effect and infer cause

Niall Broekhuizen

Marine Farm Monitoring Workshop; Nelson December 2013



Acknowledgements

- John Zeldis & team (NIWA)
- Karl Safi (NIWA)
- Max Gibbs (NIWA)
- Marlborough District Council
- MPI

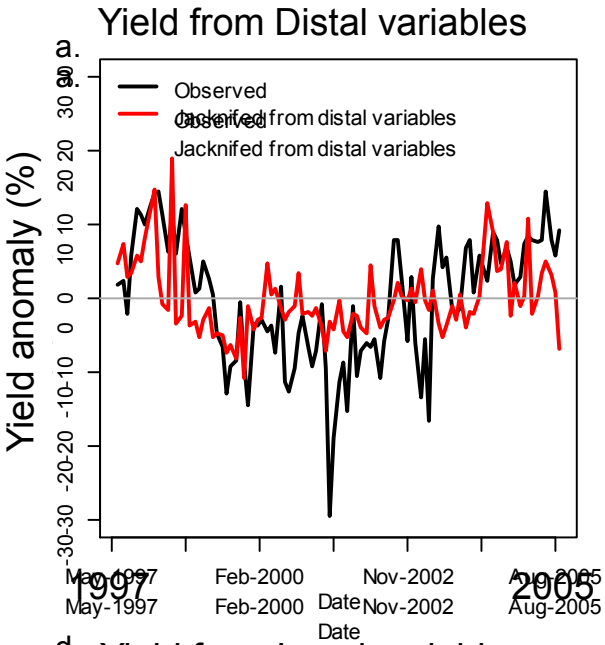
Contents

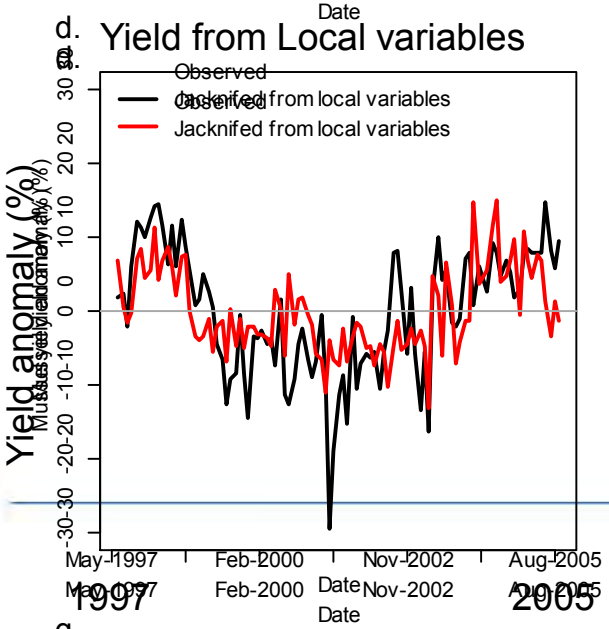
- Why monitor?
- Historical data from the Sounds
- Emerging technologies
- Modelling
- Interpreting the data

Why monitor?

- To provide objective evidence about whether a system is changing through time…
- To provide hints as to what may be driving any change …
- Up to society to determine:
  - what level of human induced change is acceptable
  - apportion ‘rights’ to induce a share of that quantum of acceptable change

Long term data gives insights





1st hypothesis accepted: distal variables can predict yield.

Summer

SOI + Wind* + (SOI:Wind)* + (Wind:Flow)**

Winter

SST + Flow**

2nd hypothesis accepted: local variables better predictors than distal.

Summer

*PN*** + Diat****

Winter

*PN****

Offers possibility that we will be able to forecast mussel yield… ongoing NIWA research

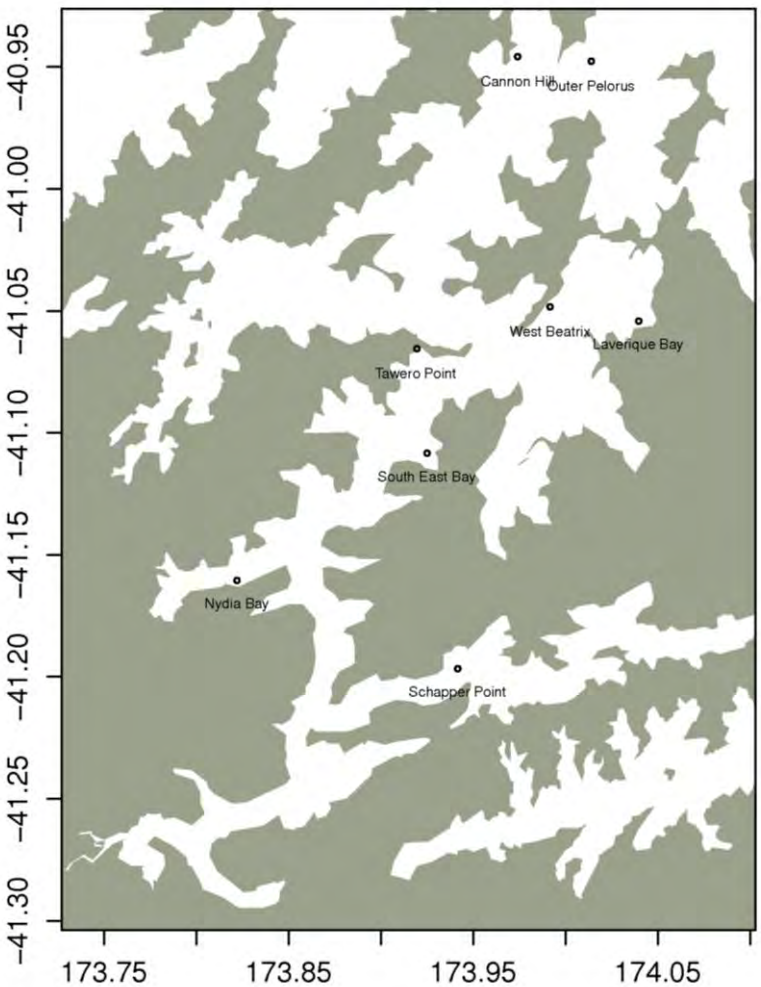
Zeldis et al. (2013) Aquaculture Environment Interactions 4:1-15

Historical data

- NIWA's data from Pelorus Sound
- NIWA's data from Queen Charlotte/Tory
- MDC data from Pelorus and Queen Charlotte/Tory
- Other data sources

NIWA's historical Pelorus data

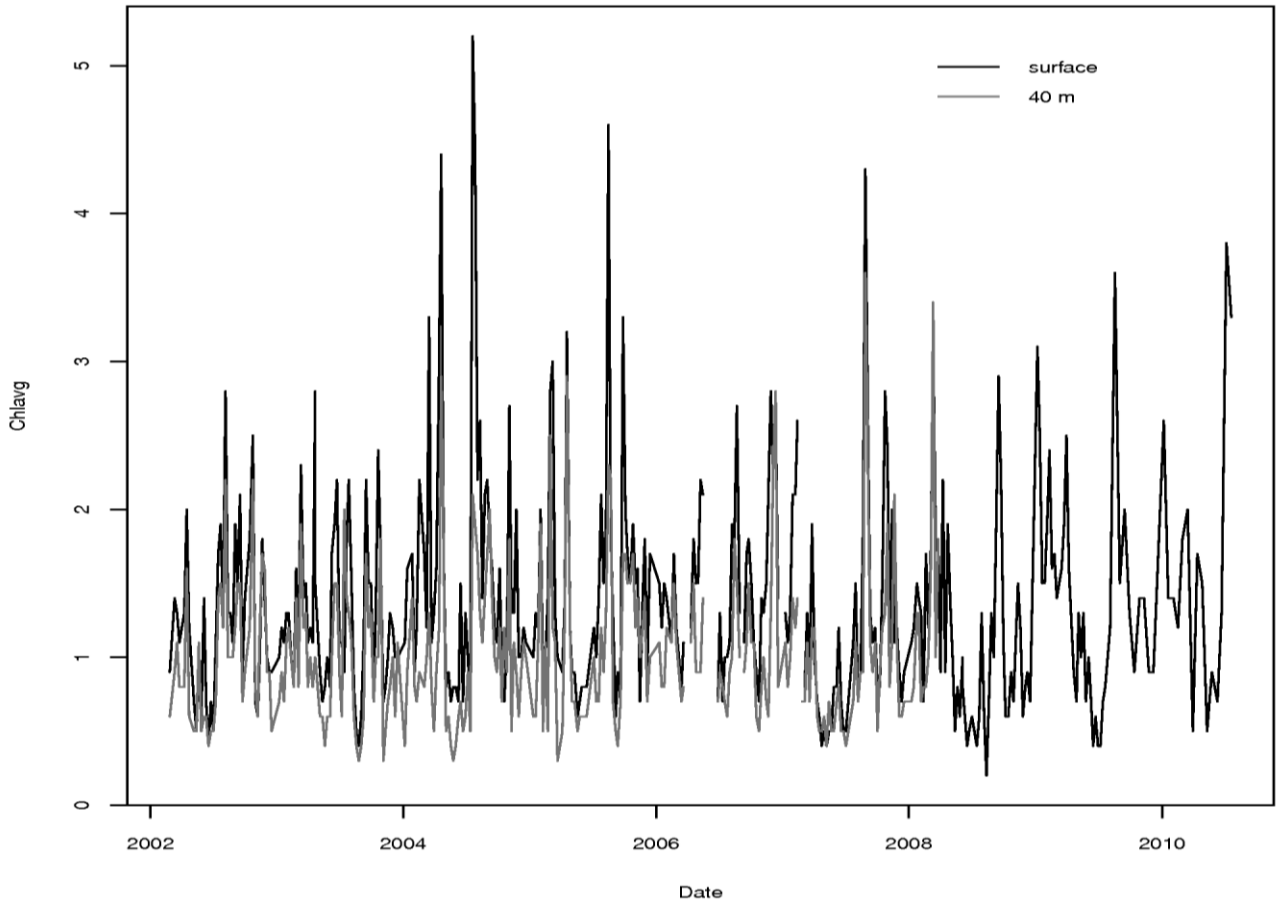
- 8 sites
- Time-series ranging from two-ish years to 10-ish years (~2000 - ~2010)
- Fortnightly resolution
- tube samples to 12 m



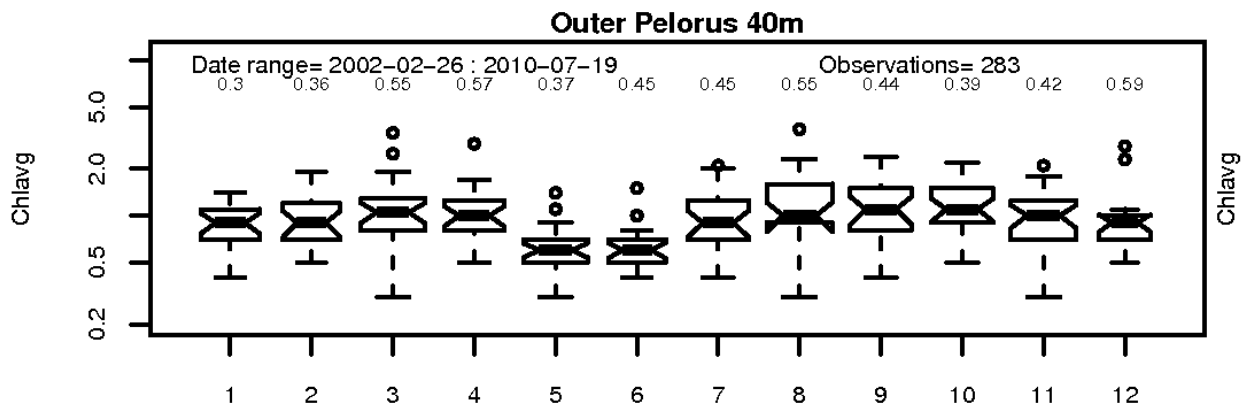
Quantities

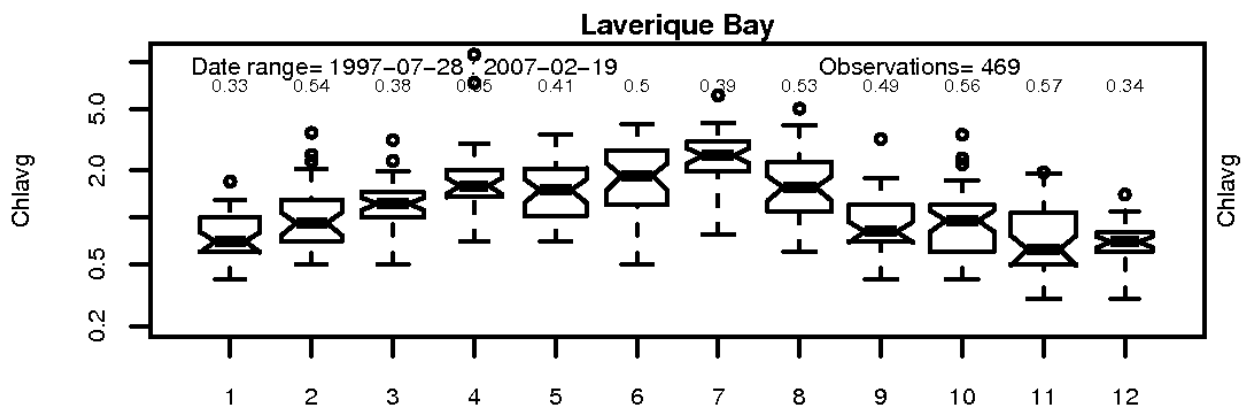
- NO3, NH4, DRP, DON, TDP, TDN,
- PC, PN, POC, PON, SS, SIS, VSS, turbidity
- Chlorophyll
- CTD casts (temperature, salinity)

Outer Pelorus Chlorophyll



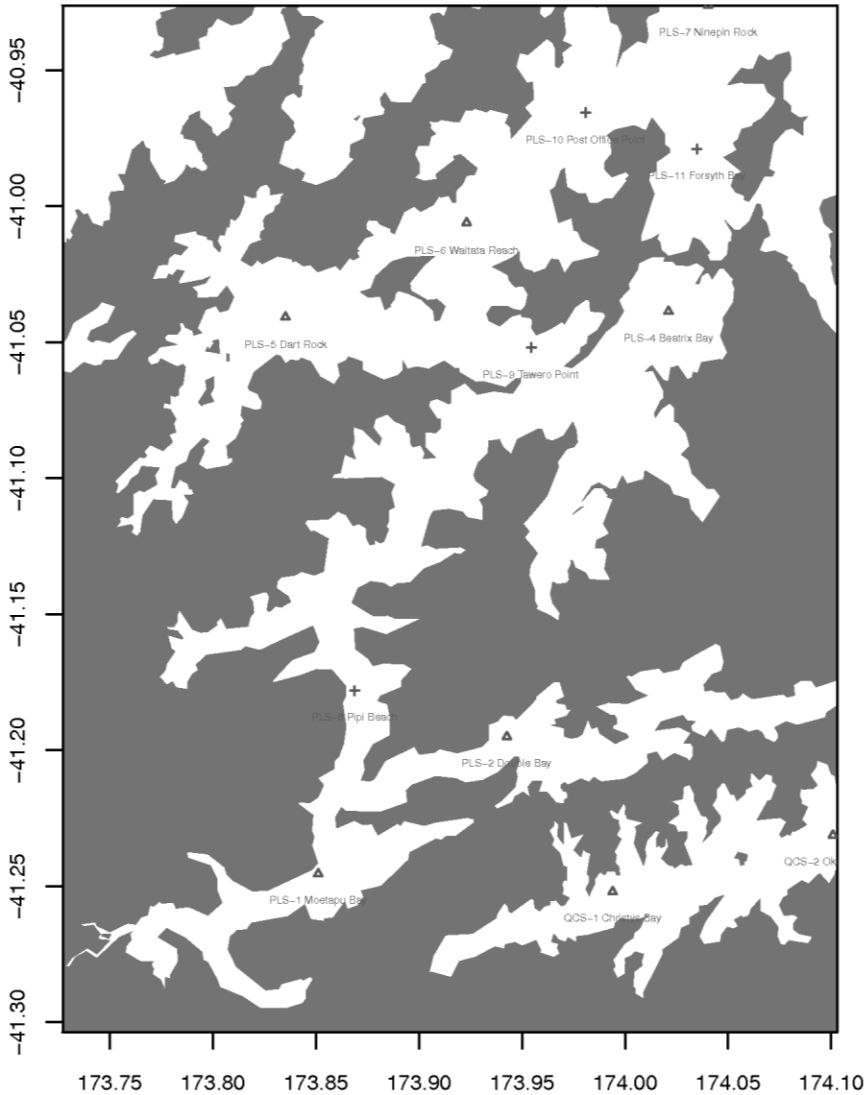
Can characterize what has been 'natural'…

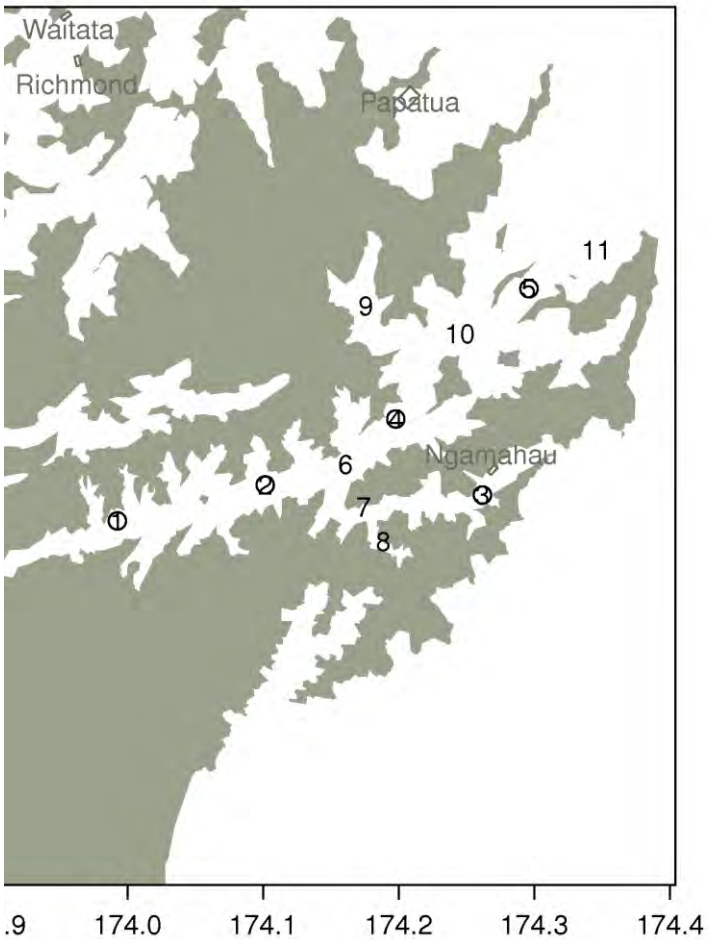




Marlborough District Council data

- Conceptually similar to the NIWA data
- QCS/Tory: July 2011 – present
- Pelorus: July 2012 – present
- Monthly resolution
- Bottle samples at 4 m below surface, and a few metres above bed





w Zealand's natural resources

NIWA
Taihoro Nukurangi

Other data sources

- Marlborough Shellfish Quality Programme (MSQP)
- NZKS historical data
- NZKS baseline data for the newly approved farms
- Cawthron Institute

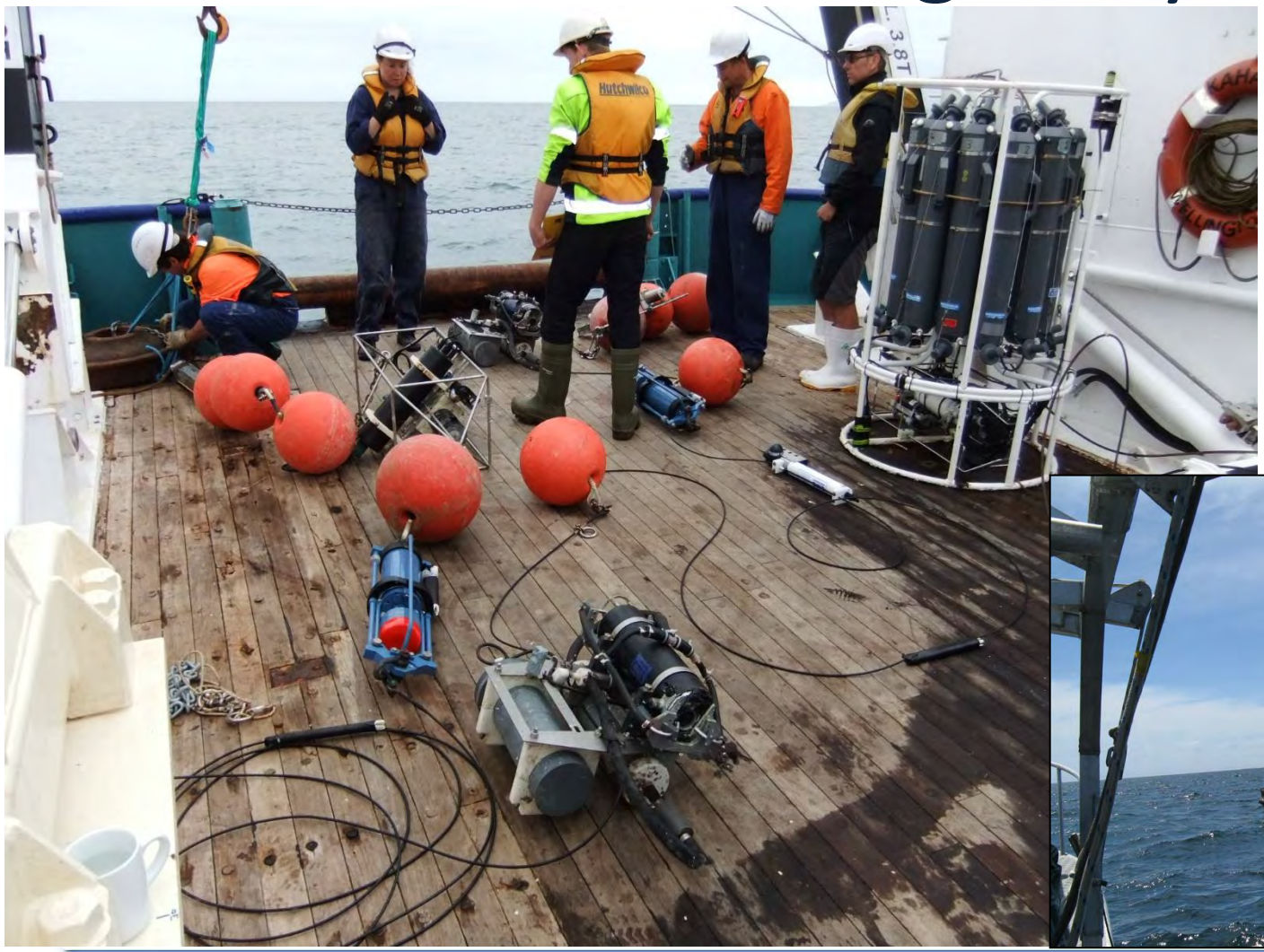
Conclusion

- By NZ standards, there are a lot of water quality data for Pelorus Sound and moderately large quantities for Queen Charlotte
- Marlborough District Council are ahead of the game
  - unlike almost all other regions they have a coastal water-quality monitoring scheme in place (with help from MPI)

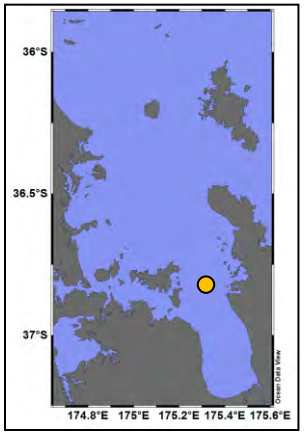
Emerging Technologies

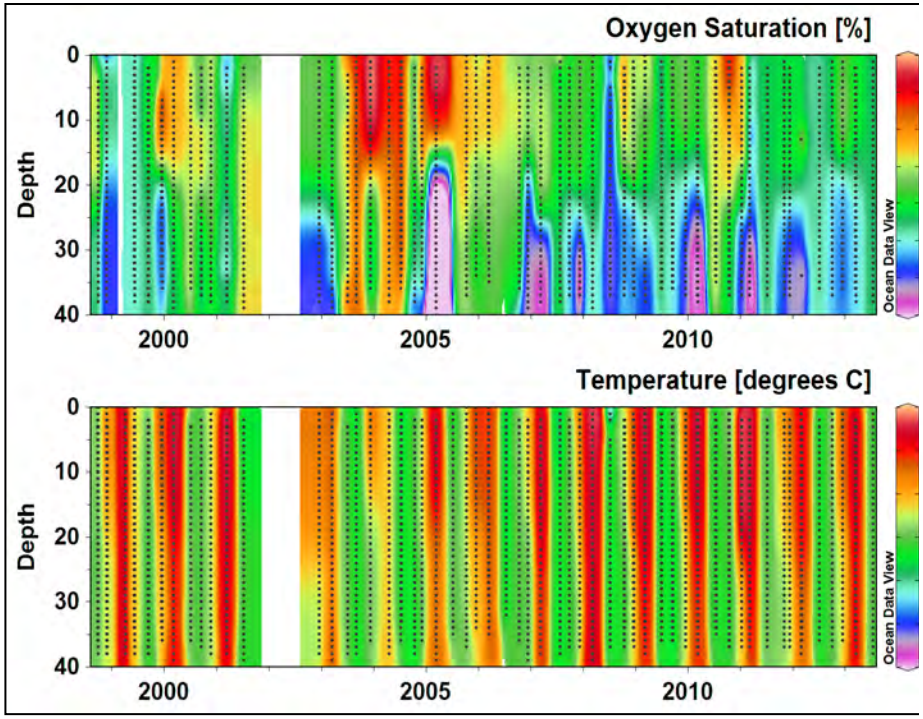
- Monitoring buoys
- Remote sensing
- FlowCam
- Autonomous Underwater vehicles
- Isotopic signatures

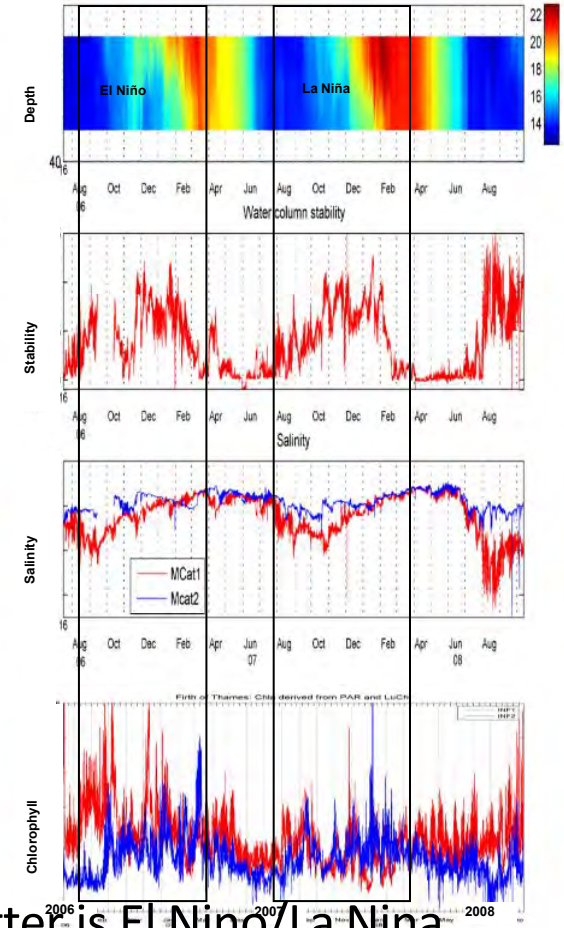
Monitoring Buoys



Long-term monitoring in the Firth of Thames

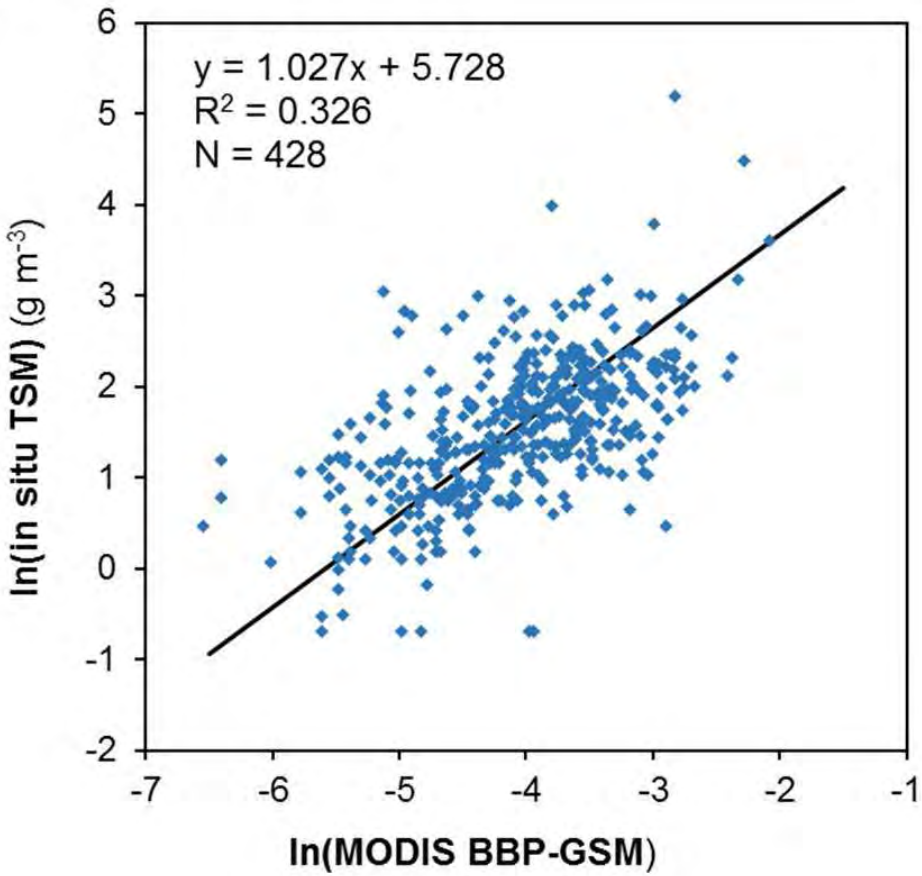


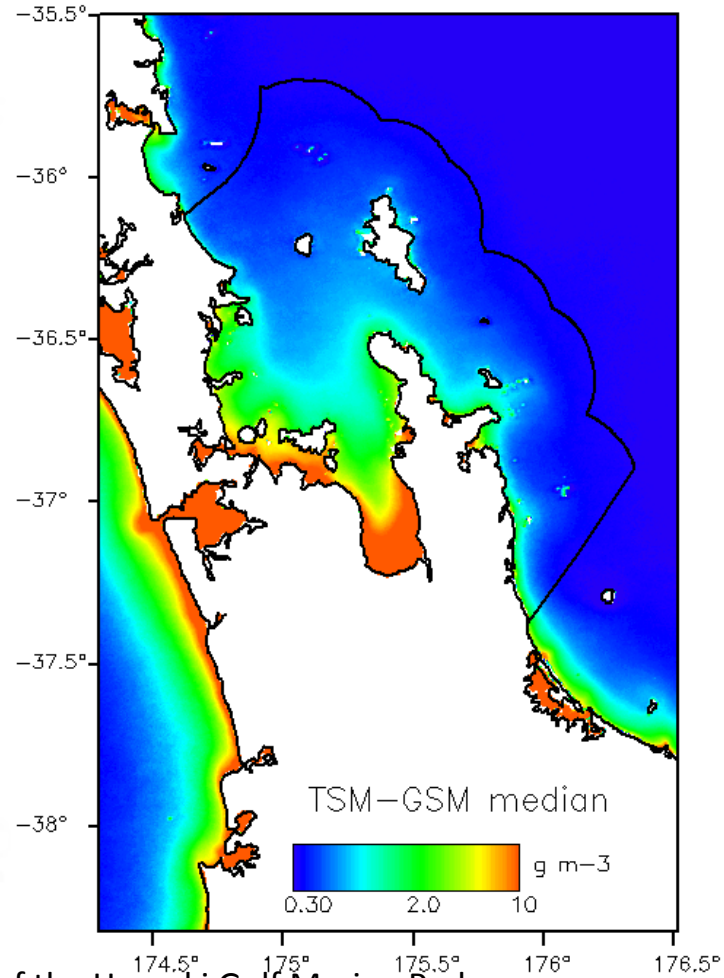




High seasonal and inter-annual variation. Some of the latter is El Nino/La Nina related

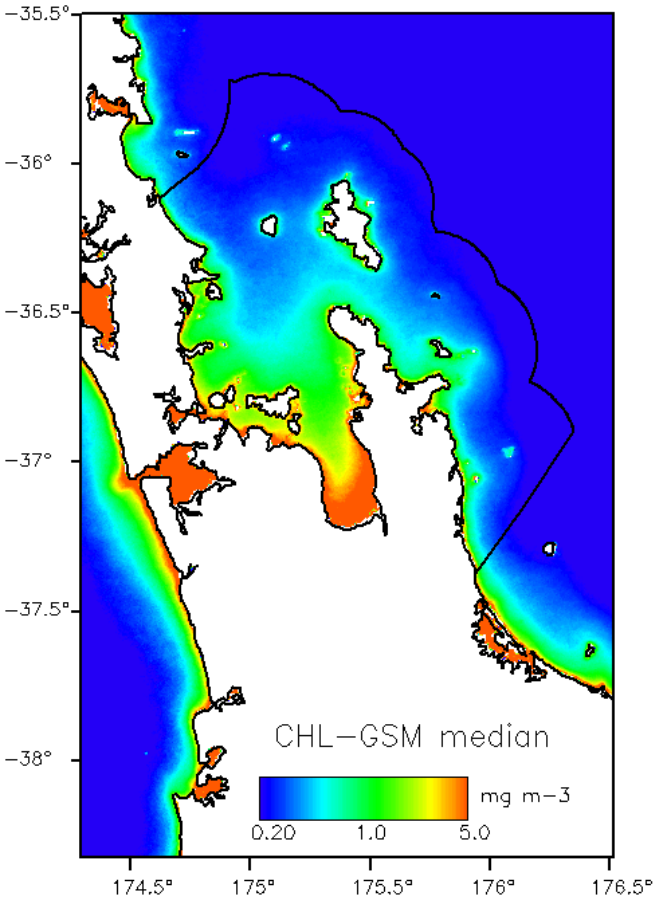
Remote sensed data: suspended solids





Pinkerton et al (2013) Satellite ocean-colour remote sensing of the Hauraki Gulf Marine Park report number WLG2013-040 (Waikato Regional Council)

Remote sensed data: chlorophyll

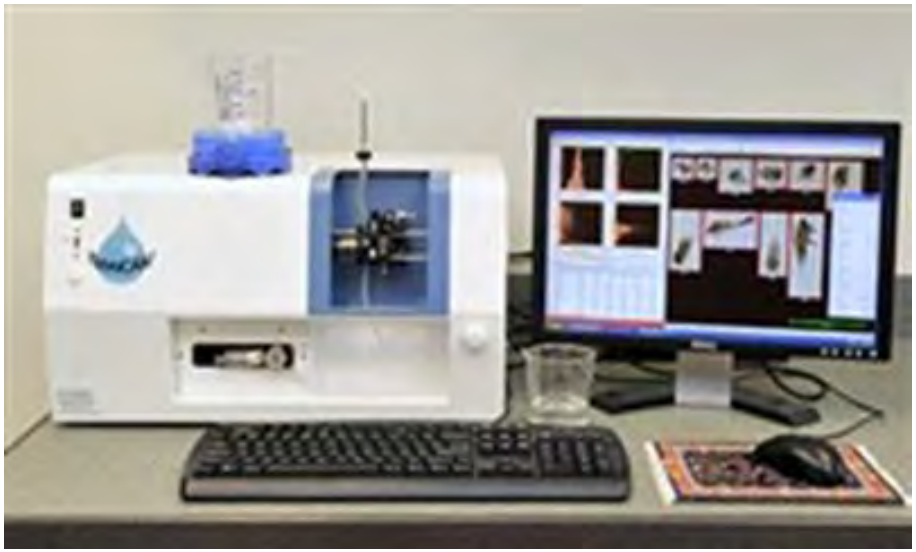


- NIWA research now aims as developing similar calibrated products for other aquaculture regions

Pinkerton et al (2013) Satellite ocean-colour remote sensing of the Hauraki Gulf Marine Park report number WLG2013-040 (Waikato Regional Council)

FlowCam

- Rapid processing of relatively larger volumes of water and numbers of samples



30 FlowCAM Image parameters

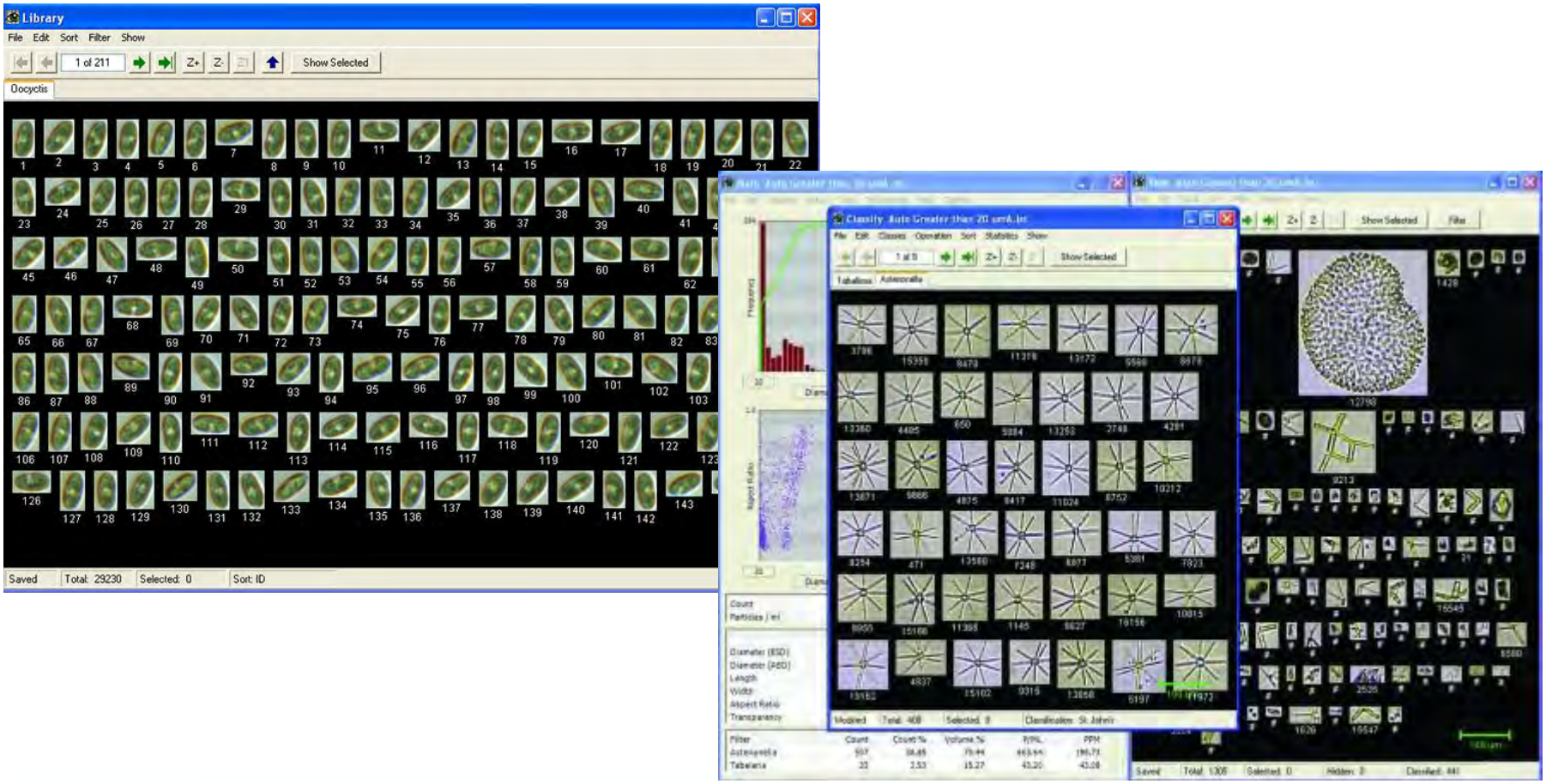
Morphological Parameters

- Length
- Width
- ESD
- ABD
- Aspect Ratio
- Elongation
- Perimeter
- Particles per chain
- Relative Chlorophyll
- Relative Phycoerythrin/Other
- Scatter Signal Value

Image Parameters

- Transparency
- Intensity
- Sigma Intensity
- Compactness
- Roughness
- Edge Gradient
- Average Red
- Average Green
- Average Blue
- Red/Green Ratio
- Blue/Green Ratio
- Red Blue Ratio

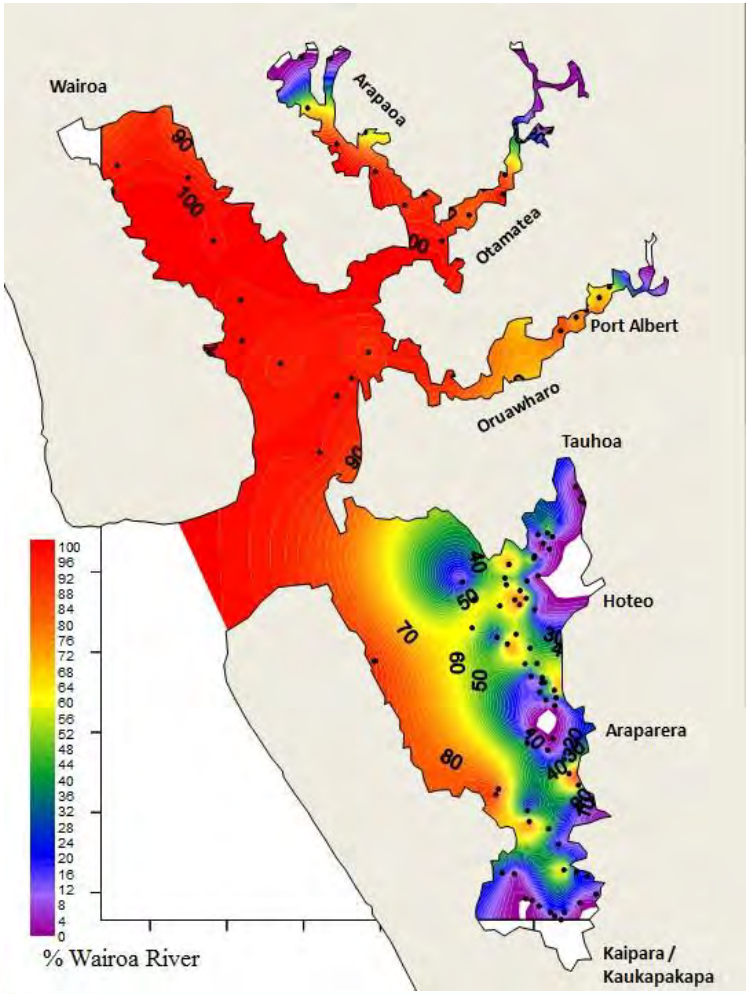
Allowing automated classification of particles for rapid identification and counting



Autonomous underwater vehicles

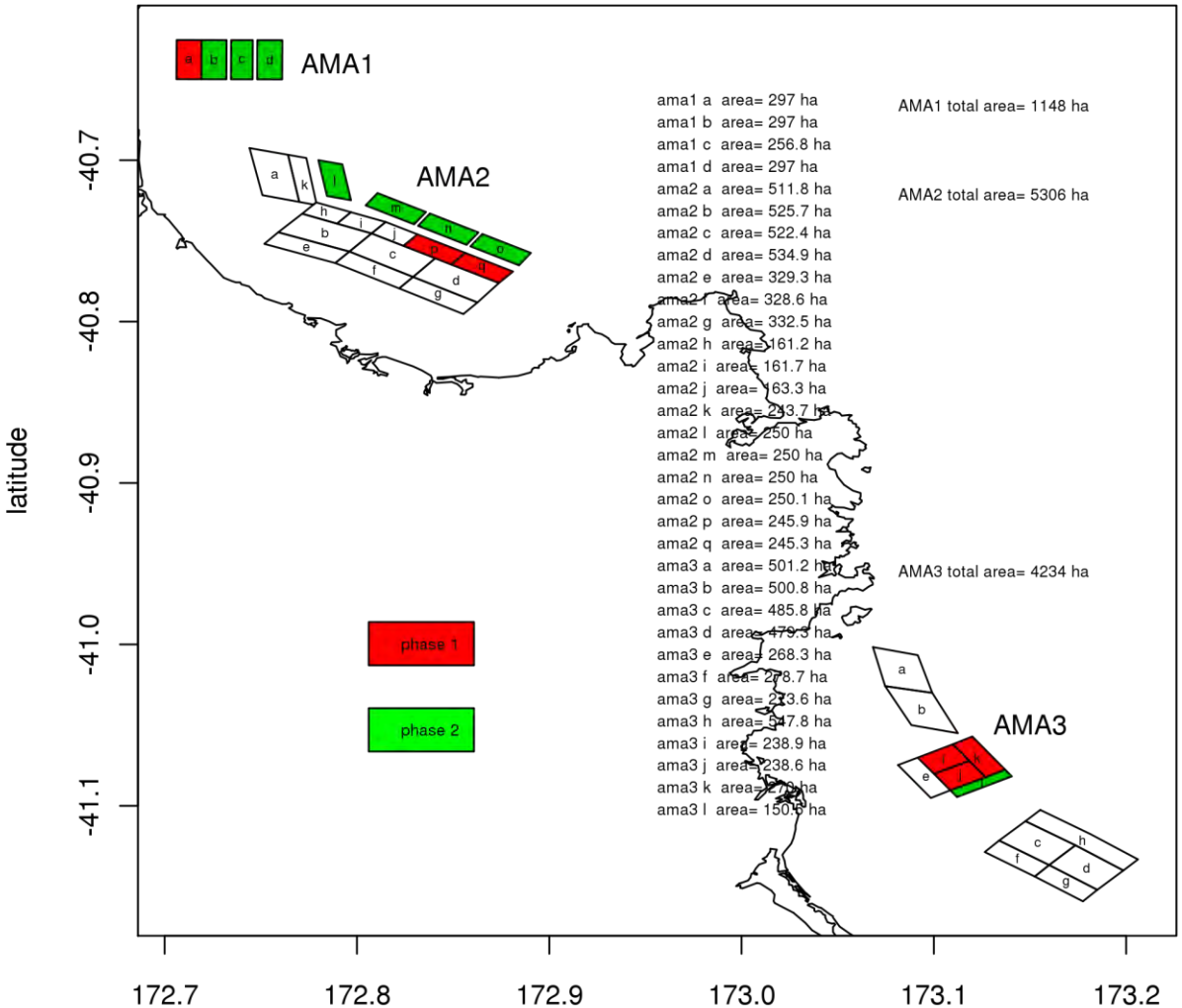
- ‘gliders’ & propelled
- Follow pre-programmed trajectories
- Carry package of sensors, eg:
  - T, S, Dissolved oxygen, Fluorimeter
- Starting to emerge as commercial tools (cf one off research tools)
  - None permanently in NZ at present?
  - But sooner or later …

Stable isotopes to identify sources



- This example used isotope tracing to identify sediment sources in Kaipara harbour
- Overseas, the technique has been used to map the footprint of fish-farms
- NIWA is applying the technique to a farm in Queen Charlotte

Numerical modelling

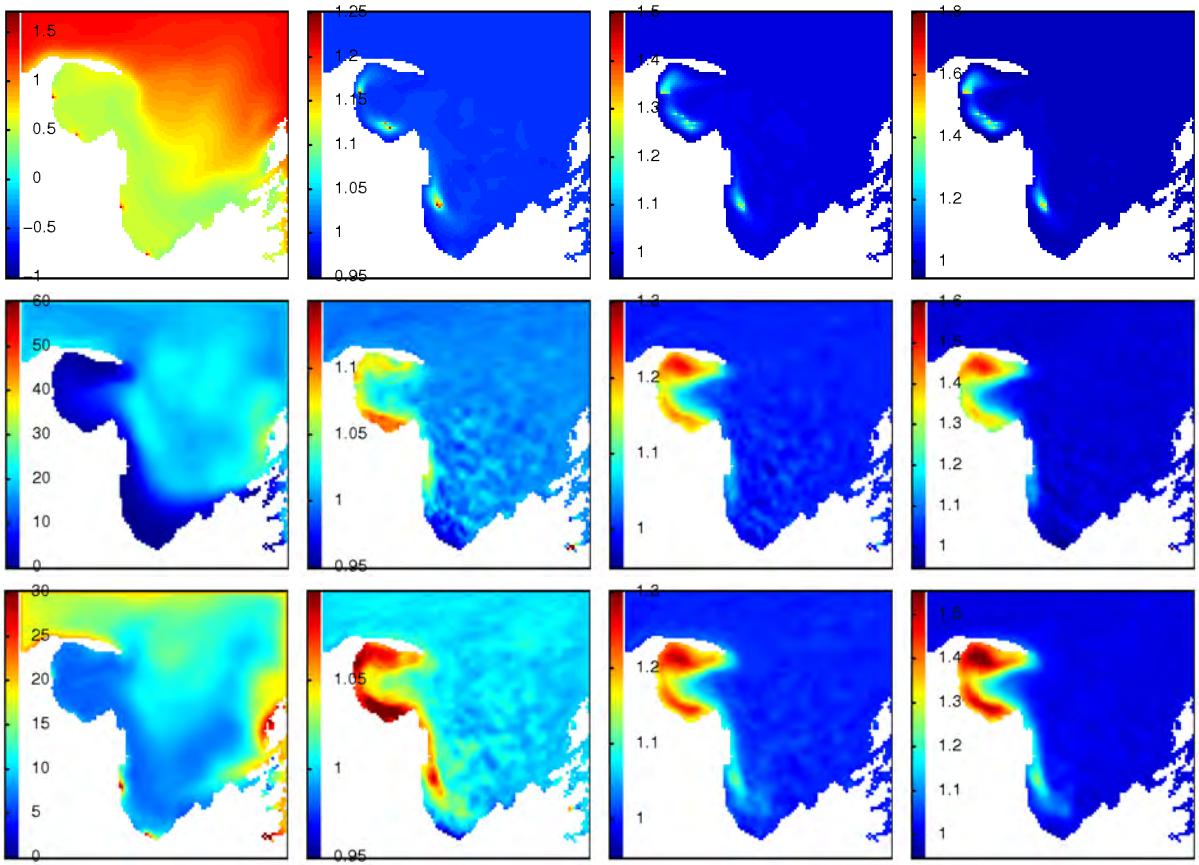


Simulations of pelagic effects of fish-farming in Tasman & Golden Bay

DIN

Diatom

Phytofl.



Concentration (no farms) | Rel. change (scenario 1) | Rel. change (scenario 2) | Rel. change (scenario 3)

Analysing the data

- Not trivial
- Depends upon the question
- There are well established statistical techniques for detecting (statistically) significant change, but…
- 'Ecological significance' is something else…
  - *A-priori* specification of what quantum of change is ecologically significant (how?)
  - Subsequent statistics to determine whether the monitoring data indicate that the quantum has been exceeded
  - appropriate statistical methods are still evolving
  - McBride, G.B., Cole, R., Westbrooke, I., Jowett, I.J. (in press) Assessing environmentally significant effects: A better weight-of-evidence than a single P value? *Environmental Monitoring and Assessment.*
- Farm induced changes will have to be very, very large or persistent if they are to be detectable in the face of the natural variability

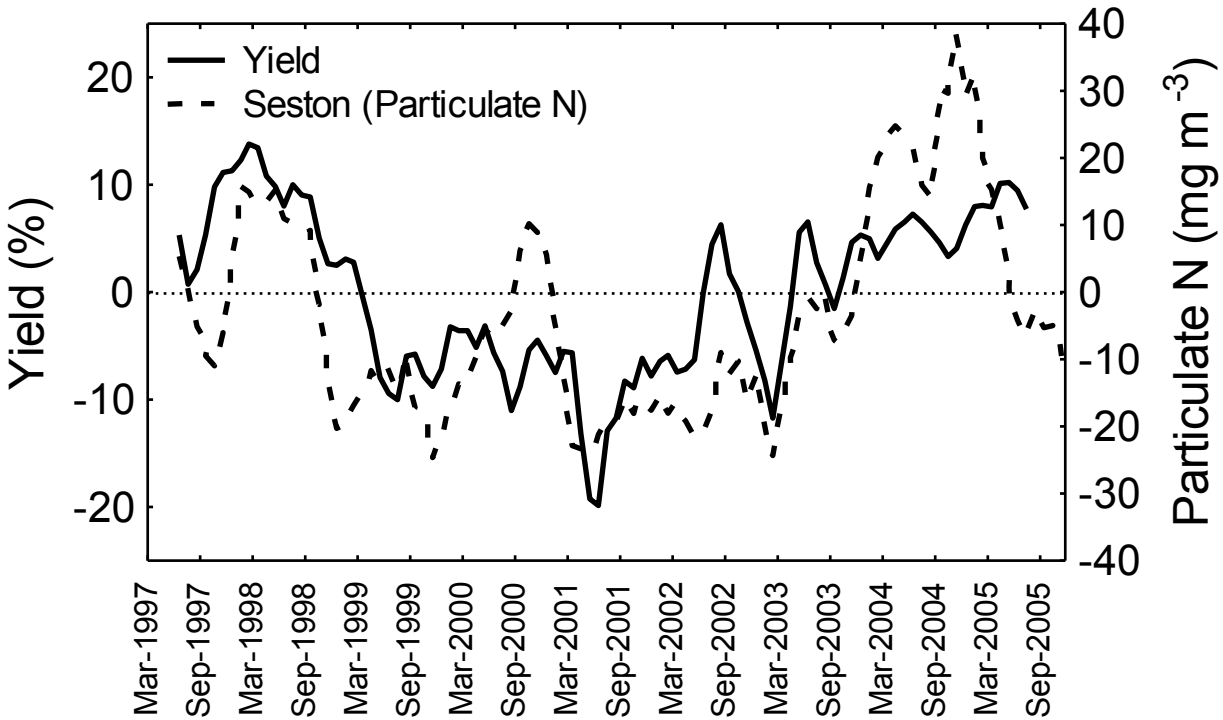
Decision making

- Natural variability vs human-induced?
  - Field data, modelling, tracer studies
- Which human activities?
  - Field data, modelling, tracer studies
- What is acceptable?
  - Field data & expert opinion can characterise historic norm
  - Expert opinion/modelling can provide hints as to critical thresholds that cannot be exceeded without dramatic phase-changes
  - Ultimately, it is a societal decision

Aquaculture: Ecological Guidance document

- In collaboration with MPI & Cawthron Institute
- http://www.fish.govt.nz/en-nz/Commercial/Aquaculture/Marine-based+Aquaculture/Aquaculture+Ecological+Guidance.htm

Long term data gives insights



Zeldis et al. 2008 Marine Ecology Progress Series 371, 131-142

A pedigree

- I lead NIWA's *Aquaculture/Environment Interactions* Programme
  - Successor to *Sustainable Aquaculture*
  - These programmes have been running for >10 years
- John Zeldis, Jeanie Stenton-Dozey, Don Morrisey, Joanne O'Callaghan, Jeffrey Ren, Craig Depree
- Worked in Firth of Thames, Marlborough Sounds, Tasman/Golden Bay, Pegasus Bay, Stewart Island
- Worked for MBIE & predecessors, MPI & predecessors, various aquaculture companies

CAWTHRON INSTITUTE

Aquaculture and cumulative effects: The big picture

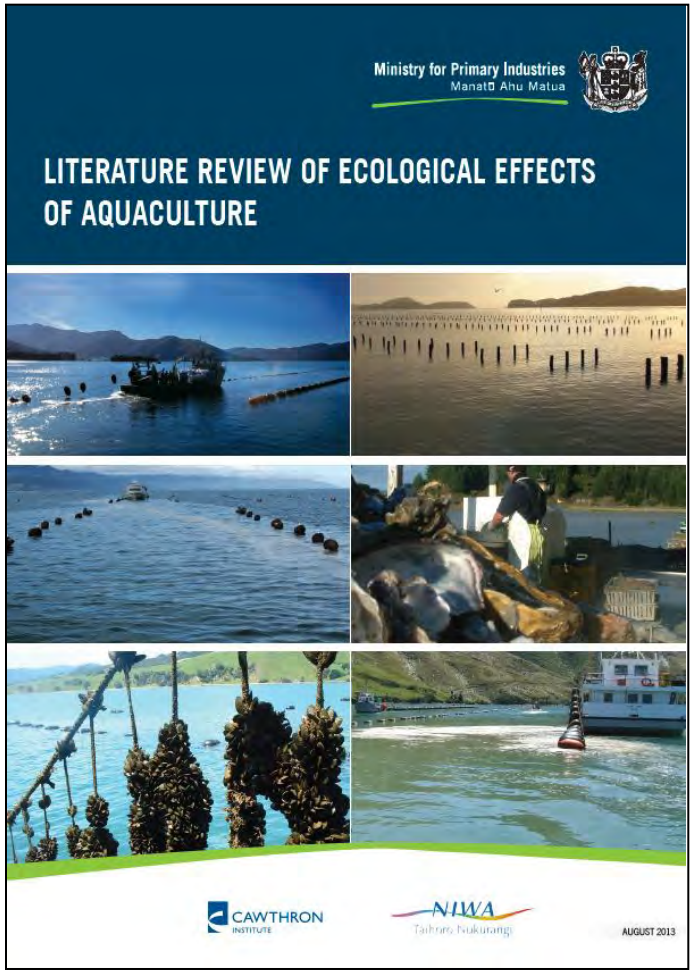
Chris Cornelisen

Lincoln MacKenzie

Hilke Giles

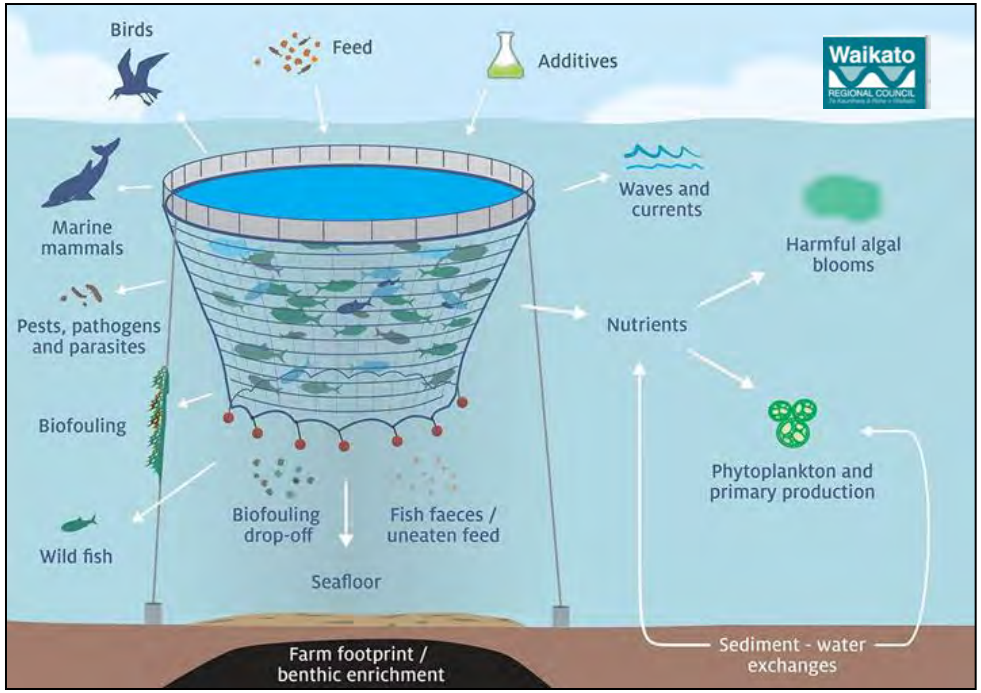
Barrie Forrest

www.mpi.govt.nz



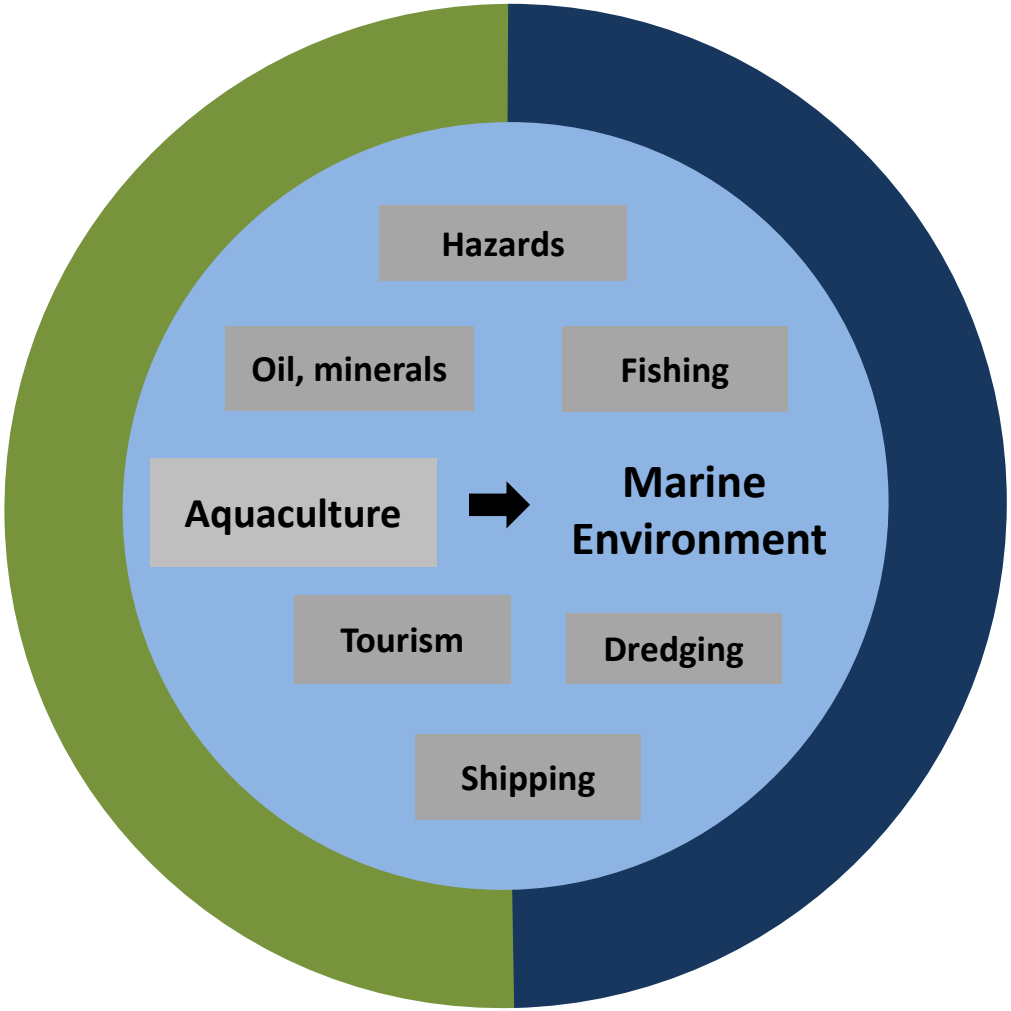
Chapters

- Pelagic effects
- Benthic effects
- Effects on marine mammals
- Effects on wild Fish
- Seabird interactions
- Biosecurity
- Escapee effects
- Effects from genetic modification
- Effects from additives
- Hydrodynamic effects
- Cumulative effects



CAWTHRON INSTITUTE

Land-based pollution
Habitat modification
Urbanisation



Ocean processes
Climate change

Multiple stressors associated with the above operate on a range of spatial and temporal scales

CAWTHRON INSTITUTE

Key threats to ocean health

Pollution
- Sedimentation
- Contamination
- Nutrient enrichment

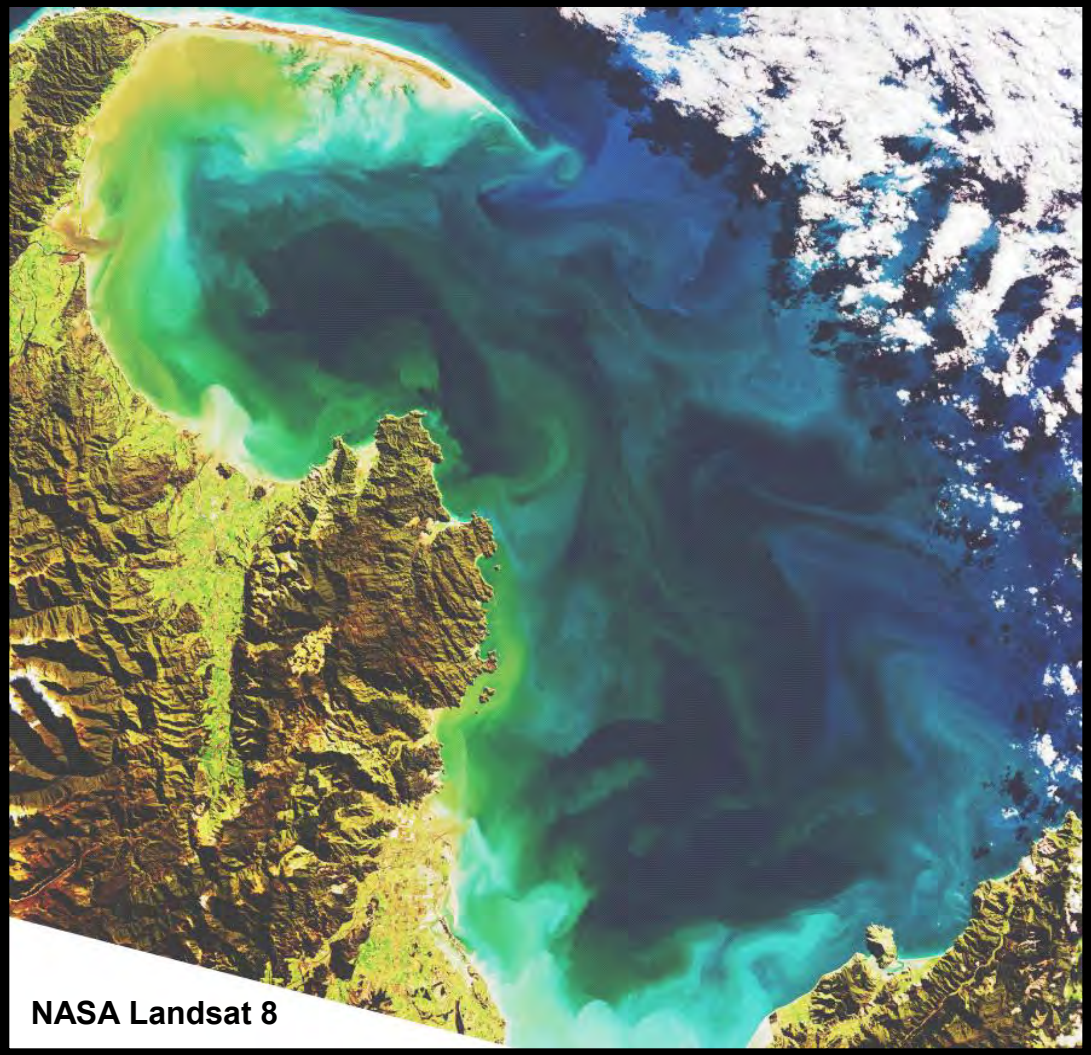
Resource exploitation

Habitat loss

Climate change

Biosecurity

Multiple stressors



Key threats to seafood

Pollution

- Sedimentation
- Contamination
- Nutrient enrichment

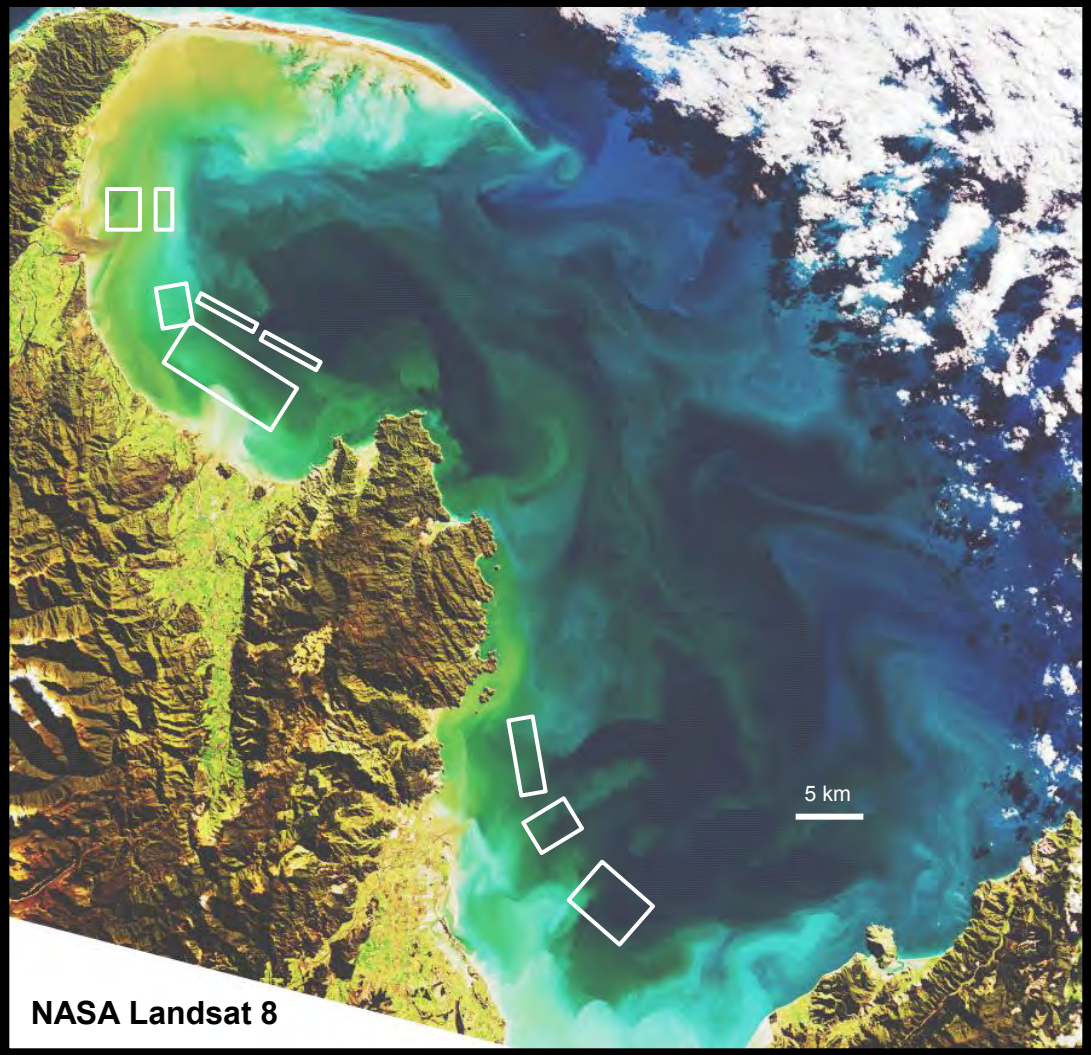
Resource exploitation

Habitat loss (e.g. seagrass)

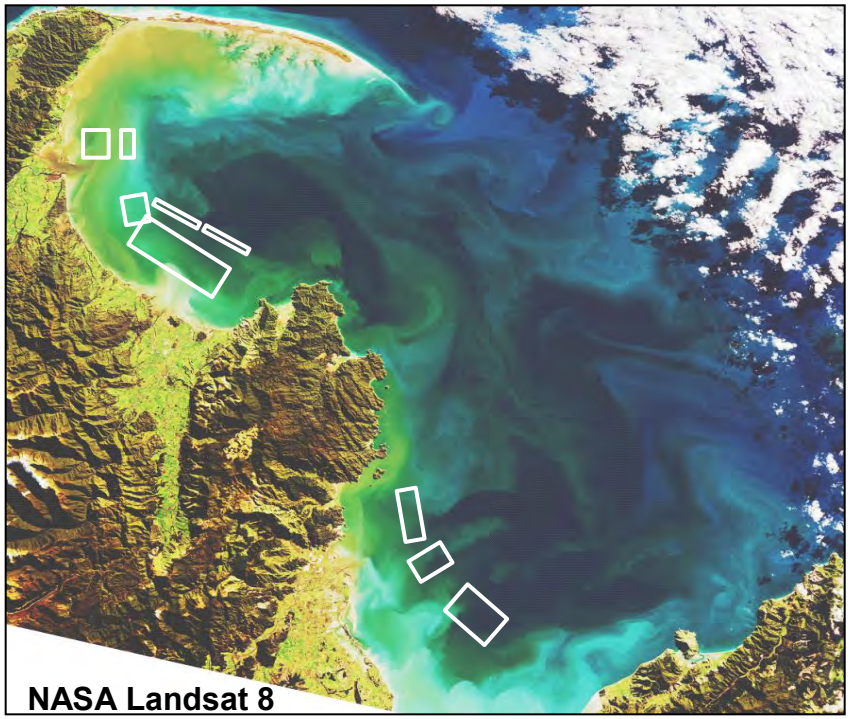
Climate change (acidification)

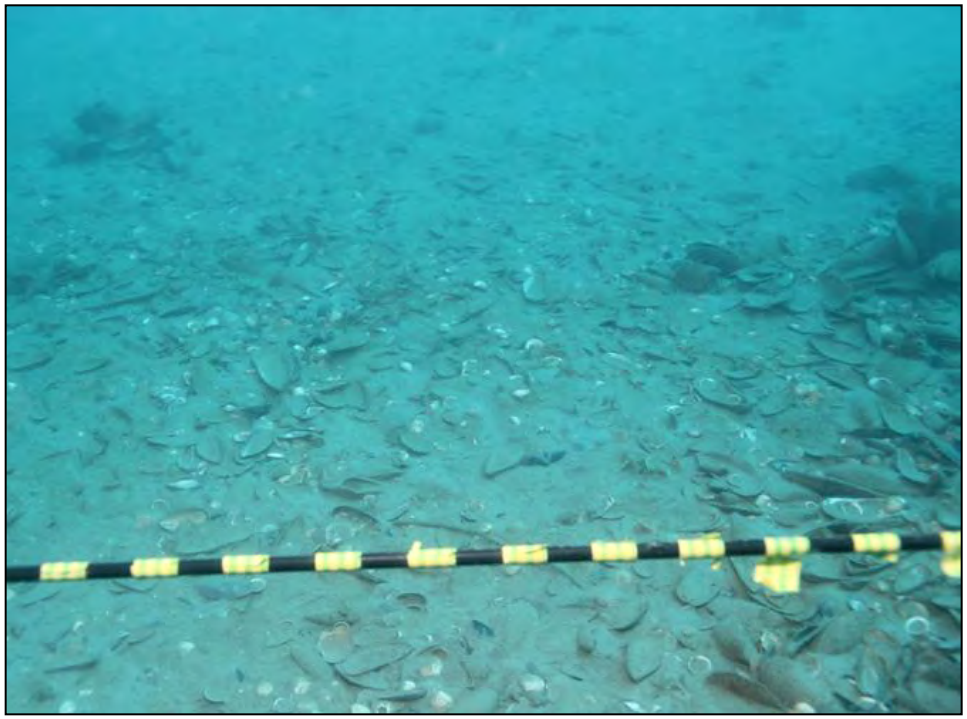
Biosecurity (pests, disease)

Multiple stressors

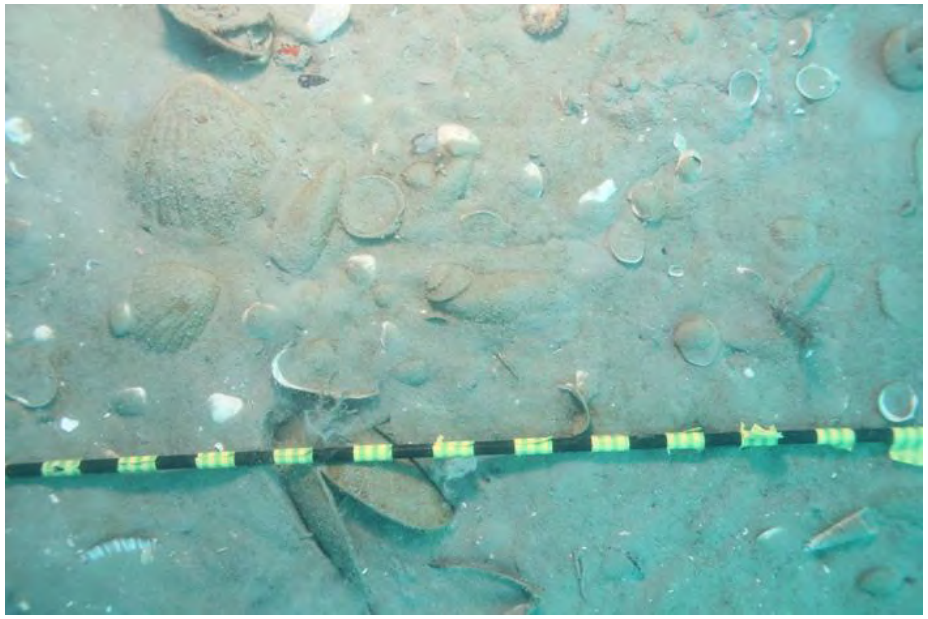


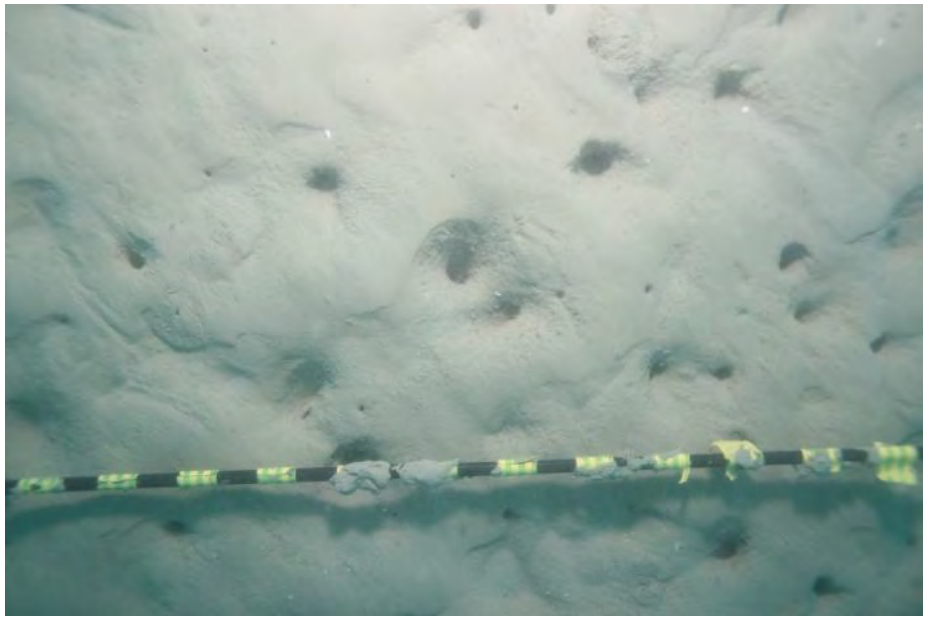
Monitoring large offshore mussel farms in Tasman Bay

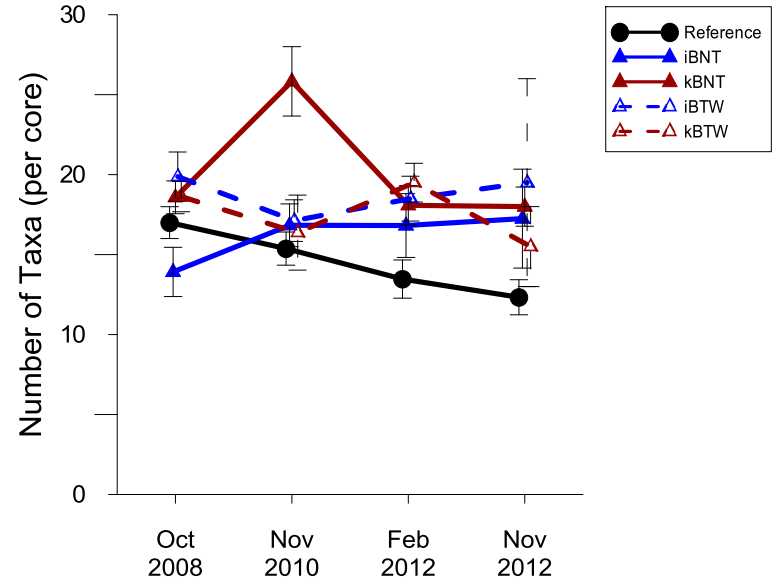


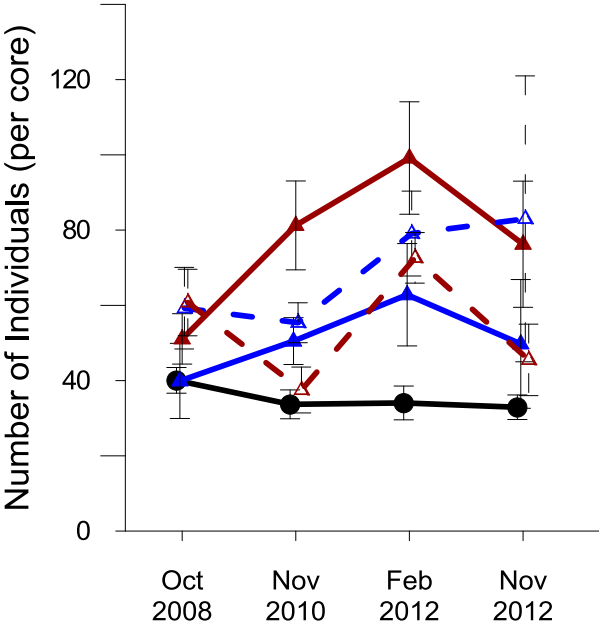


CAWTHRON INSTITUTE





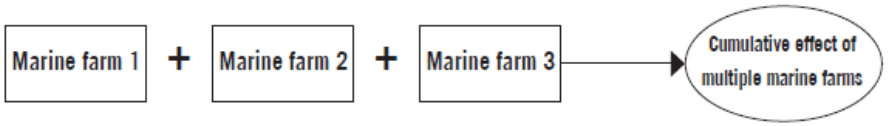




CAWTHRON INSTITUTE

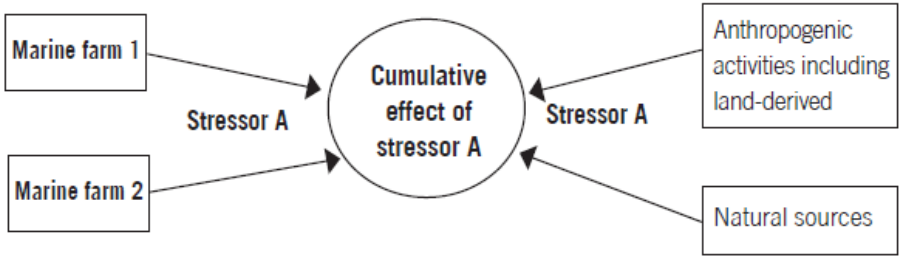
A. Additive effect of increasing numbers of marine farms

There are many examples in this category, for instance the additive effect of multiple local scale benthic footprints; incremental depletion of phytoplankton as a result of shellfish culture; or spread of pests/diseases among farms that leads to multiple reservoir populations.



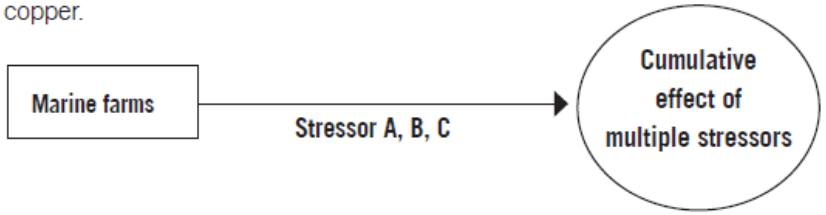
B. Additive effect of a single stressor from multiple sources in addition to marine farms

An example would be where dissolved nitrogen from marine farms adds to that from multiple diffuse and point sources leading to harmful algal blooms. These other sources could be both natural and anthropogenic, including oceanic and atmospheric inputs, consented point sources, and indirect or riverine inputs of land-derived nitrogen. In addition to ongoing inputs, there may also be those from episodic events such as rainfall or ocean upwelling.



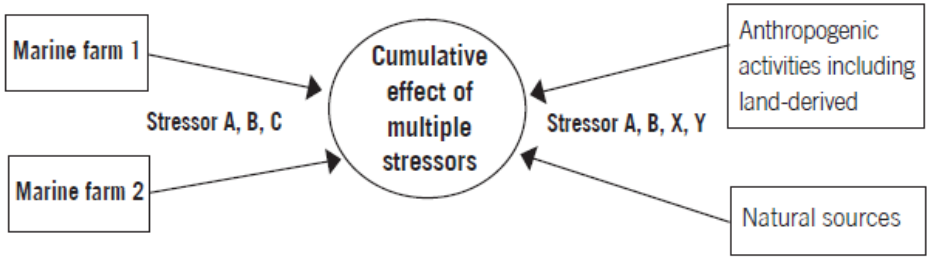
C. Additive and synergistic effects of multiple stressors from a single source

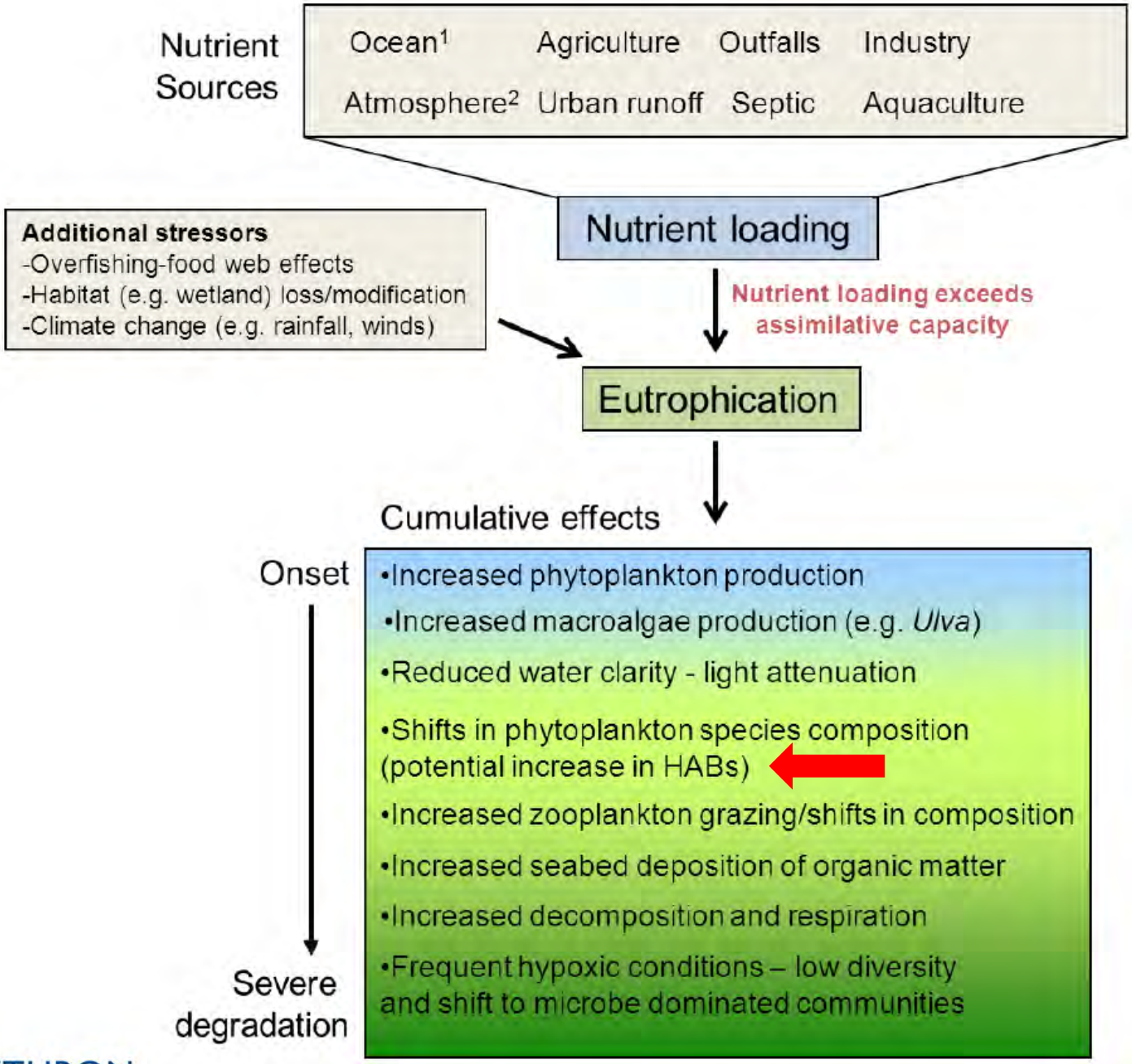
An example would be where fish farm faeces and feed leads to organic enrichment of the seabed, and is added to by potentially ecotoxic effects from copper that is used in antifouling. In that case, high levels of organic matter and sulfides in the sediment are likely to reduce the bioavailability and toxicity of the copper.



D. Additive and synergistic effects of multiple stressors from multiple sources

This situation reflects a blend of the issues above. For instance, in Tasman Bay, the benthic effects of recently-developed mussel farms will reflect multiple farm-derived stressors (e.g. fine sediments and oganic matter), effects of riverine fine sediments, high background concentrations of trace metals derived from natural sources in the catchment, and historic and ongoing disturbance from fishing.

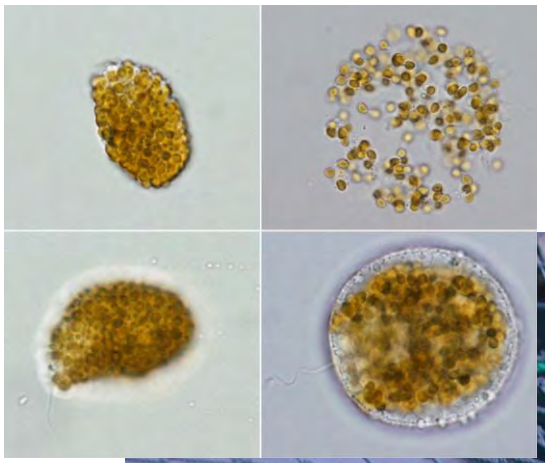


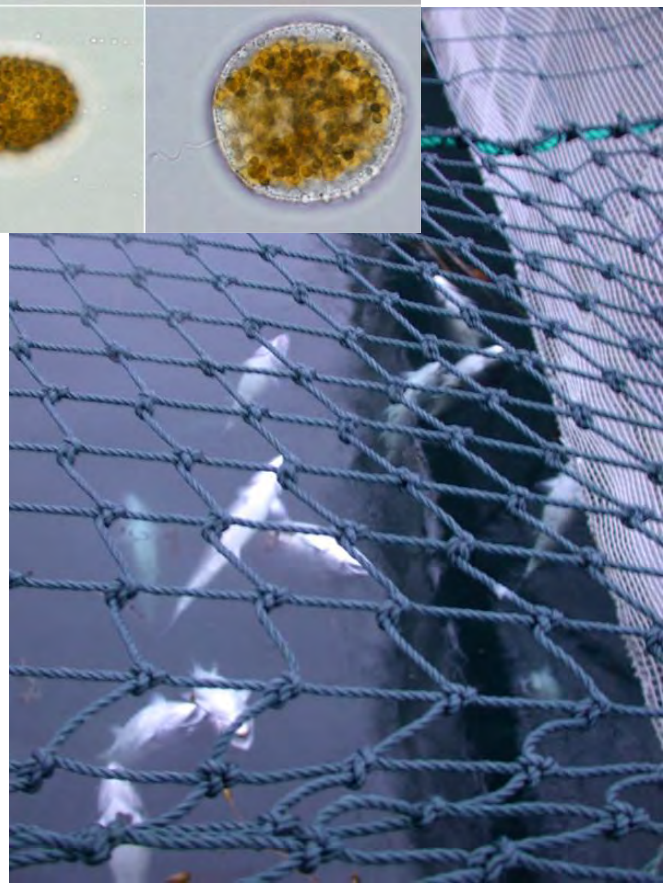


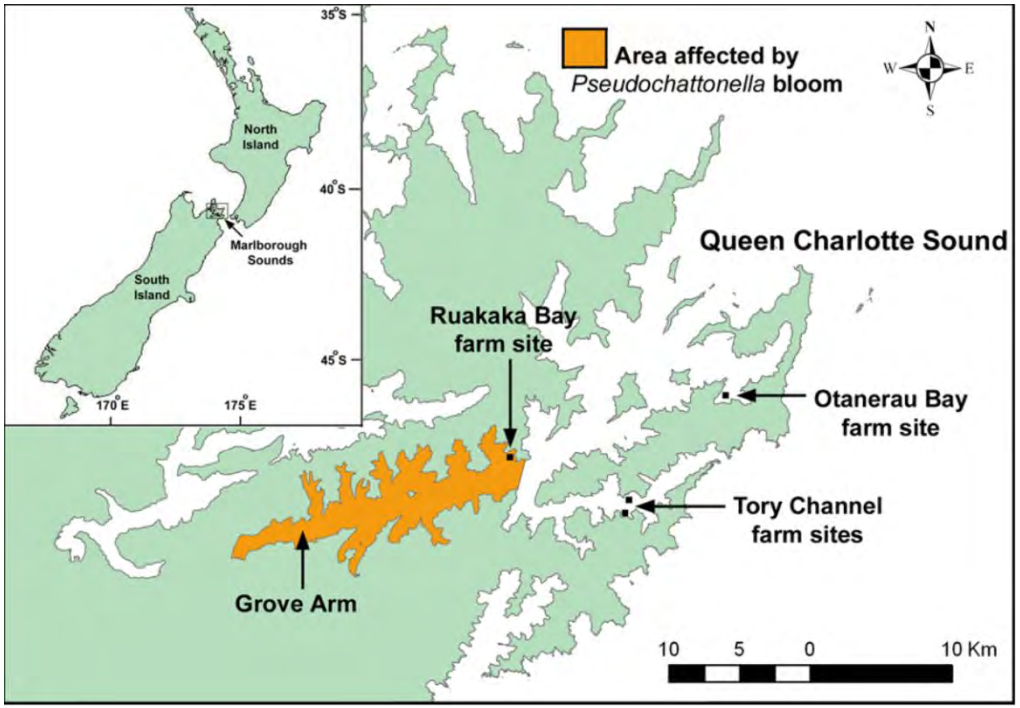
CAWTHRON INSTITUTE

Ruakaka Bay salmon kill 6 June 2010

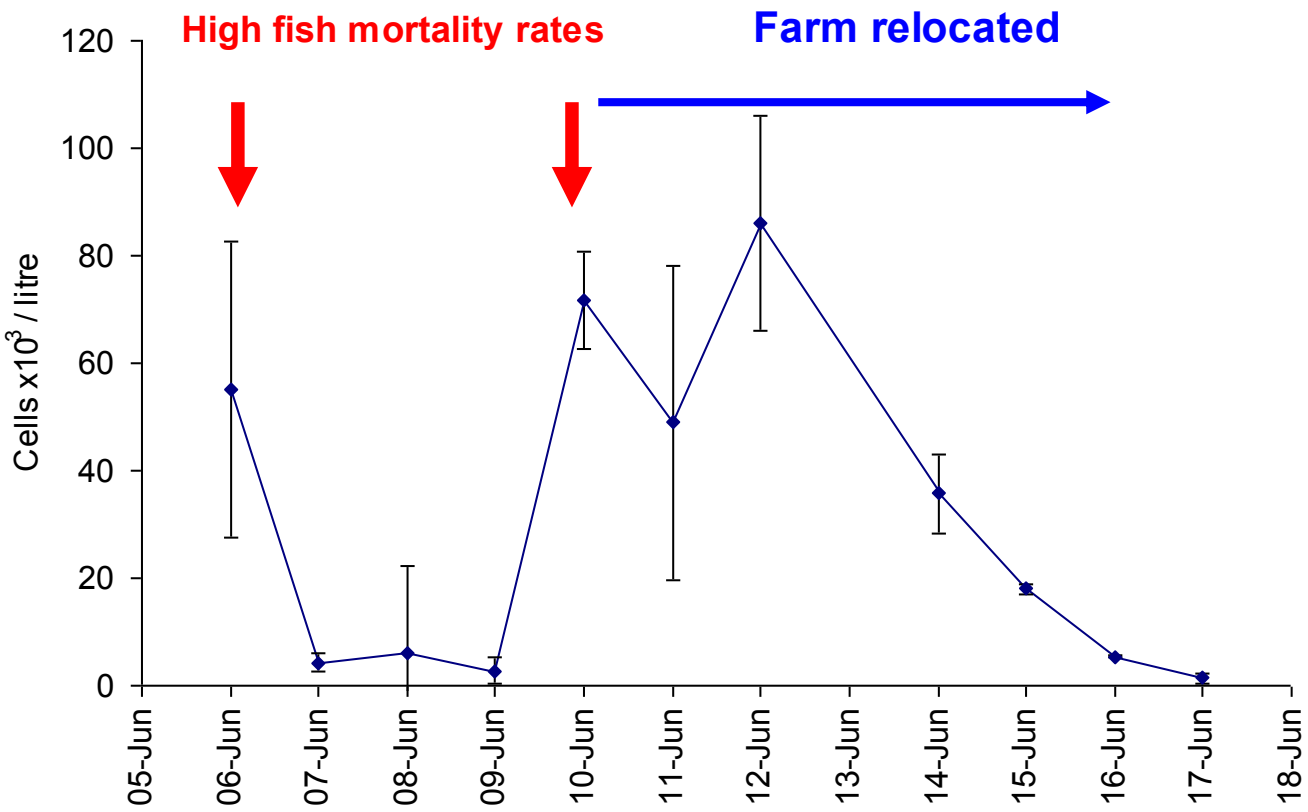
Psuedochattonella verruculosa







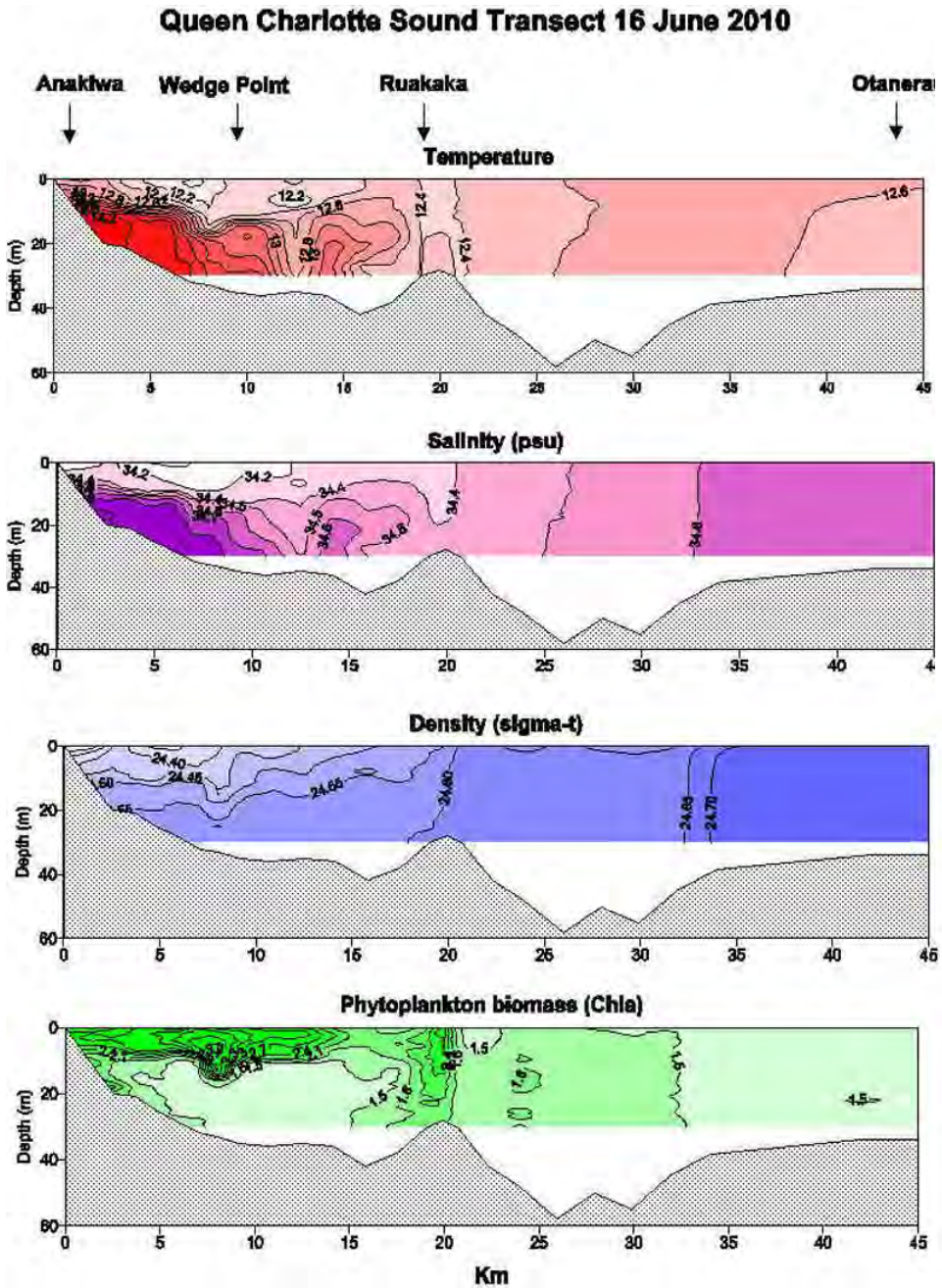
Pseudochattonella at the Rauaka farm, June 2010

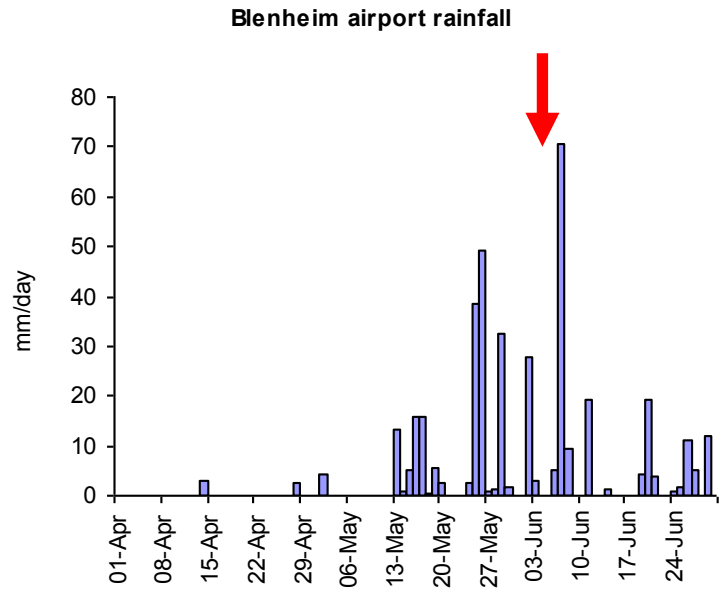


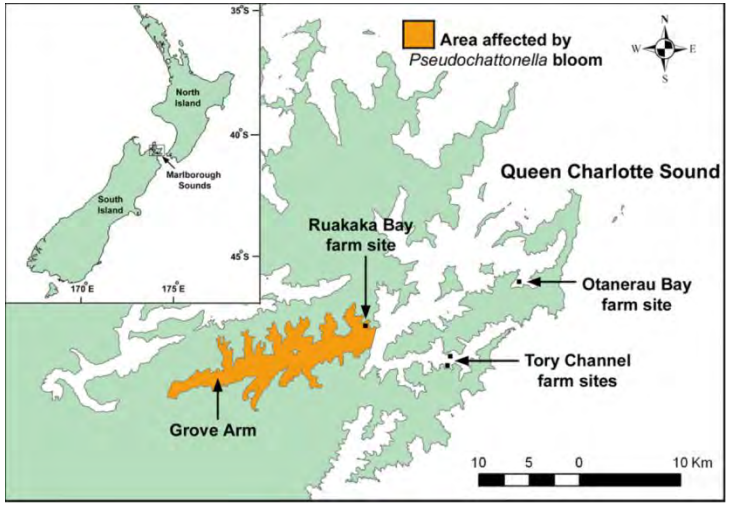
- Losses were about 15% 08 brood population; 57,000 fish / 200 tonnes
- Smaller 09 brood fish largely unaffected

CAWTHRON INSTITUTE

(Photos by Grant Lovell)

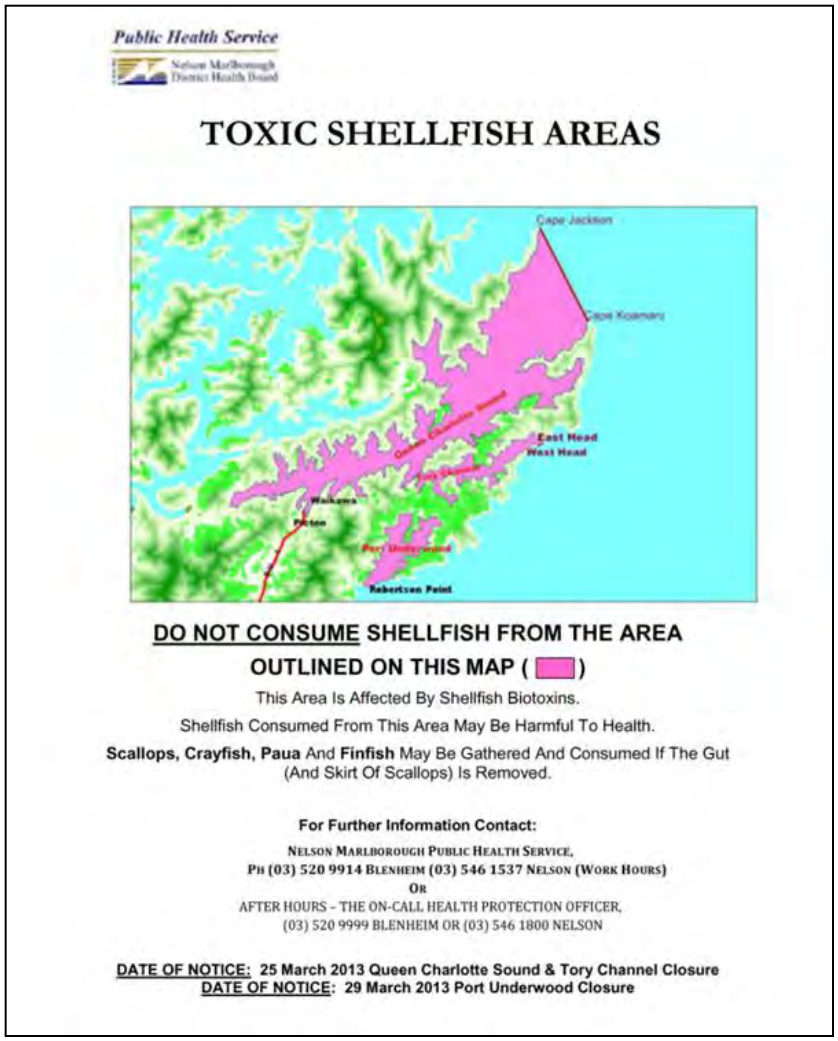

Queen Charlotte Sound Transect 16 June 2010
Anakiwa
Wedge Point
Ruakaka
Otanera
Temperature
Salinity (psu)
Density (sigma-t)
Phytoplankton biomass (Chla)
Depth (m)
Km


Blenheim airport rainfall
mm/day
01-Apr
08-Apr
15-Apr
22-Apr
29-Apr
06-May
13-May
20-May
27-May
03-Jun
10-Jun
17-Jun
24-Jun


Area affected by
Pseudochattonella bloom
North Island
South Island
Marlborough Sounds
Queen Charlotte Sound
Ruakaka Bay
farm site
Otanerau Bay
farm site
Tory Channel
farm sites
Grove Arm
10 5 0 10 Km

Toxic *Alexandrium catenella* blooms:

A "recent" problem for aquaculture in the Marlborough sounds



Public Health Service

Nelson Marlborough District Health Board

TOXIC SHELLFISH AREAS

DO NOT CONSUME SHELLFISH FROM THE AREA OUTLINED ON THIS MAP ( )

This Area Is Affected By Shellfish Biotoxins.

Shellfish Consumed From This Area May Be Harmful To Health.

Scallops, Crayfish, Paua And **Finfish** May Be Gathered And Consumed If The Gut (And Skirt Of Scallops) Is Removed.

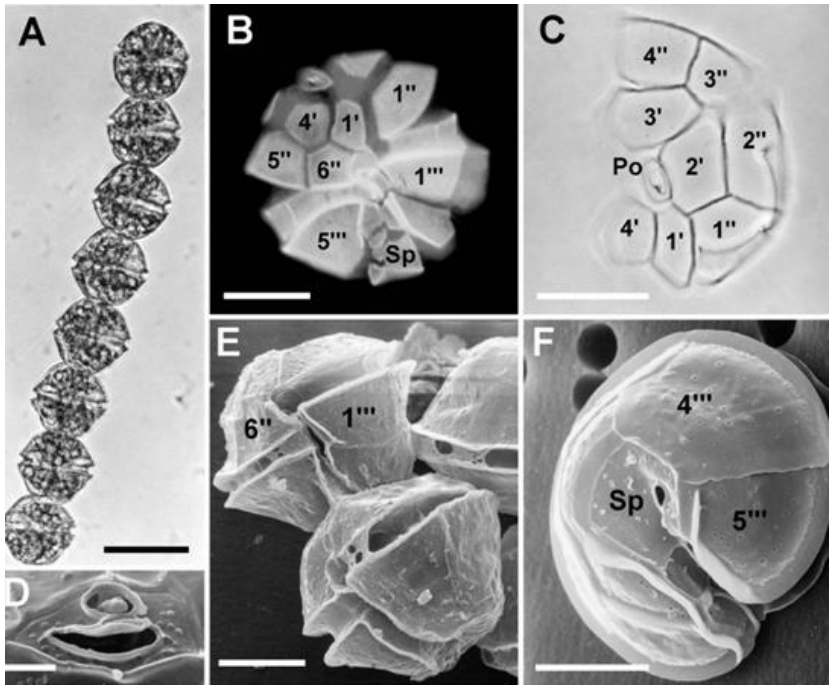
For Further Information Contact:

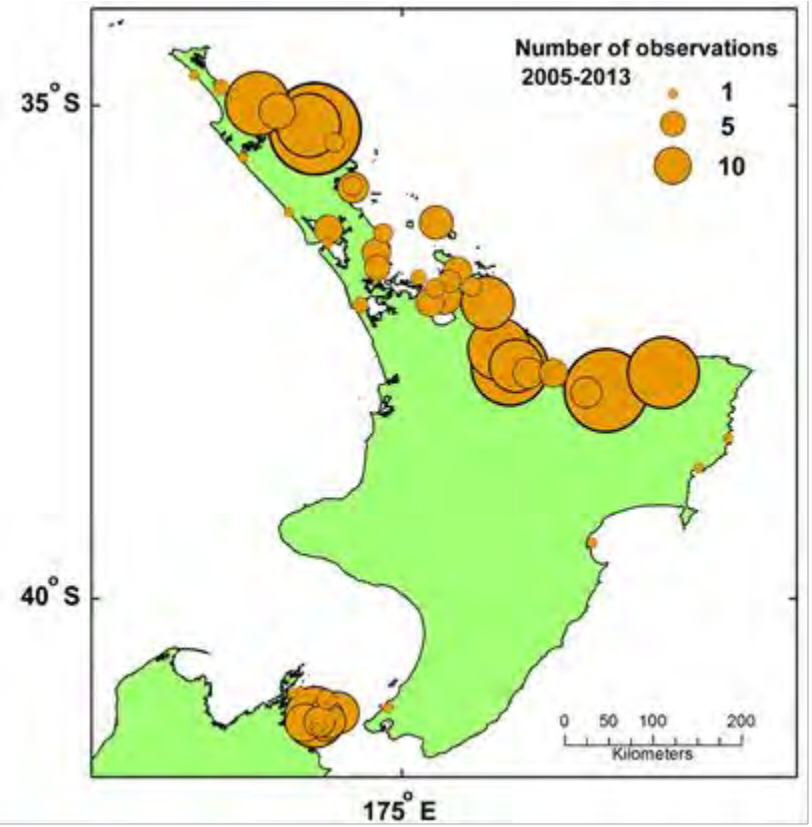
NELSON MARLBOROUGH PUBLIC HEALTH SERVICE,
PH (03) 520 9914 BLENHEIM (03) 546 1537 NELSON (WORK HOURS)
OR
AFTER HOURS – THE ON-CALL HEALTH PROTECTION OFFICER,
(03) 520 9999 BLENHEIM OR (03) 546 1800 NELSON

DATE OF NOTICE: 25 March 2013 Queen Charlotte Sound & Tory Channel Closure
DATE OF NOTICE: 29 March 2013 Port Underwood Closure

CAWTHRON INSTITUTE

Alexandrium catenella is a globally distributed dinoflagellate and common source of paralytic shellfish poisoning (PSP) toxins (saxitoxins).

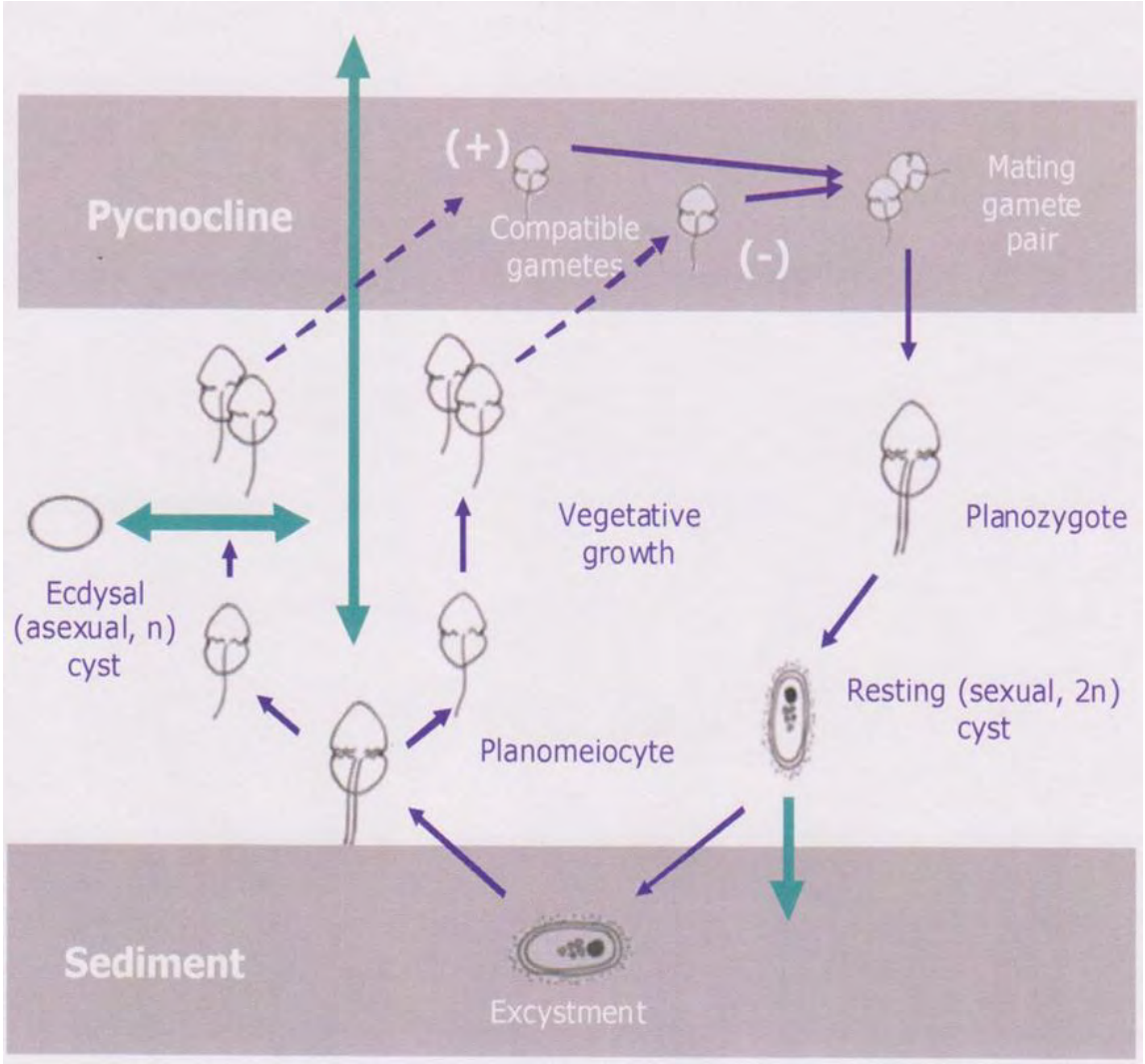




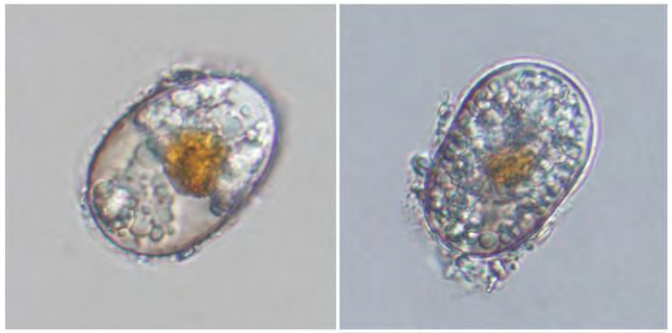
If *A. catenella* spreads throughout the Marlborough/Nelson region, it may create a chronic problem for shellfish aquaculture, requiring annual 2-3 month harvest closures.

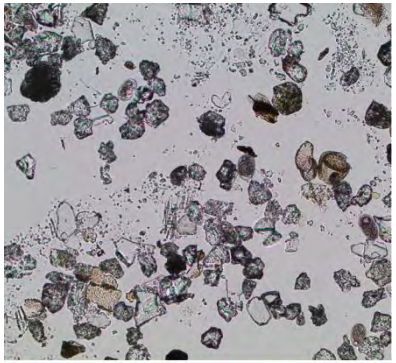
CAWTHRON INSTITUTE

A. catenella life cycle

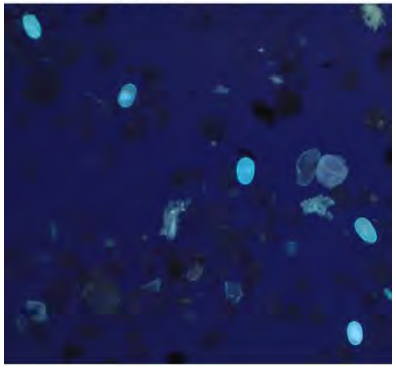


A. catenella resting cysts



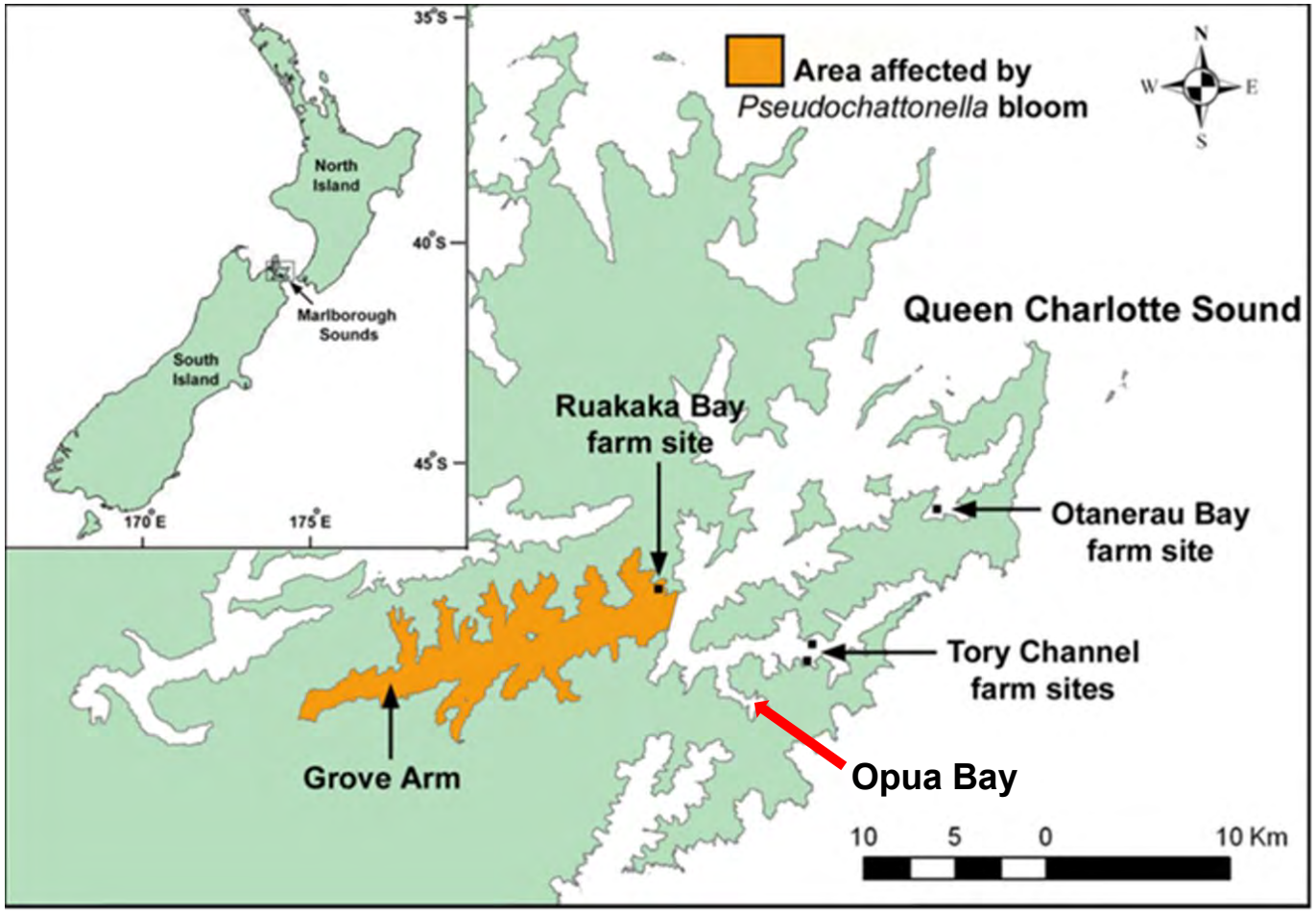


Brightfield



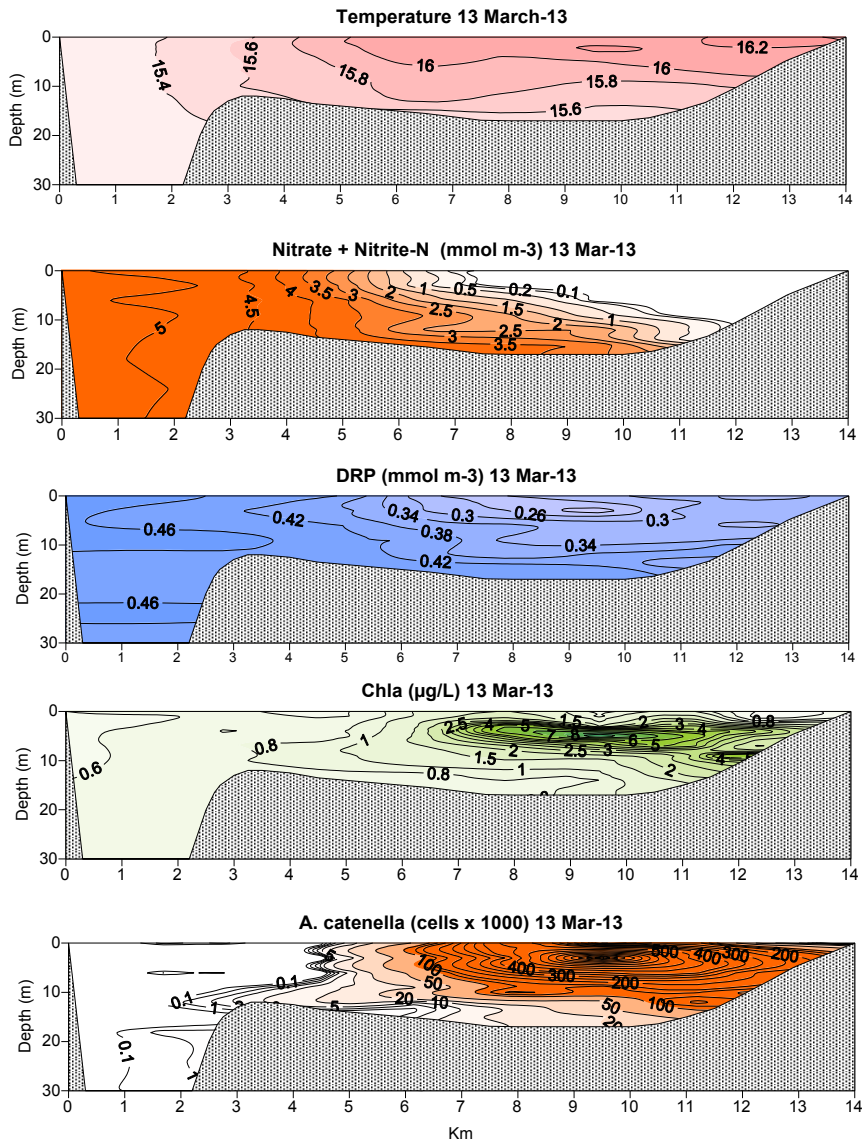
Primuline stained fluoresence

CAWTHRON INSTITUTE

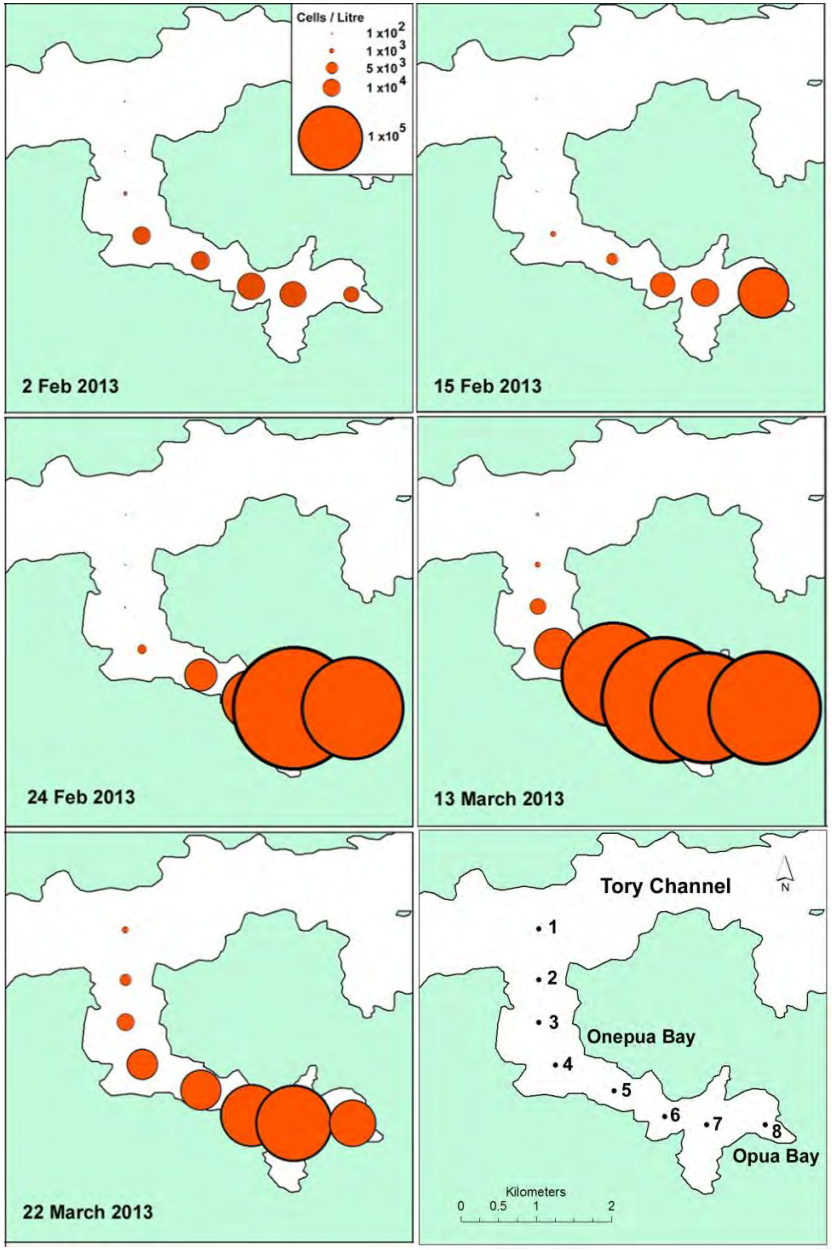


CAWTHRON INSTITUTE

Hydrography - water chemistry



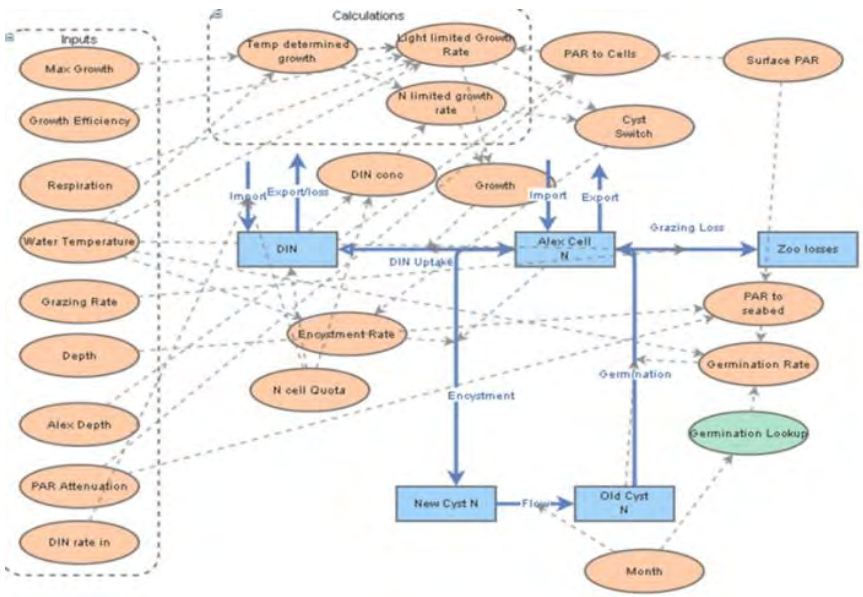
Tory Channel - Opua Bay water column transects

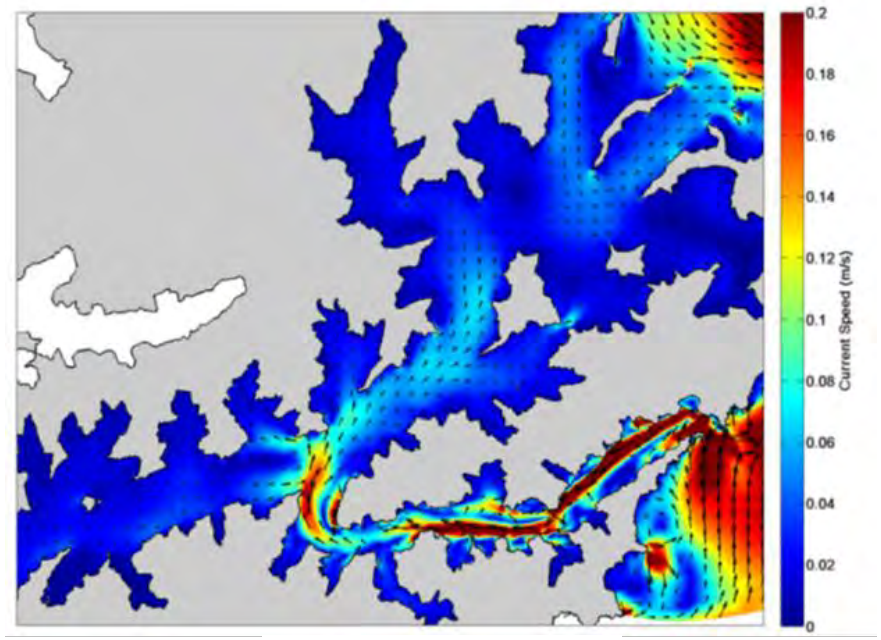


***A. catenella* in 12m integrated samples**

Some of the key messages with regard to HABs

- A number of endogenous, biological, physical and water chemistry factors influence HAB blooms
- High natural spatial and temporal variability of phytoplankton composition and biomass presents a challenge to establishing thresholds for wider environmental effects
- Biophysical models may assist in understanding HAB ecology and informing management





Mean surface currents

CAWTHRON INSTITUTE

How do we develop aquaculture in a sustainable manner while addressing cumulative effects and changes in the wider ecosystem?

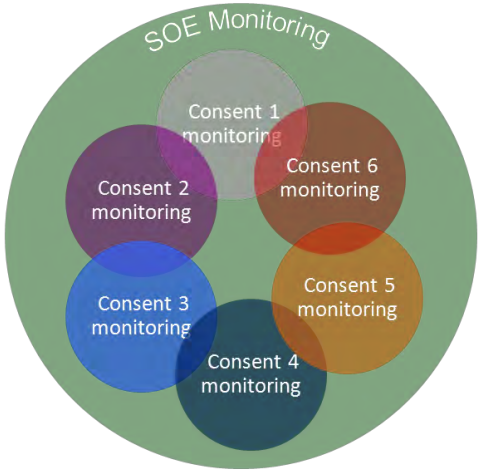
- Work within ecosystem-based management* and monitoring frameworks (mountains to sea, IEAs)

*over-arching theme of the LiCO National Science Challenge

CAWTHRON INSTITUTE

How do we develop aquaculture in a sustainable manner while addressing cumulative effects and changes in the wider ecosystem?

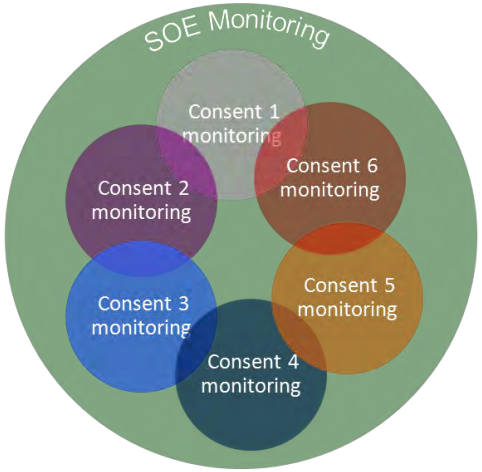
- Work within ecosystem-based management and monitoring frameworks (mountains to sea, IEAs)
- Consider and assess effects of aquaculture within the context of wider, cumulative environmental change
- Establish environmental baselines and determine the carrying capacities of water bodies (ecological, social and economic)



CAWTHRON INSTITUTE

How do we develop aquaculture in a sustainable manner while addressing cumulative effects and changes in the wider ecosystem?

- Work within ecosystem-based management and monitoring frameworks (mountains to sea, IEAs)
- Consider and assess effects of aquaculture within the context of wider, cumulative environmental change
- Establish environmental baselines and determine the carrying capacities of water bodies (ecological, social and economic)
- Develop accessible tools that aid resource managers and industry and also inform the wider public



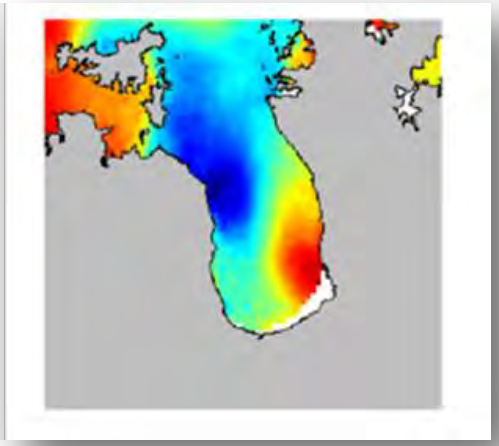
CAWTHRON INSTITUTE

Numerical modelling

+

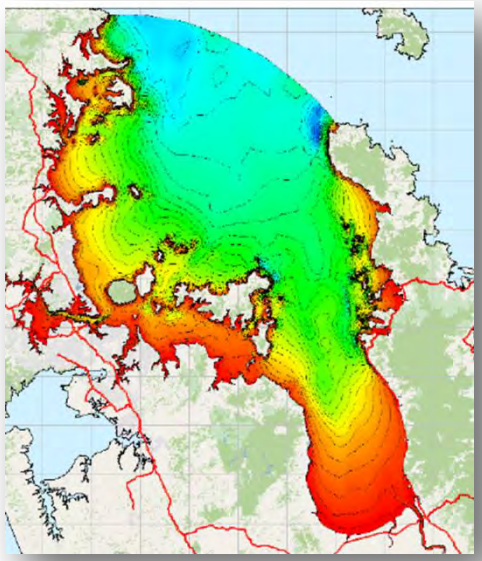
Real-time data

+



Satellite data

= Marine Management Model



Forecasting/Nowcasting

- Hydrodynamics
- Aquaculture effects
- Biosecurity
- Water quality
- Oil spill response
- Hazards
- Cumulative effects

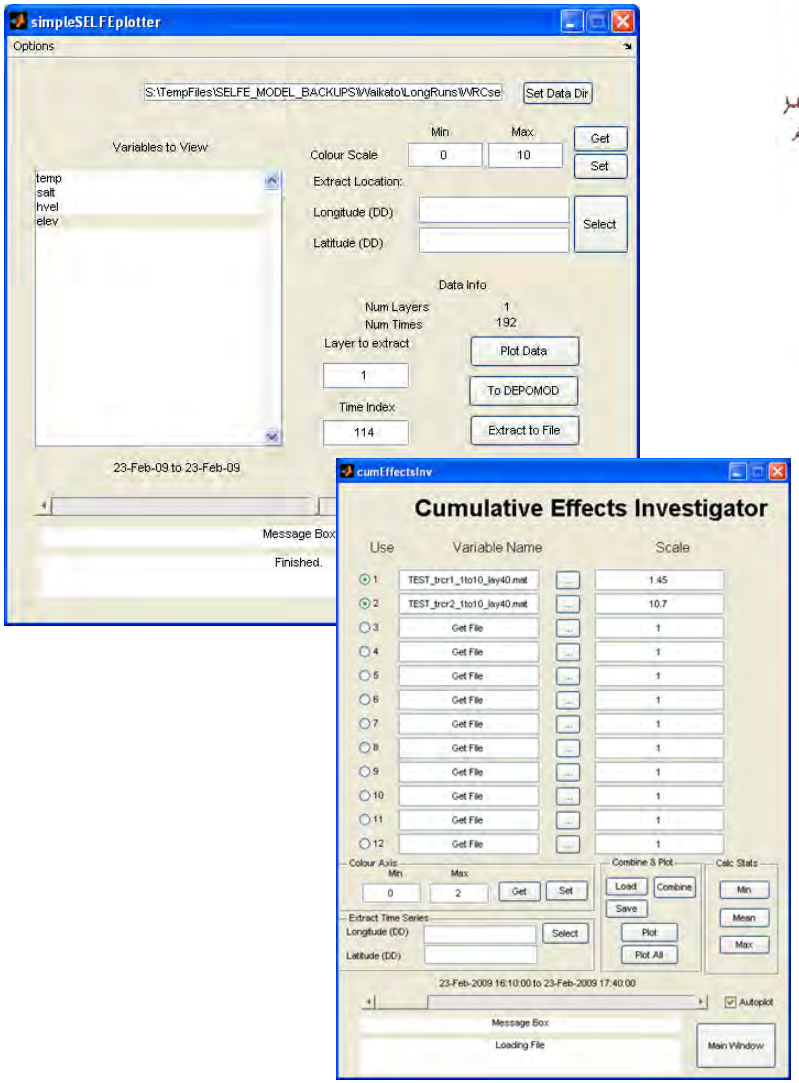
Must be Accurate, Actionable and <u>Accessible</u>

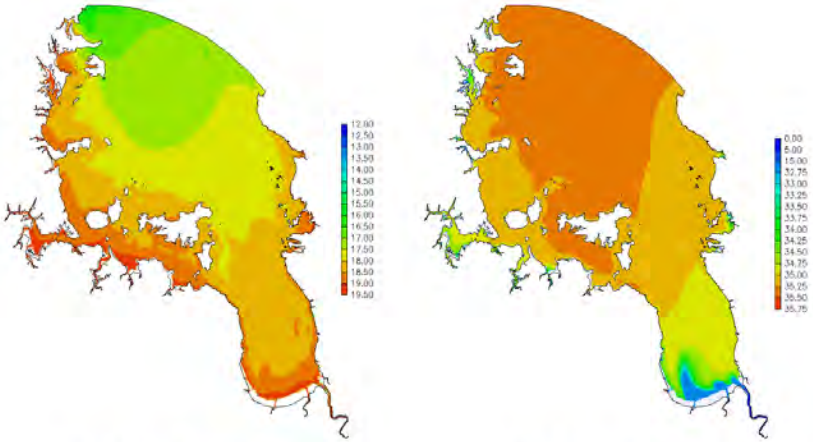
CAWTHRON INSTITUTE

MET OCEAN SOLUTIONS LTD

Waikato REGIONAL COUNCIL Te Kaunihera ā Rohe o Waikato

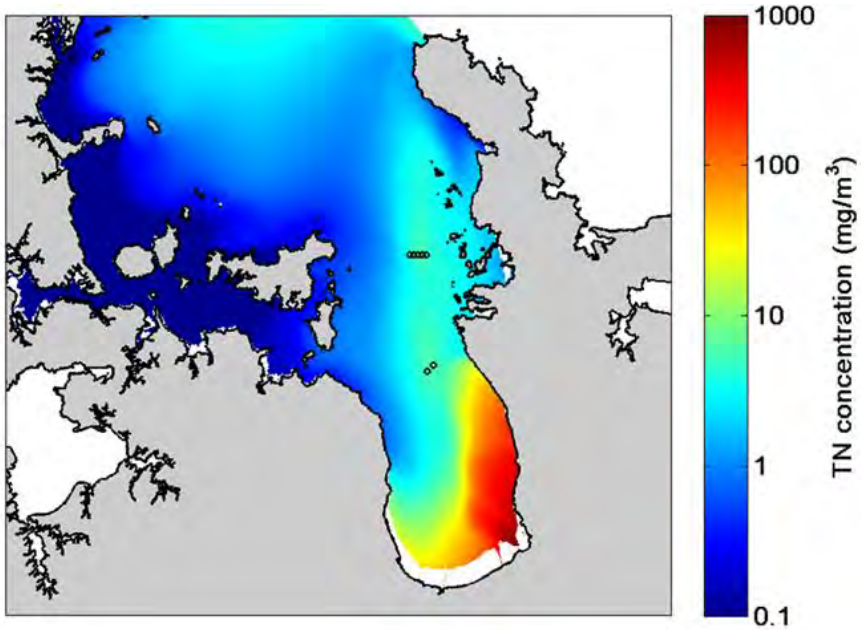
GUIs for accessibility





Surface Temperature

Surface Salinity



Cumulative nitrogen inputs

CAWTHRON INSTITUTE

MET OCEAN SOLUTIONS LTD

Waikato REGIONAL COUNCIL Te Kaunihera ā Rohe o Waikato

ACKNOWLEDGEMENTS

Barrie Forrest, Nigel Keeley, Reid Forrest, Robyn Dunmore, Dave Taylor, Deanna Clement, Dana Clark, Xavier Pochon, Ben Knight

Hilke Giles, Vernon Pickett (Waikato Regional Council)

Brett Beamsley (MetOcean)

Marlborough Shellfish Quality Programme (Noel McArthur, Mike Williams)

Cawthron Institute's Seafood Safety Programme (MBIE contract CAX0703).

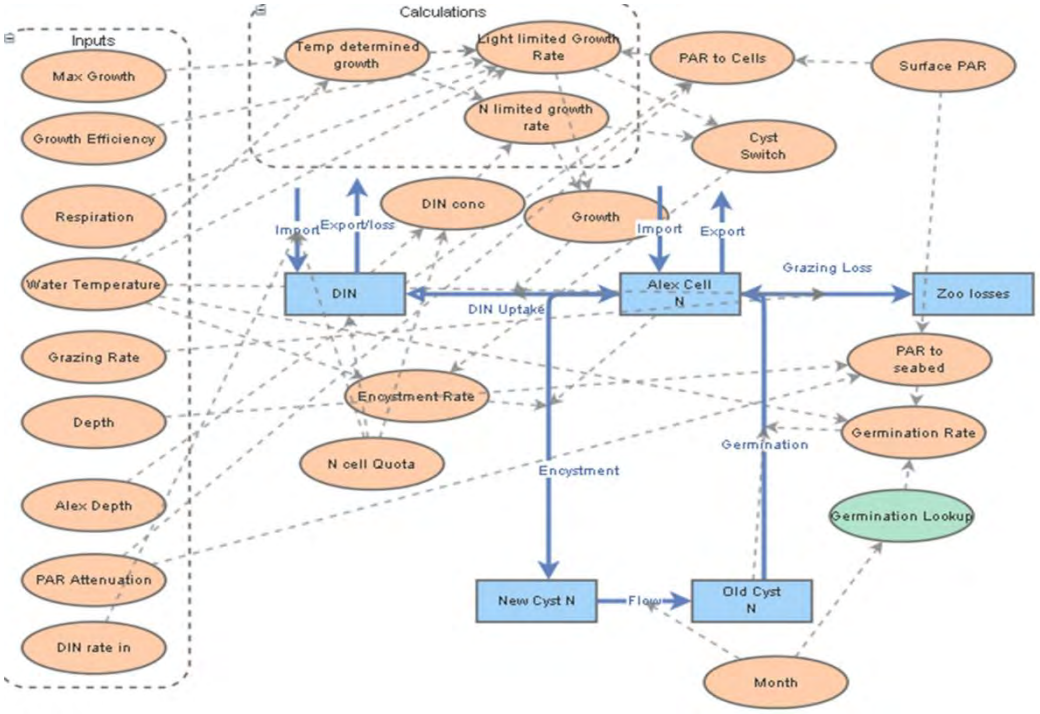
ICHA NEW ZEALAND 2014

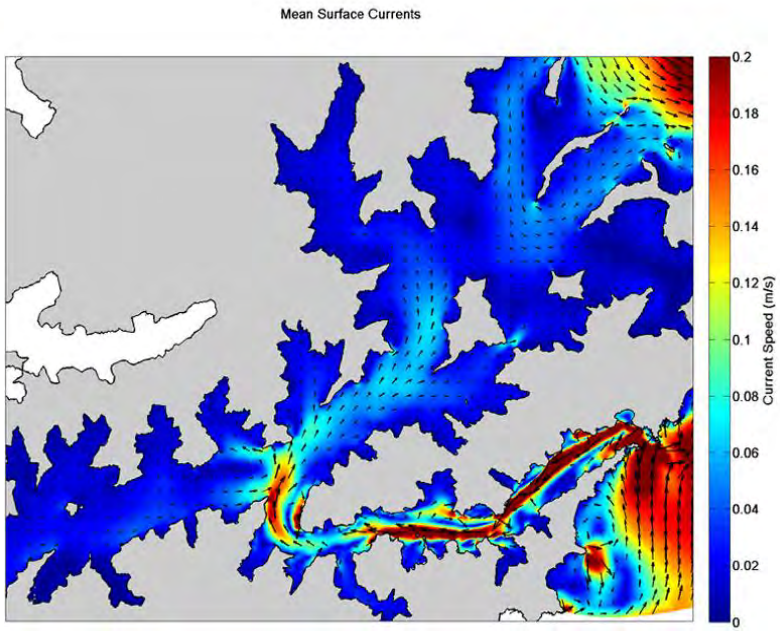
THE 16TH INTERNATIONAL CONFERENCE ON HARMFUL ALGAE

27-31 October 2014. Wellington New Zealand

CAWTHRON INSTITUTE

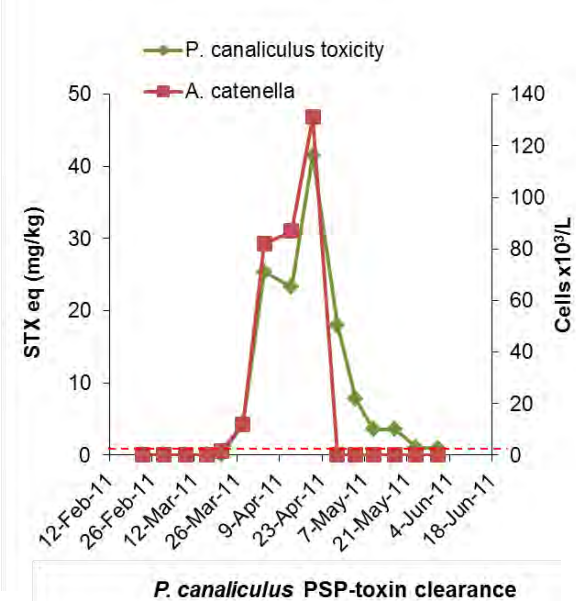
Biophysical modelling

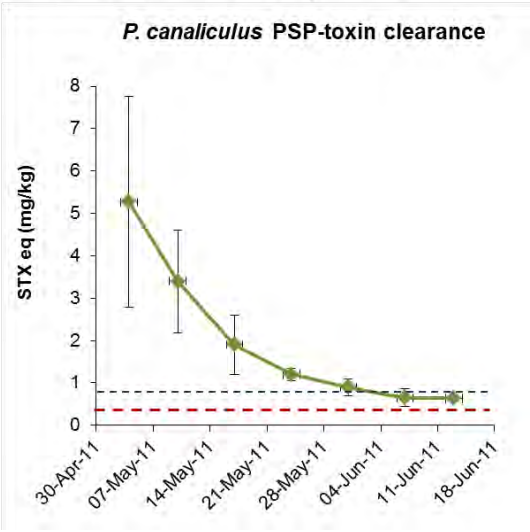


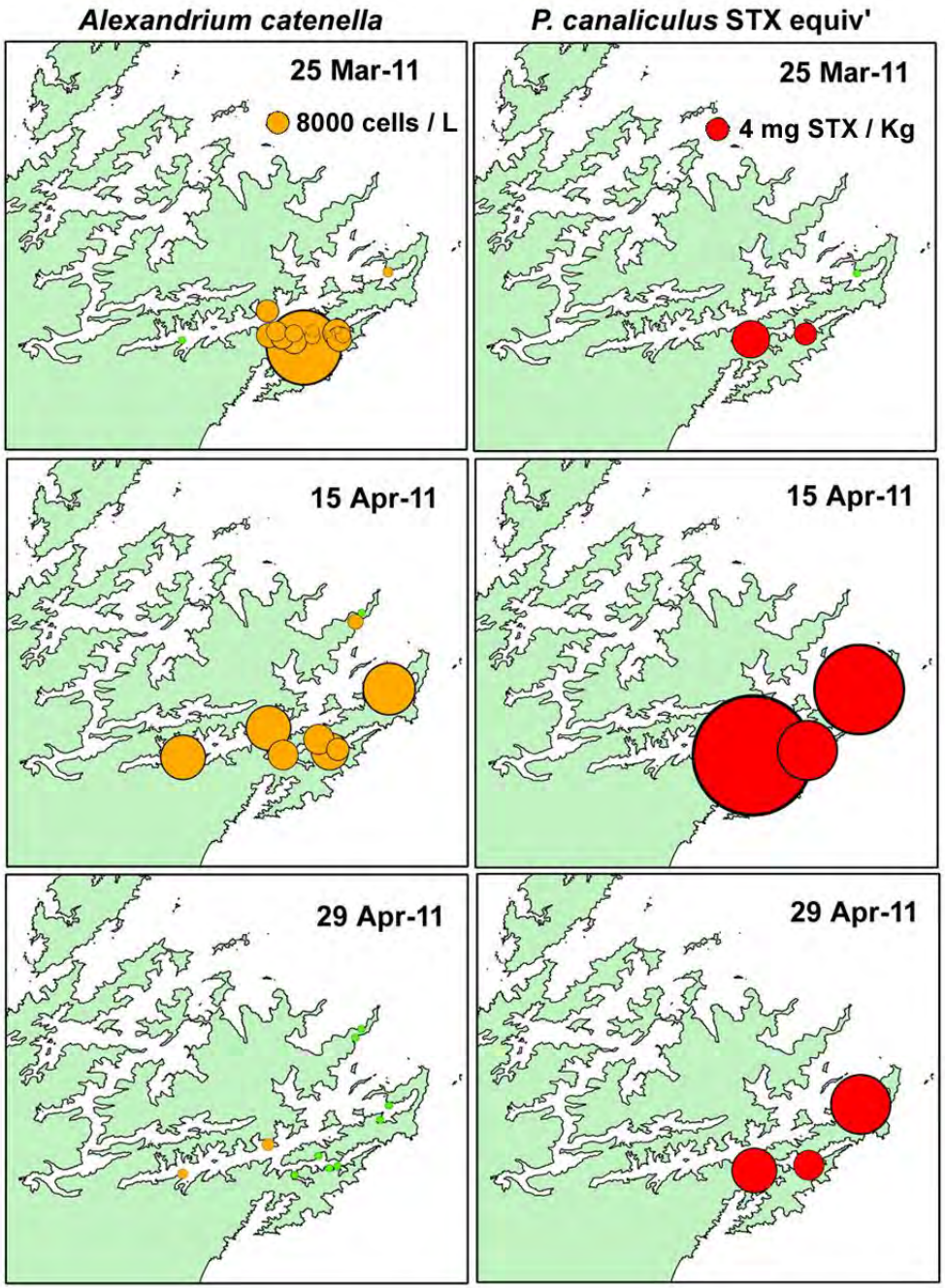


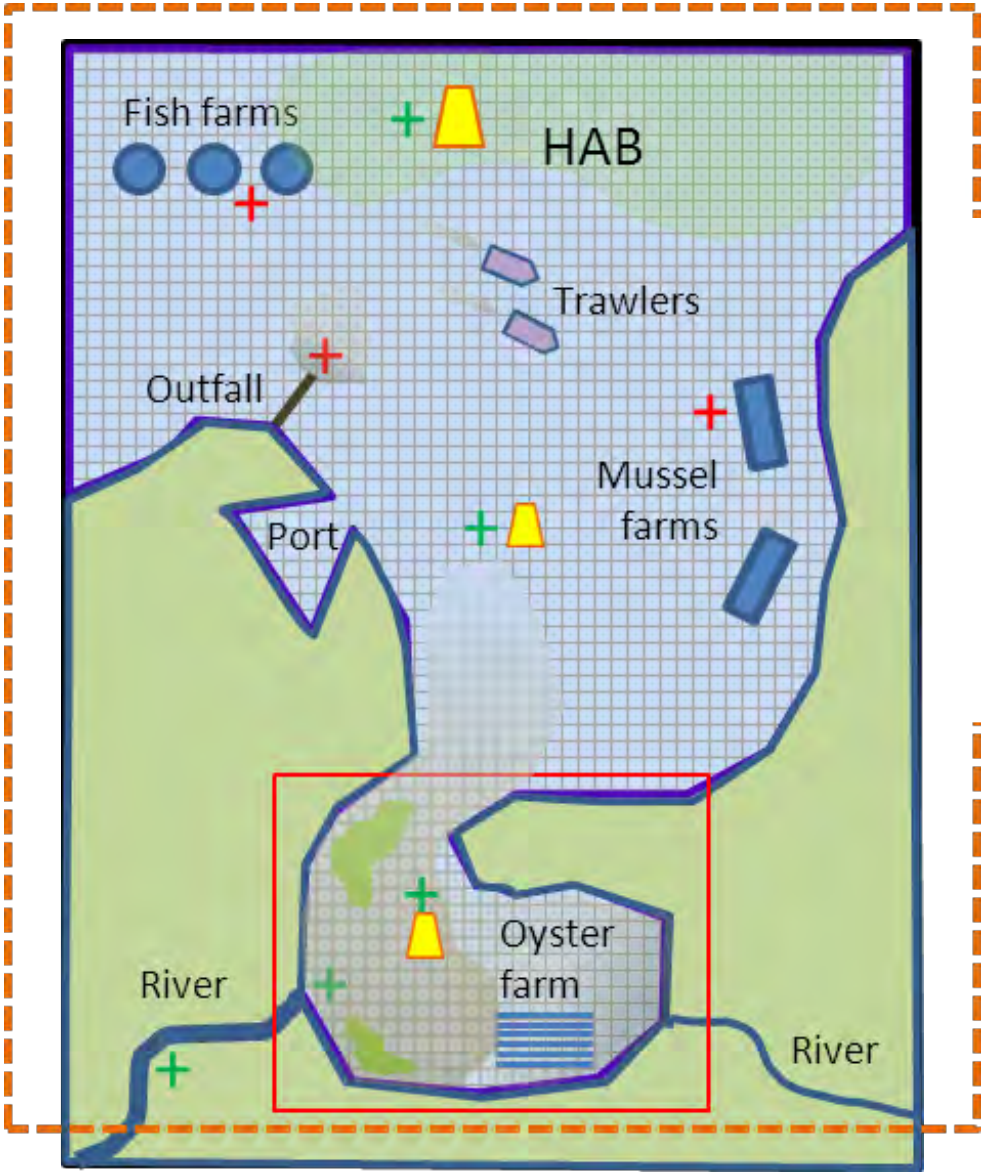
- Prediction of growth, dispersion and demise of bloom
- Integration with shellfish toxin uptake and elimination models
- Enable better management of harvesting (e.g. avoid blanket closures) during bloom episodes

In 2011 the contamination phase lasted 3-4 weeks, toxin clearance took 2-3 months



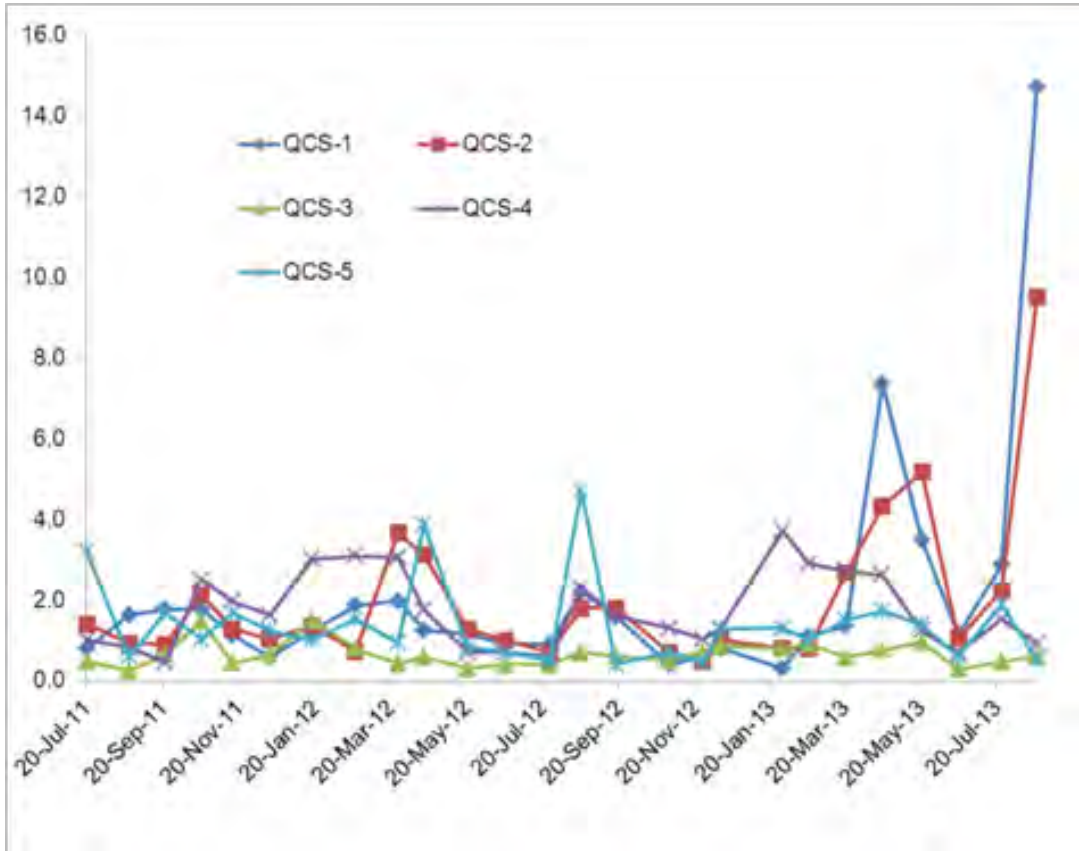






Monitoring efforts

- Consents
- SOE monitoring
- SOE habitat mapping


16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
QCS-1
QCS-2
QCS-3
QCS-4
QCS-5
20-Jul-11
20-Sep-11
20-Nov-11
20-Jan-12
20-Mar-12
20-May-12
20-Jul-12
20-Sep-12
20-Nov-12
20-Jan-13
20-Mar-13
20-May-13
20-Jul-13

An Open Access Ocean Observing System for New Zealand

Coastal Platforms

Regional Governance and Steering (Coastal SIG)

Data standards

Exchange protocols

- Firth of Thames
- Tasman Bay
- Hawke Bay
- RC
- RC

Ports, Research stations

National Backbone

Collaborative Governance

Data Management Dissemination (e.g. LINZ, EDENZ, LAWNZ)
User applications
Models
Forecast/Nowcast

Regional

SOE monitoring programmes

Ocean Platforms

Satellites

Offshore/Deep moorings

Radar

Ships of opportunity

Deep Sea sensor networks

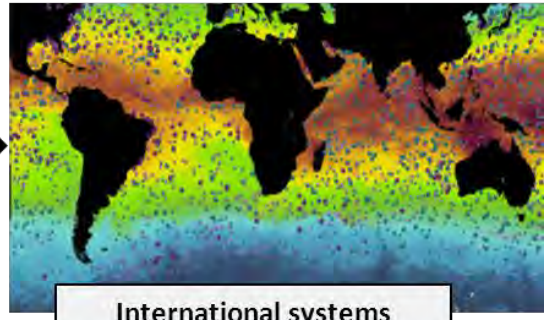
Robotic platforms (Argo, drifters, AUVs)

Communication Visualisation

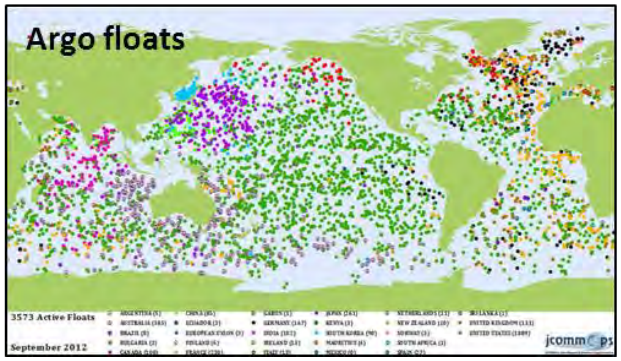
End users

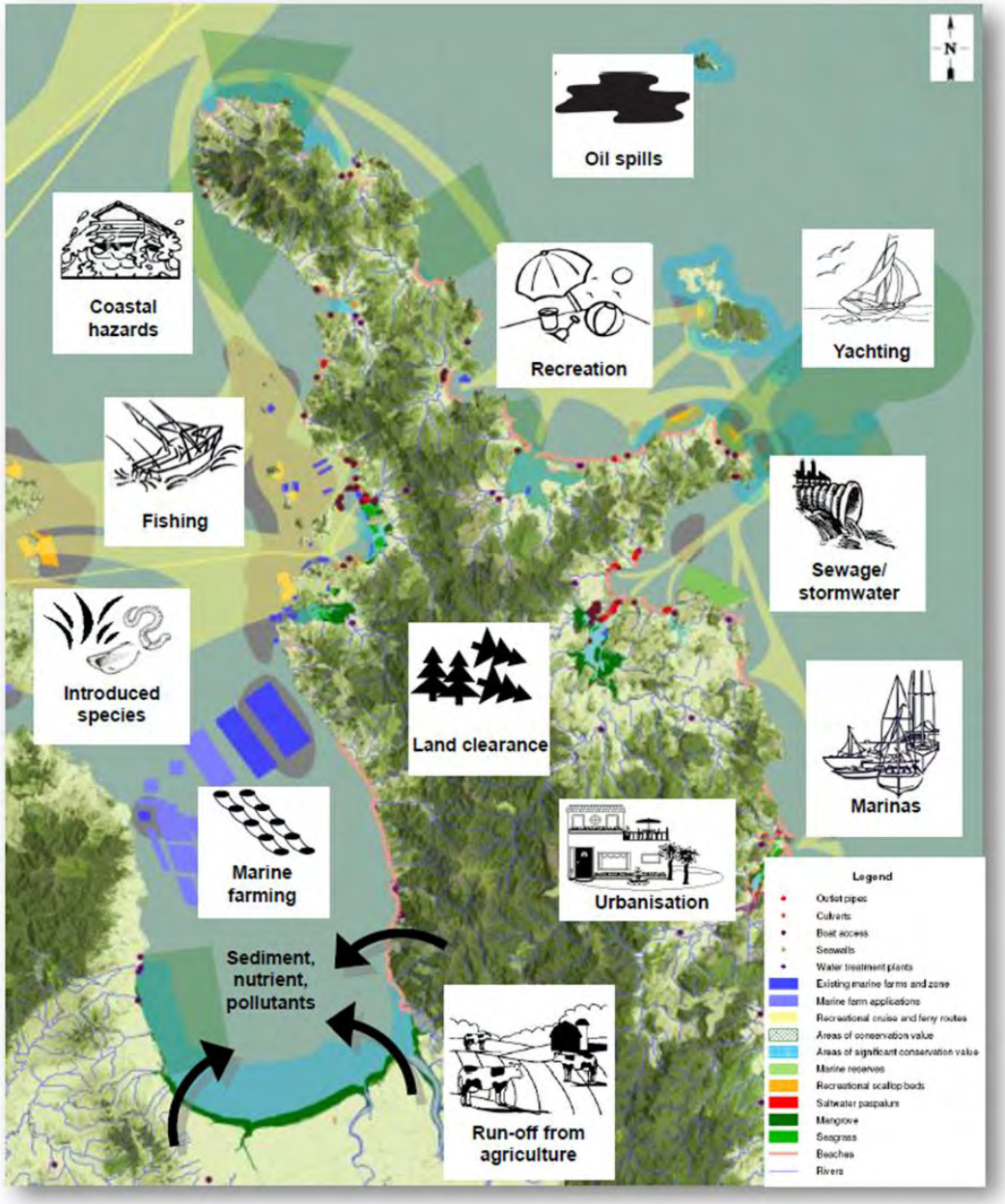
- Industry
- Management
- Policy
- Research
- Education
- Civil society

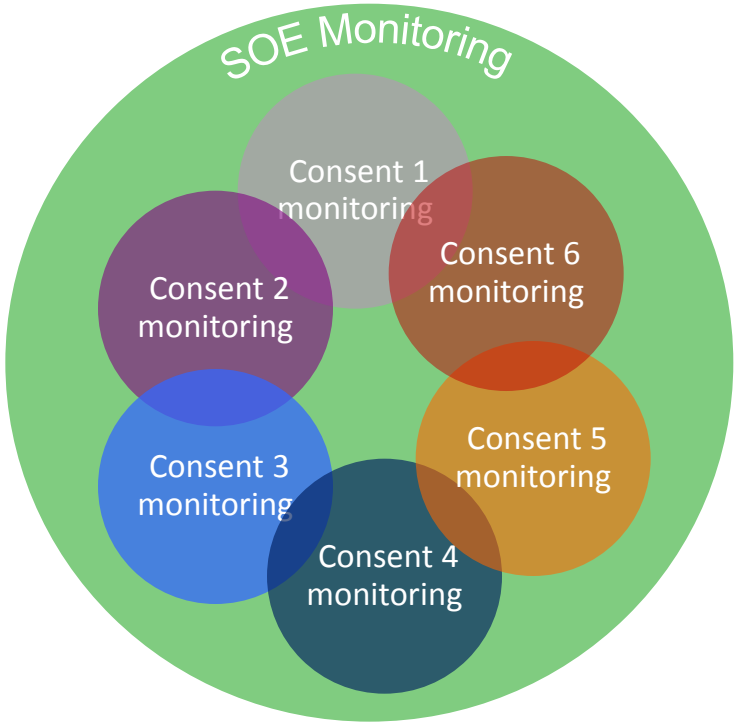
Plugging into the grid



International systems (IMOS, IOOS, GOOS)





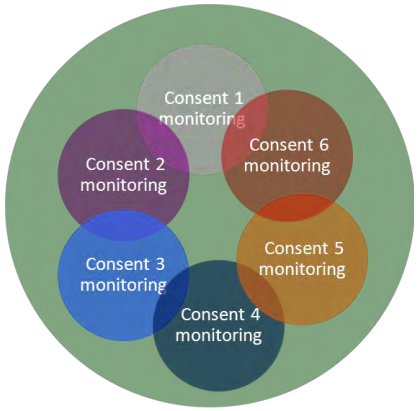


Waikato Regional Council
Te Kaunihera ā Rohe o Waikato

CAWTHRON INSTITUTE

Take Home Messages

- Develop ecosystem-based management and monitoring frameworks that place aquaculture within the bigger picture
- Need to consider and assess effects of aquaculture within the context of the wider ecosystem and cumulative environmental change
- Establish environmental baselines and determine the ecological carrying capacities of water bodies (as well as social and economic)
- Develop tools and monitoring programmes that assist (rather than burden) Industry and provide an indication of wider ecosystem health



CAWTHRON INSTITUTE

Summary

- Is *Alexandrium catenella* undergoing range expansion in the Marlborough Sounds?
- *A. catenella* cysts are confined to Queen Charlotte Sound (so far).
- Opua Bay has a resident population of *A. catenella* and is the origin of annual blooms.
- It has been established in the bay for at least 3 decades.
- The bloom was supressed by a succession of S/E gales in Feb-March 2012.
- Prolonged warm, calm, sunny weather in Feb-March 2013 allowed the bloom to flourish.
- The high nutrient environment of Tory Channel is an important driver.
- Endogenous, biological, physical and water chemistry factors control the bloom
- Biophysical models may assist management in the future