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 Table

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Result</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total abundance</td>
<td>153</td>
<td>Individuals/core</td>
</tr>
<tr>
<td>No species</td>
<td>22</td>
<td>Taxa/core</td>
</tr>
<tr>
<td>Shannon Diversity</td>
<td>1.36</td>
<td>Index</td>
</tr>
<tr>
<td>Pielou’s J’</td>
<td>0.62</td>
<td>Index</td>
</tr>
<tr>
<td>% Organic matter</td>
<td>6.8</td>
<td>% w/w</td>
</tr>
<tr>
<td>Total free sulphides</td>
<td>490</td>
<td>µM</td>
</tr>
</tbody>
</table>

- All indicators have their limitations
- Requires expert opinion / subjective interpretation
  ---> Different assessments from different people
- No single variable that incorporates biological and chemical information
Existing NZKS low flow farm standards:

<table>
<thead>
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<th>Zone</th>
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<th>Description and ‘bottom line’</th>
</tr>
</thead>
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<td>Sediments that are anoxic and azoic (i.e. no life present) will not be permitted.</td>
</tr>
</tbody>
</table>

Unclear, open to interpretation

How much higher? Over how much area?

Unclear, open to interpretation

The only prohibited condition is strict anoxia / azoic conditions. Near impossible state.
The problem

Characterising taxa for biotic indices

Using relationships derive ES

Points of contention

- Established
- Bounded
- Universal
- Ecologically orientated

Enrichment Stage (ES):

1. Pristine/natural
2. Anoxic/azoic

- Redox
- Species richness
- Shannon-Diversity (H')
- Infauna abundance
- Sediment Organic Content & Sulphides
- H₂S & methane out-gassing

Bacterial mat

Aerobic sediments

RPD layer depth

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

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

- 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
Selected for variables that:
1. Correlate well with ES
2. Are versatile
3. Are meaningful & established
4. Give complimentary information
5. Are cost effective

<table>
<thead>
<tr>
<th></th>
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<td>J'</td>
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<td>15</td>
<td>2</td>
<td>0.8265</td>
<td>28</td>
<td>12</td>
</tr>
</tbody>
</table>

Recommended:
- Macrofauna (N, S, AMBI, M-AMBI, BQI)
- Sediment chemistry (S²⁻ > redox)
- %OM – informative, but poor predictor
<table>
<thead>
<tr>
<th>SITE INFORMATION</th>
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</thead>
<tbody>
<tr>
<td>Flow environment: LF</td>
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<tr>
<td>Farm/site: Farm-X</td>
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<tr>
<td>Station: Cage1, Cage2, 50m A, 50m B, Control A, Control B</td>
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</table>

<table>
<thead>
<tr>
<th>Station</th>
<th>Cage 1</th>
<th>Cage 2</th>
<th>50m A</th>
<th>50m B</th>
<th>Control A</th>
<th>Control B</th>
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<tr>
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<td>187</td>
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<td>5275</td>
<td>177</td>
<td>234</td>
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<tr>
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<td>13</td>
<td>21</td>
<td>20</td>
<td>20</td>
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<tr>
<td>Richness</td>
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<td>0.35</td>
<td>2.32</td>
<td>3.67</td>
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<td>SWDI</td>
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<td>0.01</td>
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<tr>
<td>AMBI</td>
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<td>6.00</td>
<td>3.54</td>
<td>3.38</td>
<td>1.46</td>
<td>1.68</td>
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<tr>
<td>M-AMBI</td>
<td>0.14</td>
<td>0.05</td>
<td>0.52</td>
<td>0.76</td>
<td>0.91</td>
<td>0.86</td>
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<tr>
<td>BQI</td>
<td>1.84</td>
<td>1.22</td>
<td>3.02</td>
<td>4.74</td>
<td>9.31</td>
<td>10.46</td>
</tr>
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<table>
<thead>
<tr>
<th>ES equivalents</th>
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<tr>
<td>TOM</td>
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<tr>
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<tr>
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<tr>
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<td>BQI</td>
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<table>
<thead>
<tr>
<th>Weighting</th>
<th>Cage 1</th>
<th>Cage 2</th>
<th>50m A</th>
<th>50m B</th>
<th>Control A</th>
<th>Control B</th>
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<tbody>
<tr>
<td>0.1</td>
<td>Organic loading</td>
<td>4.01</td>
<td>5.82</td>
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<td>1.5</td>
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<td>0.2</td>
<td>Sediment chemistry</td>
<td>4.87</td>
<td>4.67</td>
<td>4.25</td>
<td>3.76</td>
<td>1.84</td>
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<tr>
<td>0.7</td>
<td>Infauna composition</td>
<td>5.27</td>
<td>5.82</td>
<td>3.49</td>
<td>2.58</td>
<td>1.71</td>
</tr>
</tbody>
</table>

Overall ES | 5.06 | 5.59 | 3.68 | 2.92 | 1.72 | 1.89 |
Back to the problem...

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

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</table>
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
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 POCHON¹, JAN PAWLOWSKI², NIGEL KEELEY¹, SUSIE WOOD¹

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

Enrichment stage:

7 6 5 4 3 2 1

- Methane out-gassing
- Redox
- Species richness
- Shannon-Diversity (H')
- Infauna abundance
- Sediment Organic Content & Sulphides
- Bacterial mat
- Anoxic sediments
- RPD layer depth
- Aerobic sediments

Recovery gradient - increasing distance/time from enrichment source

Degradation gradient - increasing exposure to organic deposition

Very high

Natural
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

by Viktor S. Poór
## Biodiversity in Tasman Bay Water

<table>
<thead>
<tr>
<th>Family</th>
<th>Genera</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthessiidae</td>
<td>Anthessius, Elminius, Limnocalanus, Euterpina</td>
<td>Anthessius sp., Elminius modestus, Limnocalanus macrurus, Euterpina agitifrons, Oithona sp., Alteuthellopsis sp., Penilia avirostris, Vaunthompsonia minor</td>
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<tr>
<td>Calanidae</td>
<td>Calanus</td>
<td>Calanus sp.</td>
</tr>
<tr>
<td>Euterpinidae</td>
<td>Euterpina</td>
<td>Euterpina sp.</td>
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<td>Oithonidae</td>
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<td>Oithona sp.</td>
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<td>Sidia</td>
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<td>Bodotria sp.</td>
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<tr>
<td>Sabelidae</td>
<td>Sabella</td>
<td>Sabella sp.</td>
</tr>
</tbody>
</table>

**Legend:**
- **Blue**: Arthropoda
- **Green**: Dinoflagellata
- **Red**: Mollusca
- **Yellow**: Echinodermata
- **Brown**: 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

Forams ID

Genetic ID

Core sediment

Database

Nov’12

Jan’13

Mar’13

http://forambarcoding.unige.ch/

Contributed sequences for ~50 NZ species
Notorotalia sp.

Reophax sp.

Rosalina sp.

Nonionella sp.
Research Plan

SAMPLING

Forams ID

Genetic ID

Database

Core sediment

DNA / RNA extract

FCI
Nov’13

NGS
Jun’13

Mar’13

http://forambarcoding.unige.ch/
NGS Data – 120 Samples

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<th>NGS OUTPUT DATA</th>
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<td>Number of reads after QC</td>
</tr>
<tr>
<td>Foram classes / orders / families / species</td>
</tr>
</tbody>
</table>
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
- 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

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Jonathan Drew (University of Otago)
Reid Forrest (Cawthron)
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, \( r^2 = 0.248, p < 0.001 \)
  - Winter, \( r^2 = 0.197, p = 0.001 \)

- **Winter**
  - SST* + Flow*
  - Winter, \( r^2 = 0.368, p < 0.001 \)
  - Winter, \( r^2 = 0.368, p < 0.001 \)

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

- **Summer**
  - PN*** + Dist***
  - Summer, \( r^2 = 0.292, p < 0.001 \)
  - Winter, \( r^2 = 0.368, p < 0.001 \)

- **Winter**
  - PN***
  - Winter, \( r^2 = 0.368, p < 0.001 \)

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

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

![Graph showing Chlorophyll levels over time.](image-url)
Can characterize what has been ‘natural’...

**Outer Pelorus 40m**

- Date range: 2002-02-26 to 2010-07-19
- Observations: 283

**Laverique Bay**

- Date range: 1997-07-28 to 2007-02-19
- Observations: 469
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
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
High seasonal and inter-annual variation. Some of the latter is El Niño/La Niña related.
Remote sensed data: suspended solids

Remote sensed data: chlorophyll

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

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

<table>
<thead>
<tr>
<th></th>
<th>Concentration (no farms)</th>
<th>Rel. change (scenario 1)</th>
<th>Rel. change (scenario 2)</th>
<th>Rel. change (scenario 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DIN</strong></td>
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<td><strong>Diatom</strong></td>
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<tr>
<td><strong>Phytofl.</strong></td>
<td></td>
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</tr>
</tbody>
</table>

enabling the benefits of New Zealand's natural resources

NIWA Taihora Nukurangi
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
- 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
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
Aquaculture and cumulative effects: The big picture

Chris Cornelisen
Lincoln MacKenzie
Hilke Giles
Barrie Forrest
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
Multiple stressors associated with the above operate on a range of spatial and temporal scales.
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
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 organic 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.
Nutrient Sources
- Ocean
- Agriculture
- Outfalls
- Industry
- Atmosphere
- Urban runoff
- Septic
- Aquaculture

Additional stressors
- Overfishing-food web effects
- Habitat (e.g. wetland) loss/modification
- Climate change (e.g. rainfall, winds)

Nutrient loading

Nutrient loading exceeds assimilative capacity

Eutrophication

Cumulative effects
- Increased phytoplankton production
- Increased macroalgae production (e.g. Ulva)
- Reduced water clarity - light attenuation
- Shifts in phytoplankton species composition (potential increase in HABs)
- Increased zooplankton grazing/shifting in composition
- Increased seabed deposition of organic matter
- Increased decomposition and respiration
- Frequent hypoxic conditions – low diversity and shift to microbe dominated communities
Ruakaka Bay salmon kill 6 June 2010

Psuedochattonella verruculosa
Pseudochattonella at the Rauaka farm, June 2010

High fish mortality rates

Farm relocated

• Losses were about 15% 08 brood population; 57,000 fish / 200 tonnes

• Smaller 09 brood fish largely unaffected
Queen Charlotte Sound Transect 16 June 2010

- Anakiwa
- Wedge Point
- Ruakaka
- Otanera

Temperature

Salinity (psu)

Density (sigma-t)

Phytoplankton biomass (Chla)

Blenheim airport rainfall

- 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

Queen Charlotte Sound farm sites

Otarama Bay farm site

Tory Channel farm sites

Grove Arm

Map scale: 0-10 Km
Toxic *Alexandrium catenella* blooms: A “recent” problem for aquaculture in the Marlborough sounds
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.
A. catenella life cycle

A. catenella resting cysts

Pycnocline

(+)

Compatible gametes

(-)

Mating gamete pair

Vegetative growth

Planozygote

Resting (sexual, 2n) cyst

Excystment

Ecdysal (asexual, n) cyst

Planomeiocyte

Sediment

Brightfield

Primuline stained fluorescence

CAWTHRON

INSTITUTE
Hydrography - water chemistry

A. catenella in 12m integrated samples

Tory Channel - Opua Bay water column transects

Temperature 13 March-13

Nitrate + Nitrite-N (mmol m\(^{-3}\)) 13 Mar-13

DRP (mmol m\(^{-3}\)) 13 Mar-13

Chla (µg/L) 13 Mar-13

A. catenella (cells x 1000) 13 Mar-13

2 Feb 2013

15 Feb 2013

24 Feb 2013

13 March 2013

22 March 2013

Onepua Bay

Opua Bay

Km

Tory Channel

Cells / Litre

1 x 10^2

1 x 10^3

1 x 10^4

1 x 10^5
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](image)
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
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)
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
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 Accessible
GUiS for accessibility

Surface Temperature

Surface Salinity

Cumulative Effects Investigator

Cumulative nitrogen inputs
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).
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.
An Open Access Ocean Observing System for New Zealand

Coastal Platforms
- Regional Governance and Steering (Coastal SIG)
- Data standards
- Exchange protocols
- Ports, Research stations

National Backbone
- Collaborative Governance
- Data Management Dissemination (e.g. LINZ, EDENZ, LAWNZ)
- User applications
- Models
- Forecast/Nowcast

Ocean Platforms
- Satellites
- Offshore/Deep moorings
- Radar
- Ships of opportunity
- Deep Sea sensor networks
- Robotic platforms (Argo, drifters, AUVs)

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

Communication Visualisation

Plugging into the grid

International systems (IMOS, IOOS, GOOS)

Argo floats
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
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 suppressed 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.