Role of Deposit Feeders in Integrated Multi-Trophic Aquaculture
A Model Analysis

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Role of Deposit Feeders in Integrated Multi-Trophic Aquaculture

Outline of talk

• Integrated Multi-Trophic Aquaculture in the West
• Supply of organic matter to the benthos
• Individual model for deposit feeders
• FARM model for population in monoculture and IMTA
• Final comments

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Integration
Southeast Asia and China

• In onshore ponds (70% of world production): effective internal re-use of materials – IMTA is almost a necessity, and was essential before electricity and diesel-driven aerators;

• In lakes and bays: whole water body re-use of materials can be soon due to scale and stocking density (e.g. 140 km² Sanggou Bay, NE China, produces 150,000 tons of shellfish, finfish, and seaweed per year (~ 1 kg m⁻²).

How does that translate into the Western model?
The I in IMTA
How can INTEGRATION work in the west?

IMTA can mean different things…

• Iberian Matador de Toros Agency
• International Mendia Txakurra Association
• Integrated Multi-Trophic Aquaculture

• Does integrated explicitly mean direct recycling, or can it be a system-scale (water body scale) budget?
• Interactions among fish cages and extractive culture in open water at densities acceptable in the West are difficult to quantify
• For shellfish and seaweeds if your layout has a budget role, do we need structures close together?
• Perhaps the only direct coupling is with the benthos, after all that’s where the impact concerns are greater.

Different layout models and stocking densities constrain the word Integrated.
Allochtonous supply of organic material to benthic deposit-feeders below a fish cage

The simplest model with no advection or dispersion considers $A_d = A_f$

- $S_b$: Background loading (g d$^{-1}$)
- $S_w$: Waste feed loading (g d$^{-1}$)
- $S_f$: Faecal loading (g d$^{-1}$)
- $A_f$: Area of polar cage (m$^2$)
- $A_d$: Area of benthic footprint (m$^2$)
- $z$: Water column depth (m)
- $Z_f$: Fish cage depth
Allochtonous supply of organic material to deposit-feeders under a fish cage

Advection shifts the dispersion footprint as a function of the residual current.
Feed Conversion Ratio (FCR) and mass apportionment

Example for 1kg of fish, FCR = 1.12

FW to DW conversion
Consider a moisture content of 73.65% for Salmo salar muscle (Atanasoff et al., 2013): 1.00 kg wet weight = 0.2635 kg DW.

FCR is the result of Input/Output. Input-Output = Total loss
Mass balance for an Atlantic salmon growth cycle

- Anabolism: 19547.9 kcal
- BMR: 3677.7 kcal
- SDA: 5864.4 kcal
- Swimming: 2669.4 kcal

Food ingestion: 5019.8 g DW

- Respiration: 62.7 kg O2
- Digestion in the gut
- Faeces: 984.4 g DW
- Excretion: 164.6 g N

Feed supplied: 5473.3 g DW

- Feed Loss: 453.5 g DW
- Organic losses: 1438.0 g DW

Cultivation: 817 days
- Current: 100 cm s^-1
- Biomass: 5000.1 g FW
- Length: 75 cm
- FCR: 1.1
- ADC (N): 87%

Matched FCR and end-point weight.
### Literature and model comparisons

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Literature</th>
<th>AquaFish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed wasted (%)</td>
<td>12</td>
<td>9.1</td>
</tr>
<tr>
<td>Ingested feed (%)</td>
<td>88</td>
<td>90.8</td>
</tr>
<tr>
<td>Ingested feed lost as faeces (%)</td>
<td>15</td>
<td>17.6</td>
</tr>
<tr>
<td>Food consumed in metabolism (%)</td>
<td>58.3</td>
<td>54.7</td>
</tr>
</tbody>
</table>

Literature data from Reid et al, 2008, and various other sources, based on measured outputs or mass balance differences.
Feed Conversion Ratio (FCR) and mass apportionment

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Feed used 1017 g DW = Fish faeces 197 g DW + Metabolism Equiv. 556.9 g DW + Fish mass 263.5 g DW

FCR 1.12
Organic Sedimentation Model - ORGANIX

• ORGANIX predicts the benthic loading footprint. Many other models (Gowen, Silvert, Cromeey, Corner, and respective co-workers) do this;

• Dispersion in 2 dimensions is based on Gaussian distribution functions;

• Advection is based on residual circulation;

• Model algorithm determines time to settle based on fall velocity. Probability distribution (dispersion) and advective shift is determined at each timestep until the plume reaches the bottom;

• Loading from culture structures is distributed over the modelled surface;

• Calibration for Atlantic Salmon, experimental data from DFO and literature. Feed pellets fall faster than faeces;

• ORGANIX does not account for physiological variation.

Calculation of bottom loading and spatial distribution under different culture and environmental conditions is essential for deposit feeder model.
Clear plume separation from a square cage - feed settles faster than faeces.
Parastichopus californicus individual growth model
Simulation of sea cucumber growth in integrated culture under salmon farms

![Graph showing growth and organic loading](image)

**Annualized organic loading to the bottom (zoomed)**

- 23 gPOM m⁻² d⁻¹
- 9 gPOM m⁻² d⁻¹
- 5.5 gPOM m⁻² d⁻¹

**Graph Details**
- Live Weight (g)
- Days
- North-South Distance (m)
- East-West Distance (m)
- Organic load (gC m⁻² y⁻¹)
General setup for sea cucumber individual model in WinDep

Loading based on highest values computed in ORGANIX for a 30 m polar cage stocked with 20,000 Atlantic Salmon (2.8 fish m⁻³).
Mass balance for a four year sea cucumber growth cycle

Parastichopus californicus weight data - large animals: 100-565 g WW (Hannah et al., 2013), 793-1483 g WW (Hannah et al., 2012).
FARM model for finfish, shellfish, seaweed, and deposit feeders.

FARM model
IMTA of Atlantic salmon and sea cucumber

Model setup: Area of 600 m (3 X 200 m sections) by 200 m; sea cucumber density for standard model: 5 ind. m\(^{-2}\); culture period for tests: 400 days; drivers as in WinFish.

FARM simulates changes to individual weight, harvest, and income.
POM in the FARM model

• FARM calculates transport and sedimentation of particulate organic matter, split into (i) natural background; (ii) aquaculture;

• Aquaculture input in IMTA is the summation of POM from different components, e.g. finfish and shellfish;

• Each component can produce larger diameter particles and smaller diameter particles;

• Smaller particles are used for water column interactions (e.g. filter-feeder use of fish waste), larger particles supply deposit-feeders;

• Particle size split estimates vary. e.g. salmon data: 13% > 2 mm diameter, or 27% suspended (in Reid et al., 2008);

• FARM is a farm-scale model (duh) but does not operate at the fine scale needed for simulating spatial distribution of waste;

• Probability distributions from ORGANIX will be combined with loading from FARM to provide appropriate spatial scaling, and a physiologically-based change in loading through the growth cycle.

*FARM allows the discrimination of POM sources to the water column and benthos.*
Synthesis of FARM outputs for deposit feeders

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mono</th>
<th>IMTA 1 0.5 fish m⁻²</th>
<th>IMTA 2 50 fish m⁻²</th>
<th>IMTA 3 Oysters</th>
<th>IMTA 4 IMTA 2 + IMTA 3</th>
<th>IMTA 5 IMTA4 + 3X Dep.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual weight (g)</td>
<td>65.5</td>
<td>67.4</td>
<td>154.4</td>
<td>107.4</td>
<td>167.1</td>
<td>167.1</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>11.2</td>
<td>11.3</td>
<td>15.1</td>
<td>13.3</td>
<td>15.5</td>
<td>15.5</td>
</tr>
<tr>
<td>Harvest (t cycle⁻¹)</td>
<td>8.73</td>
<td>9.47</td>
<td>58.1</td>
<td>29.6</td>
<td>65.9</td>
<td>197.8</td>
</tr>
<tr>
<td>APP</td>
<td>2.9</td>
<td>3.2</td>
<td>19.3</td>
<td>9.9</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Profit (k€) as EBITDA</td>
<td>161.9</td>
<td>178.7</td>
<td>1292</td>
<td>640.4</td>
<td>1473</td>
<td>4417.7</td>
</tr>
<tr>
<td>POM removal net ( t y⁻¹)</td>
<td>11.9</td>
<td>12.2</td>
<td>29.8</td>
<td>20.1</td>
<td>32.5</td>
<td>97.4</td>
</tr>
<tr>
<td>Excretion (kg NH₄ y⁻¹)</td>
<td>11.7</td>
<td>12.0</td>
<td>30.6</td>
<td>19.9</td>
<td>33.9</td>
<td>101.6</td>
</tr>
<tr>
<td>POM loading (g C m⁻² y⁻¹)</td>
<td>20.5</td>
<td>21.6</td>
<td>124.4</td>
<td>47.1</td>
<td>151.0</td>
<td>151.0</td>
</tr>
</tbody>
</table>

Scenarios for different finfish densities in IMTA, shellfish longline culture (100 ind. m⁻²), shellfish + finfish, and 3X deposit feeder density (15 ind. m⁻²).
Synthesis

• An individual model for sea cucumbers was developed in a visual platform (Insight Maker), calibrated, and tested with measured data. It was then ported to C++ (AquaDep);

• The individual model was run for various loading situations based on the settlement plume from an individual cage, simulated with ORGANIX;

• Sea cucumber individual growth drives the population component of the FARM model. The POM mass balance was completely rewritten to deal with different IMTA components;

• Deposit feeder growth in FARM is responsive to both finfish and shellfish solid emissions;

• The environmental mitigation role of deposit feeders can be quantified, as well as the economic benefits of IMTA;

• Further calibration, and validation within the IDREEM project for partner farms will allow an assessment of the relative role of bivalve shellfish and deposit feeders in western-style IMTA.

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