Environmental effects of Atlantic salmon cage culture
Modelling of growth and mitigation in IMTA

Joao G. Ferreira, R.A. Corner, J. Johansen, A.M. Cubillo

Universidade Nova de Lisboa, Portugal
Donostia, Spain, October 2014
Modelling of salmon growth in the context of IMTA
Outline of talk

• No question, no model
• Beyond FCR
• The context of offshore aquaculture
• Down on the farm
• FARM model for IMTA
• Synthesis

http://ecowin.org/simta
No question, no model
Another salmon model?

• Optimize growth with respect to feed: feed company models: match growth rates and optimize FCR. If things aren’t going well, how about this new proprietary formula?

• Benthic footprint for licensing: DEPOMOD and others, no physiological representation of growth, calculated emissions

• Site selection: models such as MOM (Stigebrandt et al) include a salmon growth module

• Carrying capacity: Aqvavis, GIS-based system, growing more complex with DEB modelling etc.

• Other modelling and monitoring systems such as the Welfaremeter
Welfaremeter operational model

- Coupled monitoring and modelling for finfish cages
- A cage can contain one million USD of fish, but little investment in monitoring of environment and fish behaviour
- Automated assessment of fish welfare in sea cages
- **Instrumentation** such as profiling CTD, DO, echosounders
- **Database** for secure data storage and retrieval
- **Expert system software** for data analysis and modelling
- **Web interface** for easy visualisation of data and expert system outputs
- Similar systems developed for gilthead and bass in the east Mediterranean

Aquafish

• Generic model for fish physiology, including not only temperature as a driver for growth, but mechanistic representation of feeding, satiation, and other processes

• Key requirements: description of growth, description of environmental effects – waste particulates (feed and faeces), metabolic byproducts (nitrogen excretion, oxygen consumption) – these provide the link to IMTA

• Partitioning of energy use: BMR, SDA, swimming (or going to the gym) – key for offshore aquaculture

• Other models address only parts of this list

• If we can simulate scope for growth, the individual model can be scaled to population – any agri or aqua business is interested in harvestable biomass, coastal managers are interested in environmental effects
A combination of models helps address different aspects of sustainability.
WinFish workbench - Atlantic salmon

Example run with IDREEM drivers to grow a 5 kg fish.
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

Feed supplied 5473.3 g DW

Respiration 62.7 kg O₂

Digestion in the gut

Faeces 984.4 g DW

Excretion 164.6 g N

Feed loss 453.5 g DW

Organic losses 1438.0 g DW

Inorganic losses 164.6 g N

Energy assimilated 7336.4 kcal

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
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.

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

Assimilation 80%

Fish intake 1017 g DW

Total loss 102.7 g DW

Feed 1120 g DW

FCR 1.12

Fish production 1000 g WW

FCR is the result of Input/Output. Input-Output = Total loss
AquaFish model analysis

Offshore current speed effects on finfish growth

Four current speed classes identified; class B optimises cultivation period and Feed Conversion Ratio (FCR)
FARM model
Monoculture and IMTA

FARML model for finfish, shellfish, seaweed, and deposit feeders.

# FARM model outputs – Fish Monoculture

<table>
<thead>
<tr>
<th>Company</th>
<th>Species</th>
<th>Declared prod. (T)</th>
<th>Model Prod. (T)</th>
<th>Diff (%)</th>
<th>Declared FCR</th>
<th>Model FCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Murphy’s</td>
<td>Salmon</td>
<td>743</td>
<td>998</td>
<td>+25.6</td>
<td>1.4 - 1.6</td>
<td>2.49</td>
</tr>
<tr>
<td>GIFAS</td>
<td>Salmon</td>
<td>2940</td>
<td>3203</td>
<td>+8.2</td>
<td>1.07</td>
<td>2.27</td>
</tr>
<tr>
<td>AQUA</td>
<td>Sea bream</td>
<td>240</td>
<td>308</td>
<td>+22.1</td>
<td>2.40</td>
<td>3.23</td>
</tr>
<tr>
<td>Seawave</td>
<td>Sea bream</td>
<td>1095</td>
<td>962</td>
<td>-13.8</td>
<td>1.8 - 2.1</td>
<td>3.69</td>
</tr>
<tr>
<td>Suf Fish</td>
<td>Sea bream</td>
<td>843</td>
<td>835</td>
<td>-1</td>
<td>2.30</td>
<td>4.04</td>
</tr>
</tbody>
</table>
To the right of the dotted line, finfish culture becomes economically uninteresting due to excessive metabolic cost of swimming

How can INTEGRATION work in the West?

IMTA can mean different things…

• 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.
**Offshore IMTA – oysters and finfish**

Oyster yield **may** increase in IMTA due to greater food availability.
Allochtonous supply of organic material to deposit-feeders under a fish cage.

Advection shifts the dispersion footprint as a function of the residual current.
Clear plume separation from a square cage - feed settles faster than faeces.
Simulation of sea cucumber growth in integrated culture under salmon farms

**Graph:**
- X-axis: Days
- Y-axis: Live Weight (g)
- Lines:
  - Red: 23 gPOM m⁻² d⁻¹
  - Green: 9 gPOM m⁻² d⁻¹
  - Blue: 5.5 gPOM m⁻² d⁻¹

**Legend:**
- 23 gPOM m⁻² d⁻¹
- 9 gPOM m⁻² d⁻¹
- 5.5 gPOM m⁻² d⁻¹

**Additional Information:**
- Annualized organic loading to the bottom (zoomed)
- North-South Distance (m)
- East-West Distance (m)
- Organic load (gC m⁻² y⁻¹)

- Colors:
  - Red: 3500
  - Orange: 3000
  - Yellow: 2500
  - Green: 2000
  - Blue: 1500
  - Light Blue: 1000
  - Light Green: 500
  - White: 0
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.
## FARM outputs for deposit feeders

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mono 0.5 fish m⁻²</th>
<th>IMTA 1 50 fish m⁻²</th>
<th>IMTA 2 Oysters</th>
<th>IMTA 3 IMTA 2 + IMTA 3</th>
<th>IMTA 4 IMTA 4 + 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>
</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>
</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>
</tr>
<tr>
<td>APP</td>
<td>2.9</td>
<td>3.2</td>
<td>19.3</td>
<td>9.9</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>
</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>
</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>
</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>
</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

• AquaFish was developed to meet several needs, including site selection for offshore aquaculture, and environmental externalities for IMTA;

• The EU IDREEM project has allowed the validation of production of various finfish species in monoculture, including salmon in Norway and Ireland;

• IMTA in Europe, US, and Canada is extensive by definition. Direct coupling is obvious only with deposit feeders;

• Trials with the FARM model show it is responsive to solid emissions from both finfish and shellfish;

• The simulation of fish physiology allows the quantification of environmental externalities within the culture cycle, and their effect on co-cultivated organisms (mitigation);

• Models such as FARM and ORGANIX allow a representation of IMTA in time and space, and can be used to optimize stocking densities and timing of culture combinations.

http://ecowin.org/simta