**AquaModel:**
Mariculture model development and testing

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Overview of Talk

- GIS known as EASy: Environmental Assessment System
- Examples of GIS use
- AquaModel within a Geographic Information System (GIS)
- General architecture of AquaModel & its origins
- Output features and application in two different ecoregions
- Short clips of model running real time
• Three dimensional system for marine applications
• Compatible with ESRI (arc-info) GIS
• Interfaces for models, spreadsheets, databases, and Internet
Species richness relative to bathymetry, water density differentials & bottom temperature

Physicochemical Characterization: Strait of Juan de Fuca 30 - 50 m Zone
Possible mariculture site with strong currents & HNLC conditions

Naturally modest [oxygen]
Drought = low Fraser Rv. flow
Low FW input = weak mixed layer, = even lower surface DO

D.O. to temperature $r = 0.92$
SST used as surrogate for D.O.

Area too dynamic to compare CTD stations without buoy system
Longitudinal and cross channel transects
- Significantly lower temperature,
- Therefore dissolved oxygen lower too
- Implications for farm siting

Rensel et al. submitted
Primary AquaModel simulation variables

Near field use:
1) carbon flux ➔ Benthic footprint of organic carbon deposition resuspension, transport and respiration
2) Oxygen flux ➔ Fish Respiration limits pen loading TOC drives sediment oxygen demand

Meso-field use:
1) Nitrogen flux ➔ Pelagic footprint
Simulates excretion of NH4, Phytoplankton growth & Zooplankton grazing
Other simulated outputs including profiles & transects:

- Instantaneous fish growth rate
- Fish biomass
- Optimal feed requirement
- Fecal carbon distribution
- Waste feed carbon distribution
- Sediment anaerobic and aerobic profiles
- Sediment deposition by component: fecal, feed, combined
- Near bottom suspended layer DO: fecal, feed, combined

All outputs from vertical profiles recorded to spreadsheet file if desired from several locations

20+ pens or farms modeled simultaneously
Hydrodynamic Module

- multibox L x W x D grid 3D model
- current meter data or simulated sinusoidal
- suited for open ocean – inshore
- validated with salmon and sea bream farm data, diffusivity constants
Fish Physiology Module

- Carbon – Oxygen – Nitrogen based
- Growth and metabolism simulation (parameterized the literature data of Brett, Fry and others)
- Varies with activity level, temperature, ration, etc.
- Spp. specific respiration, N excretion & settling rates
- Validation salmon physiology lab data, field data
Benthic Module

- Based on “G model” of carbon cycling
- Similar to DEPOMOD (salmon & sea bream) but based on our own modeling code
- Allows resuspension of particulates
- Sediment oxygen profile simulation F&W Maine
- Temperature-based carbon decomposition
- Validated for salmon farms, focus on other spp
- Sulfides, benthic infauna index capable
Benthic - Pelagic Model Linkages

gas diffusive exchange

Resuspension Zone

Sediment to Water Column

particle deposition & consolidation or transport

Deep RPD

Shallow RPD

H₂O

POC

aerobic biomass

H₂S

O₂

CO₂

SO₄

anaerobic biomass

POC

Chemo-autotrophic biomass

H₂O

CO₂

S
Nutrients – Algae - Zooplankton

- Standard NPZ construction
- Nitrogen to phytoplankton & zooplankton growth
- Recycling and losses such as grazing
- Validated with published research including DAK
Model Construction: Teamwork

- Develop a conceptual model
- Collect or obtain quality process data & linkages
- Conceive, write and link equations (Mathematica)
- Write code (visual basic)
- Debug code
- Enter data, images, polling sources
- Run and compare to validation data
- Revise equations and code, run again & again
- Sensitivity analysis (vary range of less known f)
- Validate, validate, validate…..
Cobia Cages Offshore of Puerto Rico
Rachycentron canadum

Food Ration

Ingestion

Assimilation = Ingestion \times 0.70

Growth = Assimilation - Respiration

Respiration
- basal (temperature)
- growth (growth)
- swimming
  - f (velocity & fish size)

Egestion
= 0.30 \times Ingestion

OHA 01: Transport Rose
Tabular Output Results Example:

Under cages or other selectable locations & depths

<table>
<thead>
<tr>
<th>Within or Under Cage</th>
<th>Flow Velocity</th>
<th>Growth Rate</th>
<th>Fish Biomass</th>
<th>Dissolved Oxygen</th>
<th>Nitrogen</th>
<th>Phytoplankton</th>
<th>Zooplankton</th>
<th>Fecal Carbon</th>
<th>Feed Carbon</th>
<th>Sediment Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units →</td>
<td>cm s⁻¹</td>
<td>1/d</td>
<td>MT</td>
<td>mg L⁻¹</td>
<td>µM</td>
<td>µg L⁻¹</td>
<td>µg L⁻¹</td>
<td>g m⁻³</td>
<td>g m⁻³</td>
<td>g m⁻²</td>
</tr>
<tr>
<td>Mean</td>
<td>8.4</td>
<td>0.01</td>
<td>483.9</td>
<td>5.47</td>
<td>1.06</td>
<td>0.06</td>
<td>0.09</td>
<td>0.02</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>SD</td>
<td>5.2</td>
<td>0.00</td>
<td>421.7</td>
<td>0.18</td>
<td>0.71</td>
<td>0.03</td>
<td>0.02</td>
<td>0.04</td>
<td>0.03</td>
<td>1.51</td>
</tr>
<tr>
<td>Change</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>-0.23</td>
<td>+0.91</td>
<td>-0.04</td>
<td>+0.04</td>
<td>+0.02</td>
<td>+0.06</td>
<td>+0.75</td>
</tr>
<tr>
<td>90th %</td>
<td>15.9</td>
<td>0.01</td>
<td>543.4</td>
<td>5.63</td>
<td>1.96</td>
<td>0.10</td>
<td>0.13</td>
<td>0.03</td>
<td>0.10</td>
<td>2.82</td>
</tr>
<tr>
<td>10th %</td>
<td>2.9</td>
<td>0.01</td>
<td>426.5</td>
<td>5.24</td>
<td>0.42</td>
<td>0.03</td>
<td>0.06</td>
<td>0.01</td>
<td>0.03</td>
<td>0.00</td>
</tr>
</tbody>
</table>
So what is new? (Why not use existing models?)

1) The only combined water column – benthic simulation model for aquaculture

2) Fish physiology submodel that will accept constants and functions from different fish species

3) Only real time visualization model with useful GUI

4) First windows-based package that couples to a parent GIS system (EASY)

5) Relatively easy for coastal managers to use

6) “Raises the bar” for those seeking permits to compare sites, improve and defend their choices
Potential Users of AquaModel

- Government regulators or coastal managers to assess impacts and effects

  Is a proposed operational sustainable in terms of achieving limited impact in a steady state basis?

- Mariculturists to evaluate potential sites and plan operations

  Will a candidate site be economically viable as well as environmentally acceptable?

- Researchers to provide a home for their data and means to test and visualize their submodels using the modeling within GIS features

  Cooperative efforts underway
Future Directions

Extensive additional validation: Puget Sound and S. latitudes

New culture species models, physiological characterization

Shellfish rafting effects module

Integrated Aquaculture (IMTA)

Far field hydrodynamic submodel allowing lagrangian flow field

Long term time series using several hour time steps

Looking for additional collaborations with agencies & researchers around the world
AquaModel - At a Glance

Numerical models are increasingly important for planning and permitting of marine fish farms. Models range from simple one-box simulations to complex mainframe-oceanic models potentially capable of managing entire coastal systems.

AquaModel is an information system to assess the operations and impacts of fish farms in both water column and benthic environments, the first of its kind.

AquaModel provides a real-time, three-dimensional simulation of the growth and metabolic activity of penned fish as well as the associated flow and transformation of nutrients, oxygen, and particulate wastes in adjacent waters and sediments. It runs on Windows personal computers and has drop down menus and a help menu and can be operated on different levels of complexity to suit the needs of the user.

AquaModel is being used by us as a consulting tool but that we will provide it as a complete package to governments under licensing requirements.
Model Run Demo
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**Collaborators**

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AGS Fish Farms, Inc. Puget Sound
Ocean Spar Technologies Puget Sound