Aquaculture Modeling Using a GIS-Integrated Simulation Model

North Pacific Marine Research Organization
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Dale A. Kiefer, University of Southern California & SSA
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Presentation Topics

• EASy (GIS) and AquaModel Overview
• Brief review of Model Components
• Examples of Validation Conducted
• Hubbs-SeaWorld Research Institute Offshore Site Simulation Example Model Run
Uses of AquaModel

- **Government regulators or coastal managers**
  to assess single or multiple site effects, educate decision makers & the public. Far field versions being developed.

- **Mariculturists and consultants**
  to evaluate potential sites, plan operations, obtain permits, look for site interactions.

- **Researchers**
  to provide a home for their data and means to test and visualize their submodels using the modeling within GIS features.
• Three dimensional GIS for marine applications
• Compatible with other GIS (ESRI Arc-Info)
• Interfaces for models, spreadsheets, databases, and Internet
• Accepts plug in models like AquaModel that we will focus on today
EASy = Environmental Assessment System

Gulf of Maine: Species richness relative to bathymetry, water density differentials & bottom temperature

Hydrodynamic Module

- Multibox L x W x D 3D grid
- Inputs: Single point current meter or ADCP, Regional 3D data
- Diffusivity based on data from pens
- Coupling to existing 3D models
- Multiple ADCP current meter input system planned (Quasi-3D)
Need for Model with Multiple Current Meter Inputs

Clam Bay Net Pen Farm: 443 Meters Length (Right Side)

Green Arrow: Flood Tide Vectors
Red Star: ADCP Current Meters
Need for Model with Multiple Current Meter Inputs

Clam Bay Net Pen Farm: 443 Meters Length (Right Side)

Flood Tide Current Vectors
Ebb Tide Current Vectors
AquaModel 3-D Features

- Have used JPL 3D data sets for far field version of model
- AquaModel now generates current ellipses (vector summaries)
AquaModel Coupling to 3D Hydrodynamic Models

Grid for New Hampshire Offshore Demonstration Farm Site Using ADCIRC
Dave Fredriksson (US Naval Academy)

Theoretical Multiple Farm sites in the Southern California Bight: Modified 3D AquaModel operation using the Global Circulation Model ECCO-2. Collaboration between MIT, Scripps, and NASA's Jet Propulsion Laboratory.
Fish Physiology Module

- Growth, metabolism and waste production simulation
- We parameterized laboratory measurements to create a virtual fish population
- Carbon, oxygen and nutrient (N&P) based
- Linked with fish activity level, temperature, ration, etc.
- Measured assimilation, respiration, excretion and fecal settling rates
Fish swim & static respirometers

Cobia Respiration rate vs swimming speed

\[ v = 0.214x^2 - 4.6076x + 490.55 \]

\[ R^2 = 0.697 \]

Swimming speed (cm/s)

DO consumption (mg/l/kg)

Hawaiian Moi

Cobia (Caribbean)
Nitrogen Excretion Rates
≠ Ammonia + urea
(Filterated Total N) – (TAN + Urea) = Other components (amino acids, etc.)

Sablefish Example
Fish fecal settling rate

*Sablefish Fecal Settling Rate*

*Initial Experiments*

273 g fish, 6 January 2006

NOAA - Troutlodge Inc. SBIR

Rensel, Massee, Nepper
Mass Balance Carbon/Nitrogen/Oxygen Metabolism

- Rate of loss of uneaten feed = feed rate – ingestion rate
- Ingestion rate = egestion rate + assimilation rate
- Rate of feces production = egestion rate
- Assimilation rate = rate of respiration + rate of growth
- Respiration rate = resting rate (i.e. basal) + active (swimming) + anabolic activity (growth)
- Equations invoke principle of most limiting metabolic process
- Assimilation limited by fish size, water temperature, oxygen flux, feed rate, “scope for metabolism” (Fry and Brett)
- All underlying equations publically available NOAA website, Puerto Rico Cobia Project
Assimilative Benthic Response of New Farm to Appropriately Moderate TOC Loading Rate

- Sediment Waste
- Sediment Oxygen
- Benthos Biomass

Initial Steady State Conditions → Start up transition → New Steady State

Time
Benthic - Pelagic Model Linkages

Simplified particle deposition, resuspension transport or consolidation

gas diffusive exchange

← Resuspension Zone →

Sediment to Water Column

Particulate Organic Matter

NH₄, CO₂, O₂, H₂S

H₂O, CO₂, O₂, H₂S

POC, SO₄, H₂S

anaerobic biomass

Chemoheterotrophic biomass

Shallow RPD

Deep RPD “black layer”
Oxygen Diffusion at Benthic Boundary Layer

\[
O_2 = \frac{\text{Diffusion coefficient} \times \text{Porosity} \times (O_2[\text{water}] - O_2[\text{sediment}])}{\sqrt{\frac{C_1}{\text{Velocity}}} + C_2}
\]

Findley and Watling 1997
Behavior of benthic subroutine:
Steady state conditions at low & high rates of organic carbon loading.

Organic Loading = 5 mg C *m^{-2}*day^{-1}

Organic Loading = 1 mg C *m^{-2}*day^{-1}

Rates of Respiration & Diffusion (mg*m^{-2}*day^{-1})

O2 concentration (mg/l)
Hubbs SeaWorld Research Institute Offshore Demonstration Farm
100 m deep, 5 miles offshore of San Diego, 3000 MT, 24 cages,
mean bottom current of 8 cm/s, bidirectional, immeasurable sediment effects
Theoretical Comparison Farm
75% shallower (25 m), slower current by 25%, Pens slightly closer together,
Modest nearfield 5m deep D.O. and low nearfield sediment effect
Theoretical Comparison Farm
~ same time as prior slide, showing TOC sediment impacts of 10% above ambient & within 10 m of farm
Theoretical Comparison Farm
3.5 months later

Day 137 Hydrogen sulfide footprint

Day 137 Total organic carbon footprint

Day 137 Aerobic biomass footprint

Day 137 Anaerobic biomass footprint
Real Time Simulation
## Tabular Output Results Example:

Under cages or other selectable locations & depths

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Flow Velocity (cm/sec)</th>
<th>Growth Rate (1/day)</th>
<th>Fish Biomass (kg)</th>
<th>Pen Oxygen (mg/l)</th>
<th>Pen Nitrogen (uM/l)</th>
<th>Oxygen (5:0:1) (mg/l)</th>
<th>Nitrogen (5:0:1) (uM/l)</th>
<th>Phyttoplankton (5:0:1) (uM/l)</th>
<th>Zooplankton (5:0:1) (uM/l)</th>
<th>Fecal Waste (5:0:1) (g/m³)</th>
<th>Feed Waste (5:0:1) (g/m³)</th>
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### Within or Under Cage

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<thead>
<tr>
<th>Units</th>
<th>Flow Velocity (cm s⁻¹)</th>
<th>Growth Rate (1/d)</th>
<th>Fish Biomass (MT)</th>
<th>Dissolved Oxygen (mg L⁻¹)</th>
<th>Nitrogen (µM)</th>
<th>Phyttoplankton (µg L⁻¹)</th>
<th>Zooplankton (µg L⁻¹)</th>
<th>Fecal Carbon (g m⁻³)</th>
<th>Feed Carbon (g m⁻³)</th>
<th>Sediment Carbon (g m⁻²)</th>
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Model Validation, Tuning, Sensitivity Analyses

• Critical for success, often minimal
• Validation of component submodels separately
• Tracer experiments
• Perturbation measurements: upstream vs. downstream
• Extensive published and technical report record as starting point, some trends among fish taxa for bioenergetics submodel calibration
• Poorly known factors: Sensitivity analyses, e.g., “consolidation”
• Some examples next....
Example Validation: Growth Measurements versus AquaModel calculations

Growth Rate Measured and Predicted by % BW Ration

- Growth Rate Measured and Predicted by % BW Ration
- Temperature vs. Specific Growth Rate (day)
Example of Nitrogen and Oxygen Flux Validation

Used current meters, drogues up and downstream and measured concentrations - 1990s when net-pens farms were smaller
CO₂ Production vs. Carbon Deposition

Red = AquaModel projection

Black = Literature (Findley and Watling 1997, Toothacre Cove Maine, measurements)
Outreach with Simplified Project Runs Online 1

EASY GoogleMaps, GoogleEarth, and NetViewer Projects

Enable Javascript (set security to 'Medium')
then click on image to run project!

AquaModel mariculture farm in Maine

GoogleMaps Projects

GoogleEarth Projects
(download GoogleEarth)

NetViewer Projects

Long Beach ocean currents and world web camera views

AquaModel mariculture farm in Long Beach
Outreach with Simplified Project Runs Online 2

AquaModel mariculture farm in the Nile river

AquaModel mariculture farm in Puerto Rico

Satellite tagging of great white sharks in Southern Africa

Satellite tagging of great white sharks in New Zealand
Outreach with Simplified Project Runs Online 3

Simulation of herring population survival in Prince William Sound

Display of research cruise measurements made off the coast of Iceland

Display of cruise measurements made off the coast of California

AFSC Bering Sea Trawl Survey and Trophic Interactions - Arrow tooth flounder analysis project
Concluding Comments

- **Water column effects** of fish farms are hard to measure because of advection and dilution but large numbers of farms can create problems in some situations.

- **Benthic effects** are easy to predict for depositional environments but extremely difficult to estimate without computer models.

- **Benthic effects** are difficult to predict for transitional environments (part depositional and erosional) and more research concerning sediment waste “consolidation” is required.

- When tuned to good site-specific circulation data and the growth metabolism of cultured fish, models can provide accurate predictions with minimal effort, reducing the trial and error problems seen in the past at many net pen sites.
**Funding**

NOAA Office of Oceanic & Atmospheric Research

NOAA SBIR Program

USDA SBIR Program

Hubbs Seaworld Research Institute, San Diego

Hawaii Department of Agriculture

**Collaborators**

David Fredriksson, U.S. Naval Academy, Architecture & Ocean Engineering

Katsyuki Abo, National Research Institute of Aquaculture, Japan

Mike Rust, NOAA Marine Fish Research Leader

AGS Fish Farms, Inc. Puget Sound

Cates International, O’ahu Hawaii

Google: AquaModel for more information at [www.AquaModel.org](http://www.AquaModel.org)