Aquaculture Modeling Using a GIS-Integrated Simulation Model

North Pacific Marine Research Organization
PICES Annual Meeting, Jeju Korea

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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

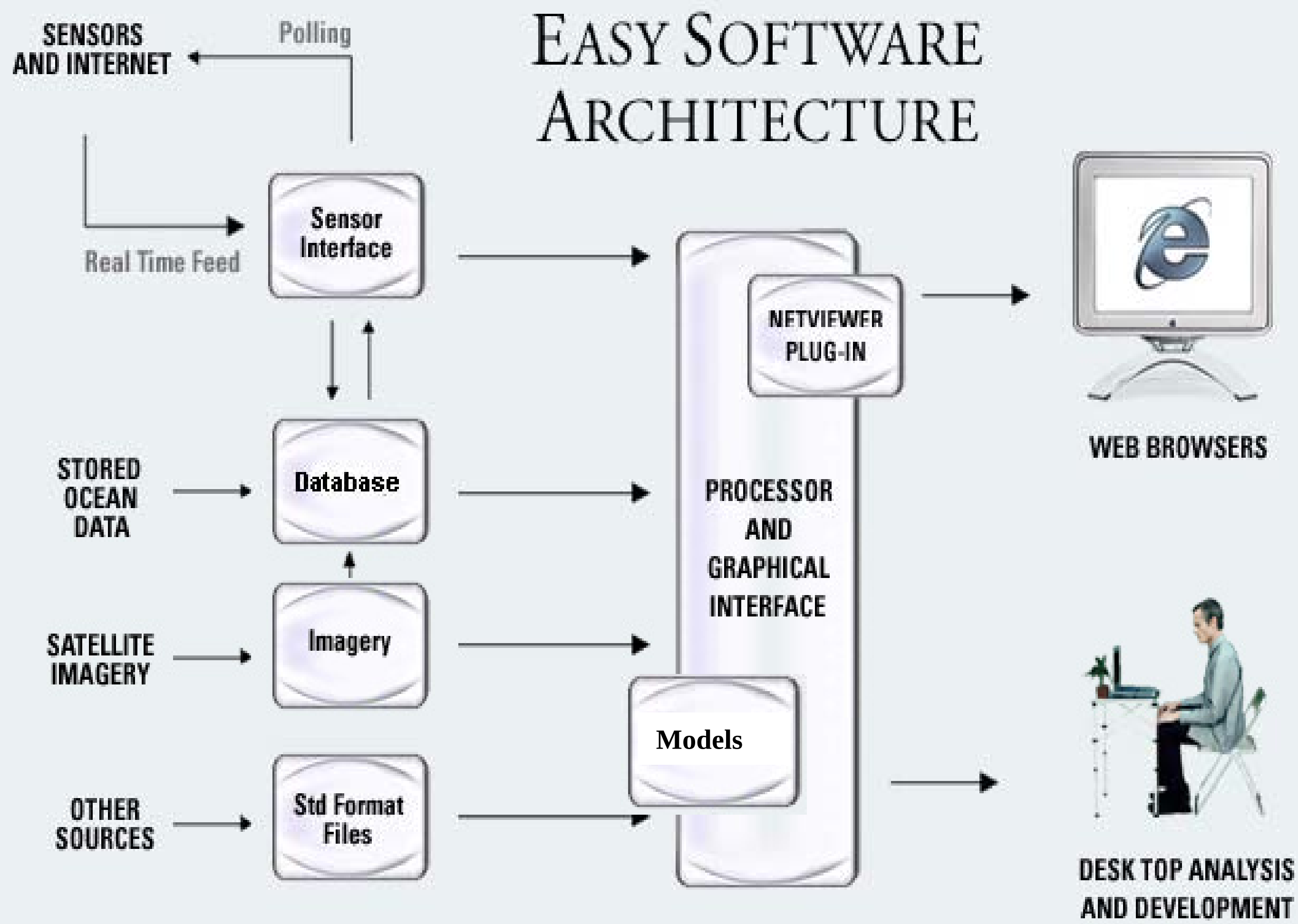
  Simulation Example Model Run

Uses of AquaModel

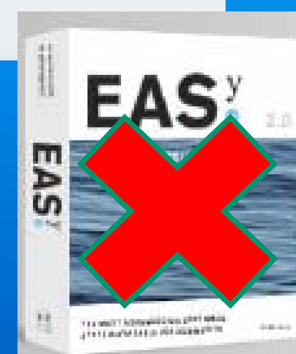
- **Government regulators or coastal managers**
  to assess single or multiple site effects, educate decision makers & the public. Far field versions being developed.

- **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

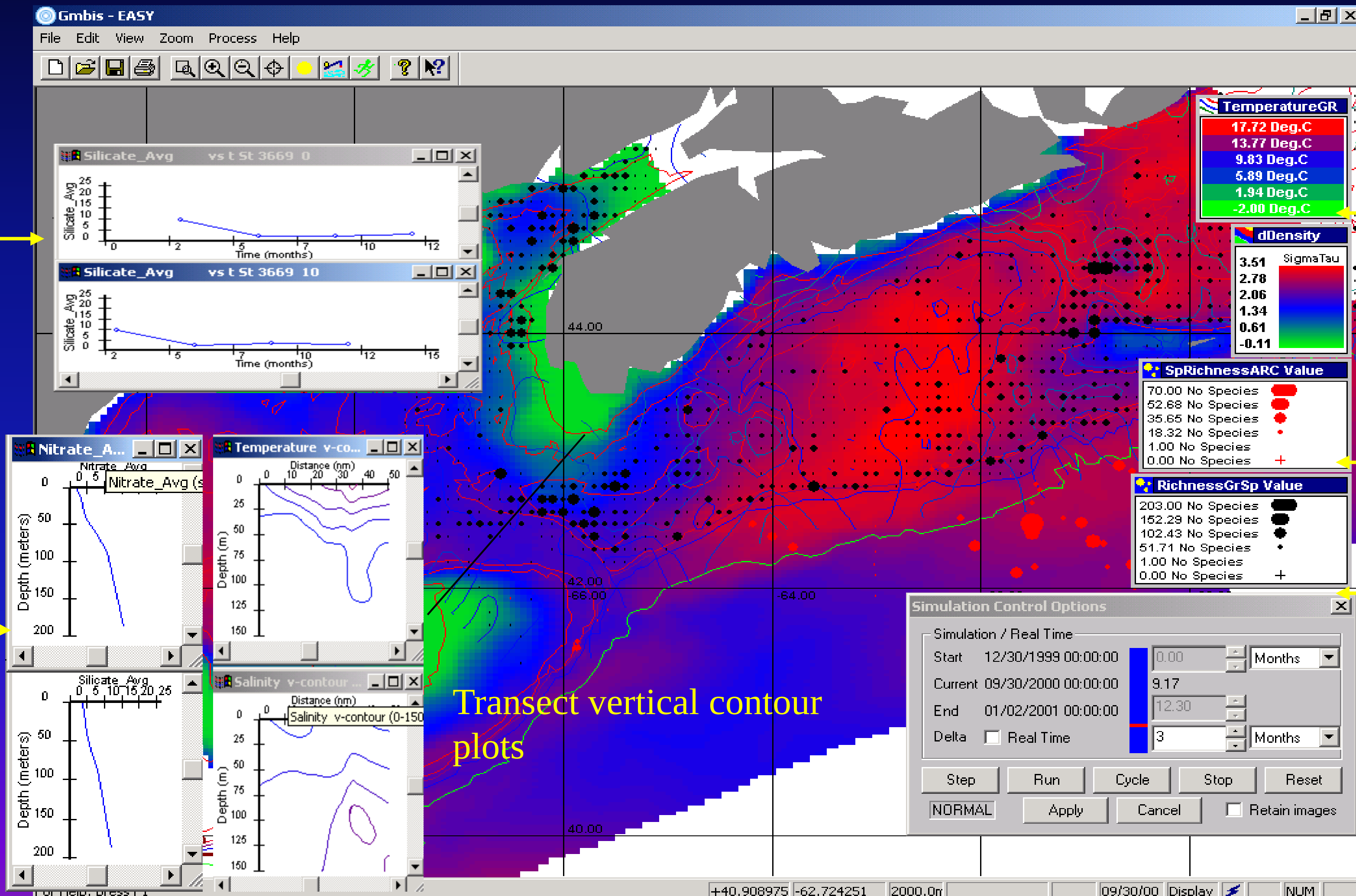


EASy = Environmental Assessment System

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

Time Series plots

Depth profile plots



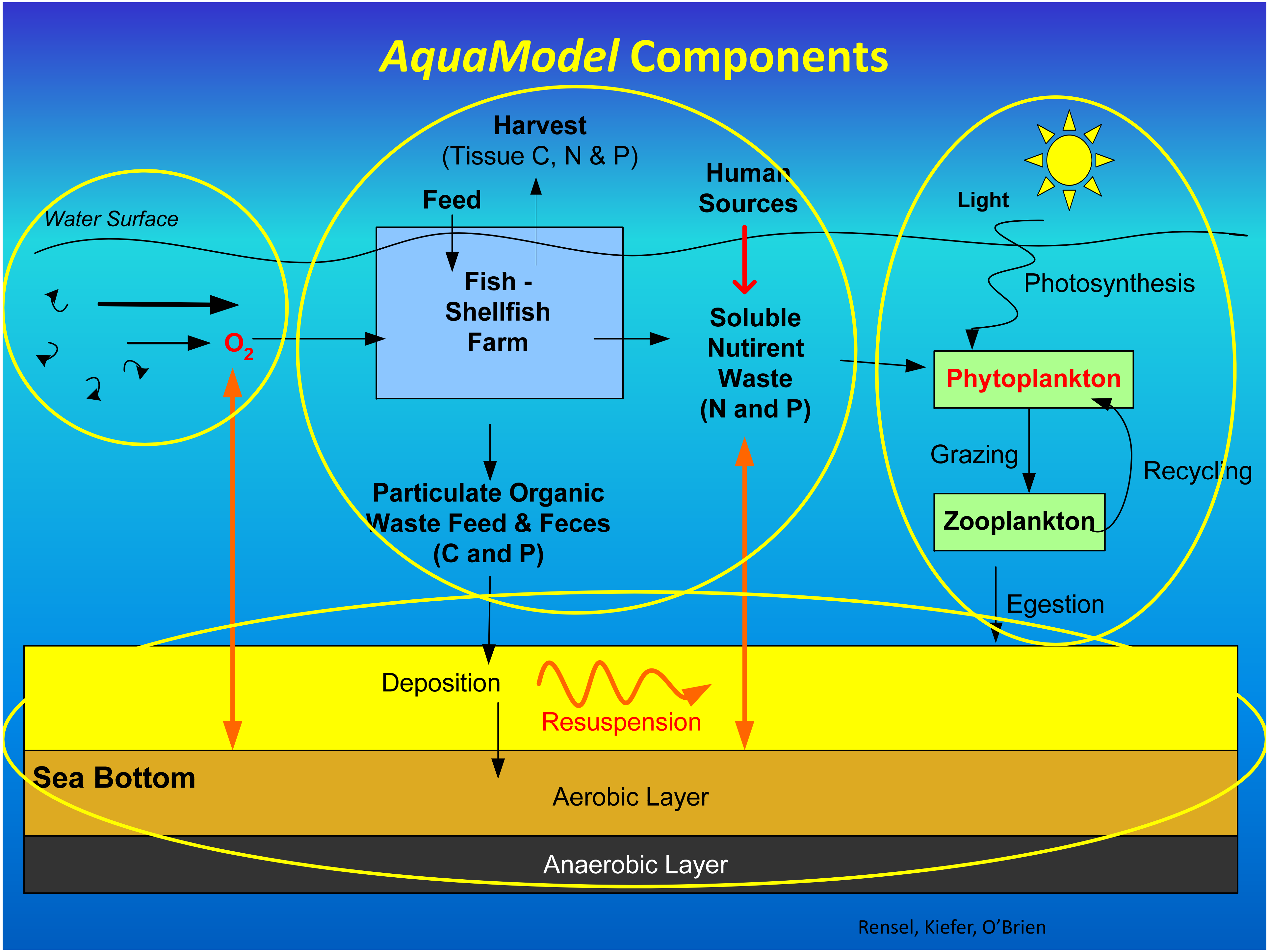
Contour plot

False color plot

Bubble Plots

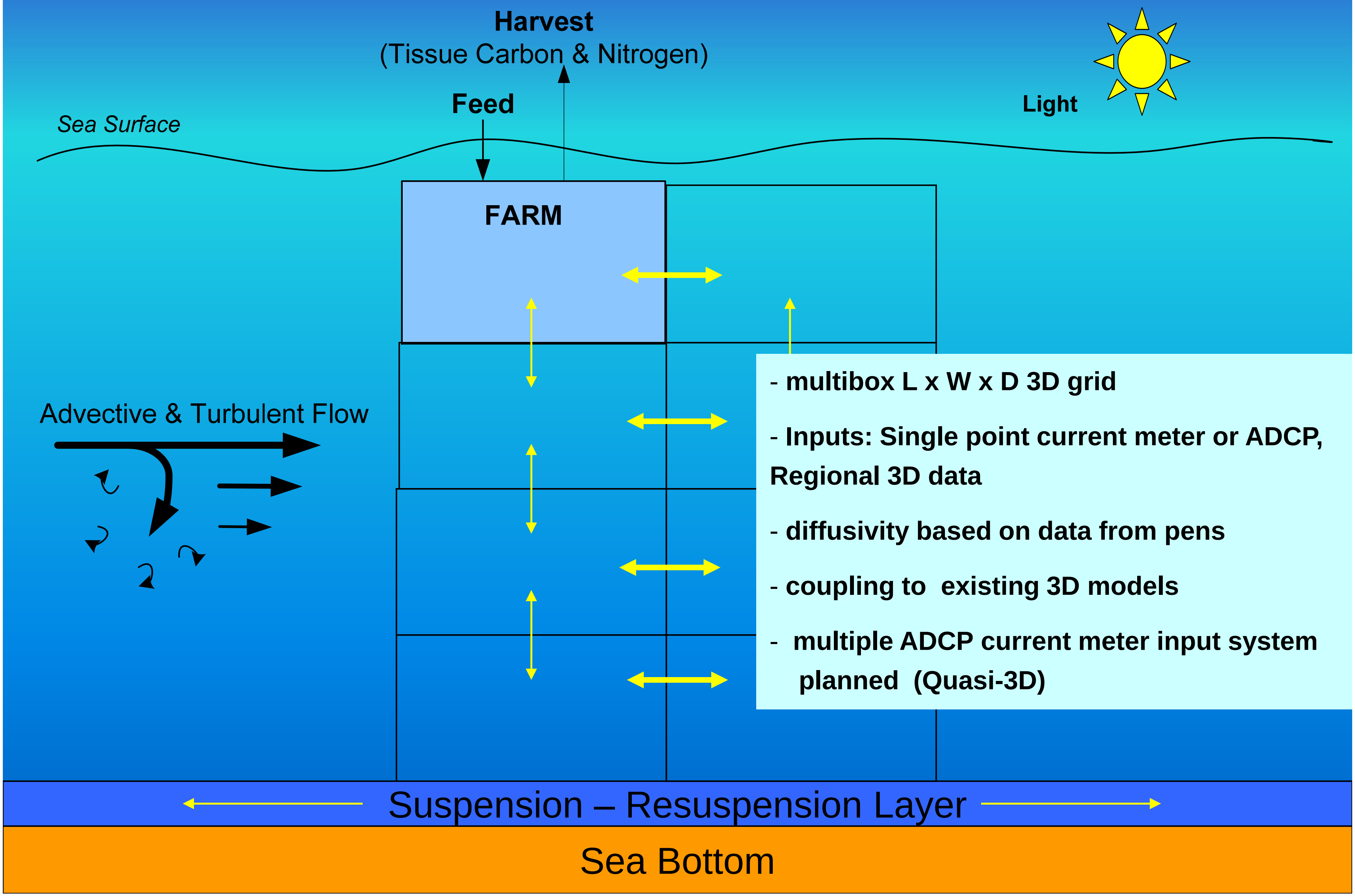
Simulation control panel

Tsontos, V. M. and D. A. Kiefer. 2000. Oceanography 13(3): 25-30.



AquaModel Components
Harvest
(Tissue C, N & P)
Feed
Human Sources
Water Surface
Light
Photosynthesis
Fish - Shellfish Farm
Soluble Nutrient Waste (N and P)
O_2
Phytoplankton
Grazing
Recycling
Zooplankton
Particulate Organic Waste Feed & Feces (C and P)
Egestion
Deposition
Resuspension
Sea Bottom
Aerobic Layer
Anaerobic Layer
Rensel, Kiefer, O'Brien

Hydrodynamic Module



Need for Model with Multiple Current Meter Inputs

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

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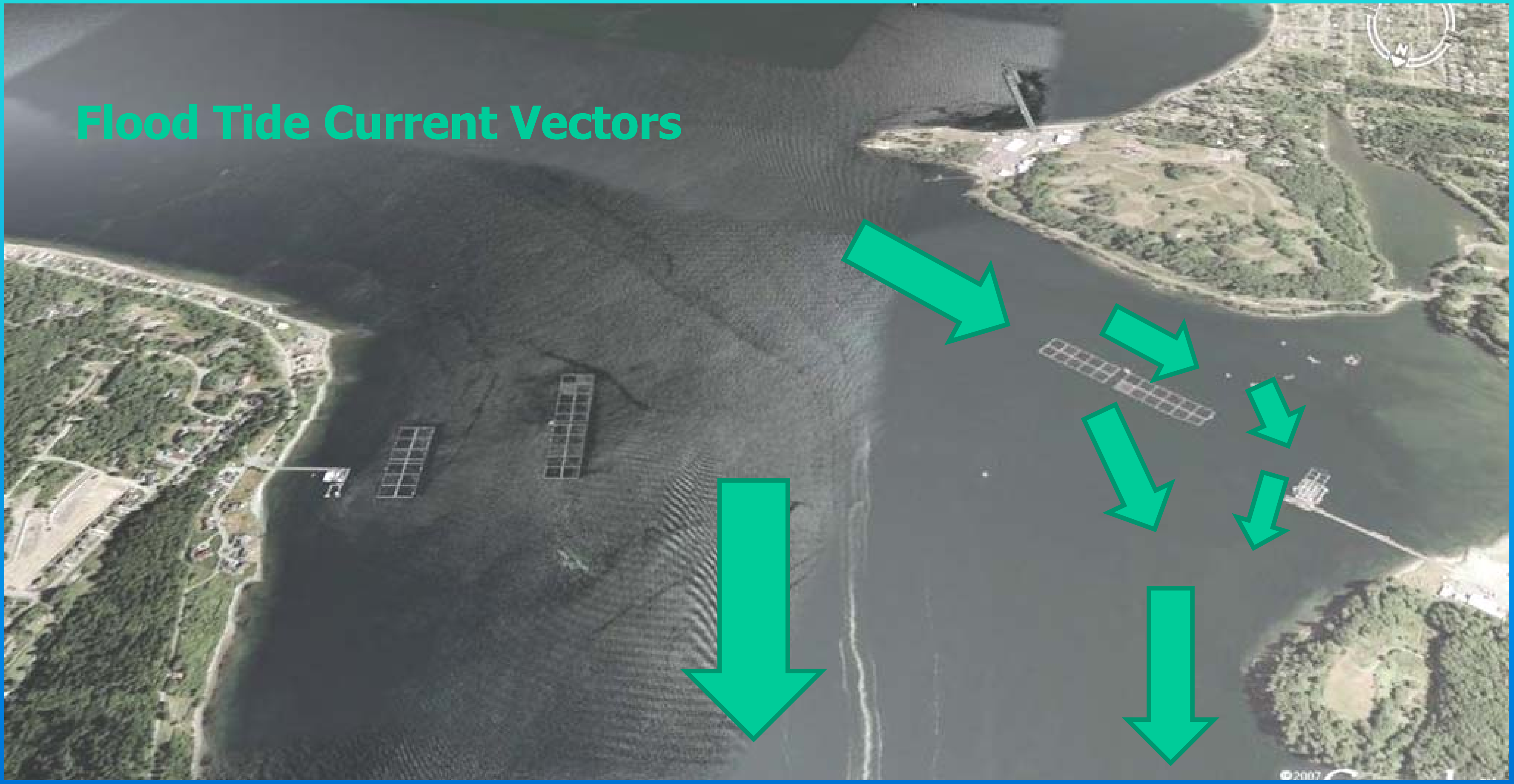
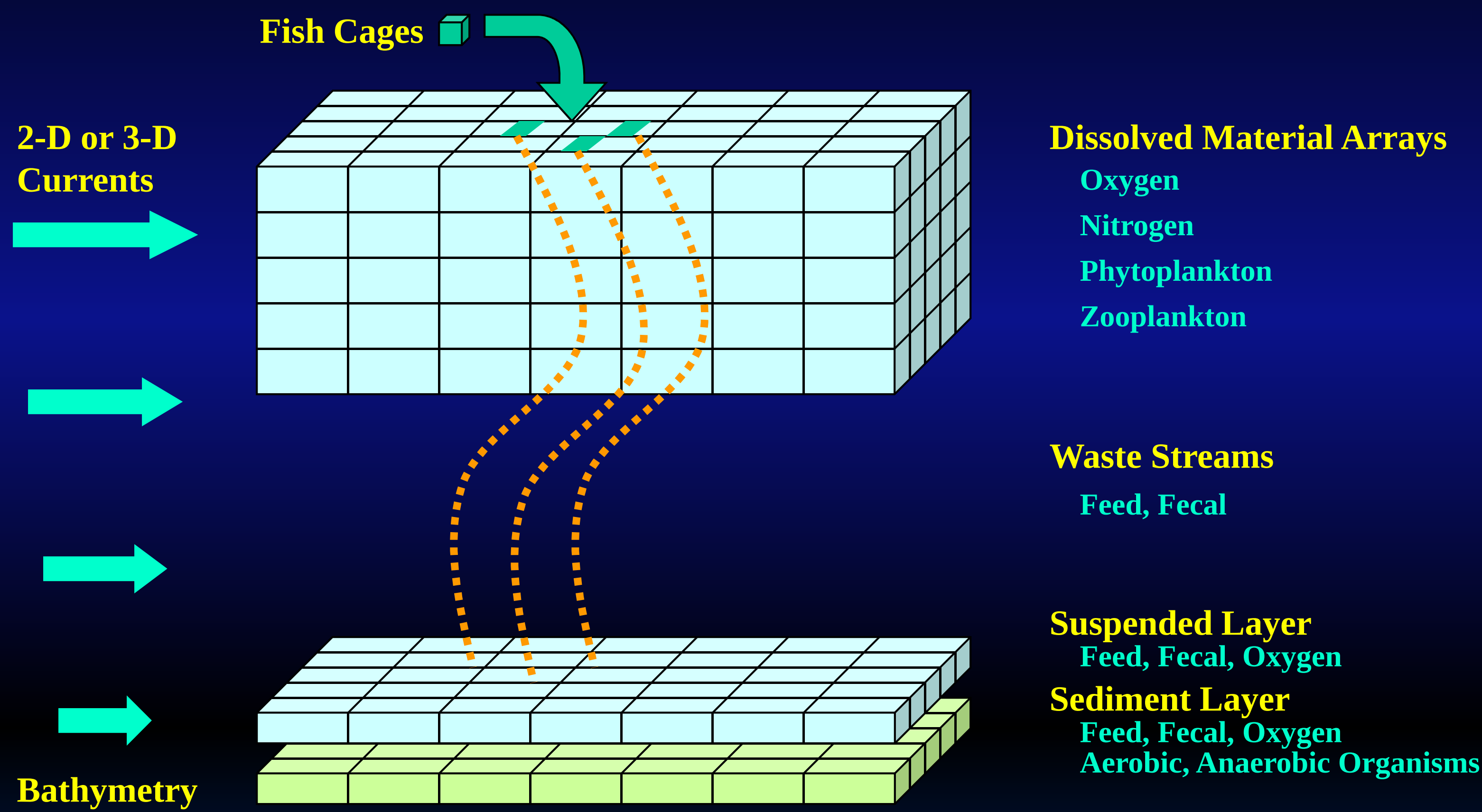



Ebb Tide Current Vectors

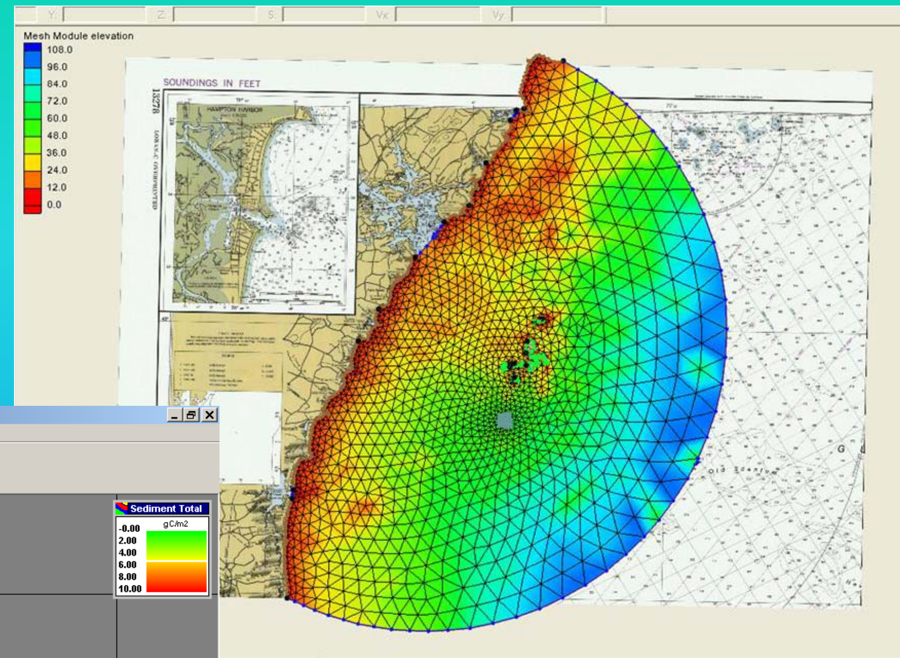
AquaModel 3-D Features

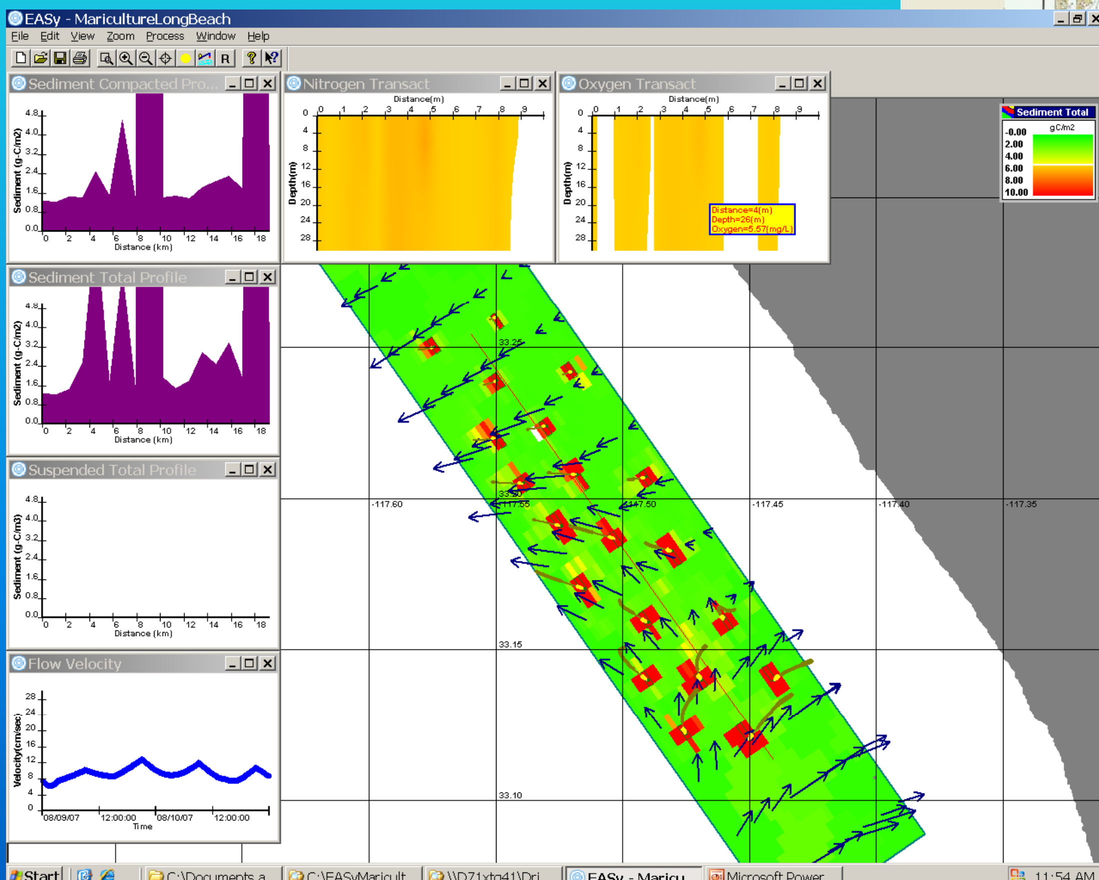


- Have used JPL 3D data sets for far field version of model
- AquaModel now generates current ellipses (vector summaries)

AquaModel Coupling to 3D Hydrodynamic Models

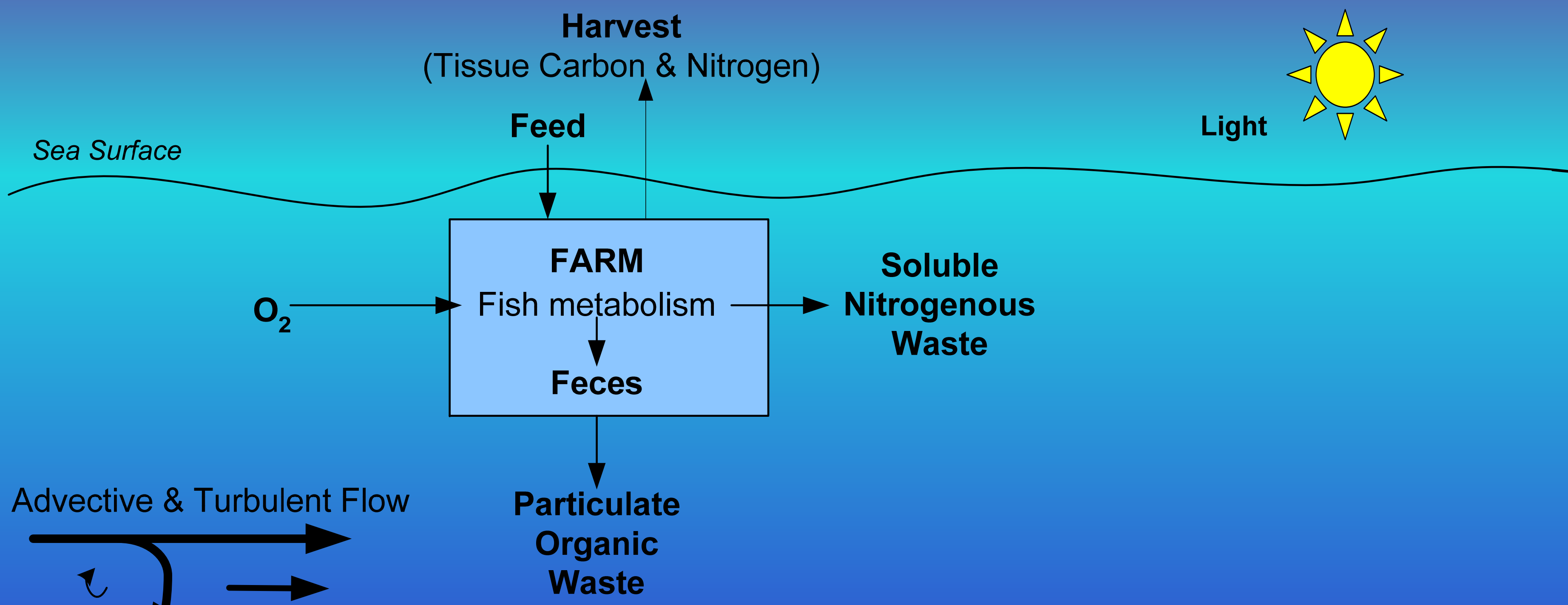
Grid for New Hampshire Offshore
Demonstration Farm Site
Using ADCIRC
Dave Fredriksson (US Naval Academy)

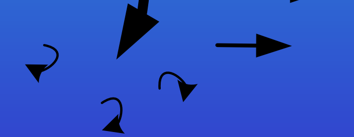




Theoretical Multiple Farm sites in the Southern California Bight: Modified 3D AquaModel operation using the Global Circulation Model ECCO-2. Collaboration between MIT, Scripps, and NASA's Jet Propulsion Laboratory.

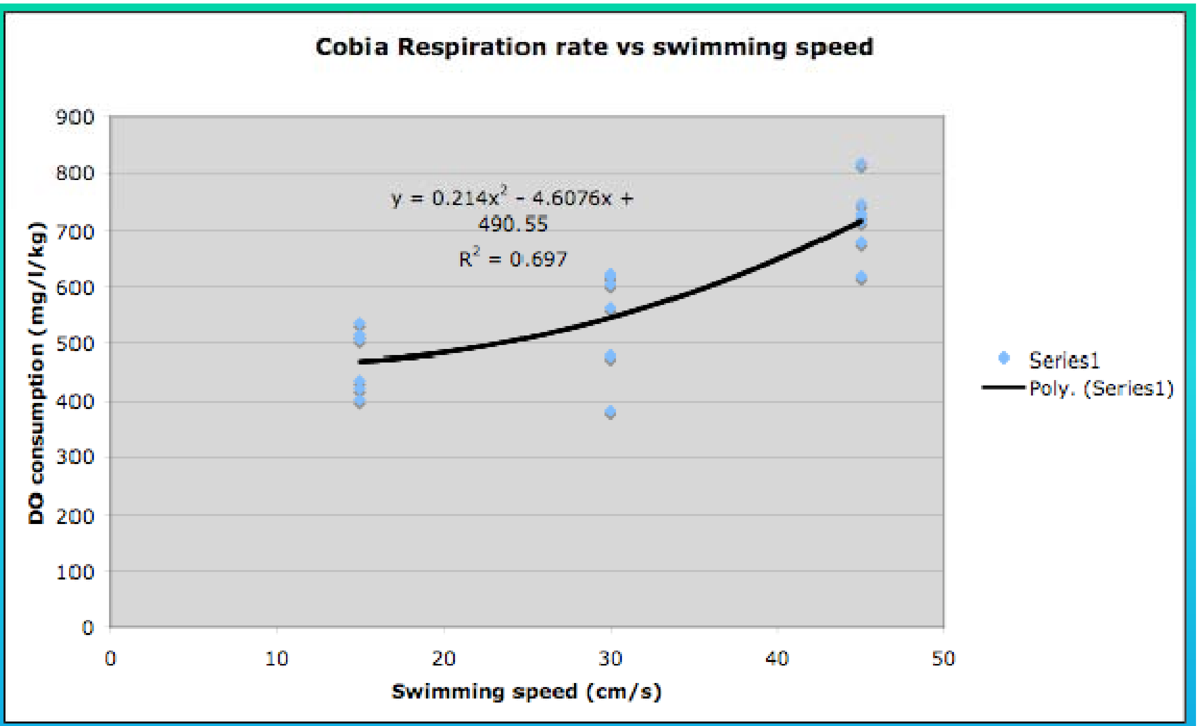
Fish Physiology Module





- **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



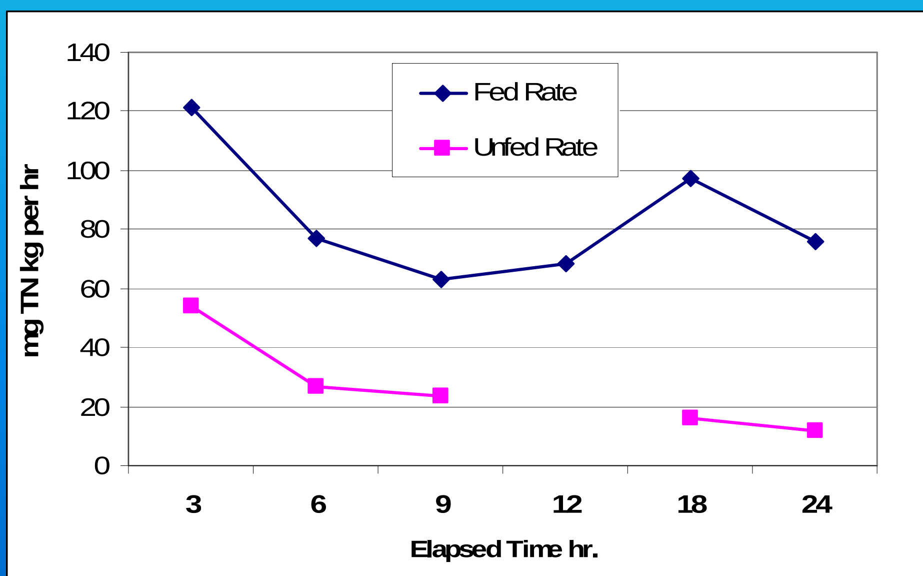
Hawaiian Moi

Cobia (Caribbean)

Nitrogen Excretion Rates

≠ Ammonia + urea

(Filtered Total N) – (TAN + Urea) = Other components (amino acids, etc.)



Sablefish Example

Fish fecal settling rate

Sablefish Fecal Settling Rate

Initial Experiments

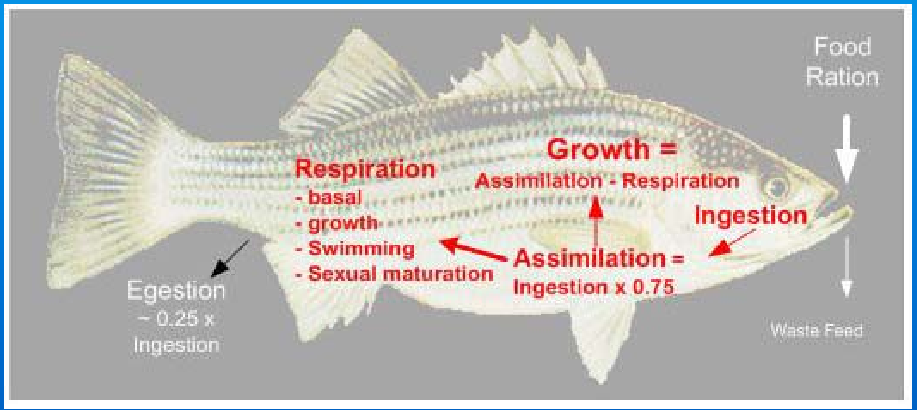
273 g fish, 6 January 2006

NOAA - Troutlodge Inc. SBIR

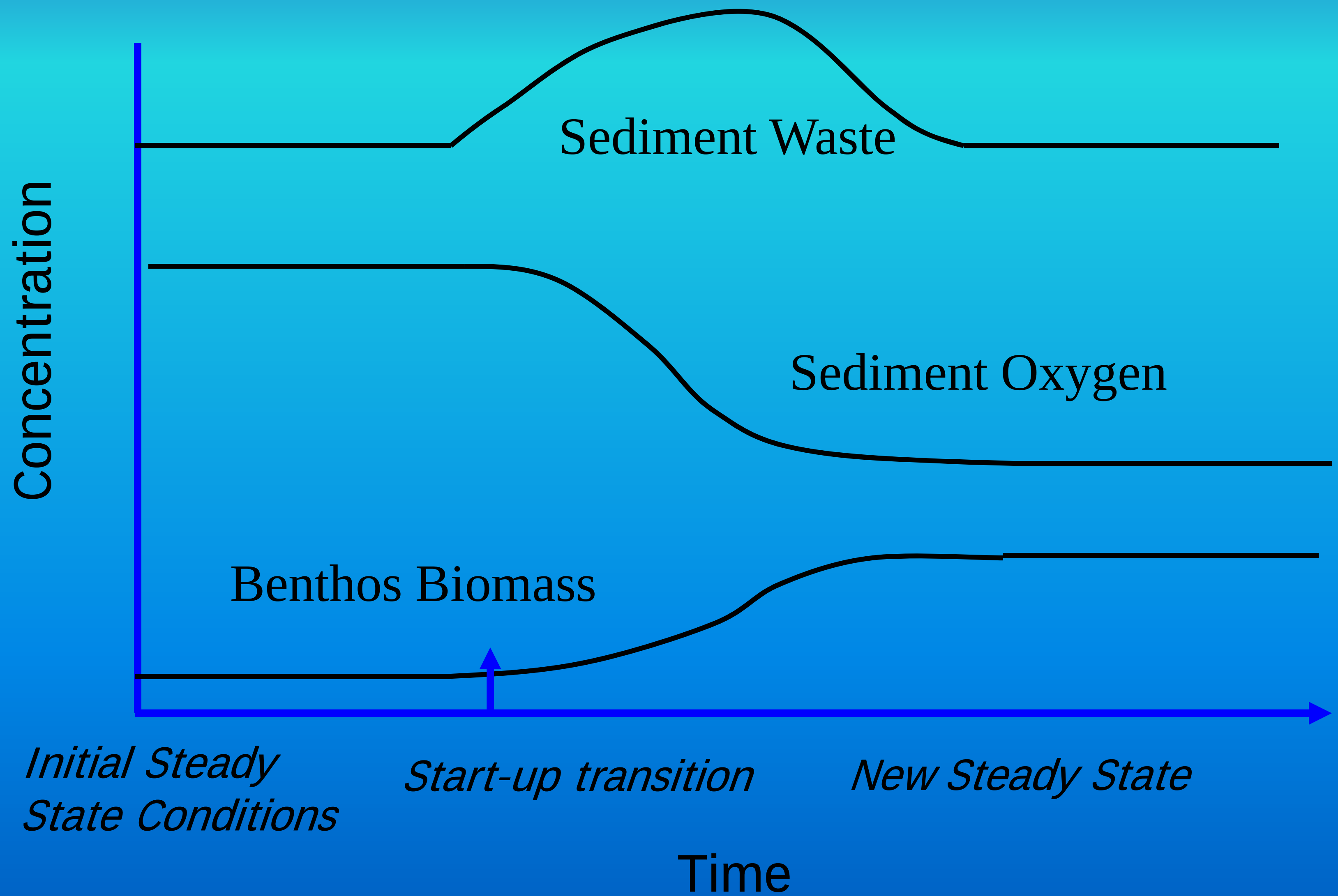
Rensel, Massee, Nepper

Mass Balance Carbon/Nitrogen/Oxygen Metabolism

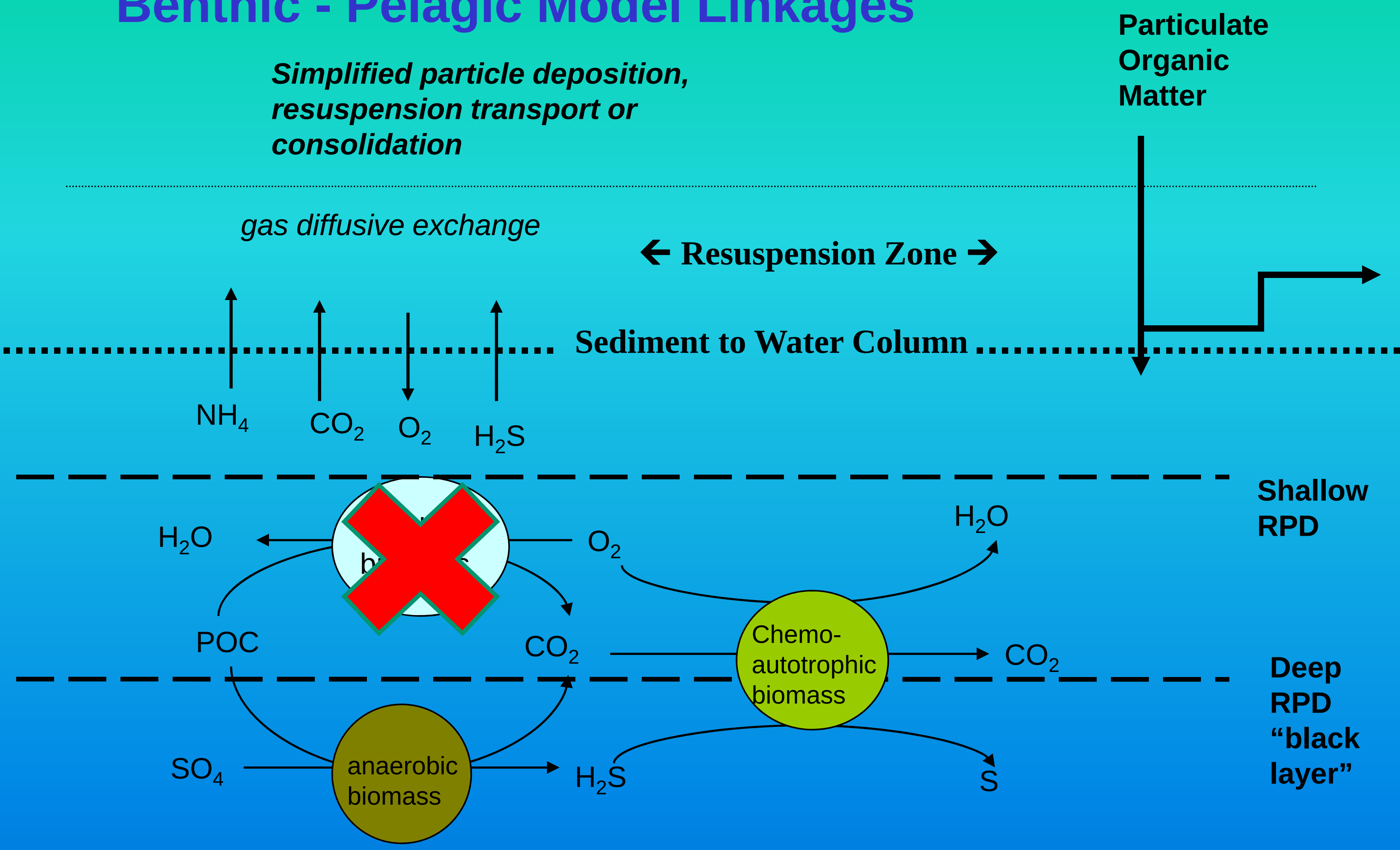
- Rate of loss of uneaten feed = feed rate – ingestion rate
- Ingestion rate = egestion rate + assimilation rate
- Rate of feces production = egestion rate
- Assimilation rate = rate of respiration + rate of growth
- Respiration rate = resting rate (i.e. basal) + active (swimming) + anabolic activity (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



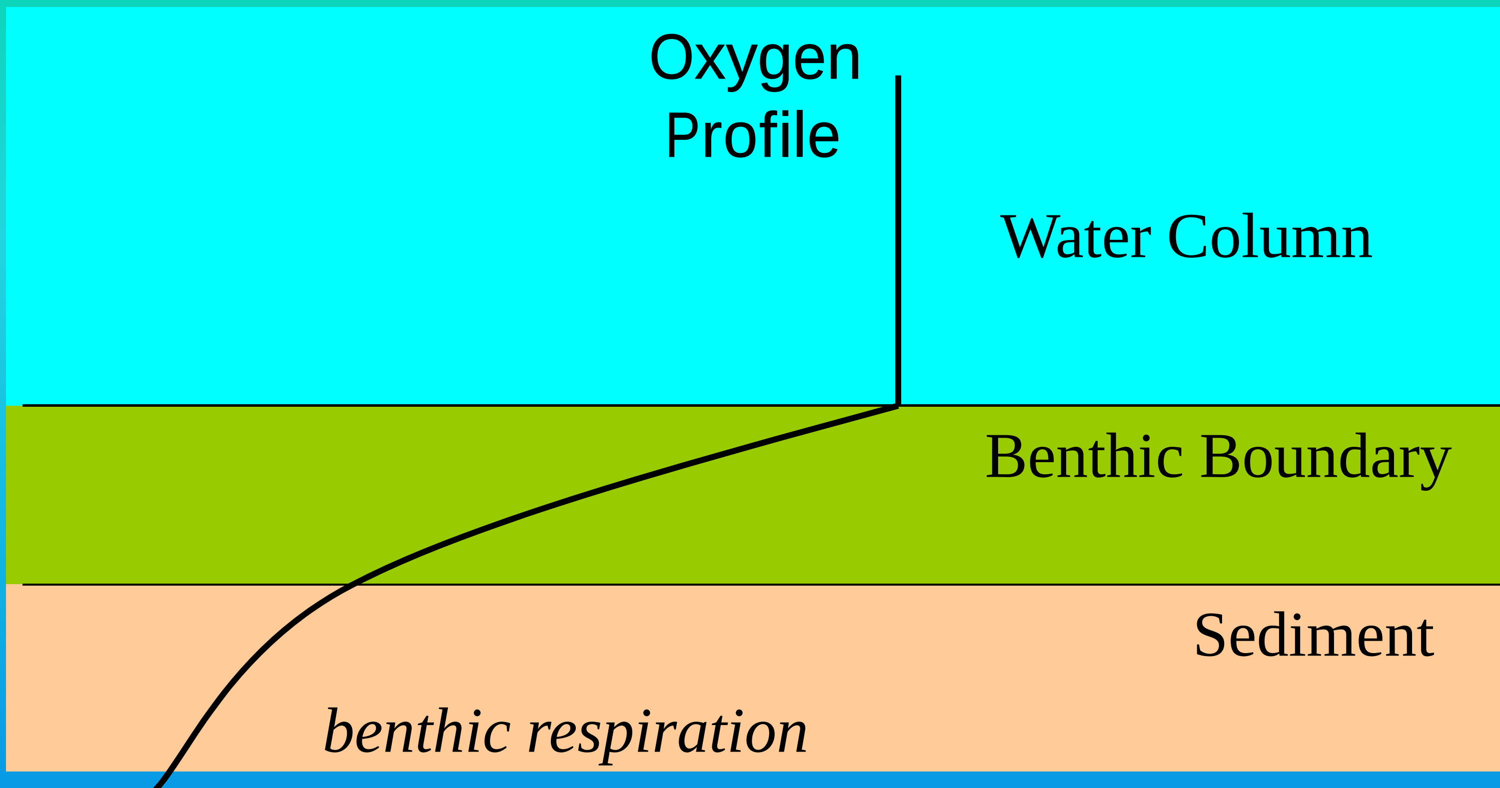
Assimilative Benthic Response of New Farm to Appropriately Moderate TOC Loading Rate



Benthic - Pelagic Model Linkages



Oxygen Diffusion at Benthic Boundary Layer

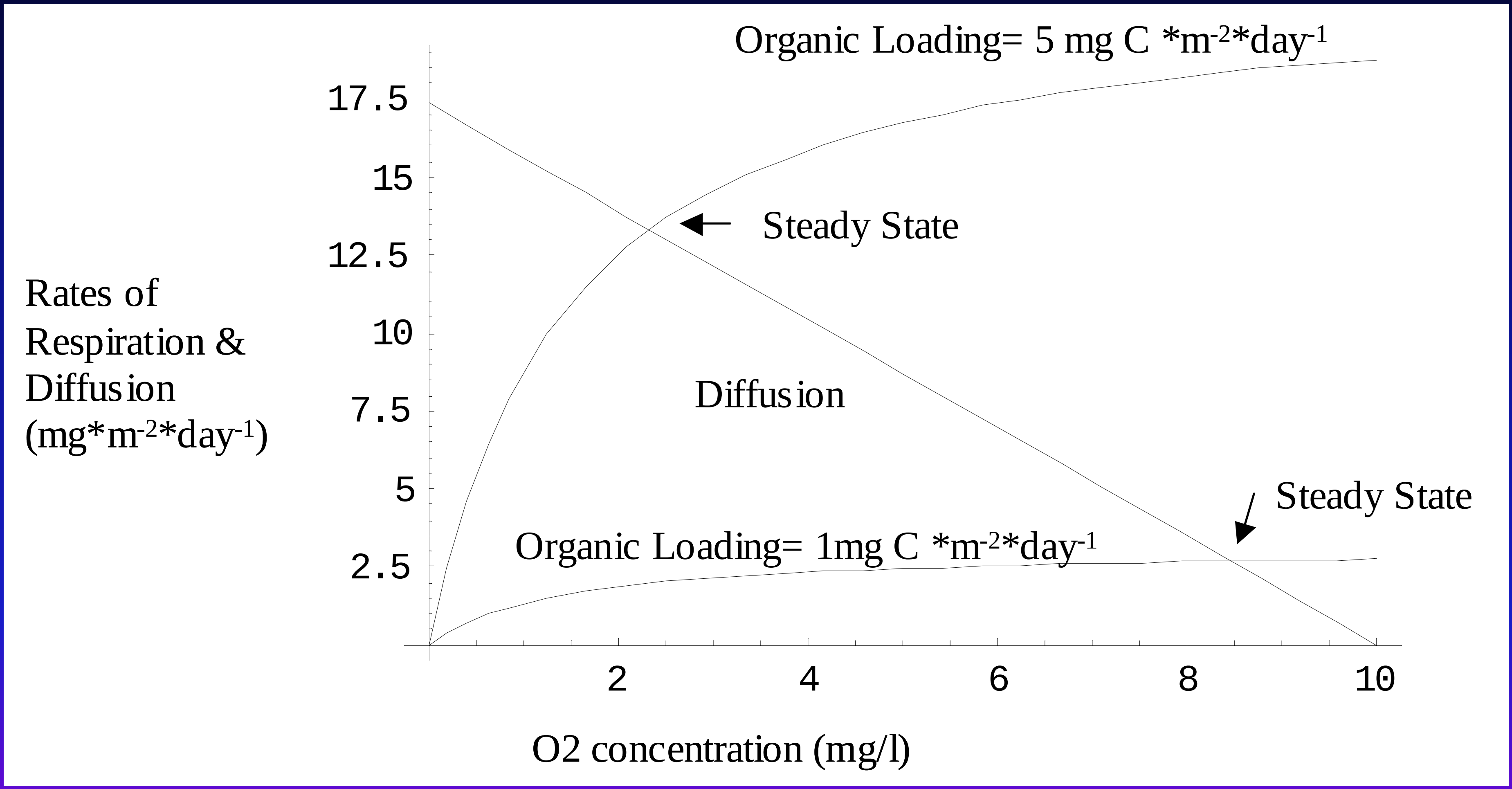


$$JO2 = \frac{\text{Diffusion coefficient Porosity } (O2[\text{water}] - O2[\text{sediment}])}{\sqrt{\frac{C1}{\text{Velocity}}} + C2}$$

Findley and Watling 1997

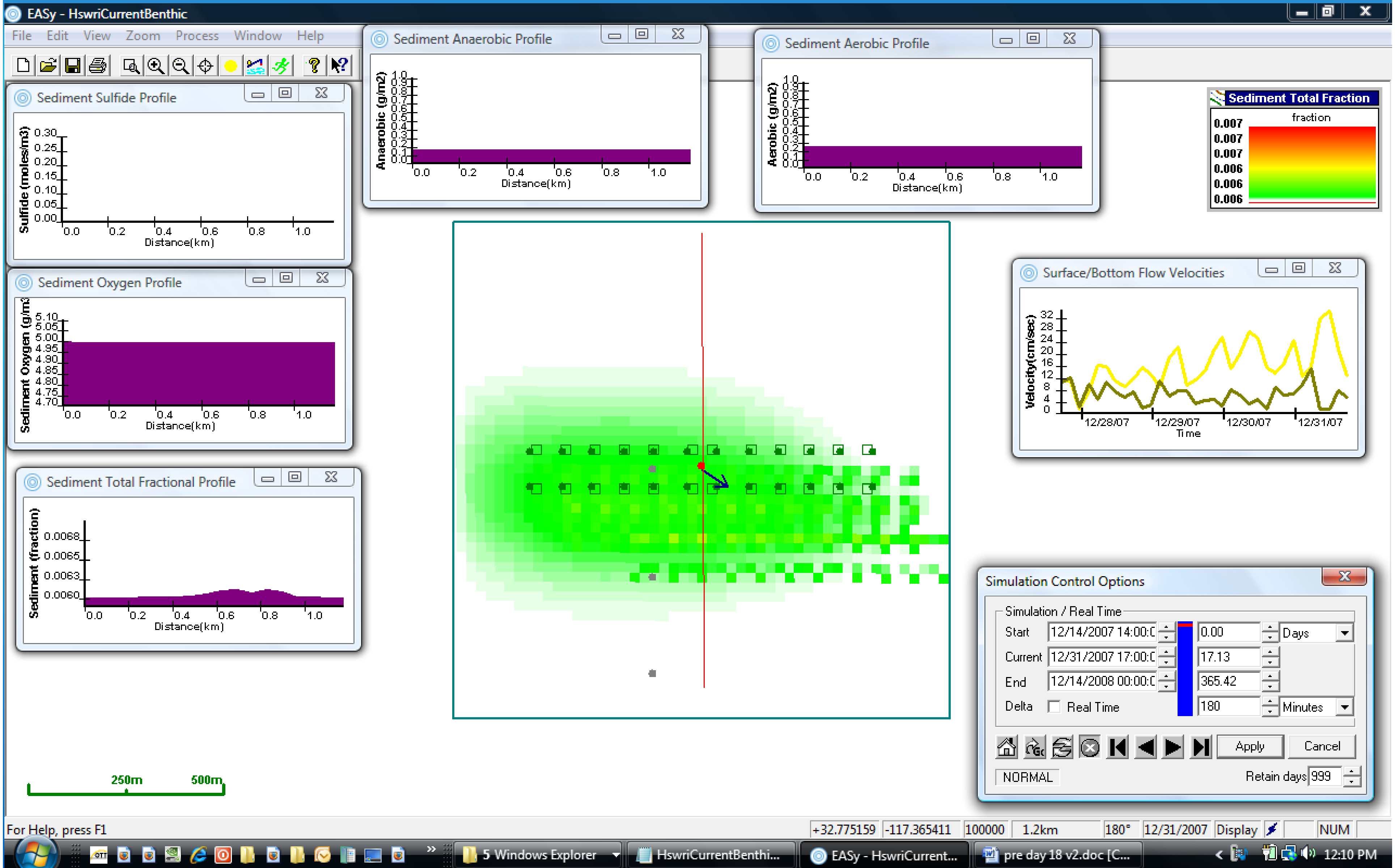
Behavior of benthic subroutine:

Steady state conditions at low & high rates of organic carbon loading.



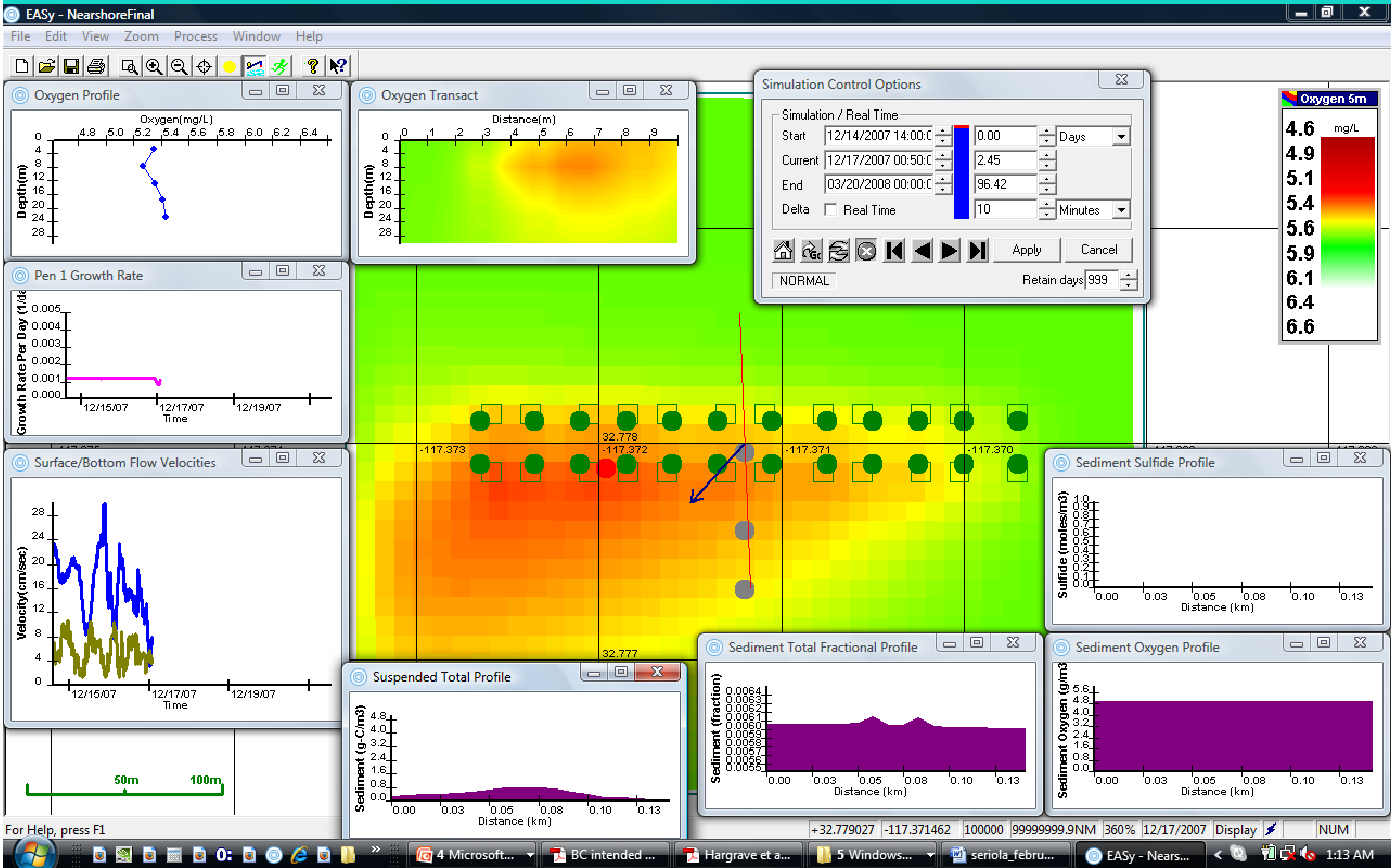
Hubbs SeaWorld Research Institute Offshore Demonstration Farm

100 m deep, 5 miles offshore of San Diego, 3000 MT, 24 cages,
mean bottom current of 8 cm/s, bidirectional. immeasurable sediment effects



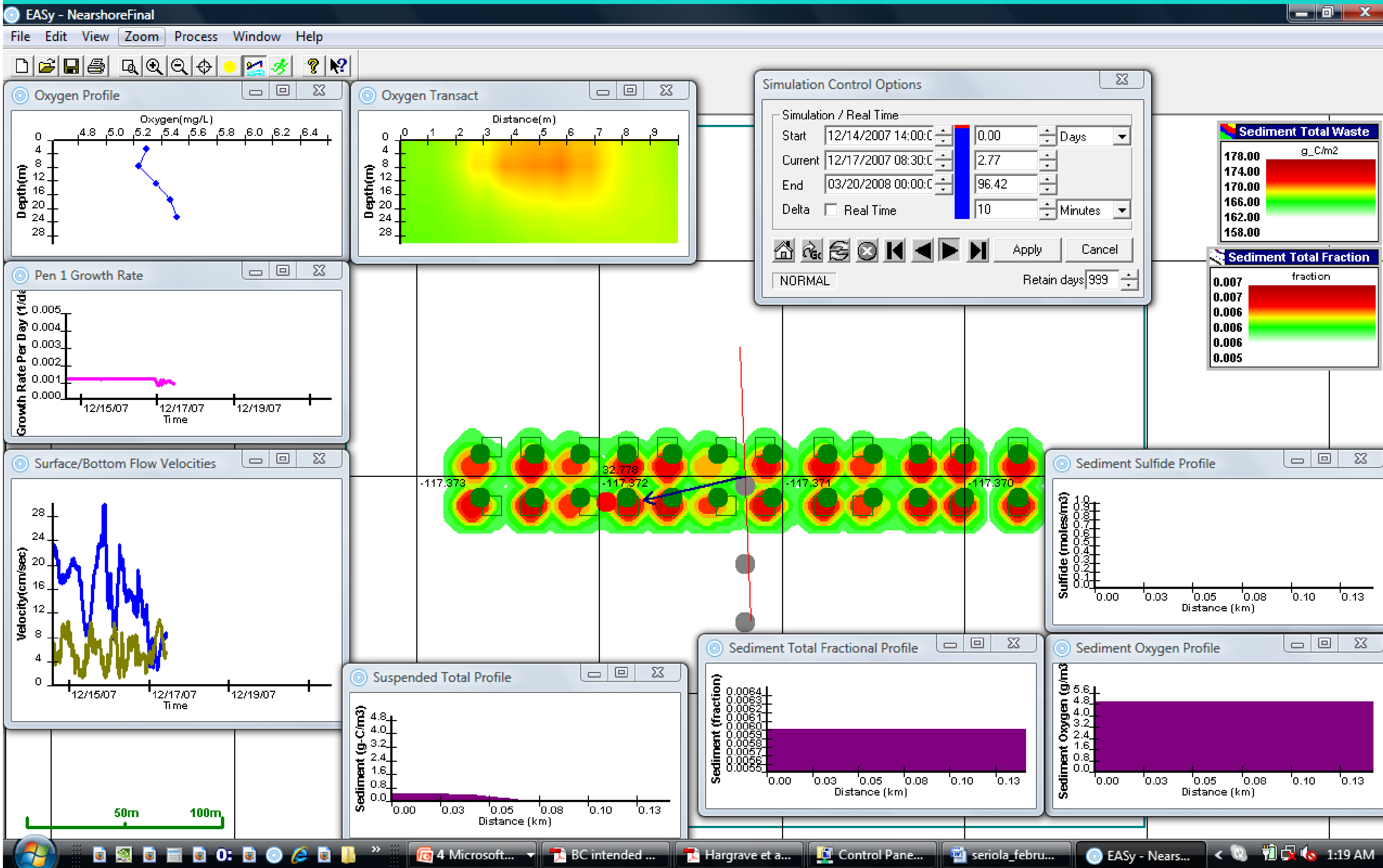
Theoretical Comparison Farm

75% shallower (25 m), slower current by 25%, Pens slightly closer together, Modest nearfield 5m deep D.O. and low nearfield sediment effect

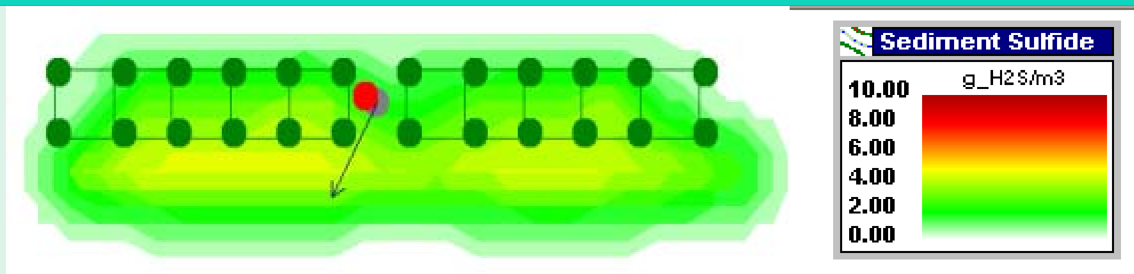


Theoretical Comparison Farm

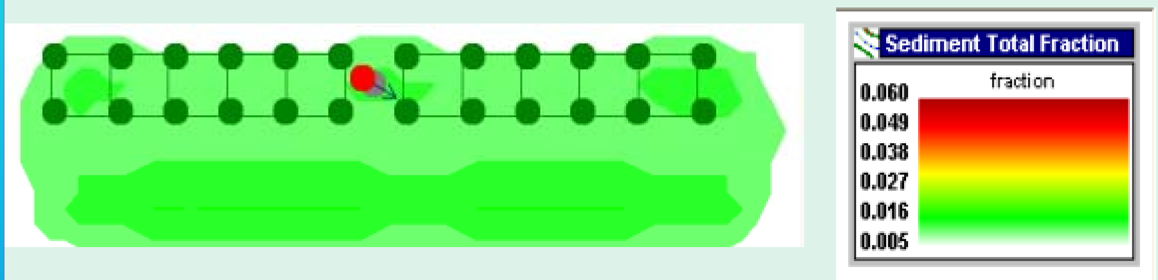
~ same time as prior slide, showing TOC sediment impacts of 10% above ambient & within 10 m of farm



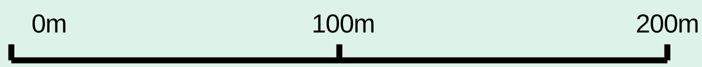
Theoretical Comparison Farm
3.5 months later

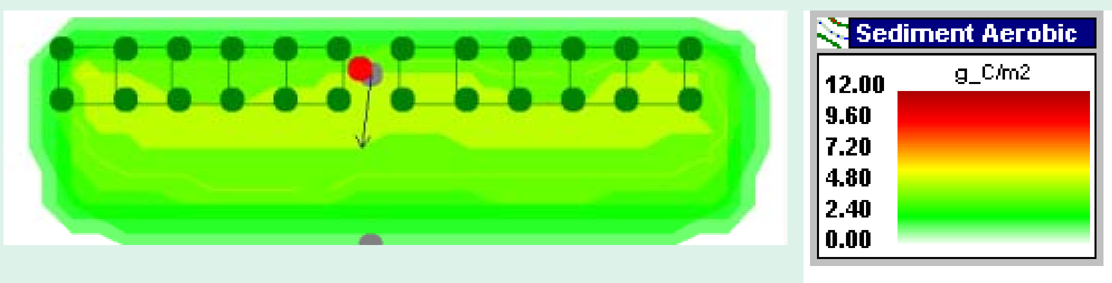


Day 137 Hydrogen sulfide footprint

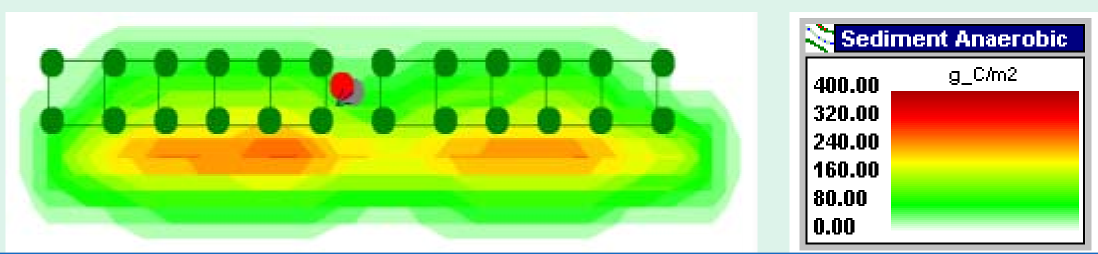


Day 137 Total organic carbon footprint





Day 137 Aerobic biomass footprint



Day 137 Anaerobic biomass footprint

Real Time Simulation

Tabular Output Results Example:

Under cages or other selectable locations & depths

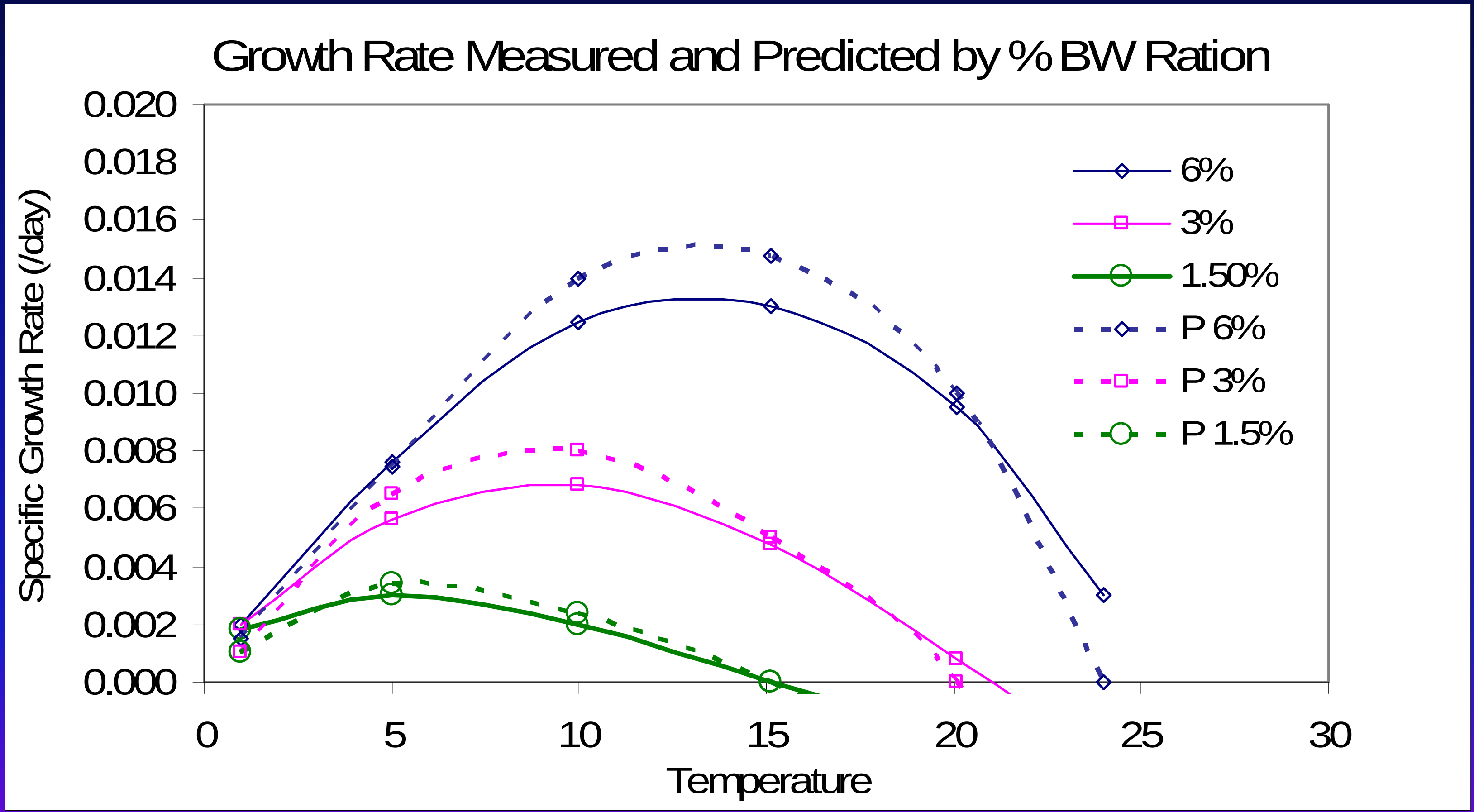
Date (mm/dd/yy)	Time (hh:mm:ss)	Flow Velocity (cm/sec)	Growth Rate (1/day)	Fish Biomass (kg)	Pen Oxygen (mg/l)	Pen Nitrogen (uM/l)	Oxygen (5:0:1) (mg/l)	Nitrogen (5:0:1) (uM/l)	Phytoplankton (5:0:1) (uM/l)	Zooplankton (5:0:1) (uM/l)	FecalWaste (5:0:1) (g/m3)	FeedWaste (5:0:1) (g/m3)
6/3/2004	00:00:00	20.3	0.0	412,965	5.7	0.6	5.7	0.5	0.1	0.1	0.0	0.0
6/3/2004	00:05:00											
6/3/2004	00:10:00											
6/3/2004	00:15:00											
6/3/2004	00:20:00											
6/3/2004	00:25:00											
6/3/2004	00:30:00											
6/3/2004	00:35:00											
6/3/2004	00:40:00											
6/3/2004	00:45:00											
6/3/2004	00:50:00											
6/3/2004	00:55:00											
6/3/2004	01:00:00											
6/3/2004	01:05:00											
6/3/2004	01:10:00											
6/3/2004	01:15:00											
6/3/2004	01:20:00											
6/3/2004	01:25:00											
6/3/2004	01:30:00											
6/3/2004	01:35:00											
6/3/2004	01:40:00											
6/3/2004	01:45:00											
6/3/2004	01:50:00											
6/3/2004	01:55:00											

Within or Under Cage	Flow Velocity	Growth Rate	Fish Biomass	Dissolved Oxygen	Nitrogen	Phytoplankton	Zooplankton	Fecal Carbon	Feed Carbon	Sediment Carbon
Units→	cm s^{-1}	1/d	MT	mg L^{-1}	µM	µg L^{-1}	µg L^{-1}	g m^{-3}	g m^{-3}	g m^{-2}
Mean	8.4	0.01	483.9	5.47	1.06	0.06	0.09	0.02	0.06	0.75
SD	5.2	0.00	421.7	0.18	0.71	0.03	0.02	0.04	0.03	1.51
Change	na	na	na	-0.23	+0.91	-0.04	+0.04	+0.02	+0.06	+0.75
90th %	15.9	0.01	543.4	5.63	1.96	0.10	0.13	0.03	0.10	2.82
10th %	2.9	0.01	426.5	5.24	0.42	0.03	0.06	0.01	0.03	0.00

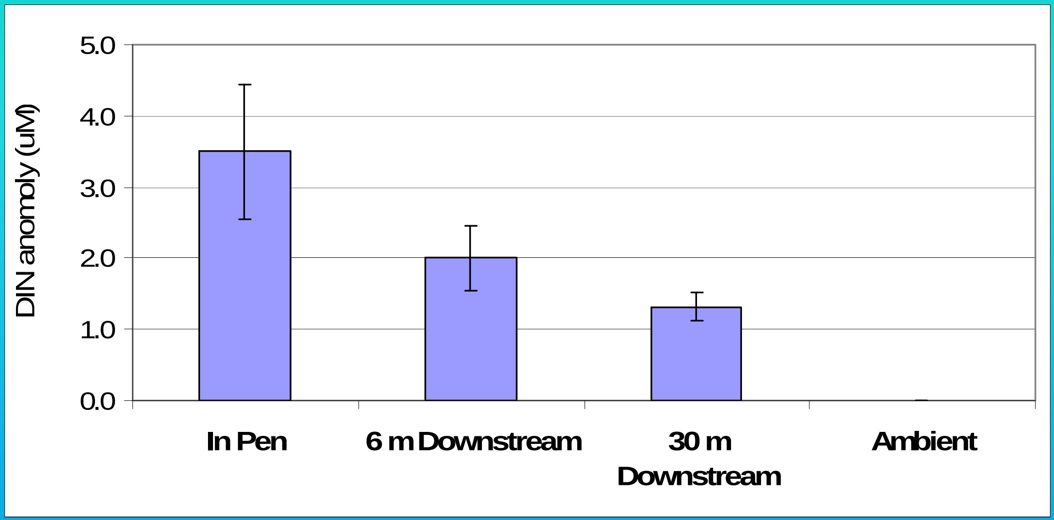
Model Validation, Tuning, Sensitivity Analyses

- 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….

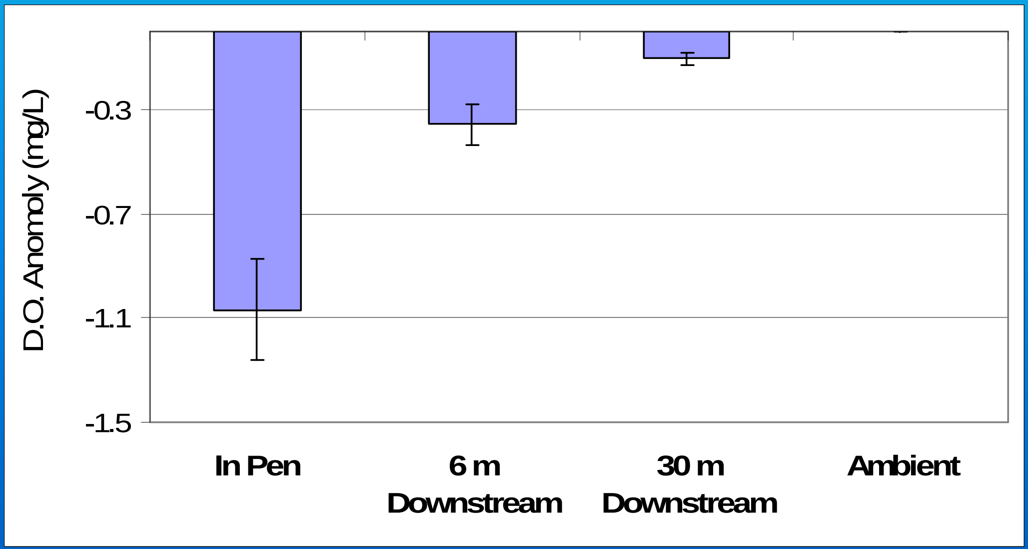
Example Validation: Growth Measurements versus AquaModel calculations



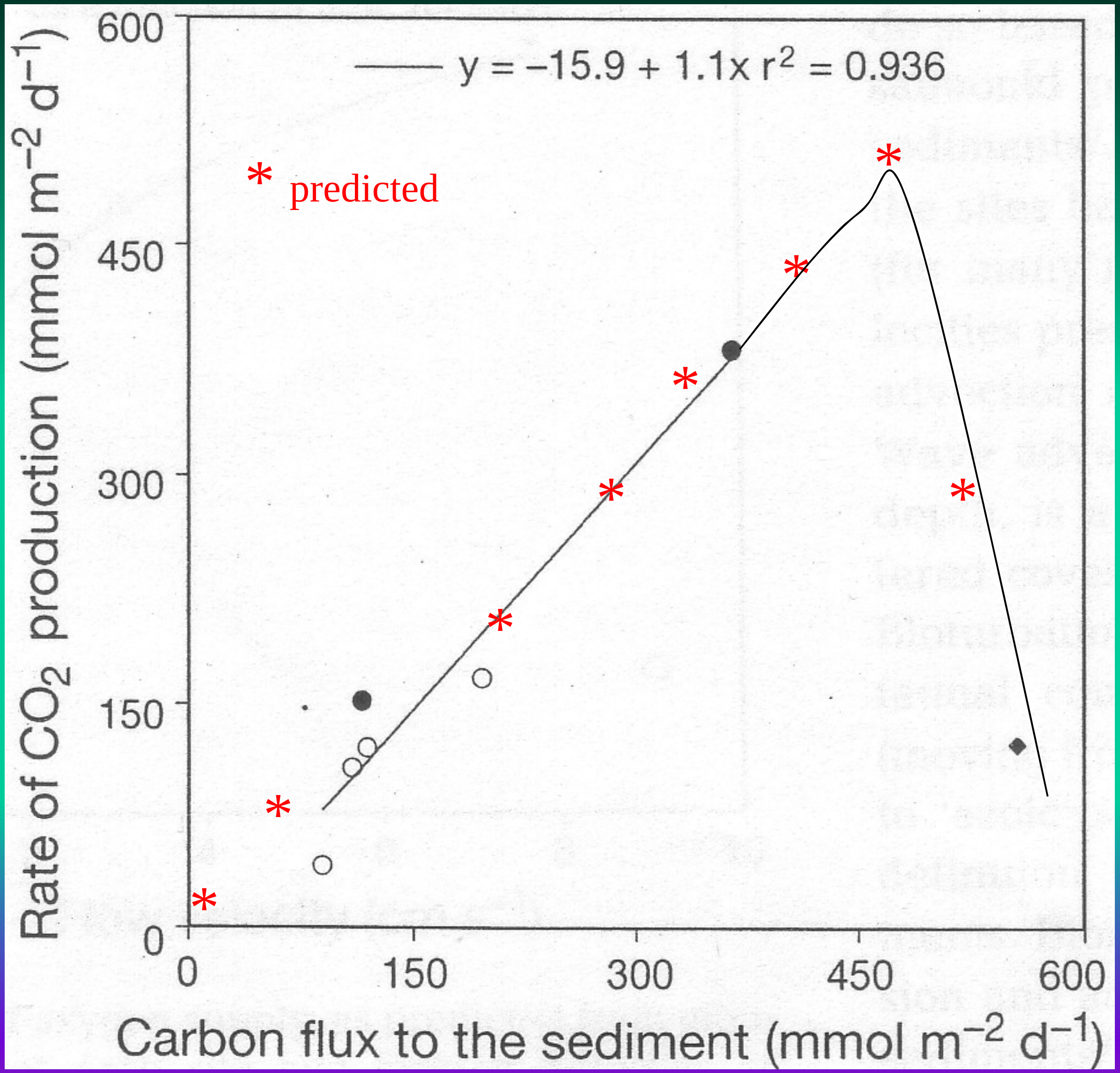
Example of Nitrogen and Oxygen Flux Validation



Used current meters, drogues up and downstream and measured concentrations - 1990s when net-pens farms were smaller



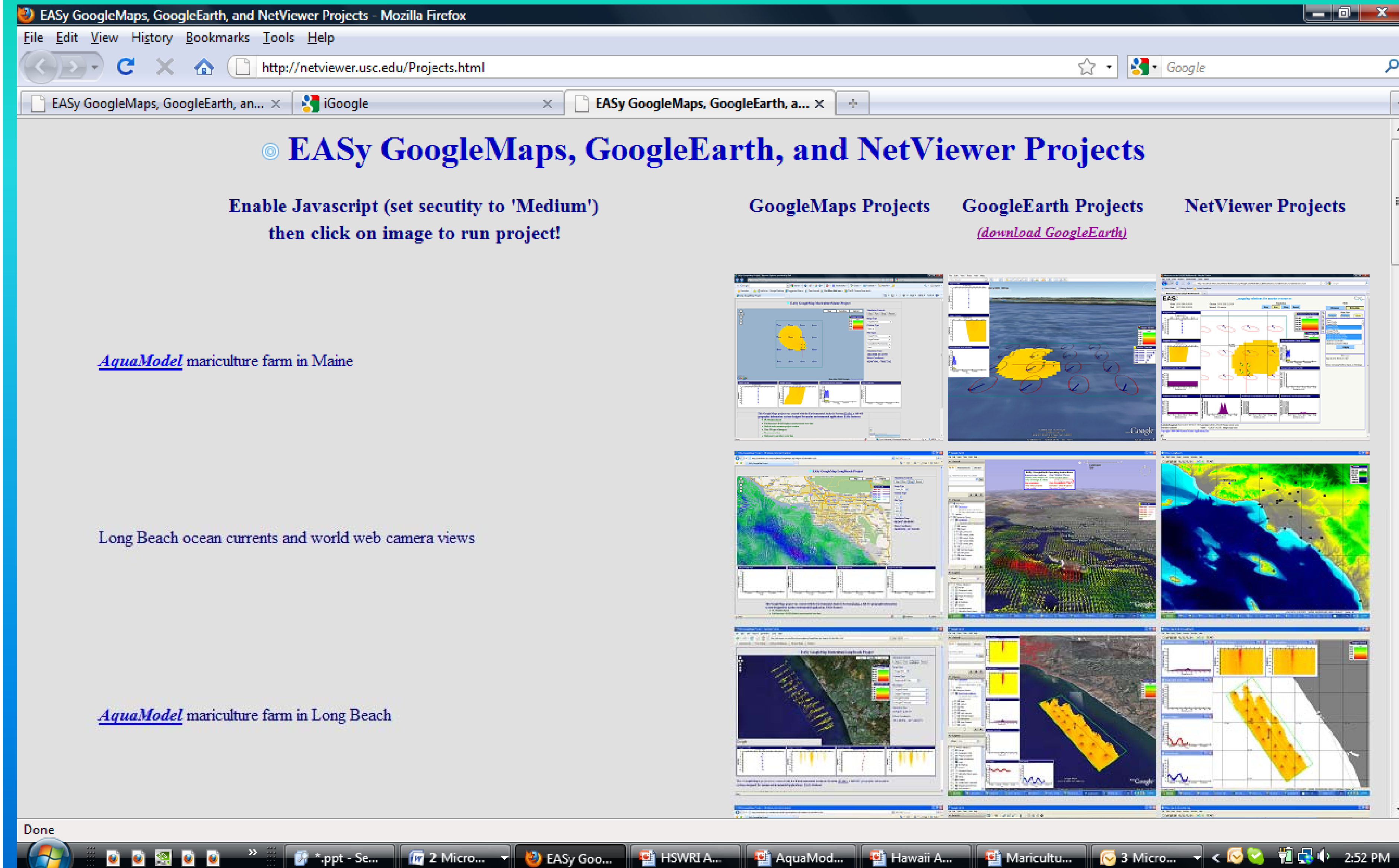
CO_2 Production vs. Carbon Deposition



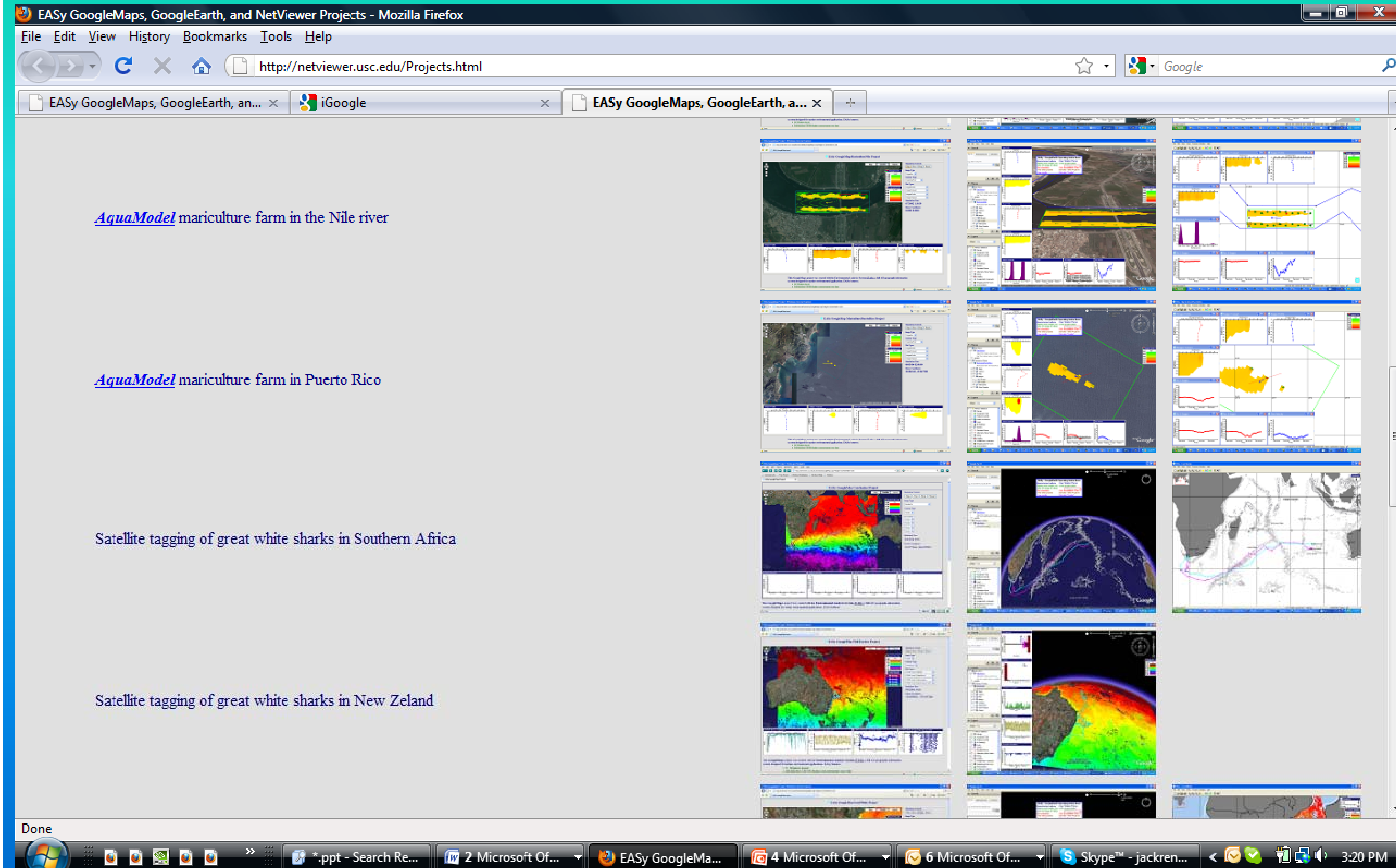
Red = AquaModel projection

Black = Literature
(Findley and Watling 1997, Toothacre Cove Maine, measurements)

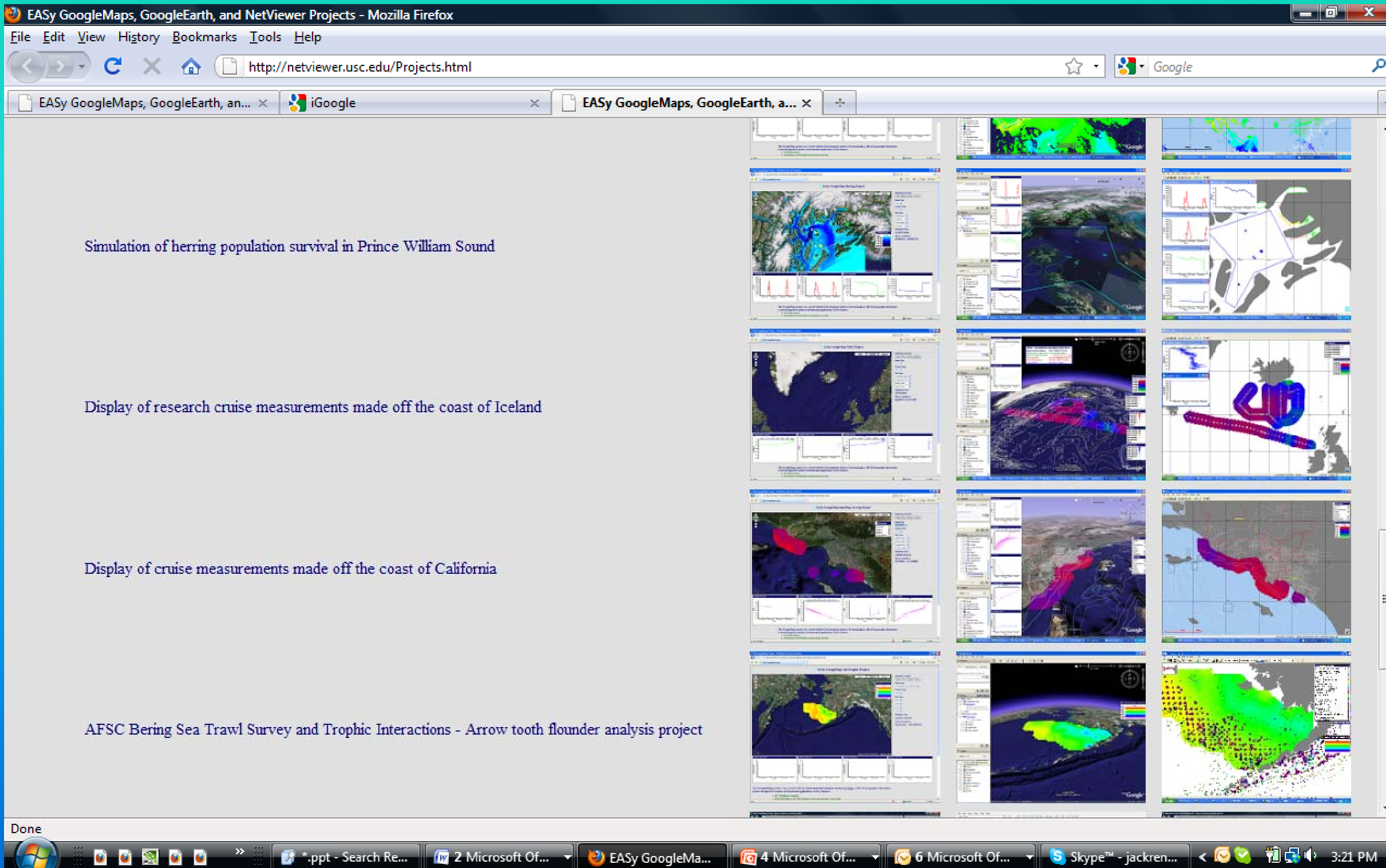
Outreach with Simplified Project Runs Online 1



Outreach with Simplified Project Runs Online 2



Outreach with Simplified Project Runs Online 3



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 provided accurate predictions with minimal effort, reducing the trial and error problems seen in the past at many net pen sites.

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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