The Hydrodynamic Environment and Phytoplankton Population Dynamics

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Agenda

1. Phytoplankton primer
2. How do we build a phytoplankton model?
   • How hydrodynamic + biological models are different
3. How do we use models?
4. Why the phytoplankton problem is challenging/Why do we need models?
5. What can our model do?
What are phytoplankton?

microscopic plants living in the water column
What do phytoplankton do?

Grow
Get eaten
Get transported
What do phytoplankton do?

Grow

Get eaten

Get transported
What do phytoplankton do?

To understand phytoplankton dynamics, we have to understand hydrodynamics.

Grow

Get eaten

Get transported
PHYTOPLANKTON CONCEPTUAL MODEL

Growth
Consumption
Transport
PHYTOPLANKTON CONCEPTUAL MODEL

- Growth
- Consumption
- Transport

All rates can change in space & time

N, P, Si
Why phytoplankton (models) matter

**PHYTOPLANKTON** = *(the most important)* **FOOD**

*Sobczak et al. ’02, Mueller-Solger et al. ‘02*
Why phytoplankton (models) matter

PHYTOPLANKTON = (the most important) FOOD

Sobczak et al. ’02, Mueller-Solger et al. ’02

Phytoplankton (food for zooplankton)

Zooplankton (food for small fish)

Small fish

Courtesy J. Cloern
Why phytoplankton (models) matter

**PHYTOPLANKTON** = *(the most important)* **FOOD**

_Sobczak et al. ‘02, Mueller-Solger et al. ‘02_

Not enough food for fish food

_Mueller-Solger et al. ‘02, Jassby & Cloern ‘00_
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Sobczak et al. ’02, Mueller-Solger et al. ‘02

Not enough food for fish food

Mueller-Solger et al. ’02, Jassby & Cloern ‘00

Plenty of nutrients, but low productivity system

Jassby et al. ’02

For future scenarios, what happens to phytoplankton biomass & productivity?
**Why phytoplankton (models) matter**

**PHYTOPLANKTON** = *(the most important) FOOD*

*Sobczak et al. ’02, Mueller-Solger et al. ’02*

**Not enough food for fish food**

*Mueller-Solger et al. ’02, Jassby & Cloern ’00*

**Plenty of nutrients, but low productivity system**

*Jassby et al. ’02*

**Dissolved oxygen**
No “finished” or “off-the-shelf” phytoplankton model exists for Delta

- a work in progress
- currently developing, refining
  - code/parameterizations
  - data sets
How do we build the model
How do we build our model?

First we need a CONCEPTUAL MODEL

growth
consumption
transport
Next represent the conceptual model MATHEMATICALLY

1. "Physics" (hydrodynamics)
2. "Reactions" (biology)
3. LINKAGE
Next represent the conceptual model **MATHEMATICALLY**

1. “Physics” (hydrodynamics)
2. “Reactions” (biology)
3. LINKAGE
Hydrodynamic Model: Delta-TRIM

Based on “TRIM3D” model

Cassuli & Cattani 1994

Old bathymetry grid

Sacramento River

San Joaquin River

SF Bay

Nancy Monsen, USGS
Delta TRIM Features

- Run in 2D or 3D (2D for most applications)
- 50 m square grid ("structured")
- Semi-implicit
- Wetting/drying of grid cells
- Can calculate baroclinic flows  
  *Baek 2006*
- Wind can be applied as a surface stress  
  *Baek 2006*

- Domain same as DSM2 (tidal boundary @ Martinez)
- Methods developed for transport time scale calculations using particle tracking techniques  
  *Monsen et al. ’02, ’07*  
  *Lucas et al. ‘02*
- Utilize input data at any time step (hourly data for Sacramento river flow)
Delta TRIM

Strengths

• Deals with all the complexities of Delta hydrodynamics (e.g. barriers, gates, Delta island consumptive use, etc.)
• Mixing in open water bodies and complex channel junctions are described physically.
• Numerical approaches well documented in the literature. 
  Cassuli & Cattani 1994
• Conserves mass. Gross et al. 1999
• History:
  - Phytoplankton modeling applied to TRIM2D & TRIM3D in South Bay
  - 10-yr hydro-phyto collaboration

Weaknesses

• Limited resolution of narrow channels
• Slow: Three month simulation takes ~1 week
• Code is used for research applications. Numerical core of hydrodynamic model is proprietary.
• No formal manual. Steep learning curve.
Next represent the conceptual model **MATHEMATICALLY**

1. “Physics” (hydrodynamics)
2. “Reactions” (biology)
3. Based on Laws (F=ma)

**LINKAGE**
Next represent the conceptual model **MATHEMATICALLY**

1. “Physics” (hydrodynamics)
2. “Reactions” (biology)
3. LINKAGE
Model of phytoplankton “Reactions”

**Process rates**
- light-driven photosynthesis & growth (assume nutrient replete)
- respiration
- zooplankton grazing
- benthic grazing

can vary spatially & temporally
Next represent the conceptual model **MATHEMATICALLY**

1. "Physics" (hydrodynamics)
2. "Reactions" (biology)
3. Empirical (no F=ma)
Empirical photosynthesis-irradiance curve

\[ P(z, t) = P_{\text{max}} \left\{ \tanh \left[ aI(z, t) \right] - r \right\} \]

*varies with species, environment, etc.*

Jassby & Platt 1976
Why there’s no F=ma for biology:

Different *species* do/like different things at different *times* and different *places*
Different *species* do/to like different things at different *times* and different *places*

- Some sink
- Some swim
- Some float
Different **species** do/like different things at different **times** and different **places**

- Some sink
- Some need special food
- Some can get food from the air
- Some swim
- Some float
Different *species* do/like different things at different *times* and different *places*

- Some sink
- Some swim
- Some need special food
- Some can get food from the air
- Some grow fast
- Some float
Different **species** do/like different things at different **times** and different **places**

- Some **sink**
- Some **swim**
- Some **float**
- Some need **special food**
- Some can **get food from the air**
- Some like **light**
- Some like **shade**
- Some grow **fast**

Different species do/like different things at different times and different places.
\[
\frac{\partial B}{\partial t} + \frac{\partial}{\partial x} (UB) + \frac{\partial}{\partial y} (VB) + \frac{\partial}{\partial z} (WB) + \frac{\partial}{\partial z} (\alpha B) = \\
\frac{\partial}{\partial z} \left( K_z \frac{\partial B}{\partial z} \right) + (\mu - ZP)B
\]
So at every grid cell and time step...

Hydro model
velocities, surface elevations, turbulent mixing coefficients

Linkage Equation

Phyto model
rates of growth, grazing, respiration
So at every grid cell and time step...

Hydro model
velocities, surface elevations, turbulent mixing coefficients

Phyto model
rates of growth, grazing, respiration

Linkage Equation
phytoplankton biomass concentration!!
How do we **USE** our model?

**Quantitative**
- seek to answer precise questions with precise numbers
- often complex, not tuned
- maybe hard to understand why

**Qualitative**
- seek to discern environmental trends
- often simpler, not tuned
- understand ‘why’
- ID process

Pilkey, Pilkey-Jarvis, Lucas
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Pilkey, Pilkey-Jarvis, Lucas
Why is this problem challenging?

(Why are models useful?)

Phytoplankton biomass is time- and space-varying a function of MANY INTERACTING PROCESSES. The overall response (up vs. down) depends on the balance between those processes.
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(Why are models useful?)

Phytoplankton biomass is time- and space-varying a function of MANY INTERACTING PROCESSES. The overall response (up vs. down) depends on the balance between those processes.

Models integrate all the processes
Models allow us to control the processes
Models check our intuition
Why is this problem challenging?

An example:

Our intuition often leads us to expect that if hydraulic residence time/flushing time goes up (transport gets slower), then phytoplankton biomass goes up.
Intuition is not necessarily right: Phytoplankton response to residence time is determined by biological sources + losses

Lucas et al. L&O In review
Intuition is not necessarily right:
Phytoplankton response to residence time is determined by biological sources+losses

CASE 1

Clear (fast growth) + low grazing

Lucas et al. L&O In review
Intuition is not necessarily right:
Phytoplankton response to residence time is determined by biological sources + losses

CASE 1
Clear (fast growth) + low grazing

CASE 2
Turbid (slow growth) + high grazing
One reason predicting phytoplankton is challenging:

We can’t know how phytoplankton biomass will respond to a change in FLOW without knowing about the balance between source+loss processes (i.e. do we have a case 1 or case 2?)
One reason predicting phytoplankton is challenging:

We can’t know how phytoplankton biomass will respond to a change in flow without knowing about the balance between source+loss processes.

To know the source+loss balance, we need either:
- DATA (for contemporary+historical cases)
- More good models (i.e. for future scenarios)
Inputs for CLIMATE CHANGE Scenarios

- stage, velocity, turb. mixing coeff's
  *(Delta Hydro. Model)*
- clam grazing rates
  *(Invasive species model)*
- photosynthetically active radiation
  *(Climate models)*
- turbidity
  *(Sediment model)*
What can our phytoplankton model do?
Represent large scale spatial patterns

April 2003 (Lots o’ Data to drive Model!)
Represent regional scale spatial patterns

MEASUREMENTS

phyto. biomass

0 to 3
3 to 6
6 to 9
9 to 12
12 to 15
15 to 18
18 to 21
21 to 24
24 to 27
27 to 30

MODELED

phyto. biomass

• Mildred Island, Sept 2001
• lots o’ data!
• 25 m grid
• UC Berkeley (Baek & Stacey) did hydro+temp
• tides+wind+heating

TRIMVIS graphics courtesy Seungjin Baek
So far, less skill on temporal development

April 2002
What “bad” results teach us:

something’s missing or wrong

In this case, it might be:

- temporal resolution of:
  - surface irradiance
  - zooplankton grazing
  - boundary conditions (phyto. biomass coming in from rivers)
- insufficient time for boundary conditions to be felt within domain
- less data for this time period
Natural progression of model development

- Run model
- Compare with observations/identify problems
- Refine model
- Reduce uncertainty
We expect that...

- model skill will vary between CASCaDE components, depending on...
  - basis in physical laws vs. empiricism
  - number+complexity of interacting processes
  - available data
  - accumulated error in inputs derived from other models
- phytoplankton model may demonstrate skill in assessing possible trends in phytoplankton biomass & productivity (up vs. down) and changes in spatial patterns, but not quantitative changes in system
1. No existing “finished” phytoplankton model for Delta (work in progress)

2. Phytoplankton dynamics is governed by several interacting physical + biological processes

3. To predict the phytoplankton response to changes in hydrodynamics, we need to also know what net biological source-loss balance will be

4. Laws form basis for hydrodynamic models but not for biological models

5. Reduction of uncertainty is an iterative, sometimes slow, process
...and we’re not even talking about an “ecosystem” model

This is just for phytoplankton!
Why modeling biology is simultaneously frustrating & liberating...

- **Frustrating**: you know you’ll never get it completely right
- **Liberating**: you know you’ll never get it completely right
  (so relax!)
How will we assess uncertainty?

*Minimum uncertainty:*

Errors of model runs for contemporary cases relative to measurements
How will we assess uncertainty?

Extreme hydro case #1

Extreme bio #1

hydro

Extreme bio #1

Extreme hydro case #2

Extreme bio #1

hydro

Extreme bio #1