Assessing San Francisco Bay-Delta phytoplankton and clams for CASCaDE scenarios of change

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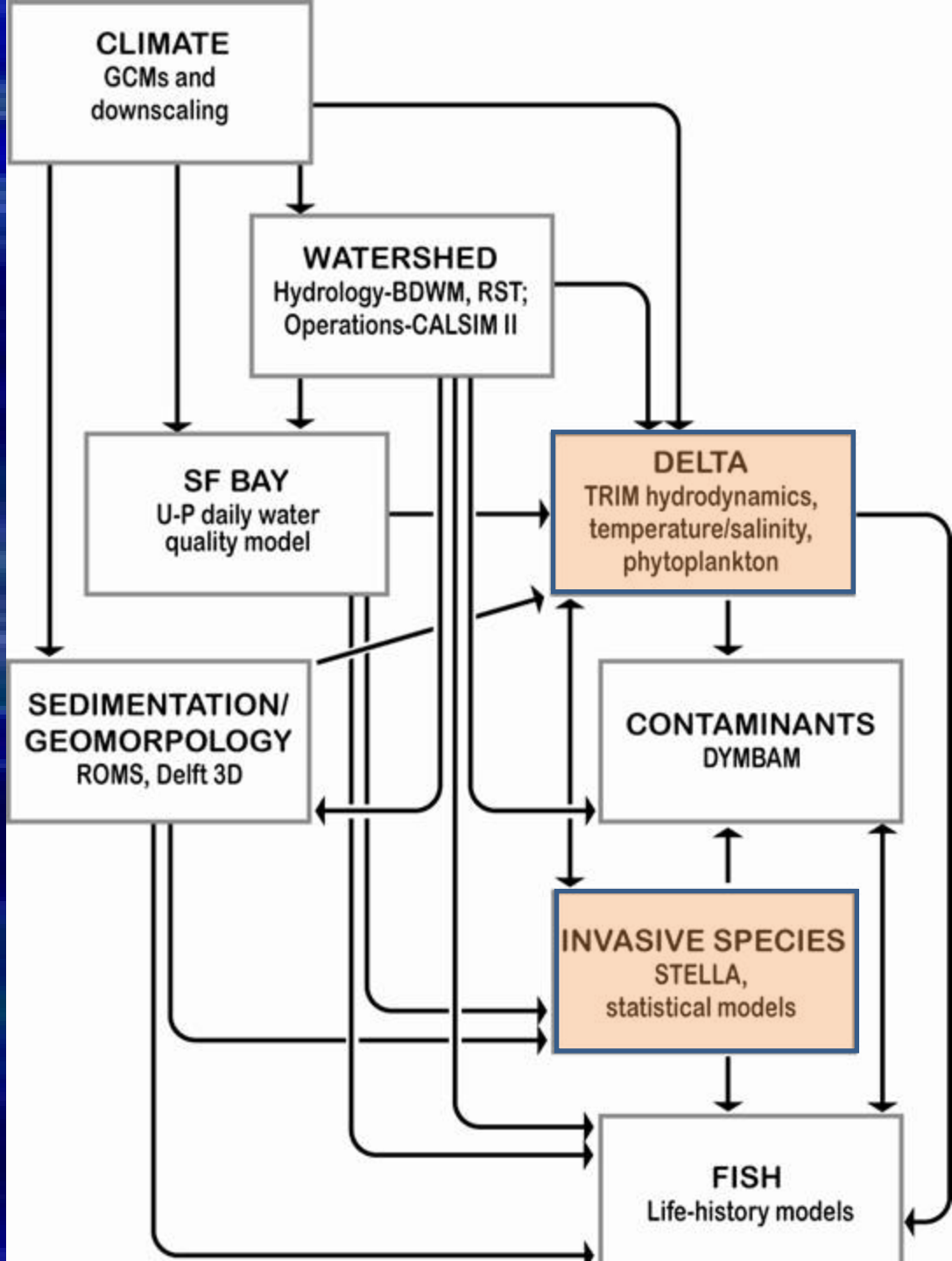


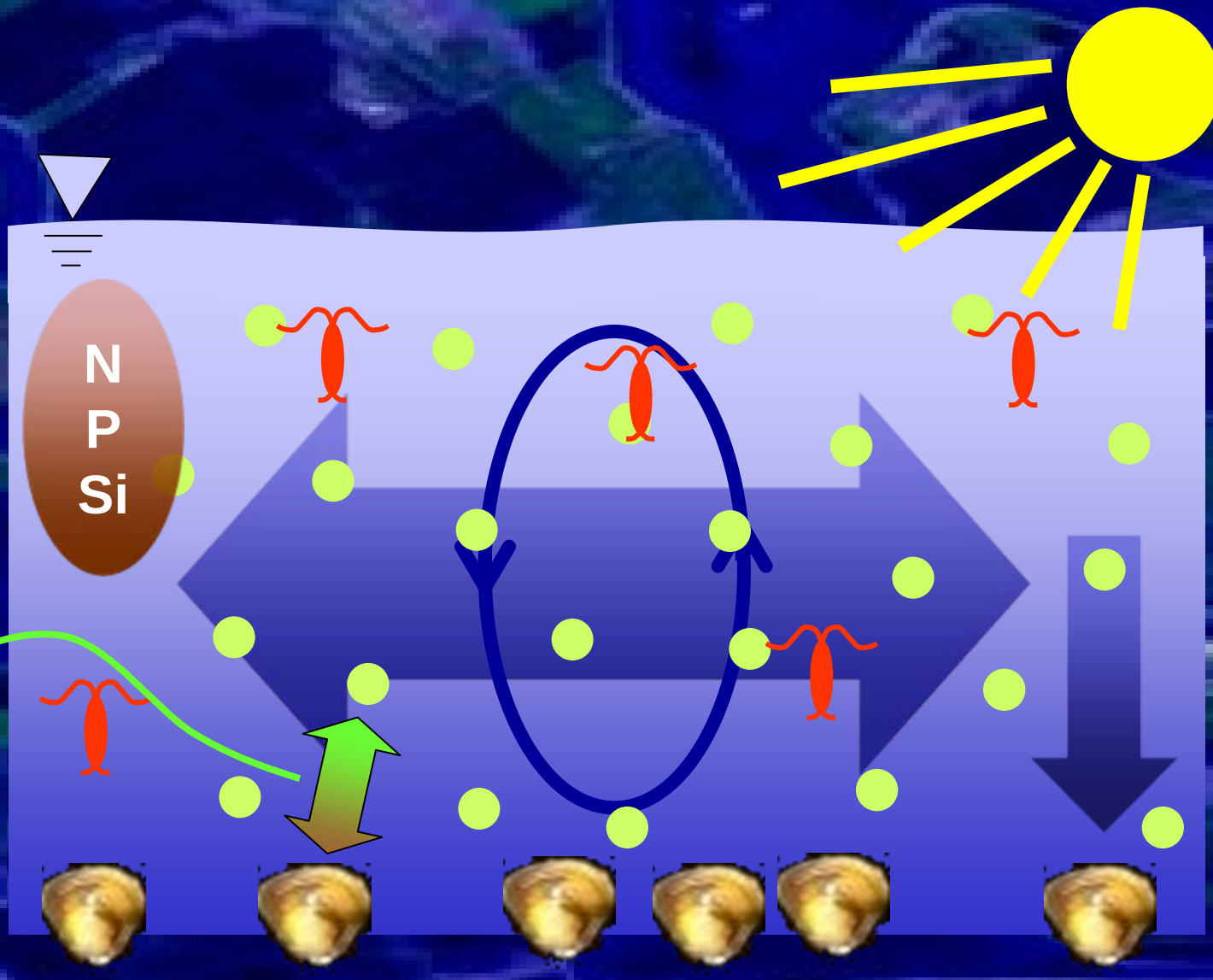
PHYTOPLANKTON CONCEPTUAL MODEL

<u>Growth</u>

<u>Consumption</u>

<u>Transport</u>

Strong link between phytoplankton and clams!



In the Delta:

1) **phytoplankton are a critical food resource** *Sobczak et al. '02*
2) **phytoplankton concentrations are generally limiting**

Mueller-Solger et al. '02

Phytoplankton
(food for zooplankton)

USEPA Great Lakes National Program

Zooplankton
(food for small fish)

Upper Midwest Environmental Sciences Center - USGS

Small fish

Peterson / USFWS

A CASCaDE question:

How will phytoplankton biomass and production respond to future changes in:

- ✓ *turbidity/light*
- ✓ *clam distributions/abundance/biomass*
- ✓ *hydrodynamics (flow, flushing)*

We're developing detailed coupled models of clam populations & phytoplankton

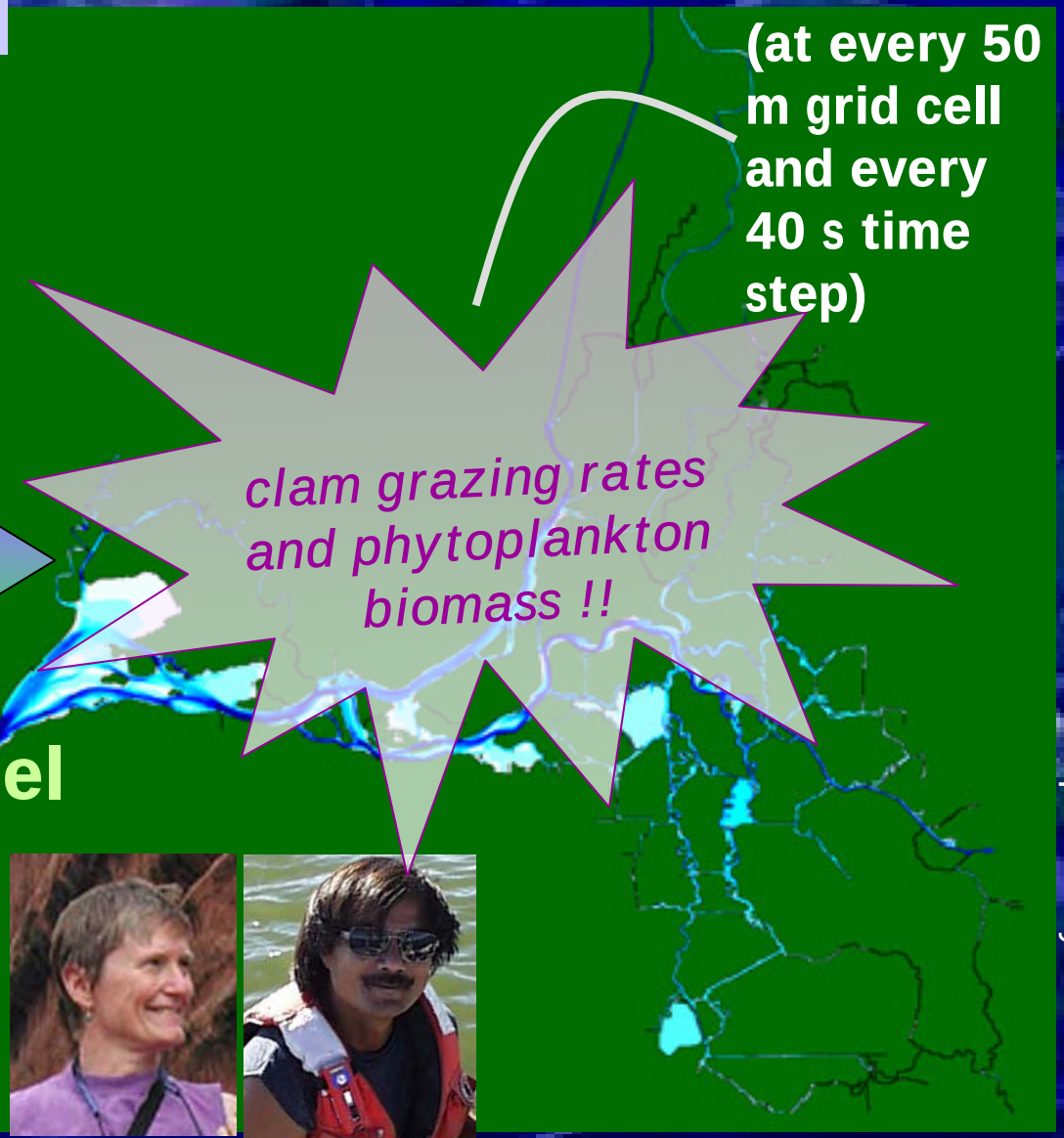
Hydro model

velocities, surface elevations, turbulent mixing coefficients (3D)

Coupled physical-biological model

Biology model

rates of growth, respiration, grazing



(at every 50 m grid cell and every 40 s time step)

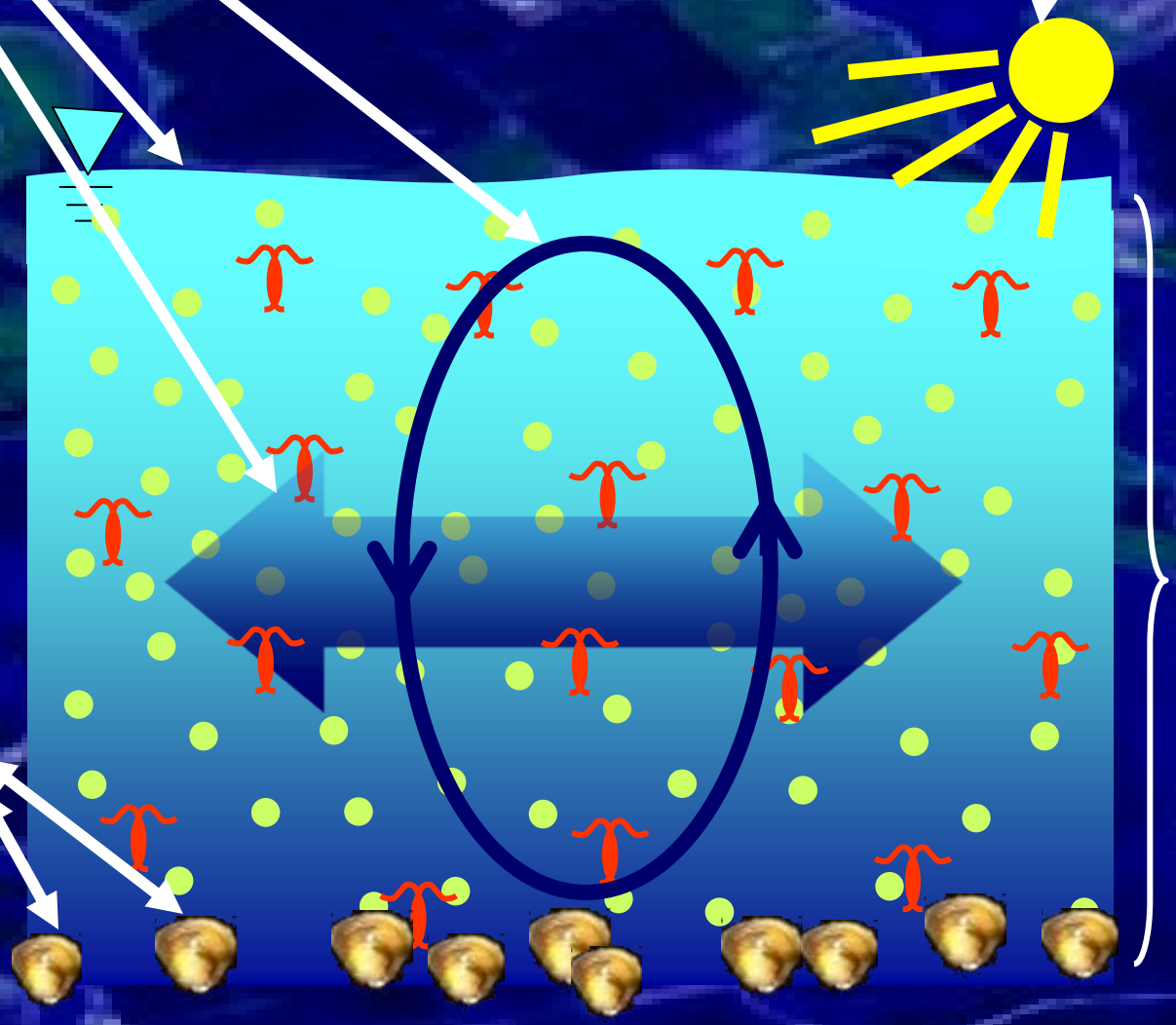
clam grazing rates and phytoplankton biomass !!

Map courtesy N. Monsen

Inputs for CLIMATE CHANGE Scenarios

stage, velocity, turb. mixing coeff's *(Delta Hydro. Model)*

photosynthetically active radiation *(Climate models)*



turbidity *(Sediment models)*

temperature *(Temp. model)*

clam grazing rates *(Invasive species model)*

For future scenarios of change, we will run the fancy, detailed numerical model of coupled hydrodynamics+biology

In addition and in parallel, we are developing some *simpler* approaches as an *intermediate* step in assessing future changes to phytoplankton in the Delta

INDICES

Lucas, Thompson, Brown L&O In press

An example of using *INDICES* for understanding ecosystem function and assessing future scenarios:

τ^*_{loss} →

An INDEX relating:

1) the local balance between phytoplankton growth and loss

("phytoplankton-enhancing" vs. "phytoplankton depleting")

2) phytoplankton biomass will respond to a change in transport time (e.g. residence time)

Lucas, Thompson, Brown L&O In press

Across the globe, there are many examples where slower flow or flushing triggers or exacerbates intense algal blooms. *Paerl & Huisman 2008*

POSITIVE
phytoplankton-transport time relationship

The prevalence of this result may lead us to expect that if we slow down transport (i.e. hydraulic residence time/flushing time goes up), then phytoplankton biomass will increase.

Positive P-T doesn't apply everywhere

The literature show a range of phytoplankton-transport time (P-T) relationships, including negative relationships and cases where there's no apparent relationship

A new conceptual model explains why:

- **Biomass, as a function of growth and grazing, can go up or down (or not change at all) with an increase in transport time**
- **Phytoplankton sign of change is not determined by transport time, but rather by biological growth-loss balance**

Lucas, Thompson, Brown L&O In press

$$\tau^*_{loss} = \frac{\tau_{loss}}{\tau_{growth}}$$

τ_{growth} = timescale for growth

τ_{loss} = timescale for losses

a simple INDEX of whether a habitat is
"*phytoplankton-ENHANCING*"
OR
"*phytoplankton-DEPLETING*"

(based on assumption of steady state conditions; captures local process)

Lucas, Thompson, Brown L&O In press

$$\tau^*_{loss} = \frac{\tau_{loss}}{\tau_{growth}}$$

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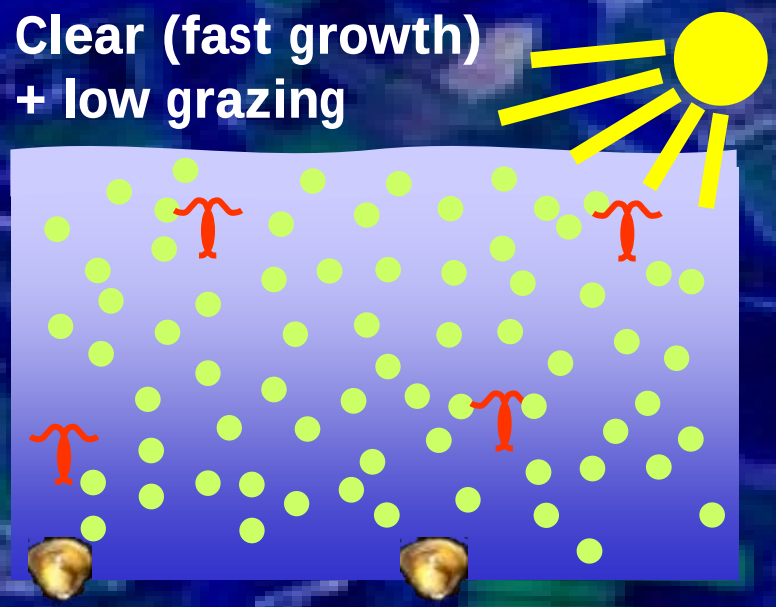
CASE 1: $\tau^*_{loss} > 1$

(phytoplankton-enhancing)

$\tau^*_{loss} < 1$

Clear (fast growth)
+ low grazing



As transport time

Phyto

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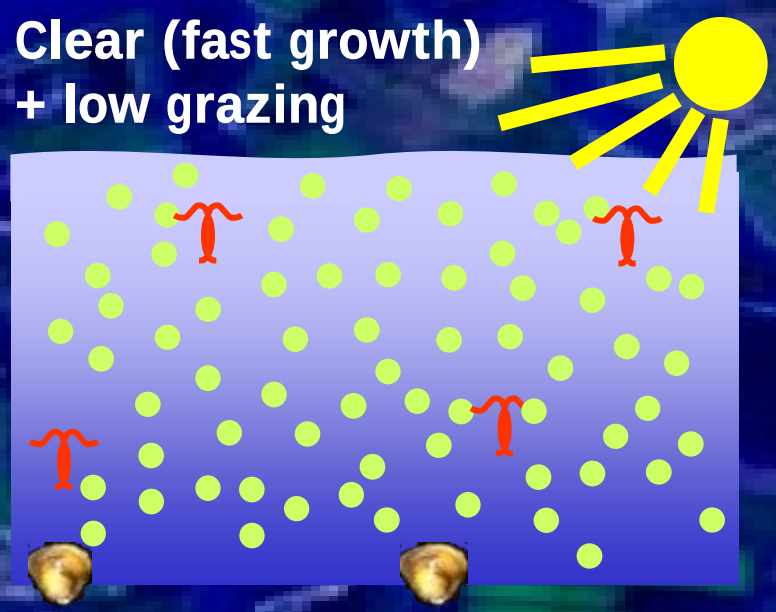
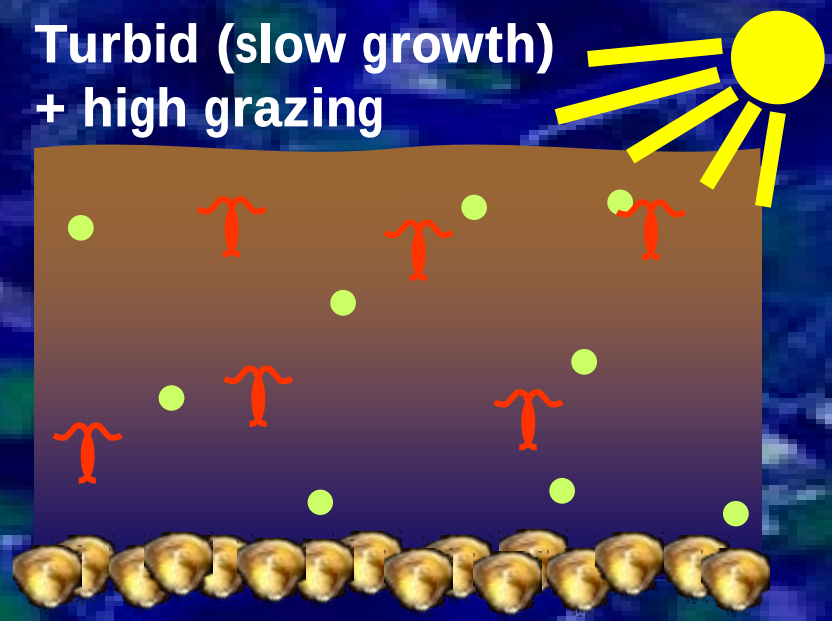


As transport time ↑ Phyto ↑

CASE 2: $\tau^*_{loss} < 1$

(phytoplankton-depleting)

Turbid (slow growth)
+ high grazing



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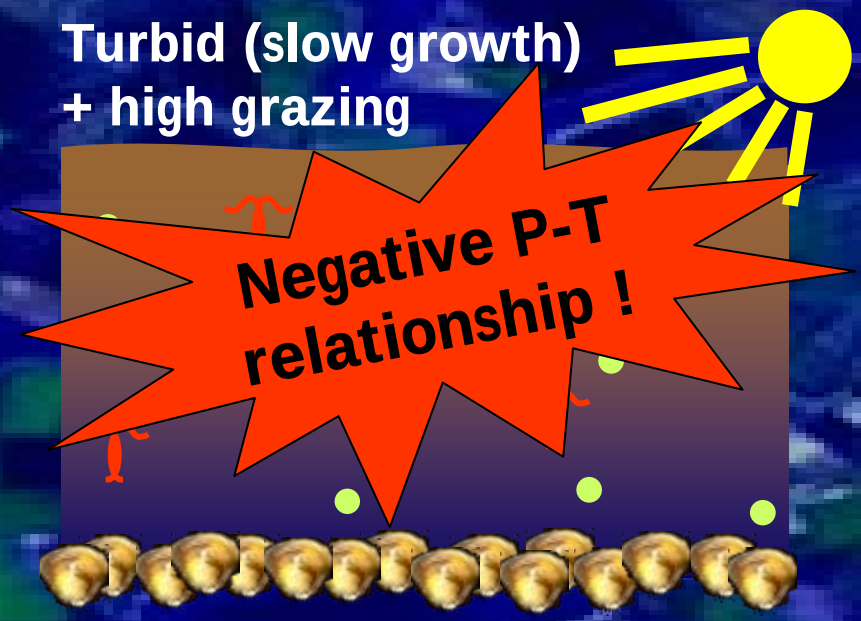


As transport time ↑ Phyto ↓

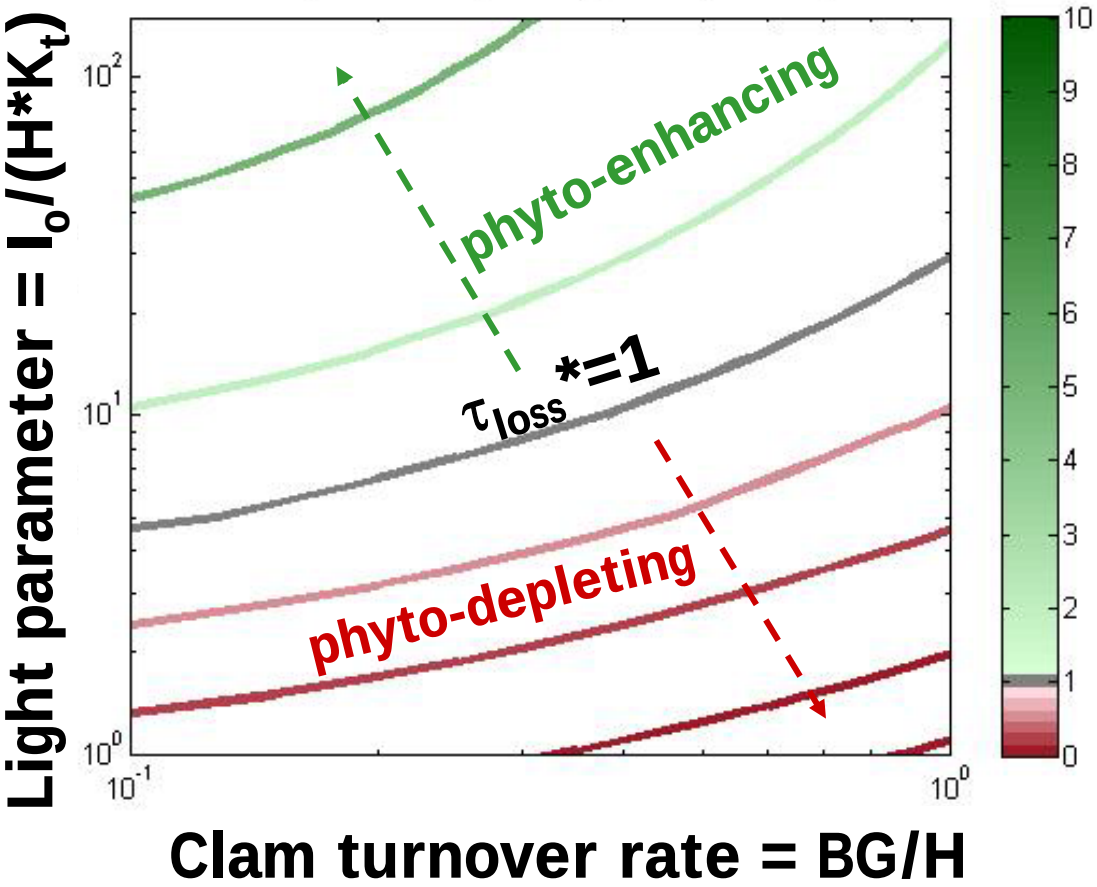
We can't know how phytoplankton biomass will respond to a change in FLOW or FLUSHING unless we know about the balance between GROWTH and LOSS

(i.e. do we have a case 1 or case 2?)

!!! FOR THE DELTA, we can't know if plugging holes in levees around an open water habitat will increase phytoplankton production and biomass unless we know whether phytoplankton growth rate will dominate over losses such as grazing !!!

τ_{loss}* for the Delta

τ_{loss}* for Delta



$$\tau^*_{loss} = \frac{\ln\left(0.08\left[\frac{I_o}{H \cdot K_t}\right] + 0.985\right)}{0.2 + \left[\frac{BG}{H}\right]}$$

Following:

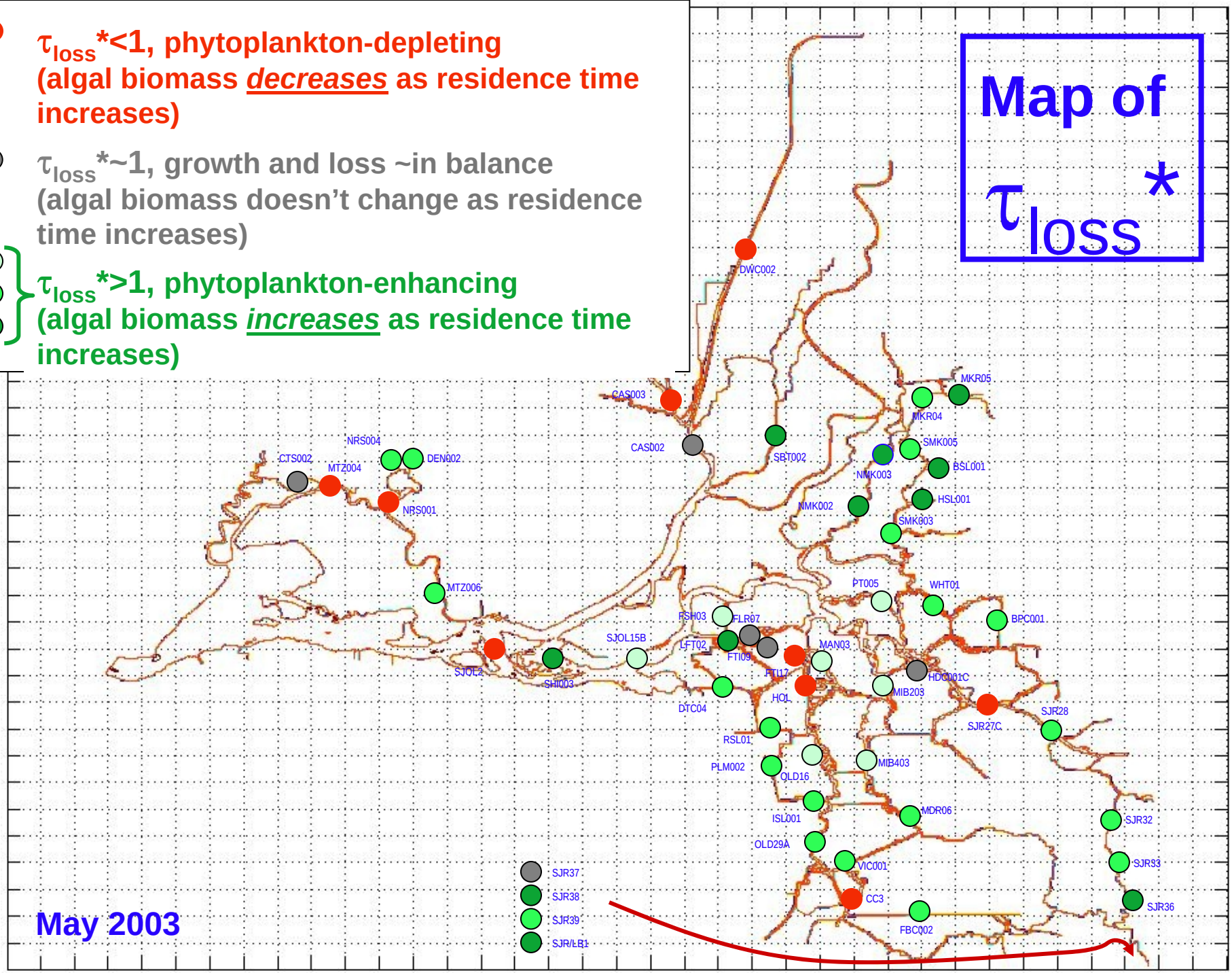
Jassby et al. 2002,
Lopez et al. 2006
Cloern et al. 1995
Cole & Cloern 1980

BG=benthic grazing rate
H=water depth
I_o=daily surface irradiance
K_t=light attenuation

Assuming:
ZP=zooplankton grazing=0.2 d^{-1}
C:Chl=35 (Sobczak et al. 2002)

Map of τ_{loss}*

- τ_{loss}*<1, phytoplankton-depleting (algal biomass *decreases* as residence time increases)
- τ_{loss}*~1, growth and loss ~in balance (algal biomass doesn't change as residence time increases)
- τ_{loss}*>1, phytoplankton-enhancing (algal biomass *increases* as residence time increases)



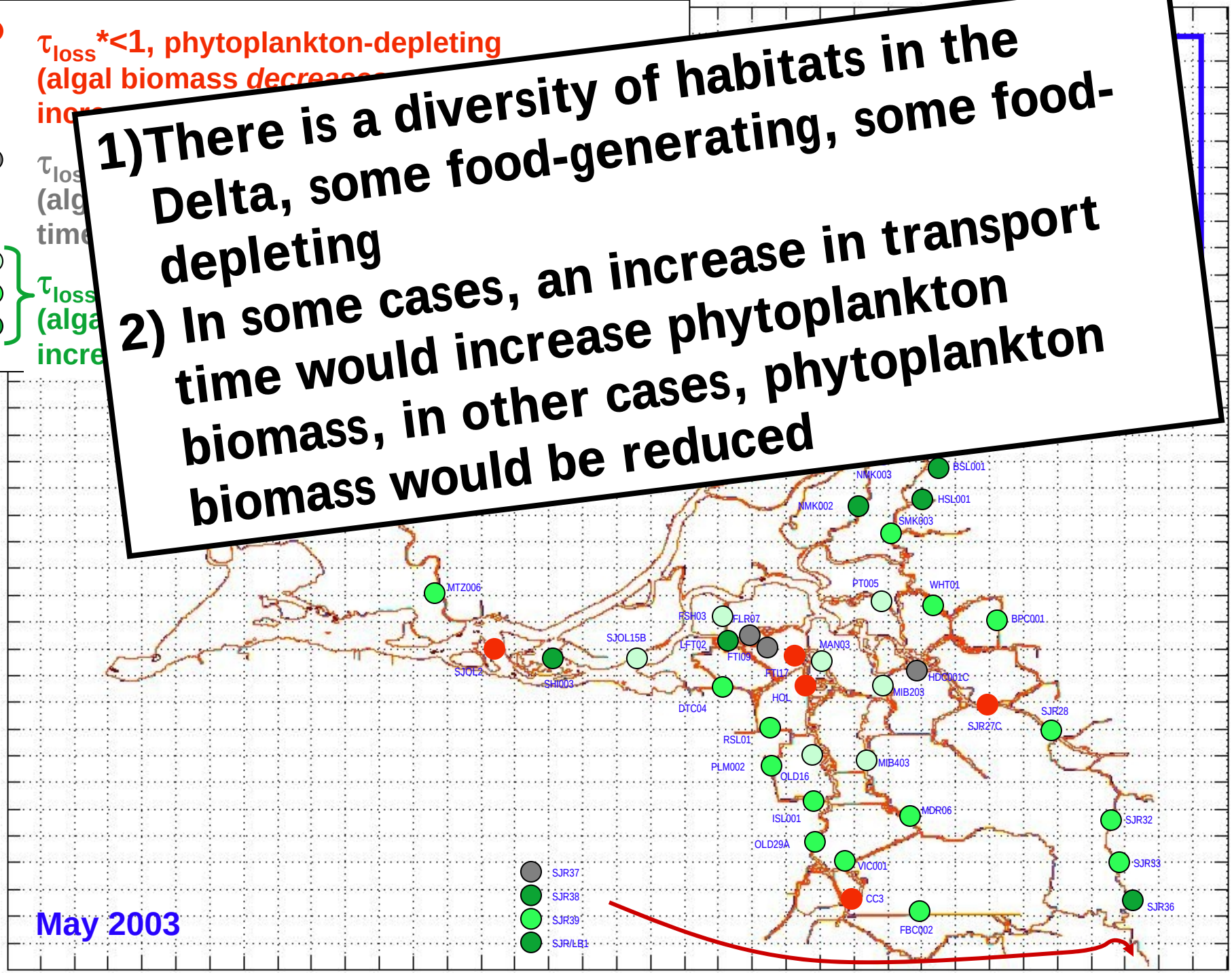
τ_{loss}*<1, phytoplankton-depleting
(algal biomass *decrease*
incre

τ_{los
(alg
time

τ_{loss
(alga
incre

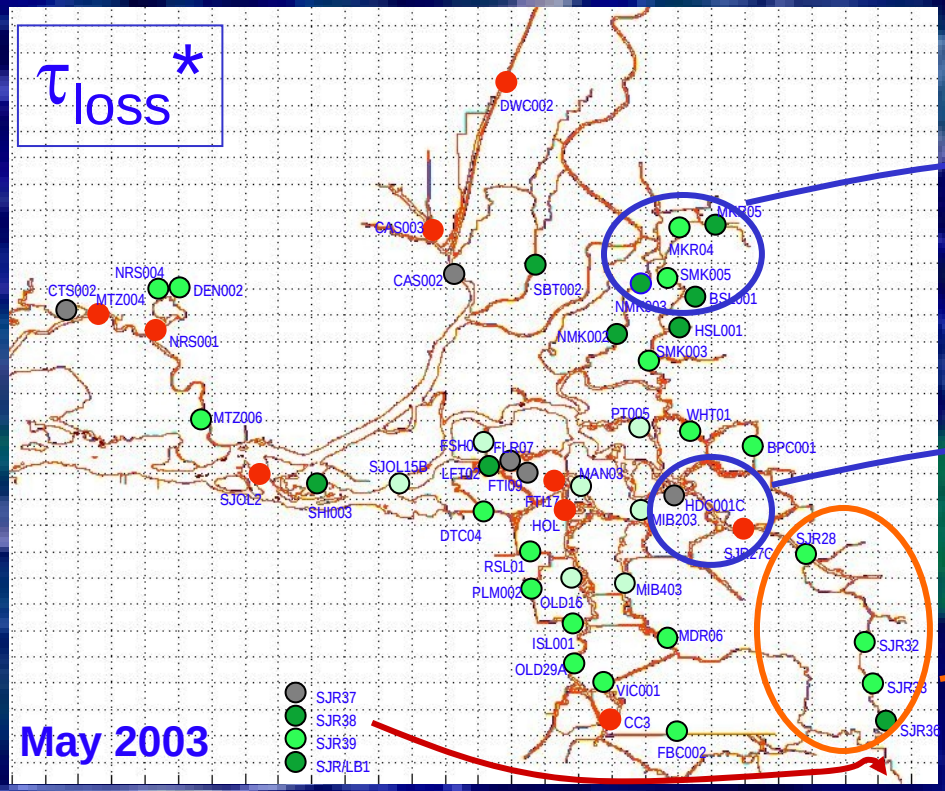
1)There is a diversity of habitats in the Delta, some food-generating, some food-depleting

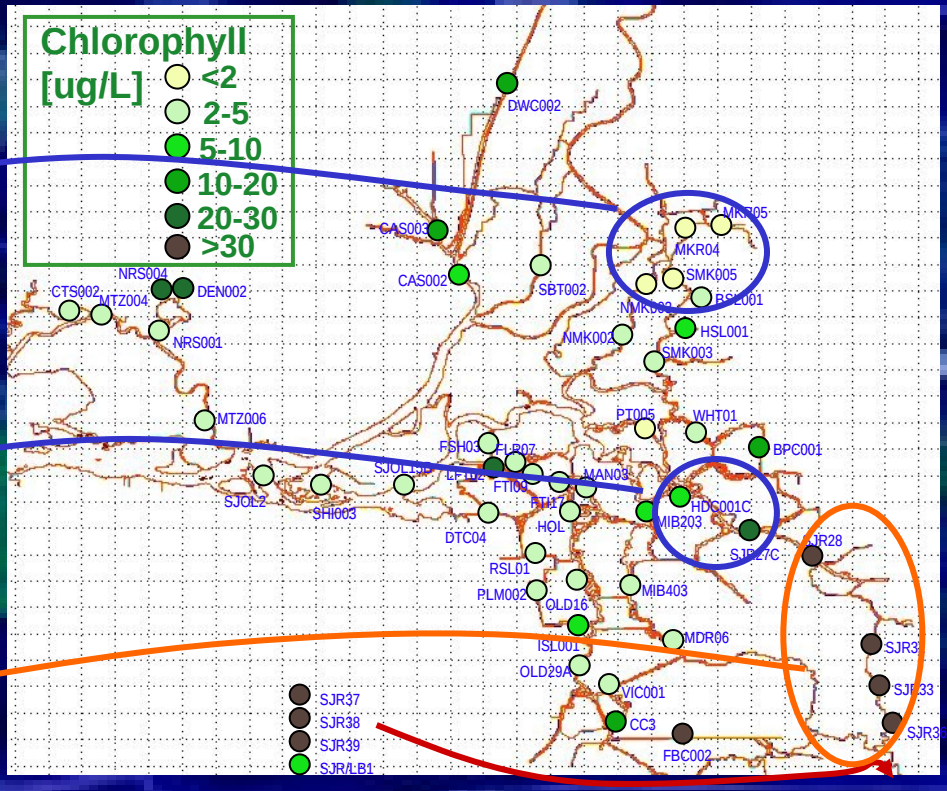
2) In some cases, an increase in transport time would increase phytoplankton biomass, in other cases, phytoplankton biomass would be reduced



Does τ_{loss}* correspond with phytoplankton biomass?

IF local processes dominate over transport between different τ_{loss}* habitats





Does τ_{loss}* correspond with phytoplankton biomass?

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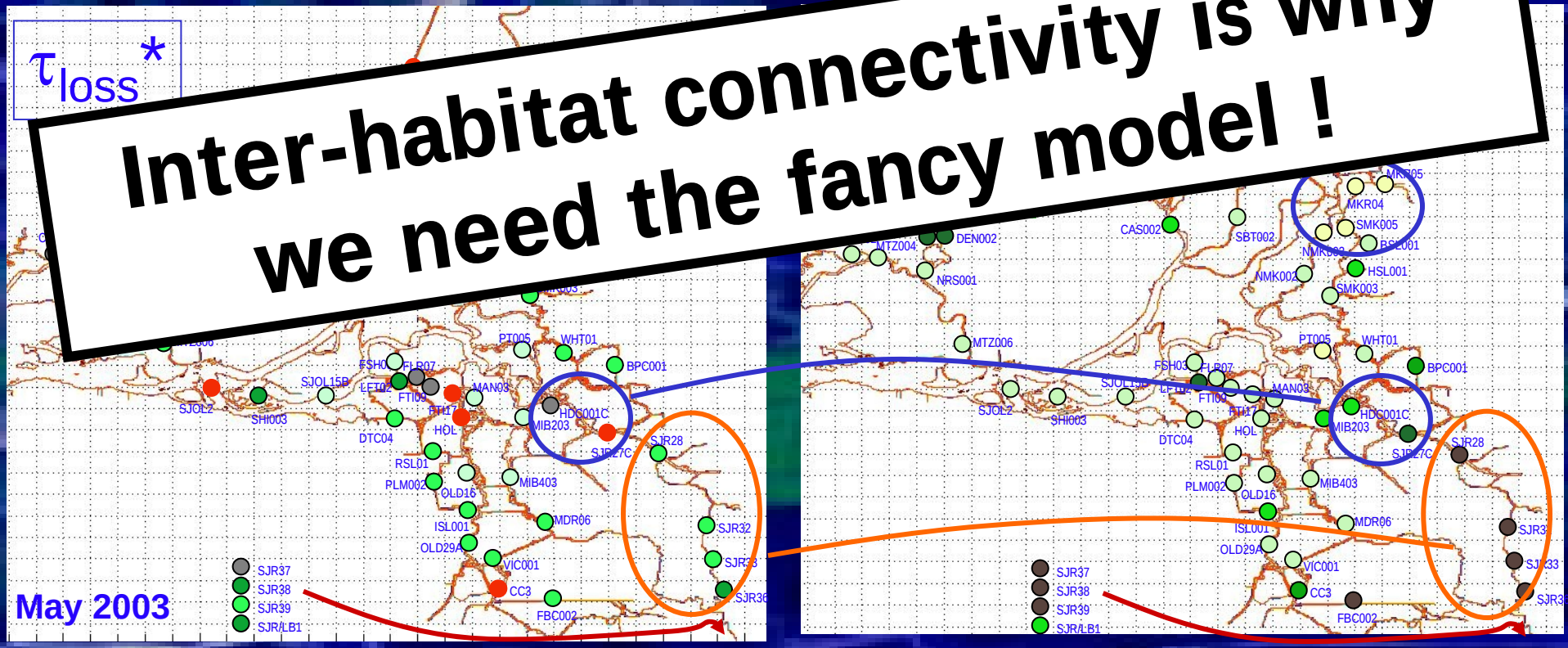
Inter-habitat connectivity is why we need the fancy model !



For future scenarios, combine patterns of Delta-wide…

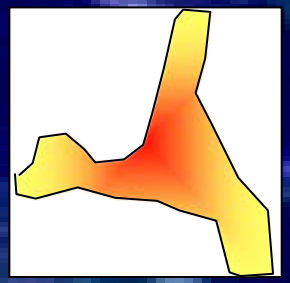
Water temperature

+

Salinity

+

Insolation



+

Turbidity

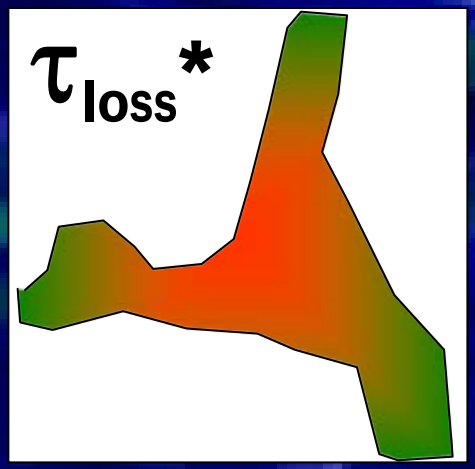
+

Water depth

+…

to get

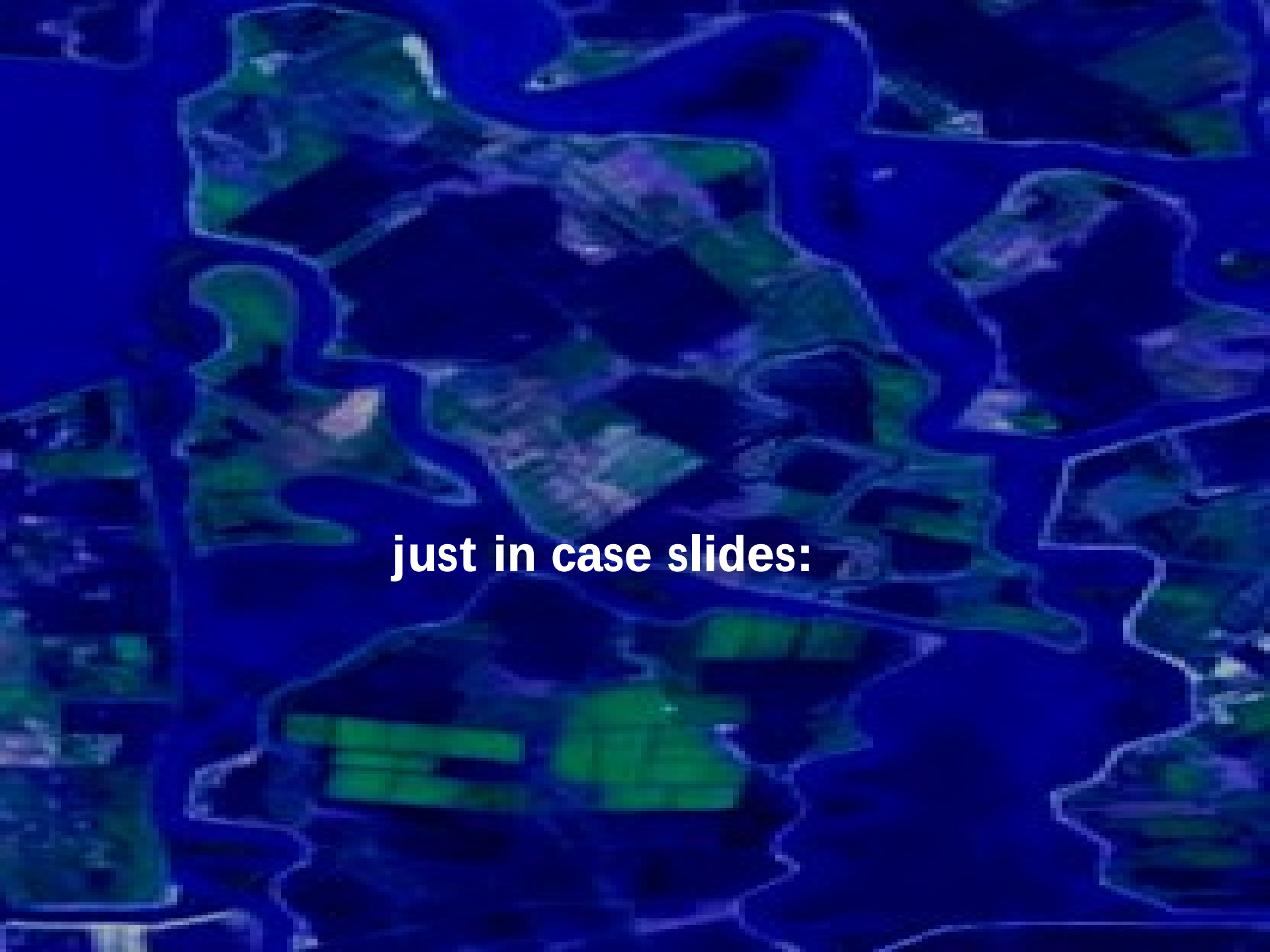
(map of projected "phytoplankton-enhancing" and "phytoplankton-depleting" habitats)



(also, the sign of P-T relationship)

Future work (rest of CASCaDE)

- refine and apply "fancy" dynamic model of coupled hydrodynamics+biology to assess phytoplankton responses to scenarios of change
- in parallel, assess the power of simple indices (e.g. τ_{loss}*) to project how ecosystem might respond to climate+anthropogenic change



just in case slides:

A simple model of steady-state algal growth, loss & transport

phyto. growth rate

phyto. loss rate (e.g. grazing)

downstream phyto. biomass

$$B_{out} = B_{in} \exp\left(\frac{\mu_{growth} - \mu_{loss}}{u} x \right)$$

upstream phyto. biomass

velocity

domain length

Lucas, Thompson, Brown L&O In review

Express model in terms of time scales:

$$B_{out} = B_{in} \exp\left(\frac{\mu_{growth} - \mu_{loss}}{u} x \right)$$

$$B_{out} = B_{in} \exp\left(\frac{\tau_{tran}}{\tau_{growth}} - \frac{\tau_{tran}}{\tau_{loss}} \right)$$

τ_{tran} = timescale for transport

τ_{growth} = timescale for growth

τ_{loss} = timescale for losses

$$B^*_{out} = \frac{B_{out}}{B_{in}} = \exp\left(\left[1 - \frac{1}{\tau^*_{loss}} \right] \tau^*_{tran} \right)$$

Define time scale ratios:

$$\tau^*_{loss} = \frac{\tau_{loss}}{\tau_{growth}}$$

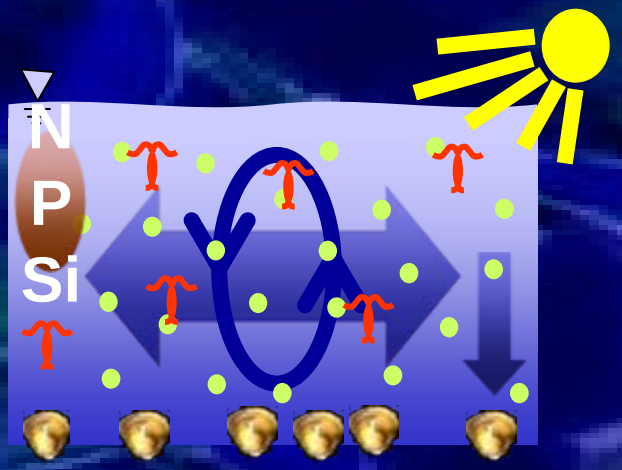
$$\tau^*_{tran} = \frac{\tau_{tran}}{\tau_{growth}}$$

Express model in terms of time scale ratios:

$$B_{out} = B_{in} \exp\left(\frac{\tau_{tran}}{\tau_{growth}} - \frac{\tau_{tran}}{\tau_{loss}} \right)$$

$$B^*_{out} = \frac{B_{out}}{B_{in}} = \exp\left(\left[1 - \frac{1}{\tau^*_{loss}} \right] \tau^*_{tran} \right)$$

How can models help?



- Integrate all the processes
- Examine responses to simultaneous and interacting processes
- Highlight critical processes & sensitivities
- Check our intuition
- Control processes/examine scenarios

A simple INDEX of whether phytoplankton biomass will increase or decrease with transport time

$$\tau^*_{loss} = \frac{\tau_{loss}}{\tau_{growth}}$$

τ_{growth} = timescale for growth

τ_{loss} = timescale for losses

1. $\tau^*_{loss} > 1$ **growth dominates losses, phyto ↑ as transport time ↑**

2. $\tau^*_{loss} < 1$ **losses dominate growth, phyto ↓ as transport time ↑**

3. $\tau^*_{loss} = 1$ **growth balances losses, phyto insensitive to trans. time**

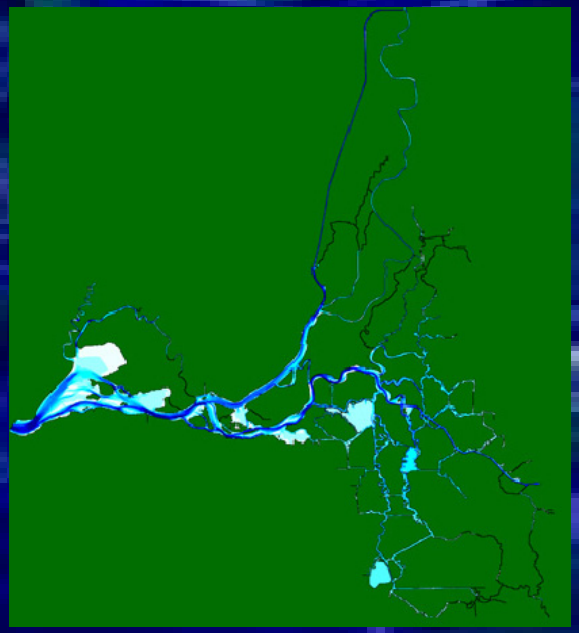
Lucas, Thompson, Brown L&O In Press

Indices offer an intermediate, semi-quantitative approach to assessing possible responses to future scenarios of change

Guessing/
Intuition

INDICES

Dynamic,
multi-dimensional
models



Continuum of approaches

Phytoplankton response to transport time is determined by biologic sources+losses

CASE * * <1

Clear (fast growth) + low grazing

If we know about the local sources and losses, then we also know whether phytoplankton biomass will increase or decrease with changing transport time !

Transport time ↑ Phyto ↑

Transport time ↑ Phyto ↓

τ_{loss}* --- what is it good for?

Advantages

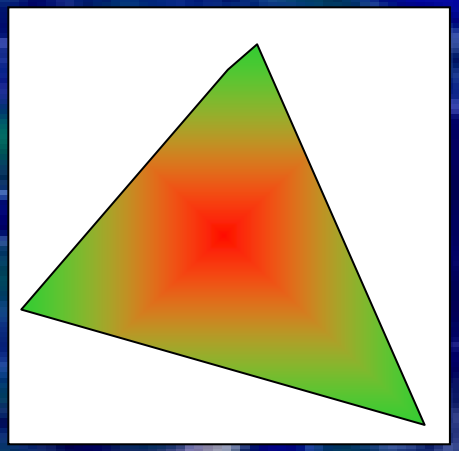
- simple, useful shortcut
- guide/check intuition
- free of computational constraints *(can do way more scenarios than computationally intensive model)*
- commonsense check for complex models

Disadvantages

- purely local processes
- does not account for hydrodynamically driven interactions between habitats (import, export, tidal sloshing, dispersion)

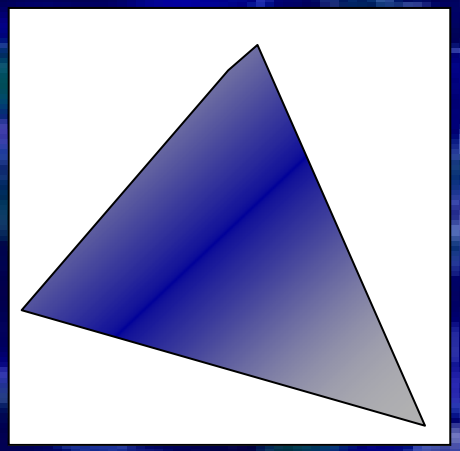
WHY WE NEED THE FANCY MODELS !!

τ_{loss}*



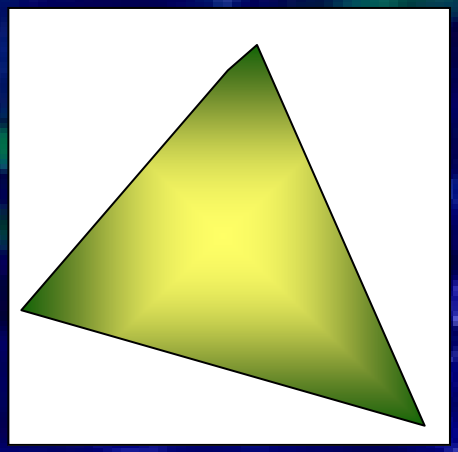
+

Change in transport time



(relative to baseline case)

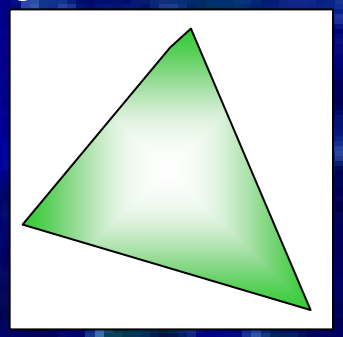
Change in local tendency for phytoplankton accumulation or depletion



Conclusions

- Detailed numerical models allow us to quantitatively describe multiple interacting processes in a dynamic, spatially variable system
- Indices provide a semi-quantitative short-cut approach for assessing ecosystem responses to change
- Phytoplankton biomass can go up or down with increased transport time, depending on the growth-loss balance
- A simple index (τ_{loss}*) tells us the sign of change for phytoplankton biomass as transport time changes

Phyto.
growth rate



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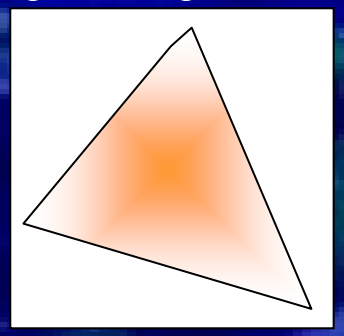
Benthic
grazing rate



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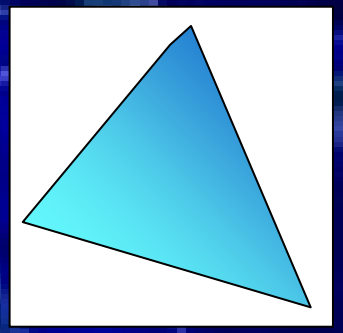
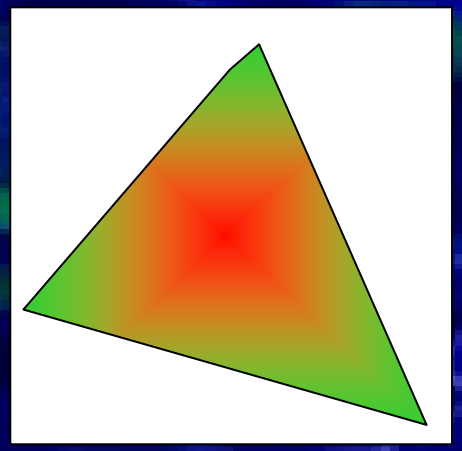
Water depth



τ_{loss}*



(map of projected "phytoplankton-enhancing" and "phytoplankton-depleting" habitats)

(also, the sign of P-T relationship)