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What caused the diatom decline in Suisun Bay after 1986?

Lisa V. Lucas

Jeffrey R. Koseff

Mark T. Stacey

James E. Cloern

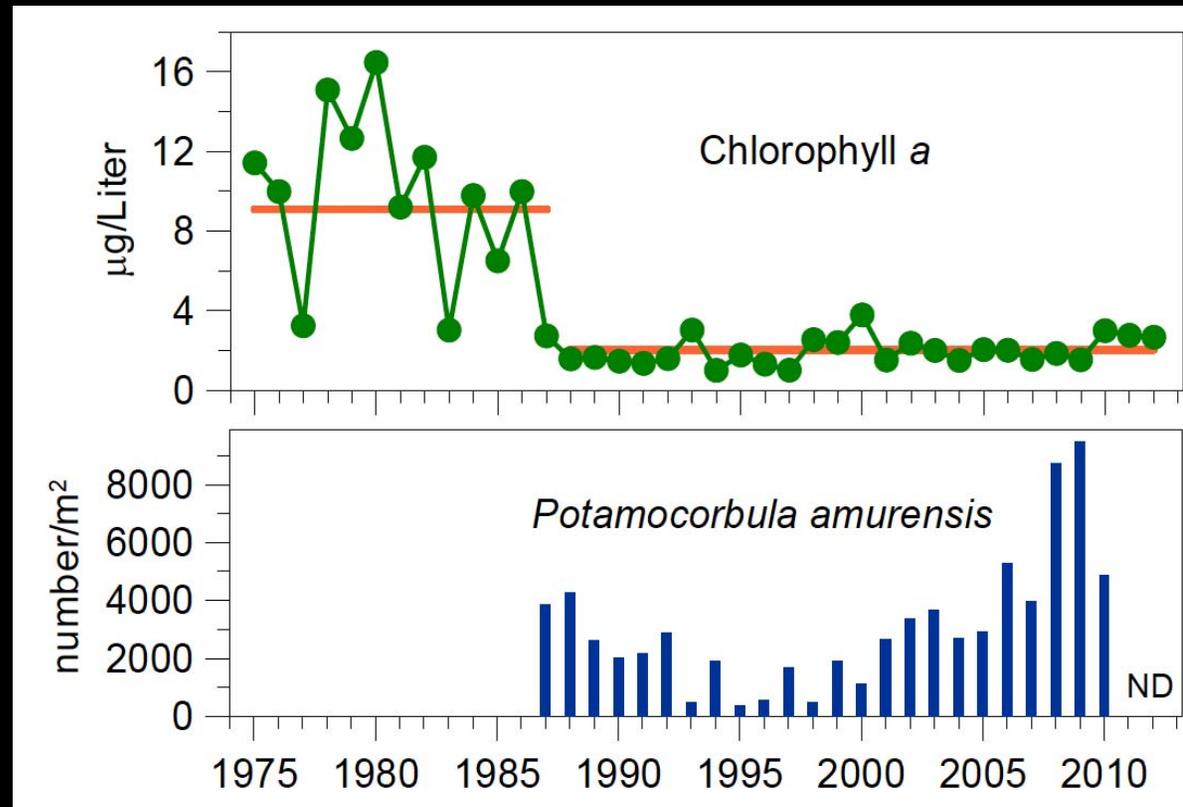
Stephen G.

Janet K. Thompson

Monismith



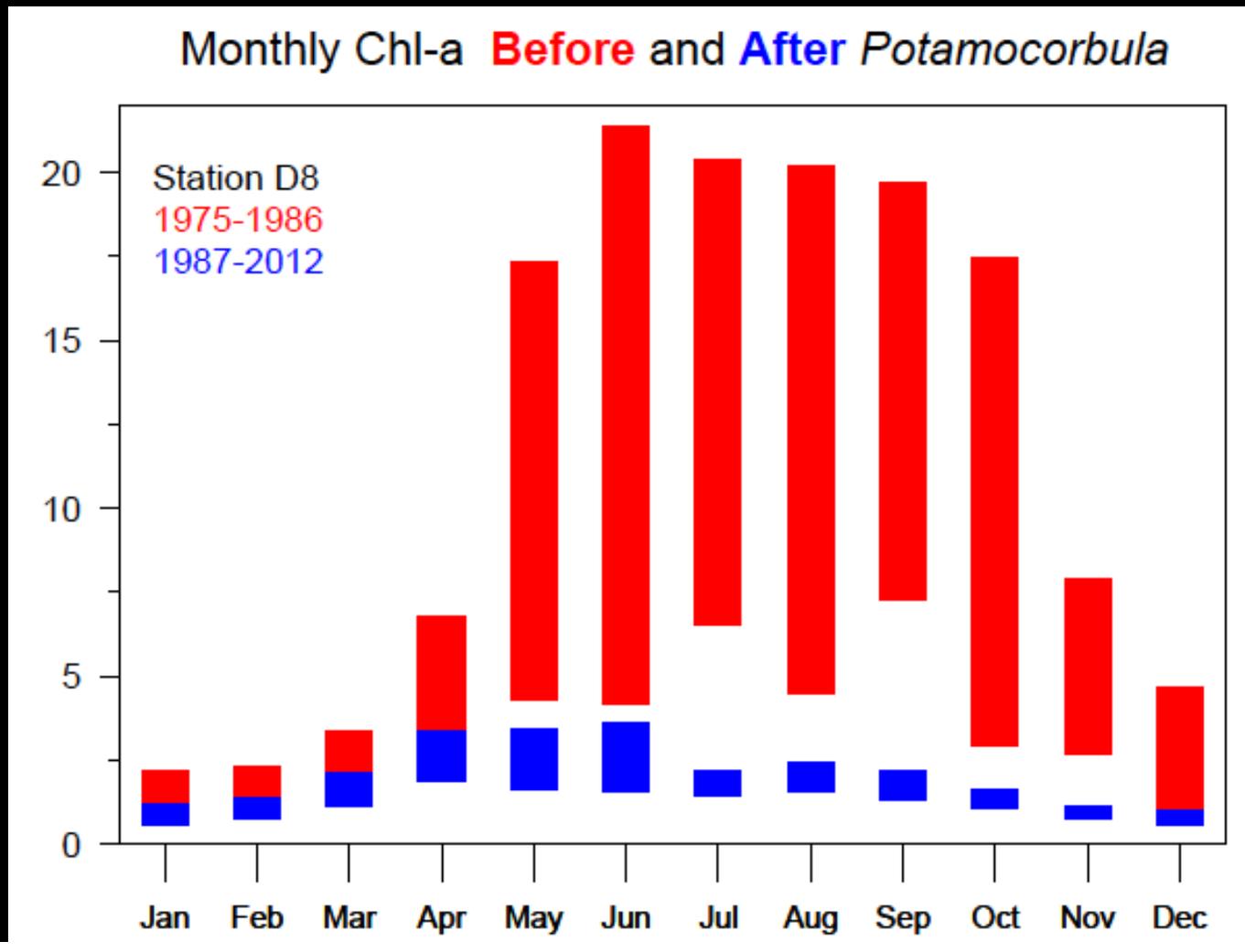
We know: 5-fold chlorophyll decline, synchronous with clam



PRELIMINARY

Data: IEP-EMP. Plot: Cloern et al. 2015, IEP Newsletter

We know: Most of Chl decrease was loss of Summer bloom

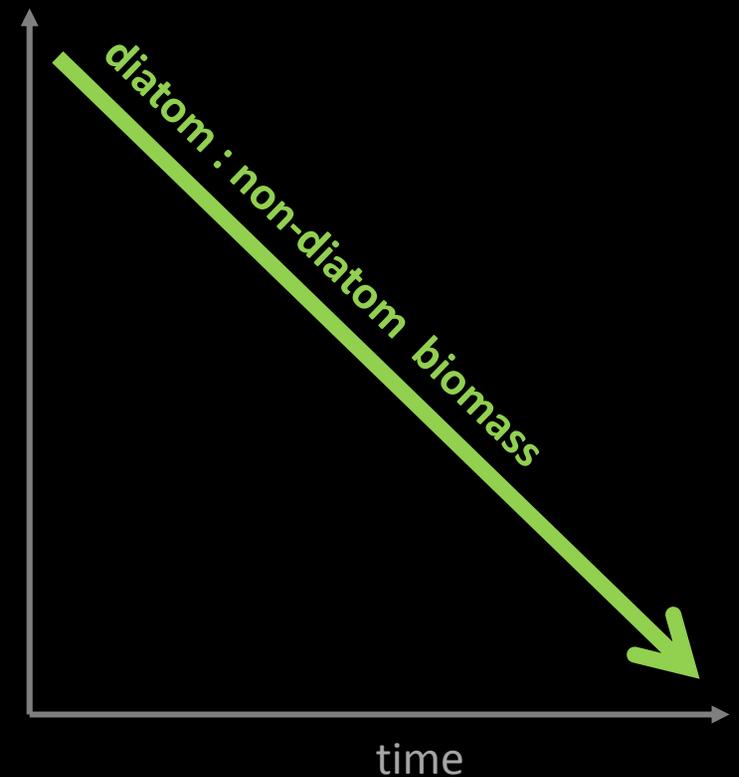


PRELIMINARY

Data: IEP-EMP. Plot: Cloern & Jassby 2012

Existing Hypotheses

(1) Shift from **diatoms**
to **non-diatoms**
(*uncertain*)

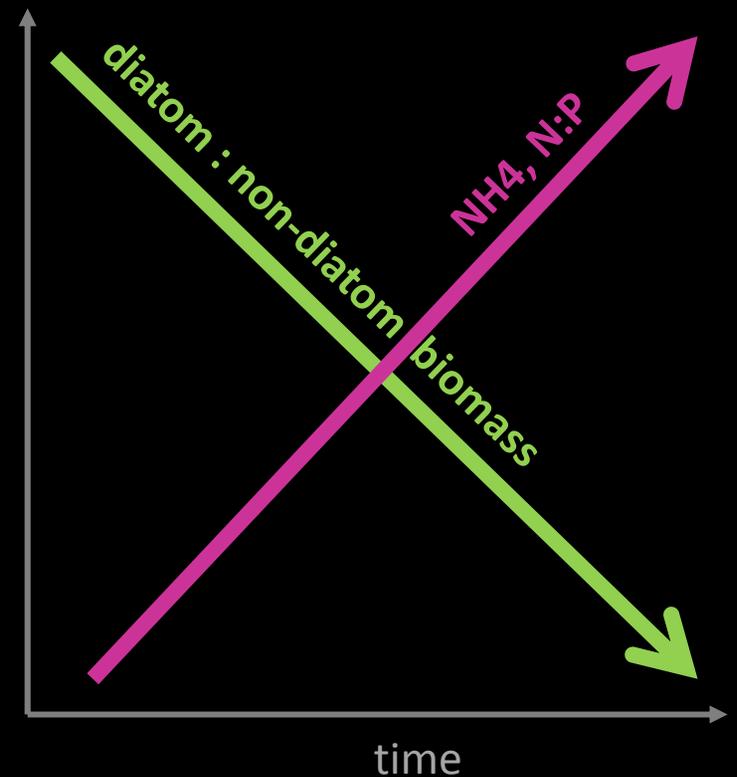


PRELIMINARY

Existing Hypotheses

(1) Shift from **diatoms** to **non-diatoms**
(uncertain)

(2) Shift explained by **nutrient** forms and ratios



PRELIMINARY

Assuming the shift from diatoms to non-diatoms has occurred...

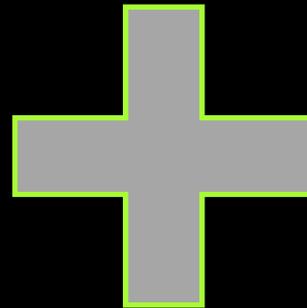
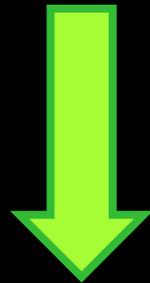
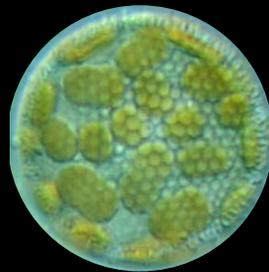
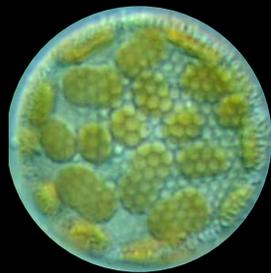


Are there any other possible explanations for the shift?

PRELIMINARY

New Hypothesis:

After *Potamocorbula* invaded, the combination of **sinking and grazing** by clams selectively removed diatoms.



Thalassiosira eccentrica:

<http://pinkava.asu.edu/starcentral/microscope>

Image copyright: Bob Andersen and D. J. Patterson, Provasoli-Guillard National Center for Culture of Marine Phytoplankton

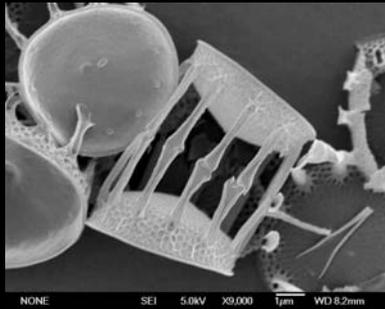
PRELIMINARY

Potamocorbula amurensis: USGS

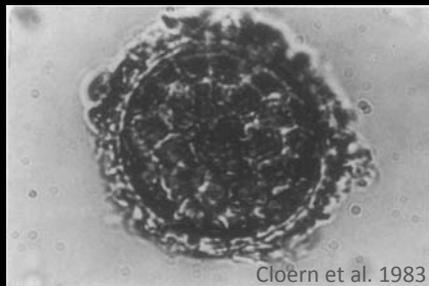
Diatoms sink

(up to 100 m/d)

silica shells



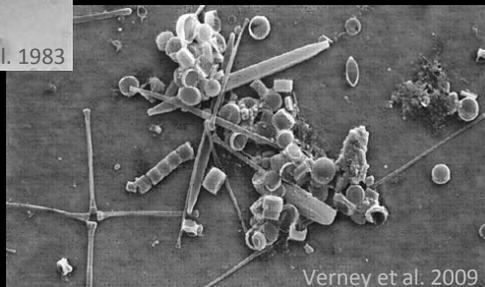
sticky secretions



*sticking to
mineral
particles*

Cloern et al. 1983

"flocs"



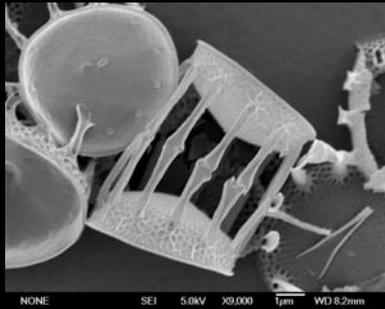
Verney et al. 2009

PRELIMINARY

Diatoms sink

(up to 100 m/d)

silica shells

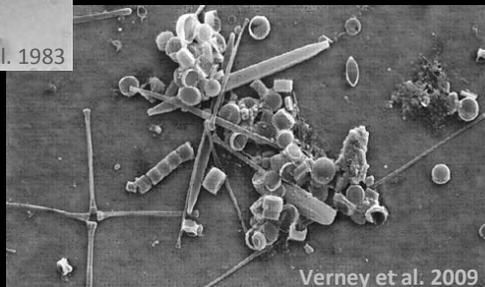


sticky secretions



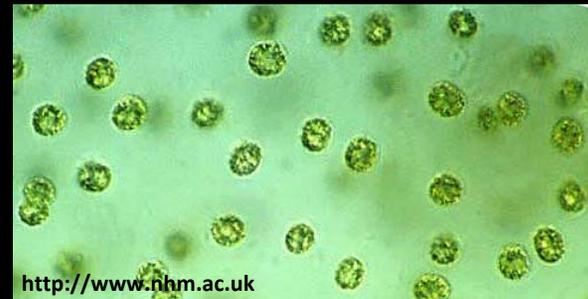
sticking to mineral particles

"flocs"



Non-diatoms can float or swim

Microcystis (floater)

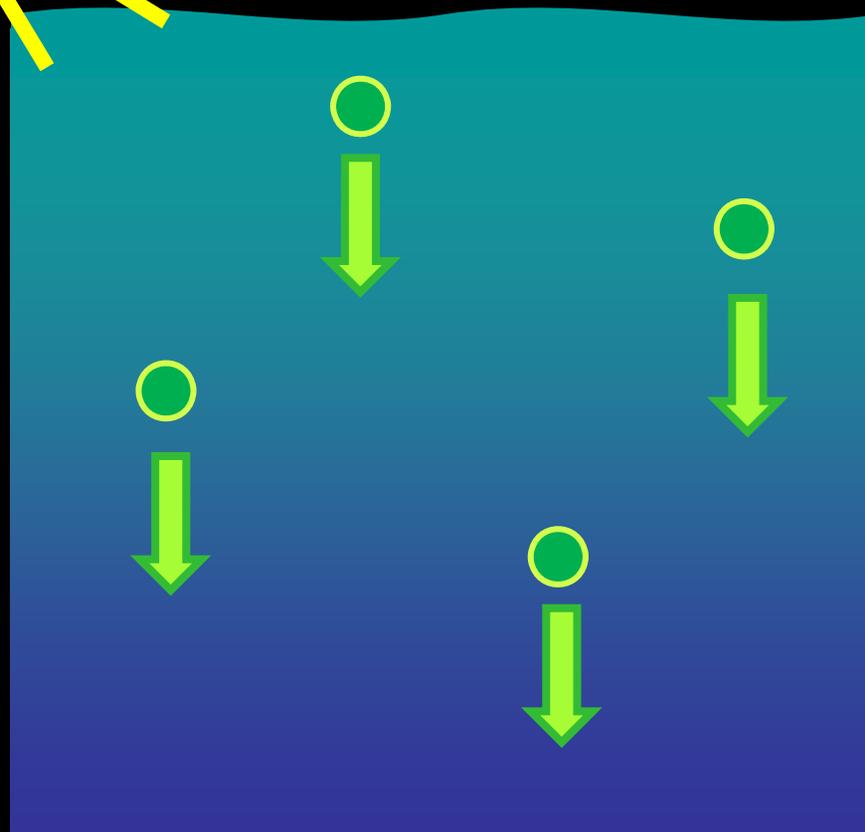
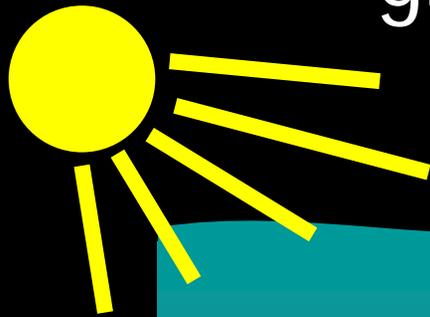


Dinoflagellates (swimmer)



PRELIMINARY

Sinking controls light exposure and growth rate

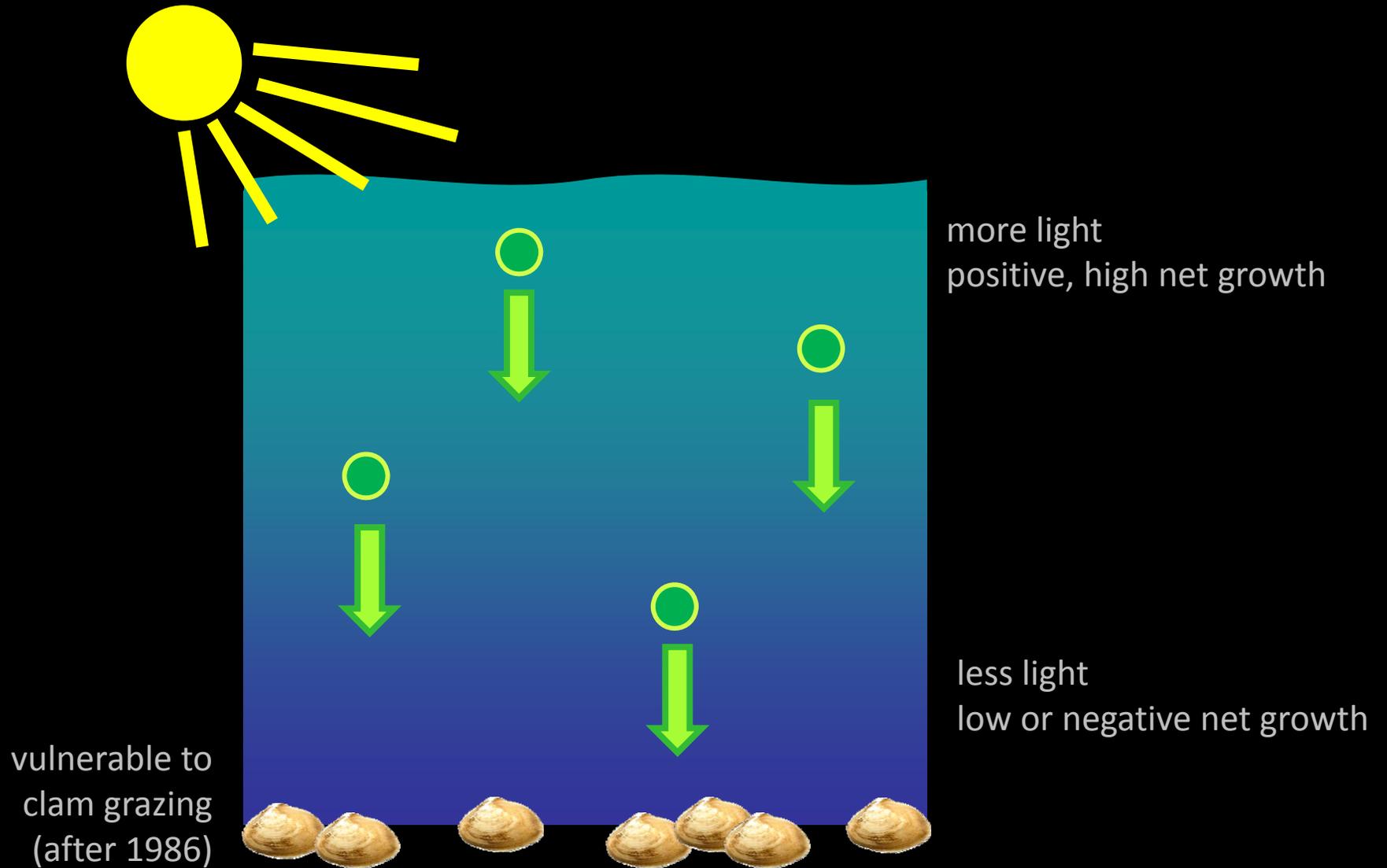


more light
positive, high net growth

less light
low or negative net growth

PRELIMINARY

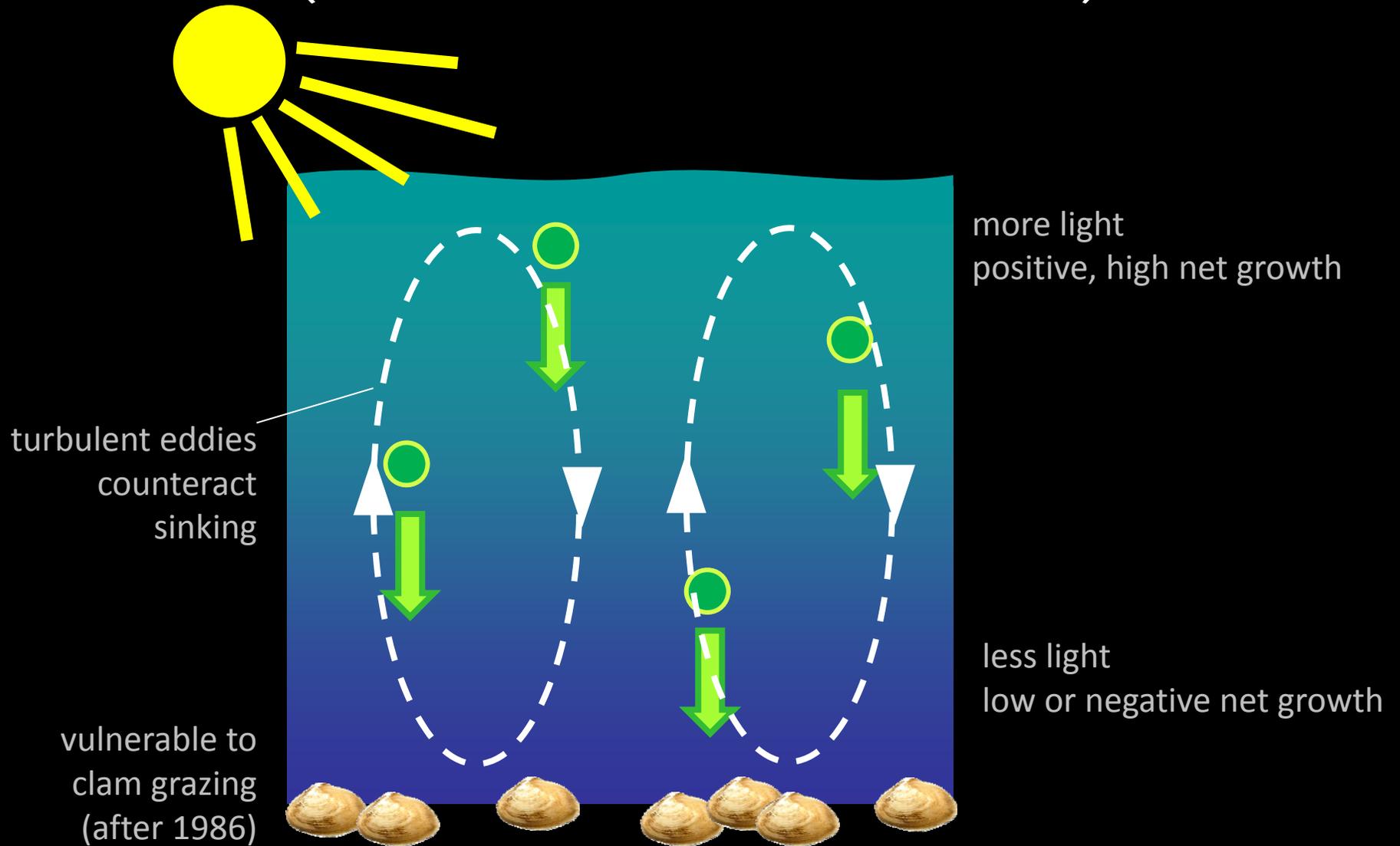
Sinking accelerates delivery to clams



PRELIMINARY

Clam image: www.manandmollusc.net

Turbulence can suspend sinkers (stratification kills turbulence*)



PRELIMINARY

*Prof. C. Rehmann

Clam image: www.manandmollusc.net

A model to test the new hypothesis

channel

shoal

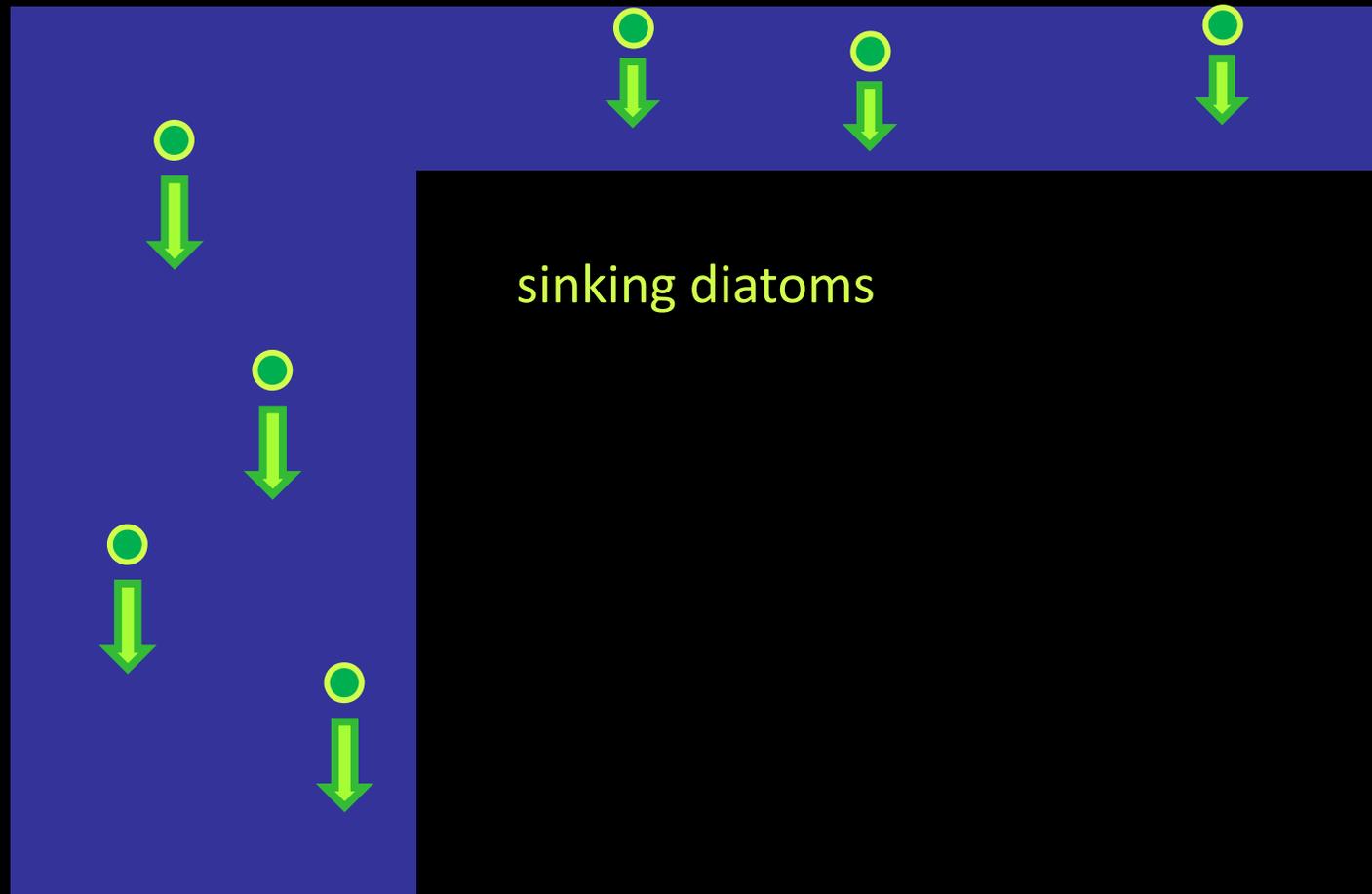


PRELIMINARY

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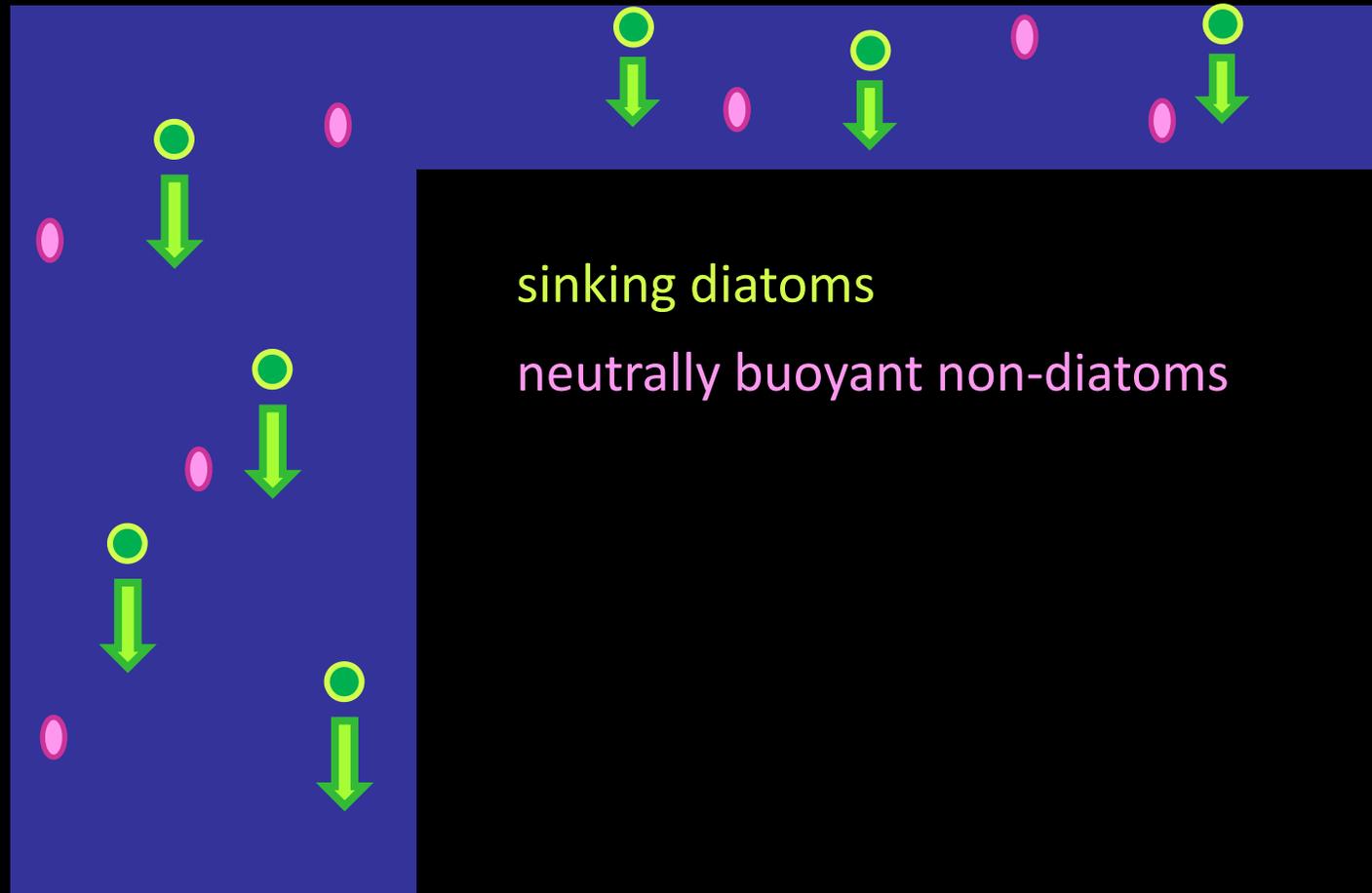


PRELIMINARY

A model to test the new hypothesis

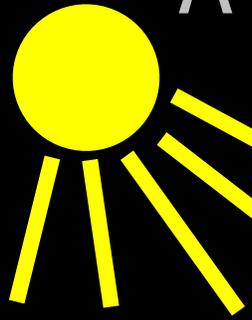
channel

shoal



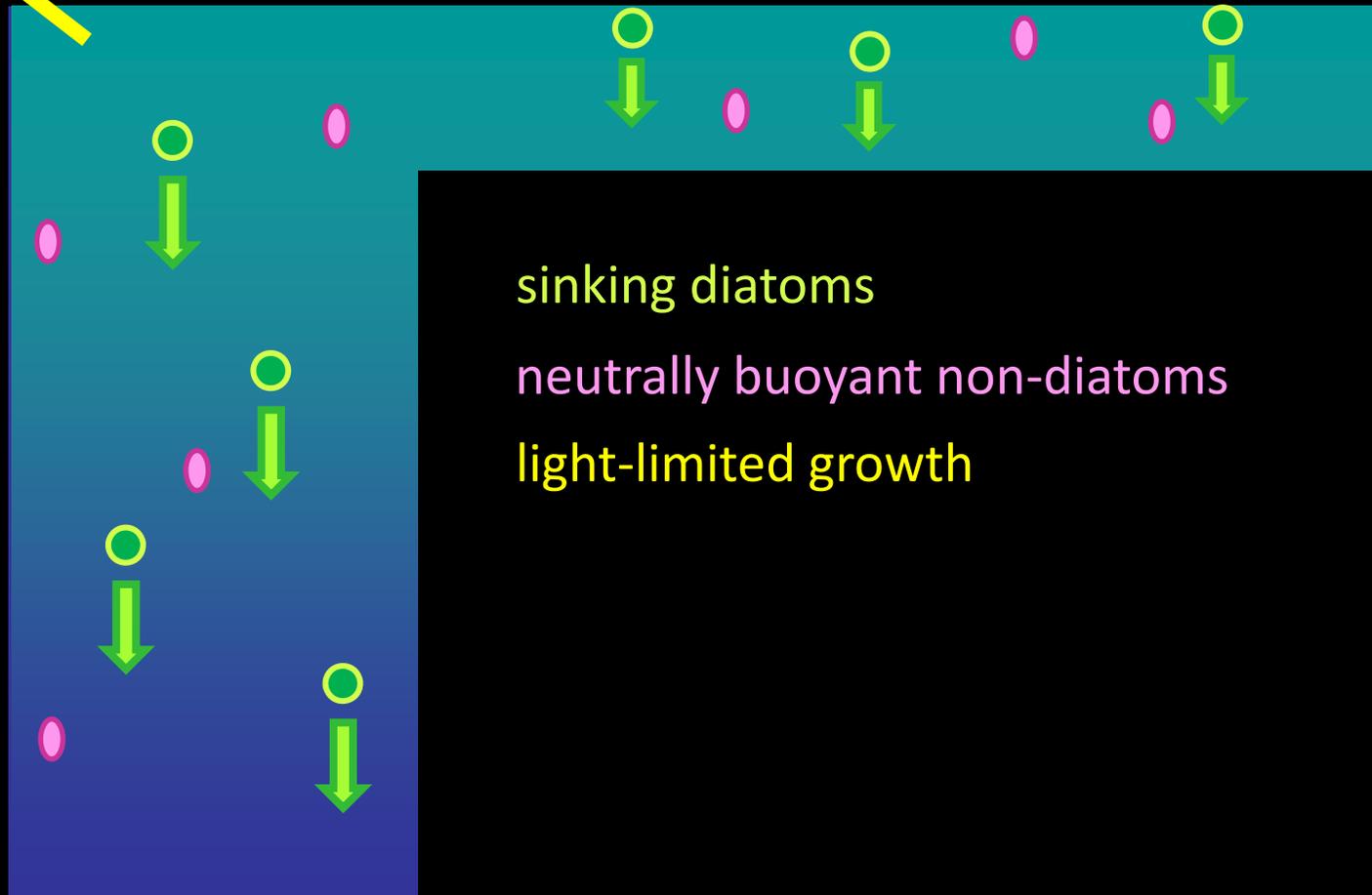
PRELIMINARY

A model to test the new hypothesis



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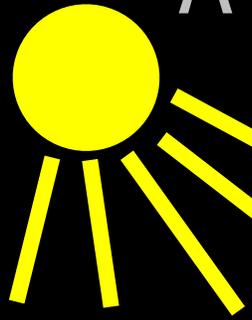
sinking diatoms

neutrally buoyant non-diatoms

light-limited growth

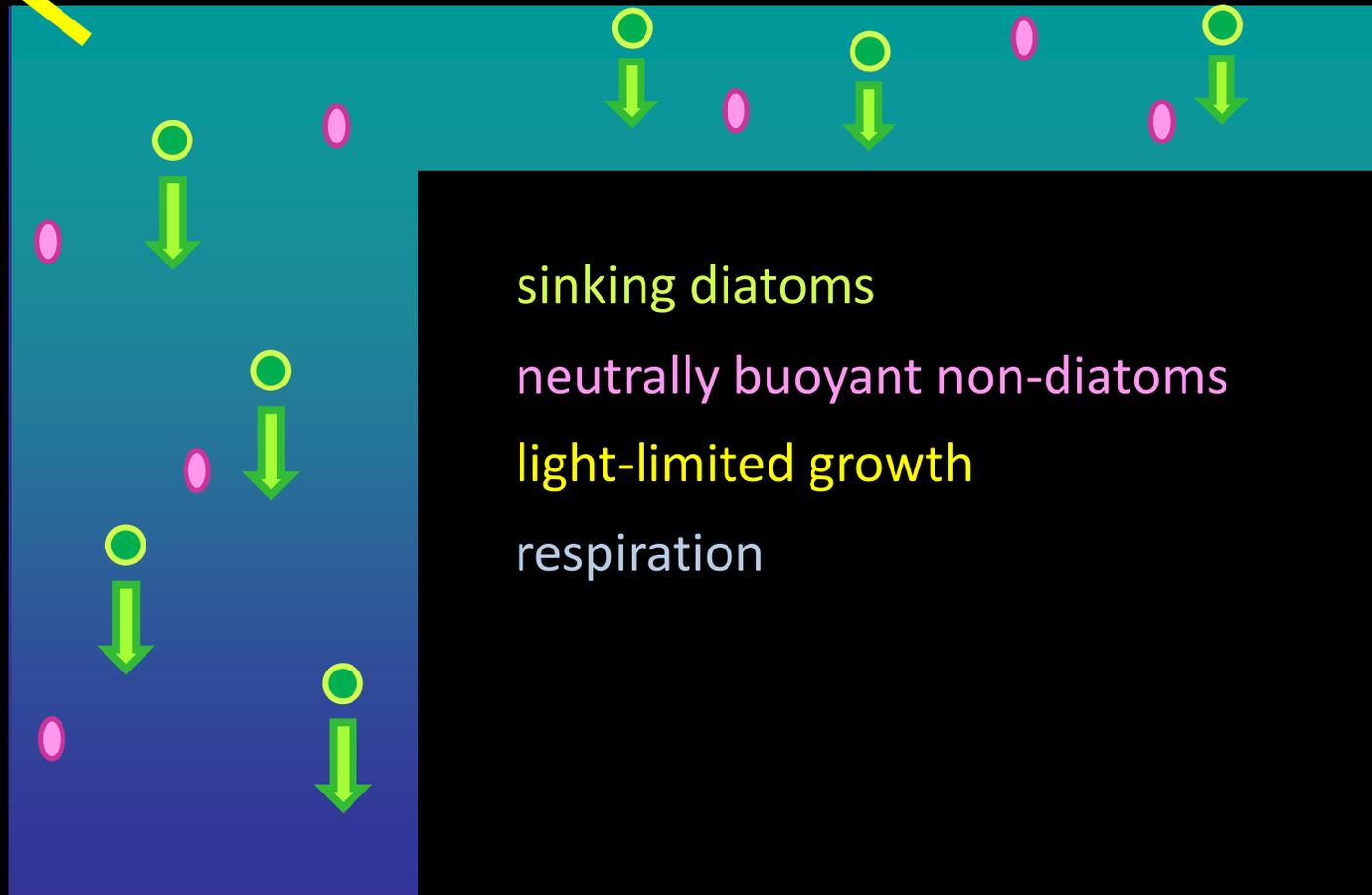
PRELIMINARY

A model to test the new hypothesis



channel

shoal



sinking diatoms

neutrally buoyant non-diatoms

light-limited growth

respiration

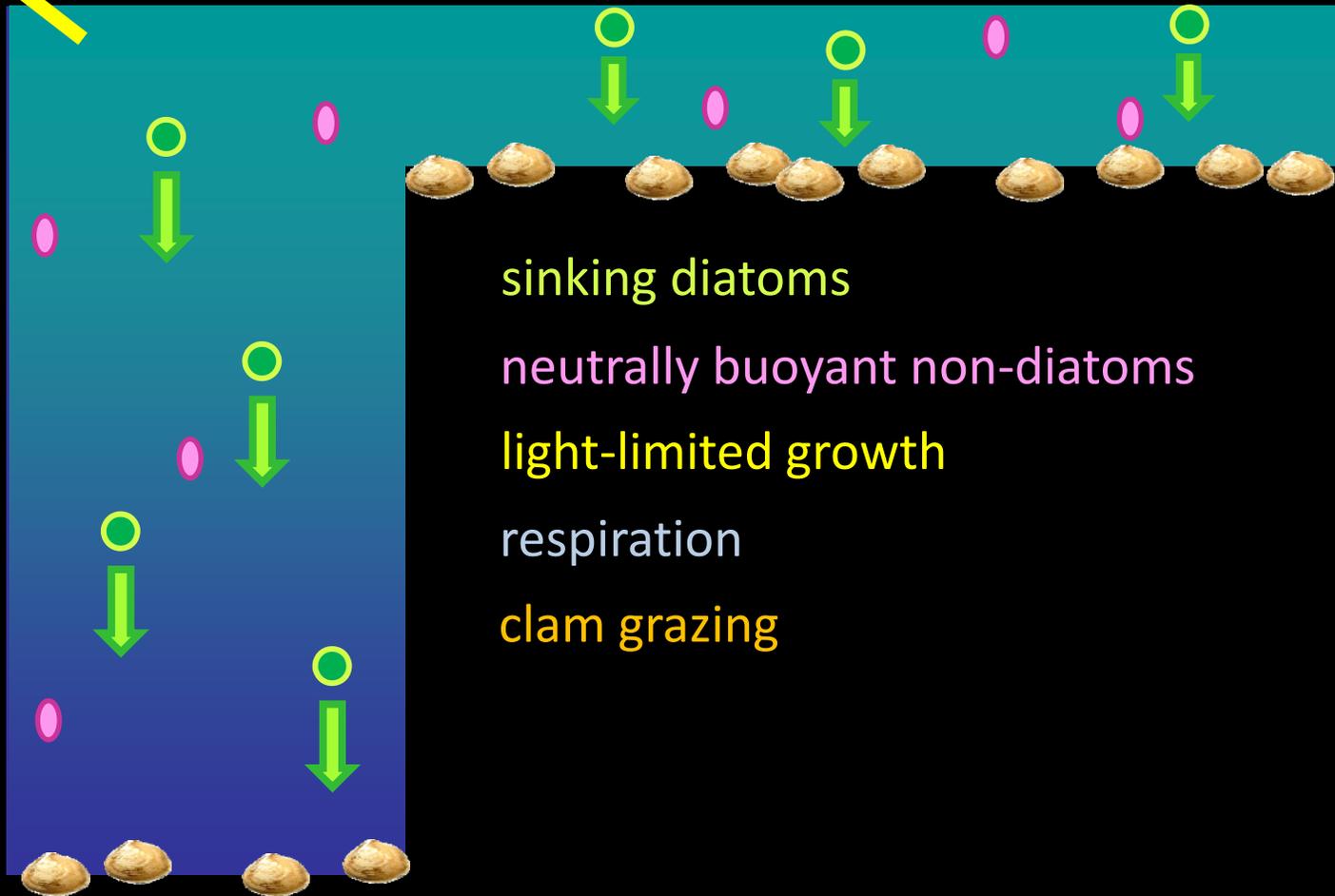
PRELIMINARY

A model to test the new hypothesis



channel

shoal



sinking diatoms

neutrally buoyant non-diatoms

light-limited growth

respiration

clam grazing

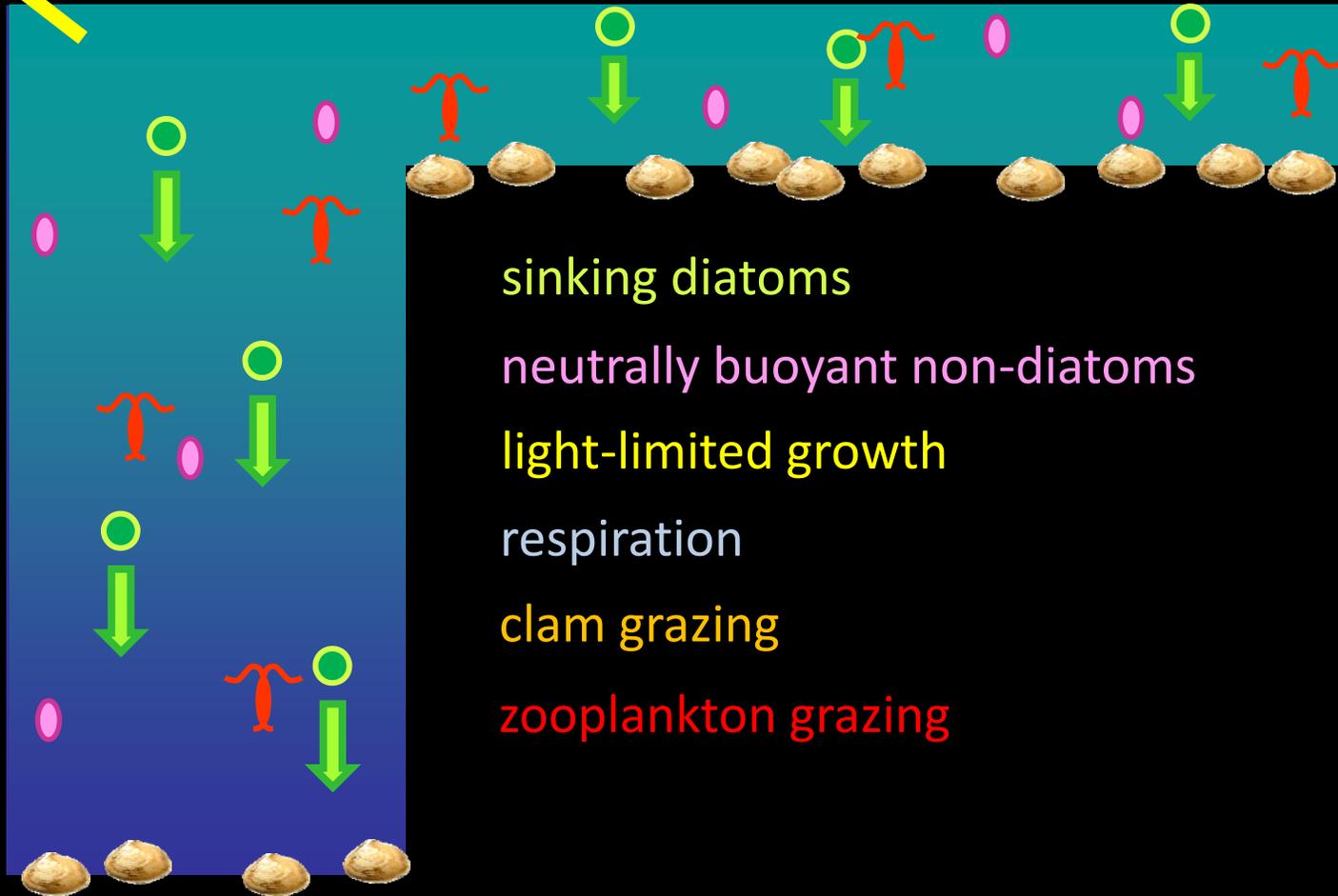
PRELIMINARY

A model to test the new hypothesis



channel

shoal



sinking diatoms

neutrally buoyant non-diatoms

light-limited growth

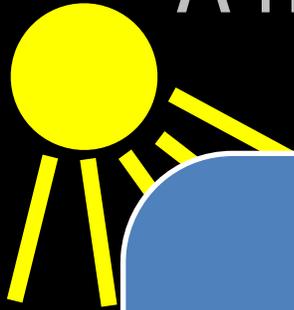
respiration

clam grazing

zooplankton grazing

PRELIMINARY

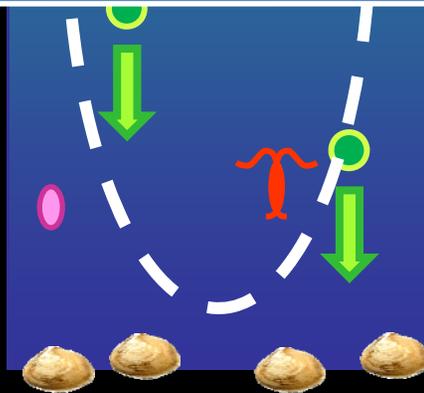
A model to test the new hypothesis



2 Cases

- 1 – tidally periodic stratification (~unstratified)
- 2 – persistent stratification during neap

Turbulence Model: Blumberg et al. 1992, Monismith et al. 1996



respiration

clam grazing

zooplankton grazing

vertical turbulent mixing/stratification

PRELIMINARY

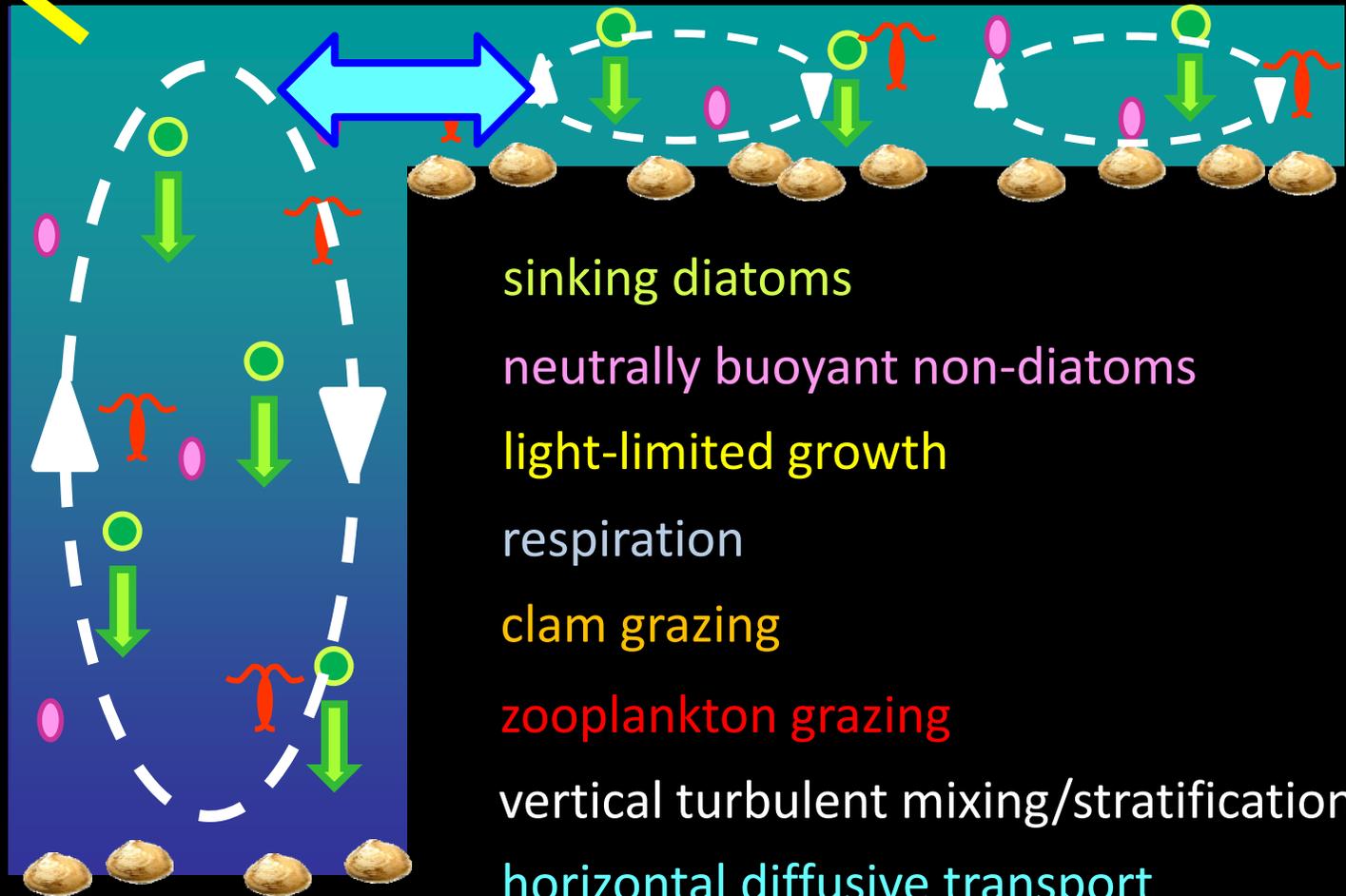
Clam image: www.manandmollusc.net

A model to test the new hypothesis



channel

shoal



sinking diatoms

neutrally buoyant non-diatoms

light-limited growth

respiration

clam grazing

zooplankton grazing

vertical turbulent mixing/stratification

horizontal diffusive transport

PRELIMINARY

A model to test the new hypothesis



channel

no

Parameters
representative of
summertime
Suisun Bay



atoms

ng

oplant on grazing

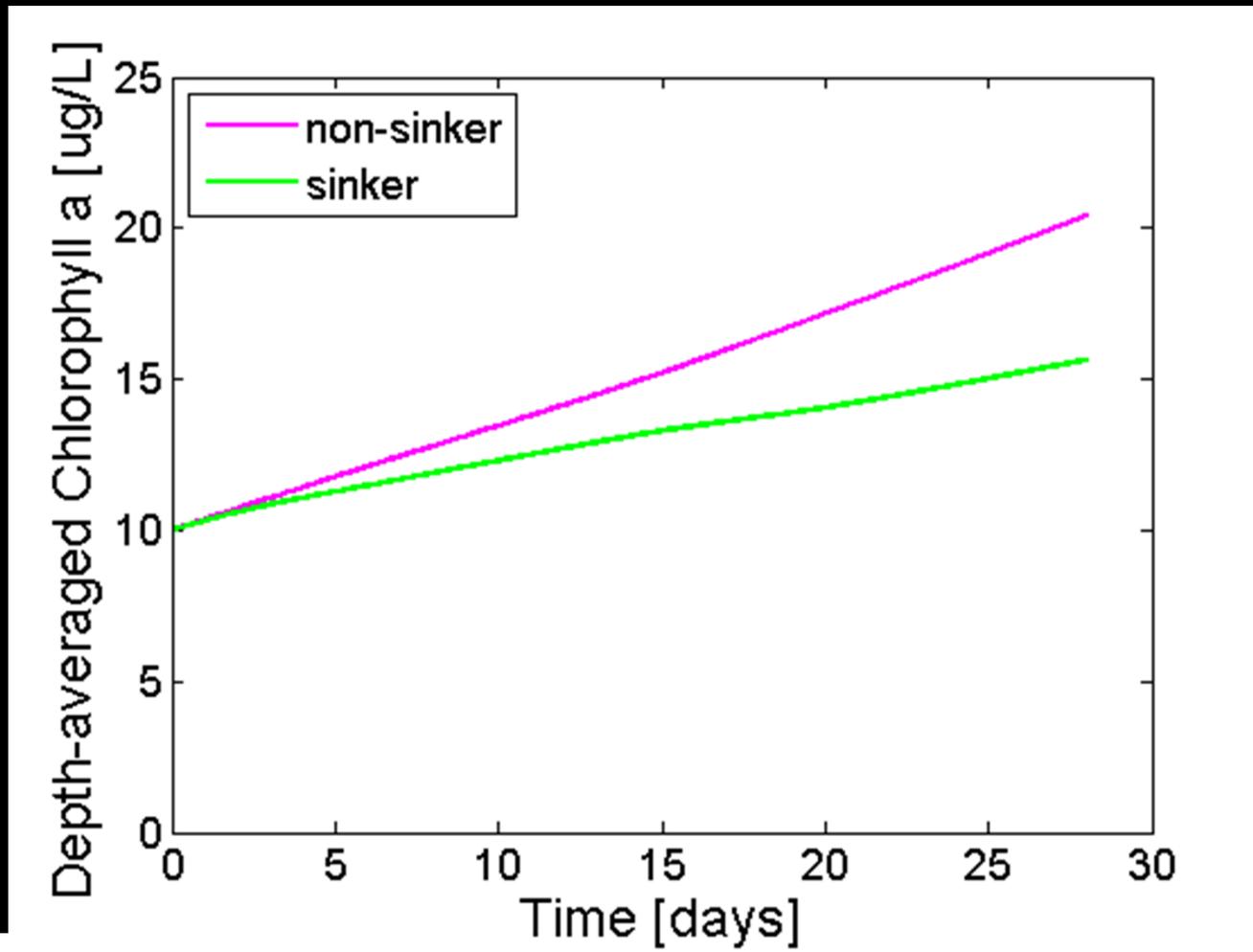
vertical turbulent mixing/stratification

horizontal diffusive transport

PRELIMINARY

Model results

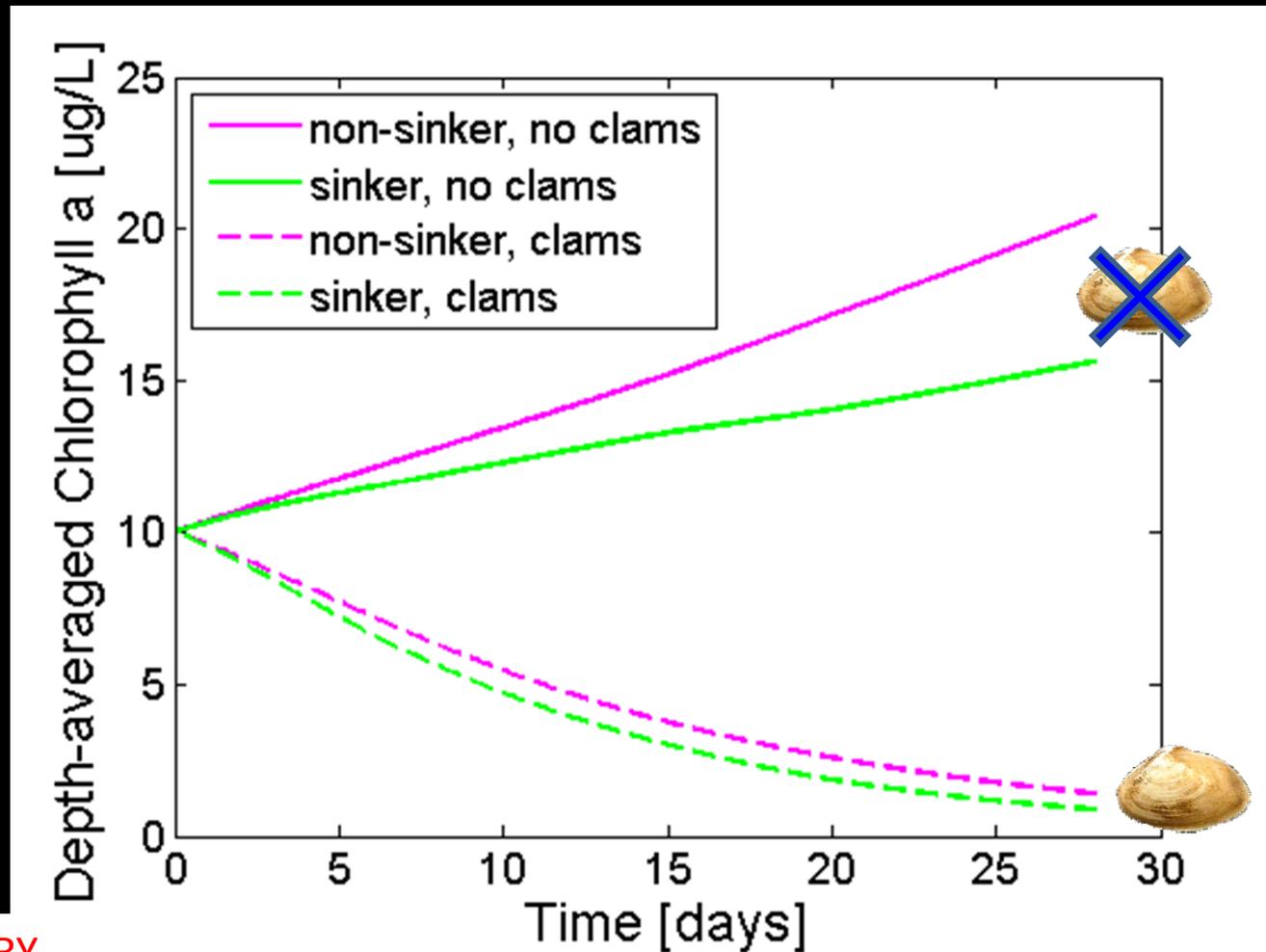
Even without clams, sinking hurts diatoms



PRELIMINARY

Channel • Zero benthic grazing • Tidally Periodic Stratification • Equal Max Growth

Clams can kill off everyone, but diatoms faster

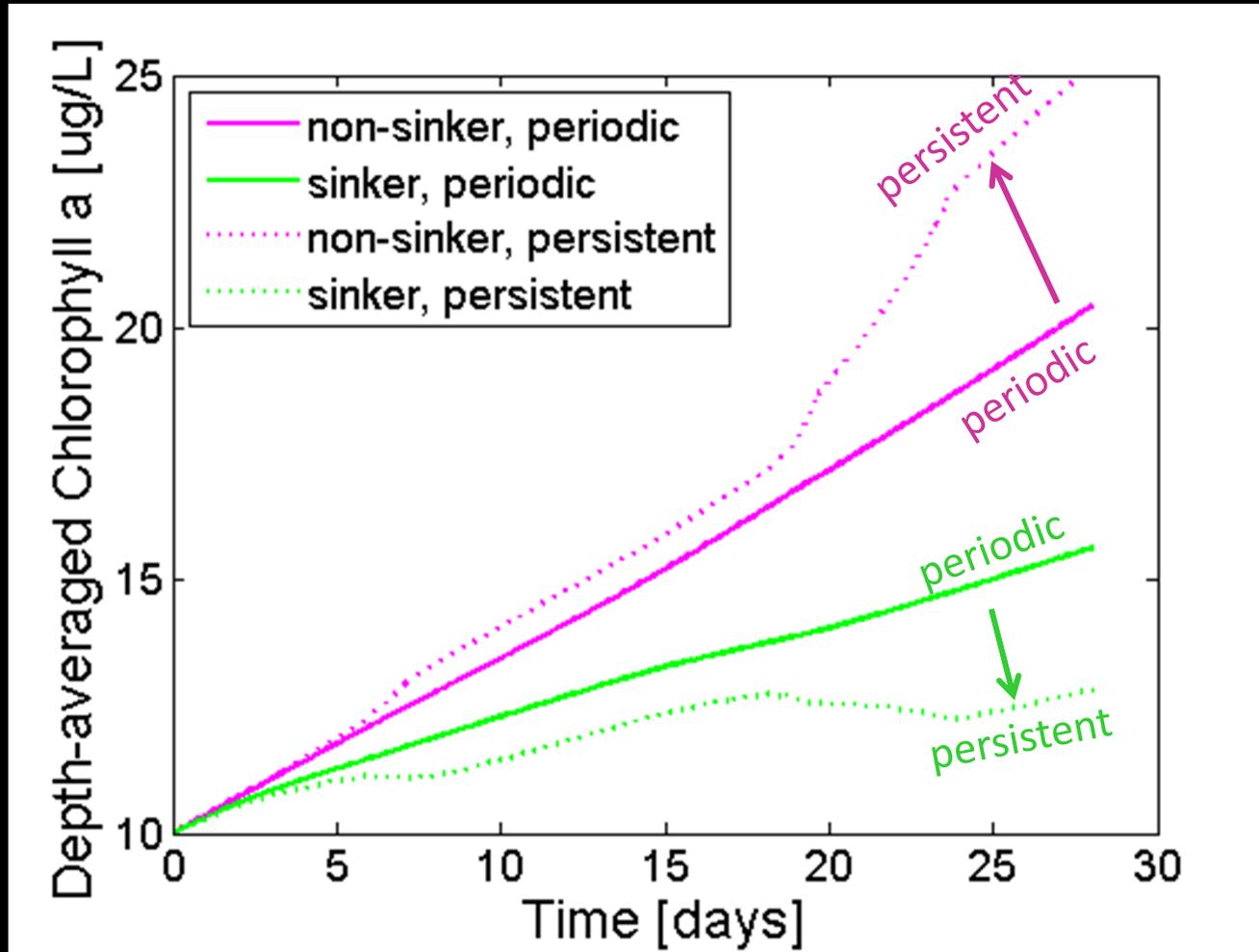


PRELIMINARY

Clam image: www.manandmollusc.net

Channel • Benthic grazing = 0, Q1 • Tidally Periodic Stratification • Equal Max Growth

Stratification hurts sinkers, helps non-sinkers



PRELIMINARY

Channel • Benthic grazing = 0 • Equal Max Growth

Parameters varied

Mixing/Stratification	Tidally Periodic, Persistent during Neap	
Sinking	0-6 m/d	Cloern et al. 1983, Arthur & Ball 1979
Benthic Grazing	0, Q1, Q2, Q3	1988-2007 Suisun Channel & Shoal (Data: USGS & DWR. Analysis: J. Thompson)
Diatom max growth rate, μ_{\max}	1, 1.5 x non-diatom μ_{\max}	Chai et al. 2002

PRELIMINARY

Parameters varied

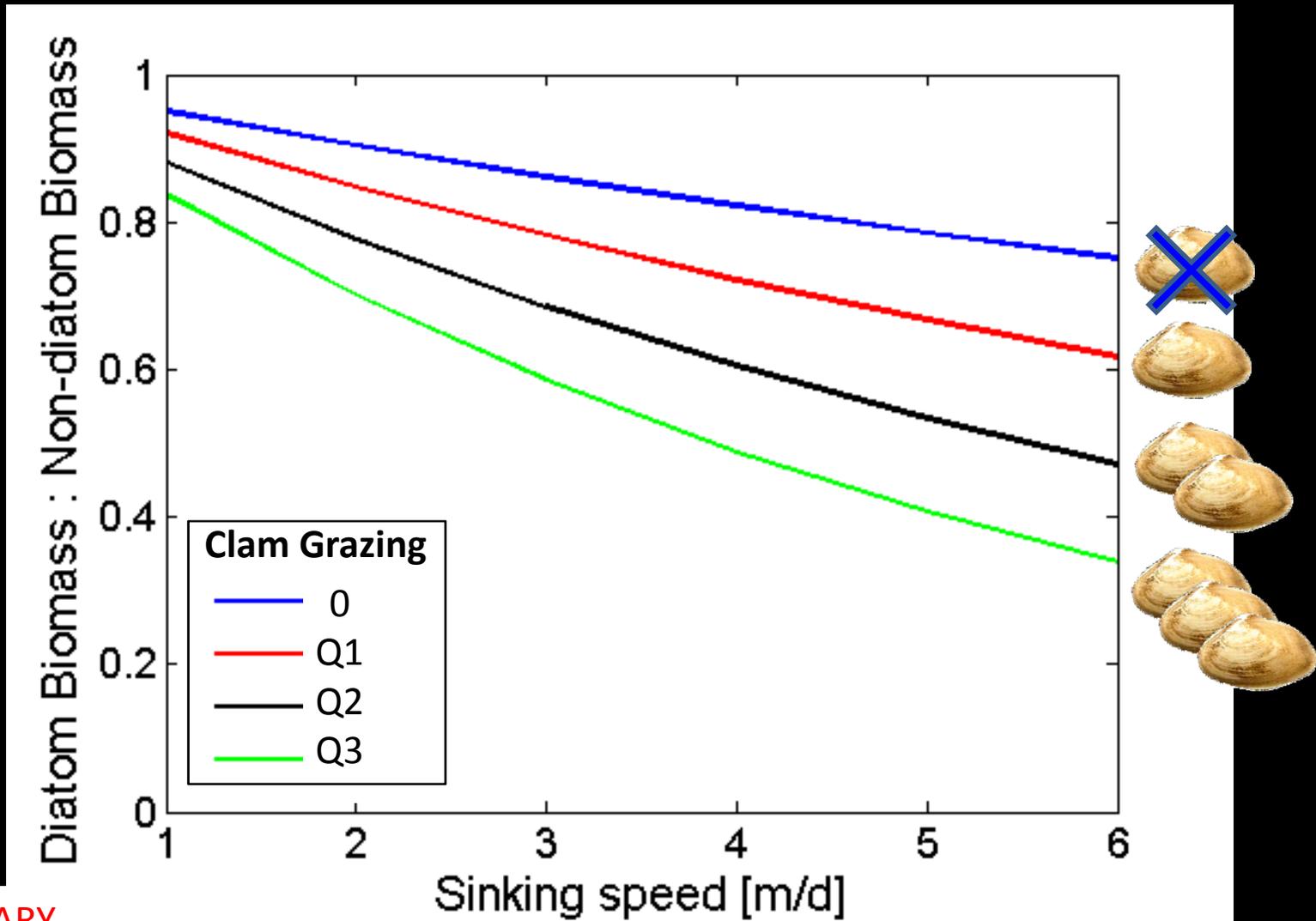
Mixing/Stratification	Tidally Periodic, Persistent during Neap	
Sinking		1983, 1979
Ber...		un l J.
Diatom rate, μ_{\max}	non-diatom μ_{\max}	2002

Index of selectivity:

diatom biomass

non-diatom biomass

Sinking & grazing intensify selective loss of diatoms

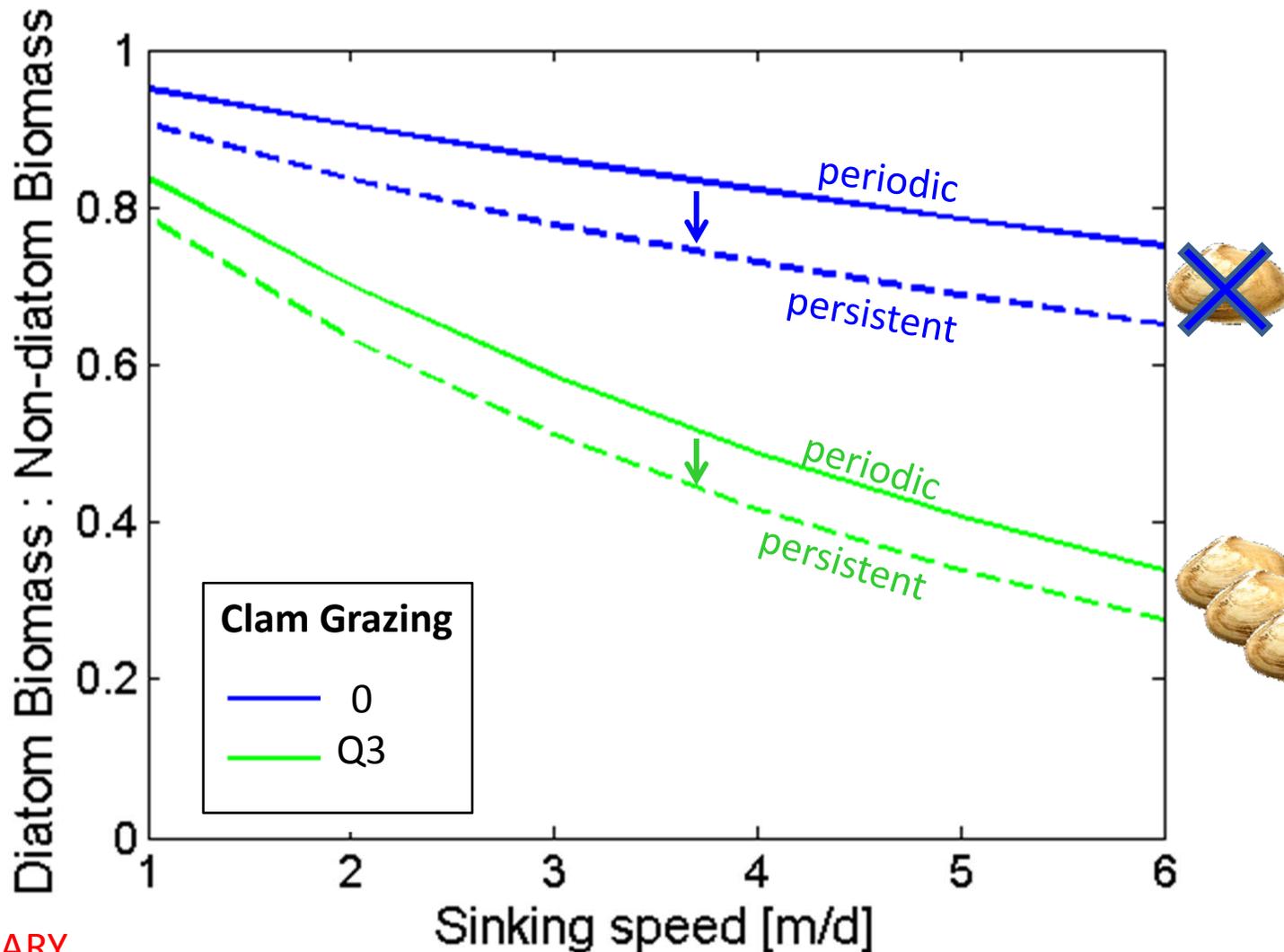


PRELIMINARY

Clam image: www.manandmollusc.net

Whole system • Tidally periodic stratification • μ_{max} 's equal

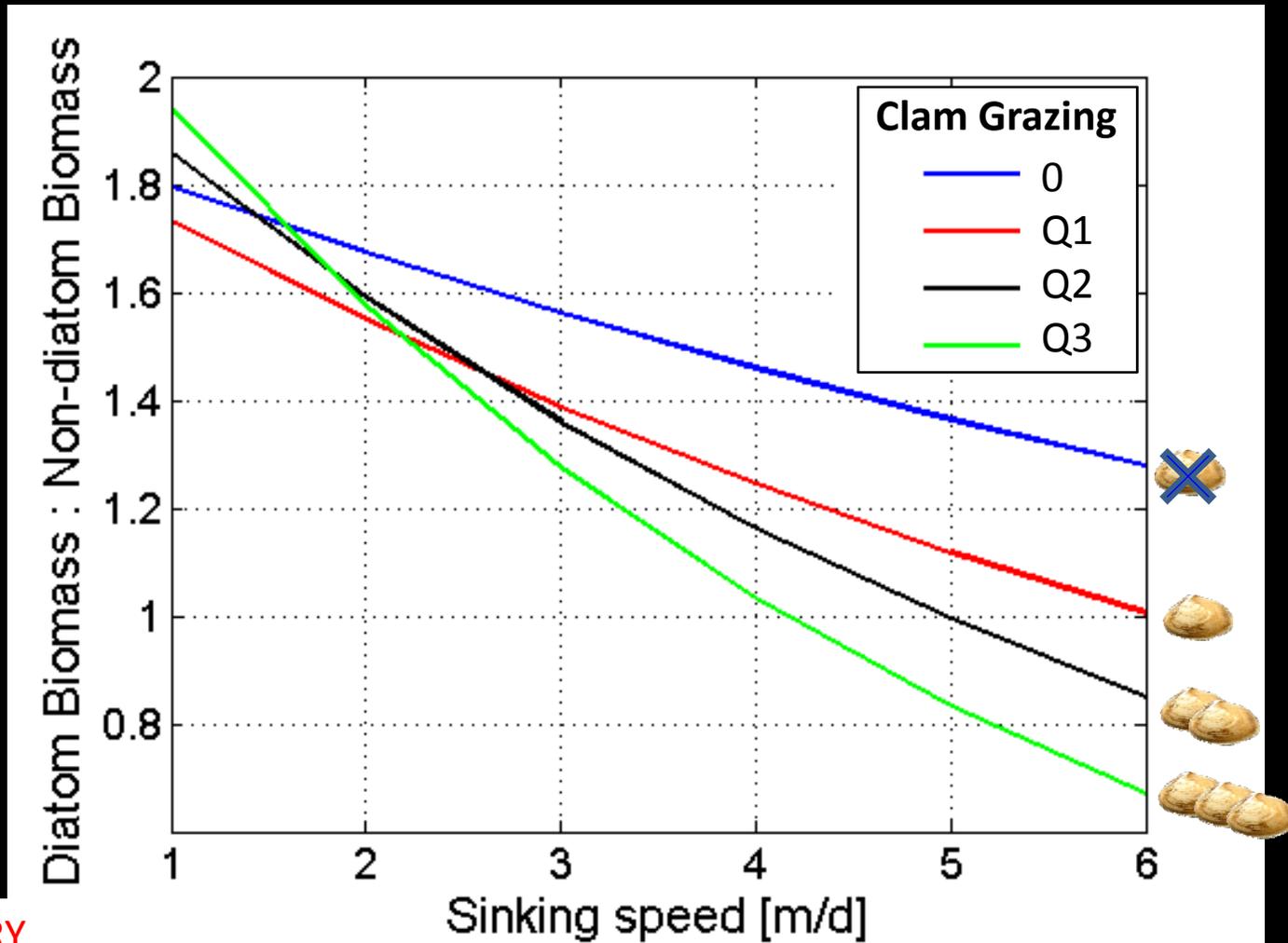
Persistent stratification makes life harder for diatoms



PRELIMINARY

Clam image: www.manandmollusc.net

Extra-fast growth may or may not compensate for sinking & grazing



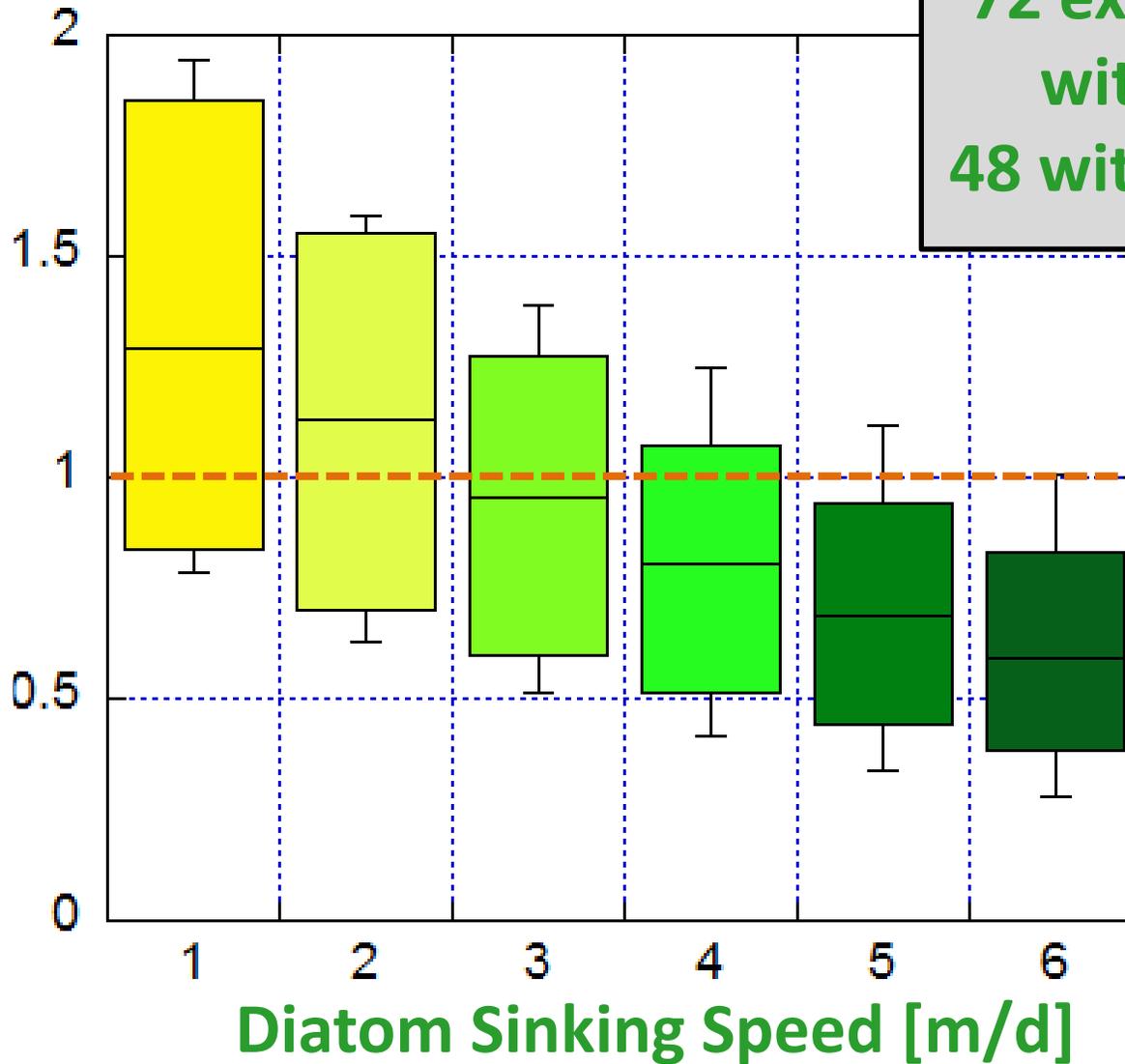
PRELIMINARY

Clam image: www.manandmollusc.net

Tidally periodic stratification • Diatom $\mu_{max} = 1.5(\text{Non-diatom } \mu_{max})$

When you've got clams, sinking matters

Diatom Biomass: Non-diatom Biomass



PRELIMINARY

*Is it plausible that the combination of **sinking** and **benthic grazing** could have selectively reduced diatoms in Suisun Bay???*

PRELIMINARY

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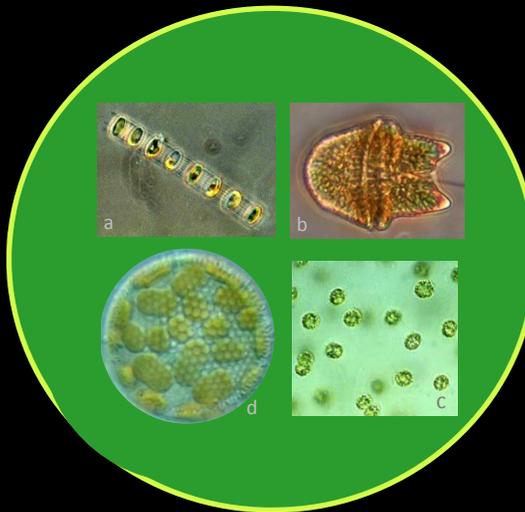
YES

PRELIMINARY

Considering individual influences in an ecosystem context

Growth
light, nutrients,
temp ...

**Phytoplankton Biomass &
Community Composition**



Mortality
grazing,
disease, ...

(import or
export)

Transport

sinking/motility
hydrodynamics (tides,
river, wind, density)

a: <http://cfb.unh.edu/phycokey>
b: USGS
c: <http://www.nhm.ac.uk>
d: <http://pinkava.asu.edu/starcentral/microscope>.
Photo: B. Anderson & D.J. Patterson

PRELIMINARY