



Extracellular Release of Dissolved Organic Carbon in the Amazon River Plume

Andrew Kalmbach

Thesis Defense

5/18/2016

Talk outline

A grayscale microscopic image showing various biological structures. On the right, there is a large, circular cell with a dense, granular interior and a darker nucleus. To its left, there are several elongated, segmented structures that appear to be part of a developing embryo or a specific tissue type. The background is light and shows some faint, scattered particles.

Introductions

Objectives

Methods

Results

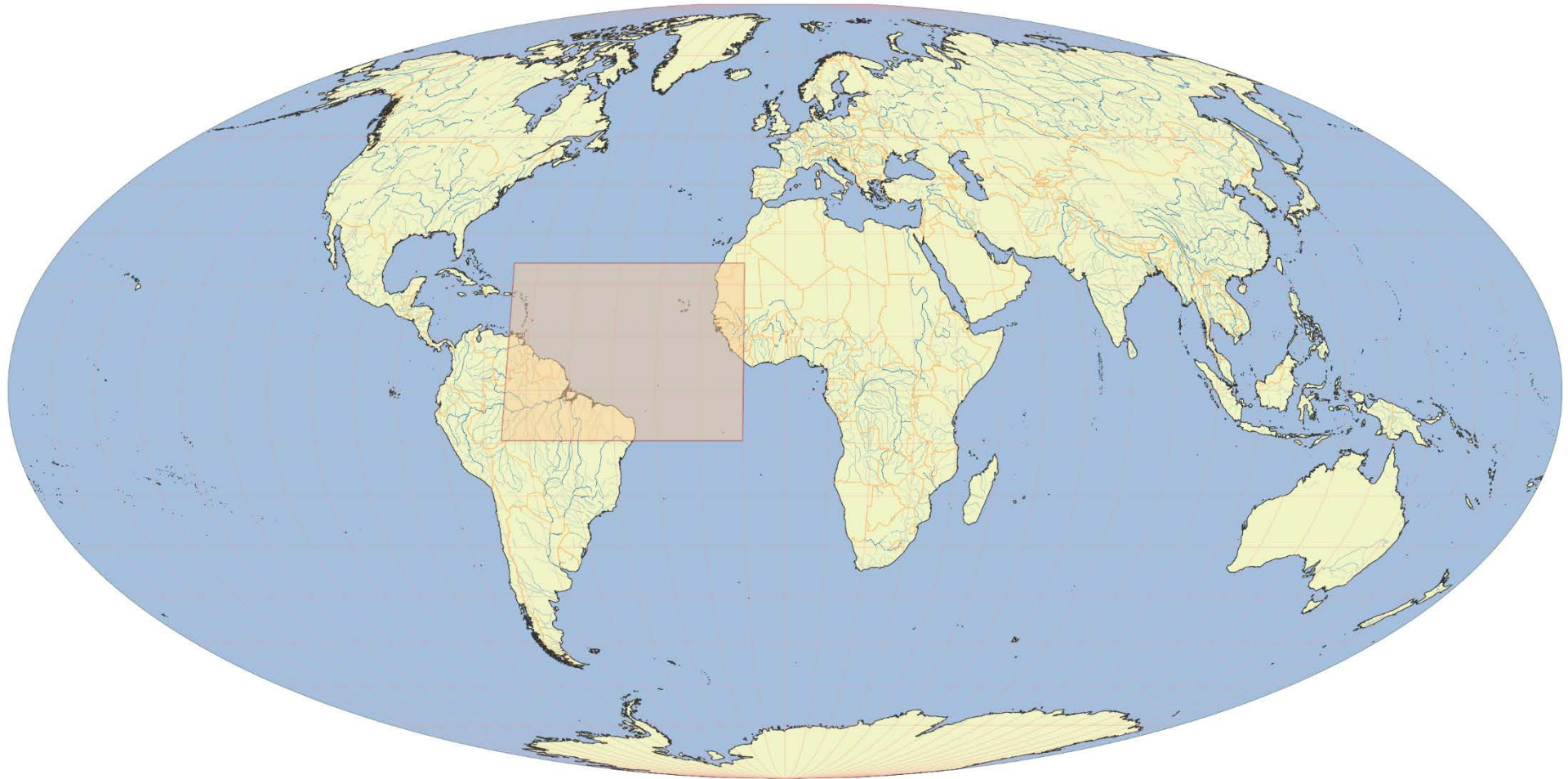
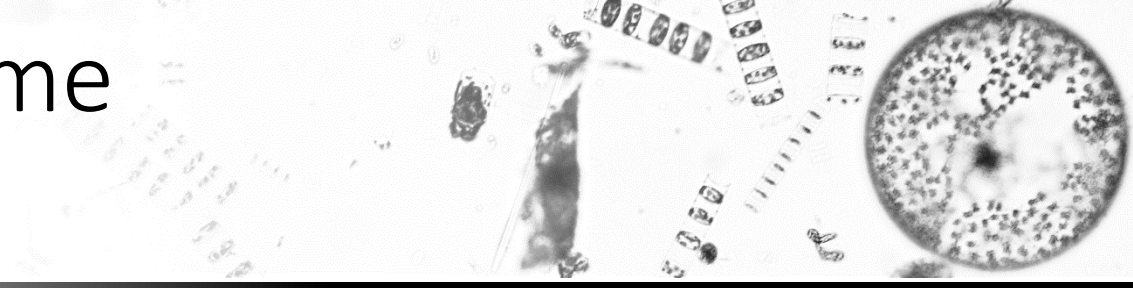
Conclusions

Talk outline

Introductions

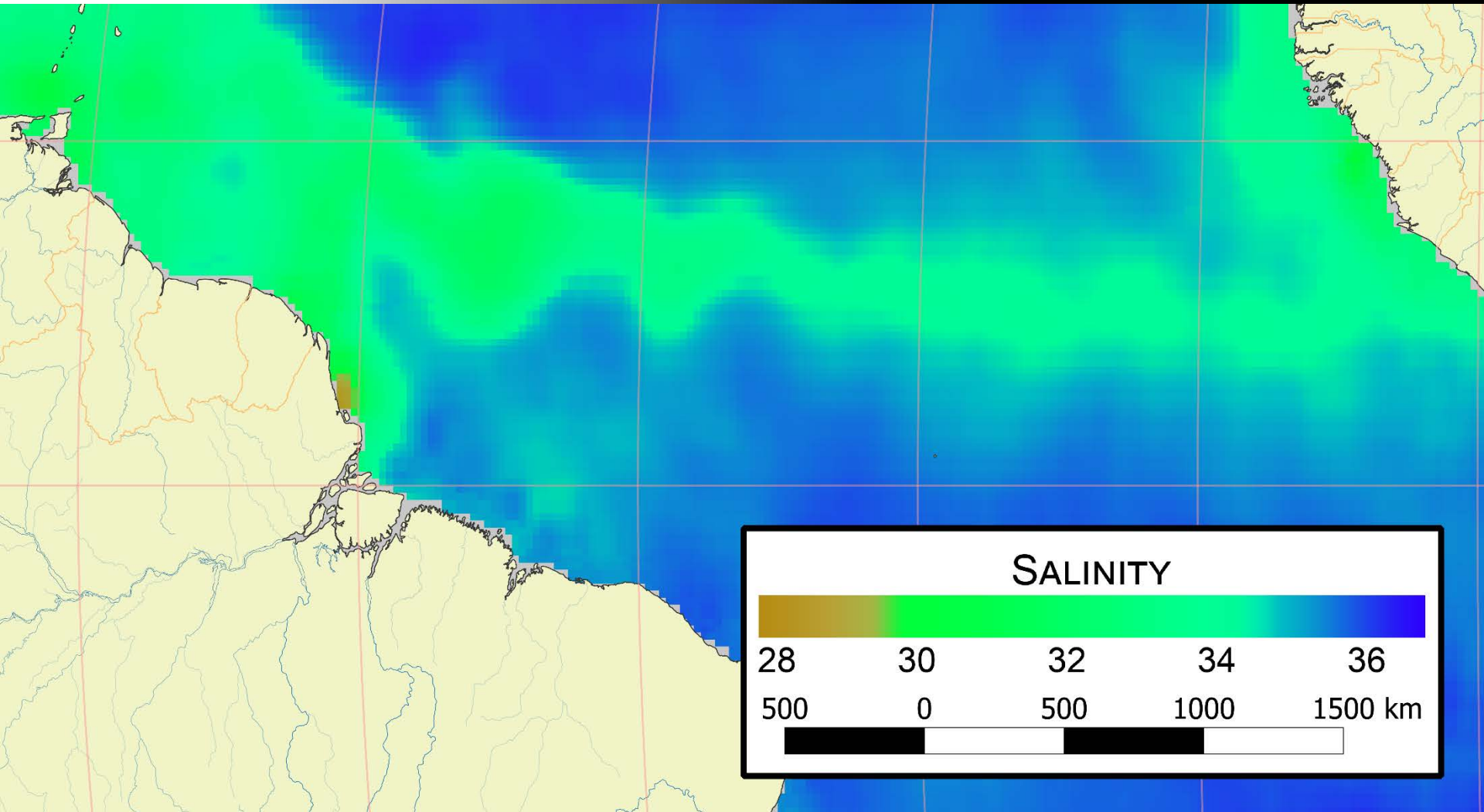
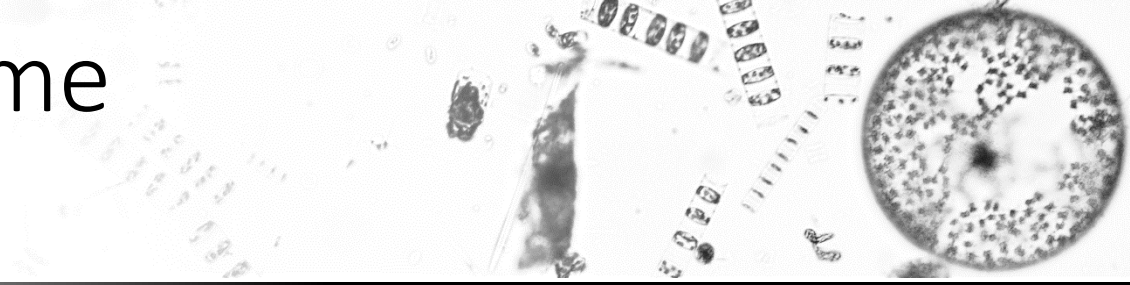
Amazon River Plume

Where is it?



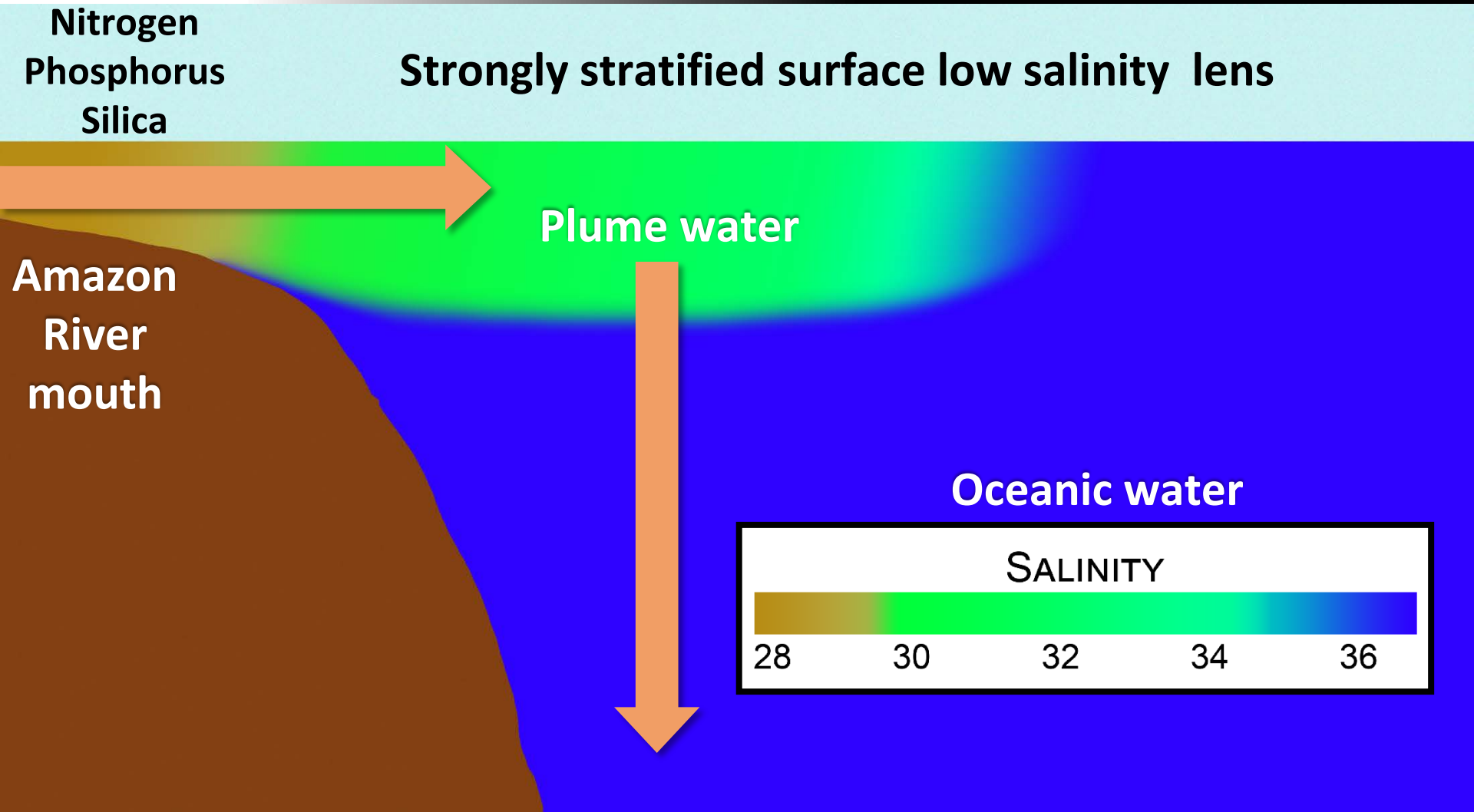
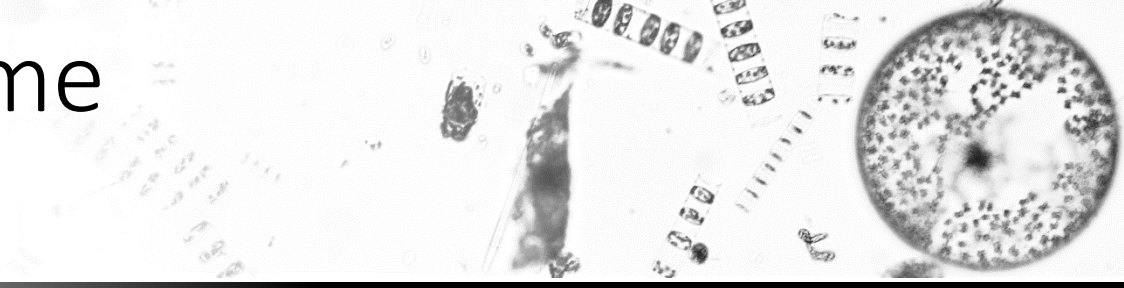
Amazon River Plume

Where is it?

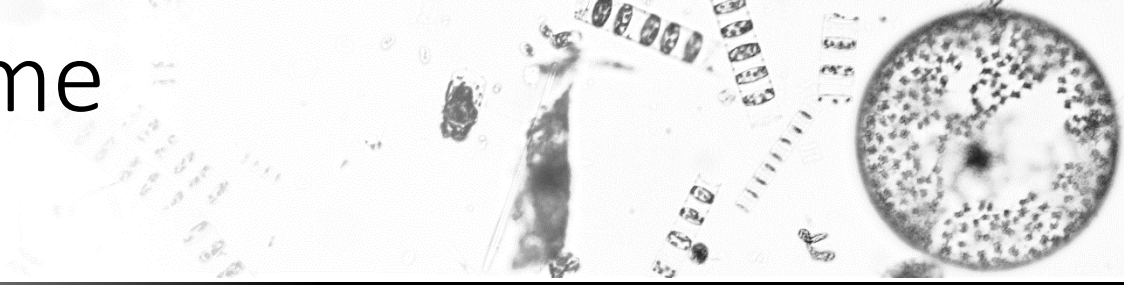


Amazon River Plume

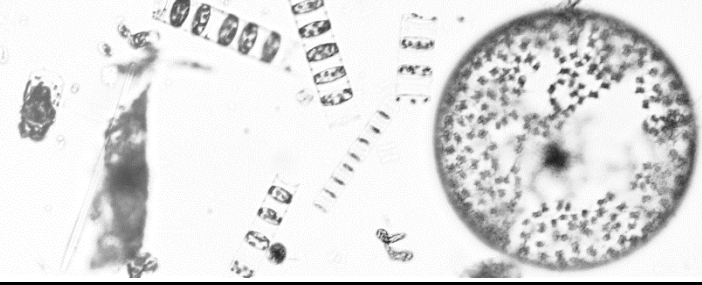
Highly productive



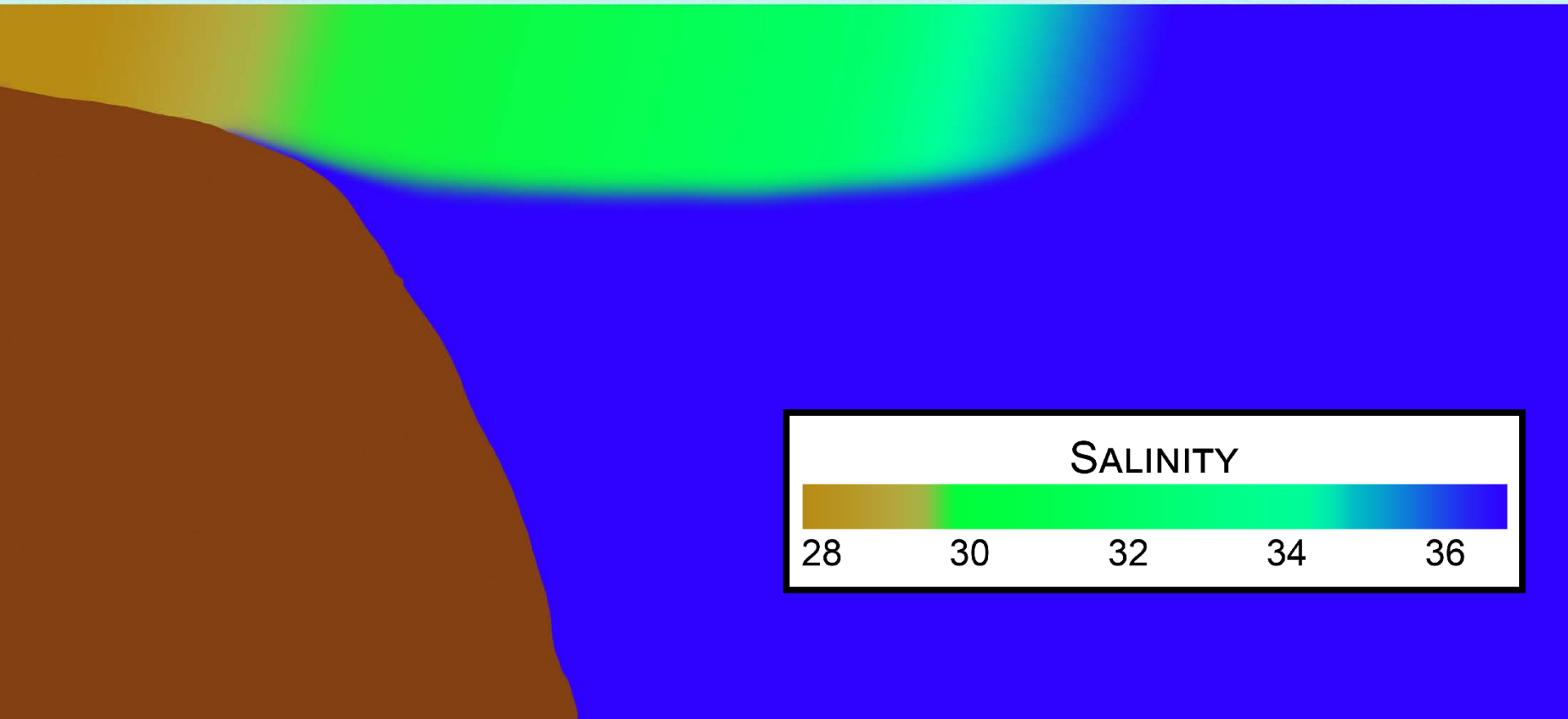
Amazon River Plume Turbid mouth



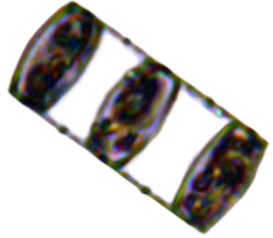
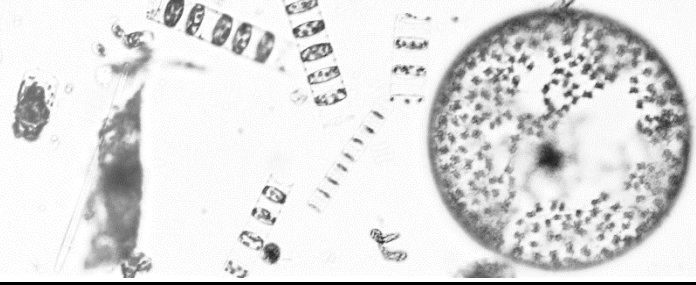
Amazon River Plume Phytoplankton assemblages



Nitrogen
Phosphorus
Silica

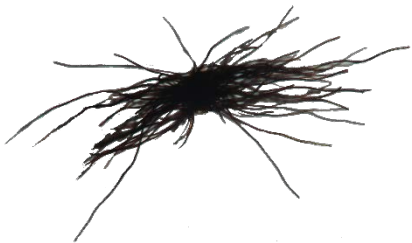
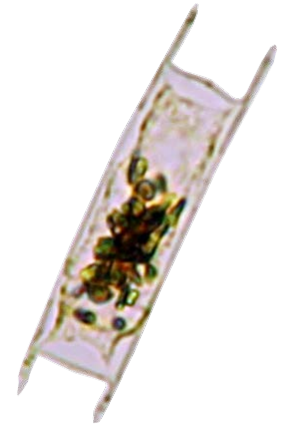


Amazon River Plume Phytoplankton assemblages



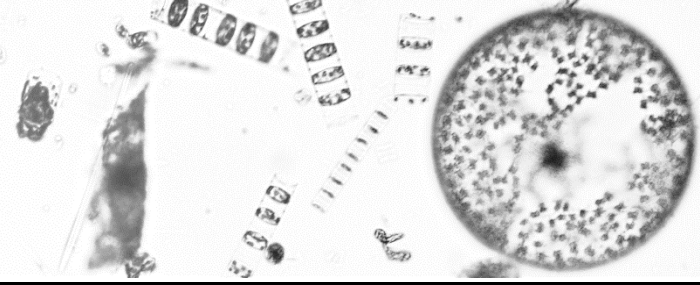
Coastal Phytoplankton

Diatom Diazotroph Associations (DDA)



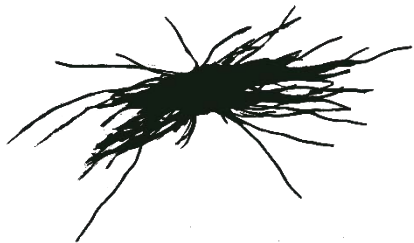
Trichodesmium

Amazon River Plume Phytoplankton assemblages



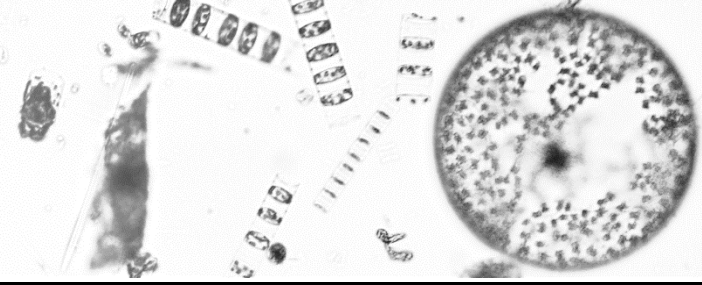
Coastal Phytoplankton

Diatom Diazotroph Associations
(DDA)



Trichodesmium

Amazon River Plume Phytoplankton assemblages



Nitrogen
Phosphorus
Silica

Nitrogen
Phosphorus
Silica

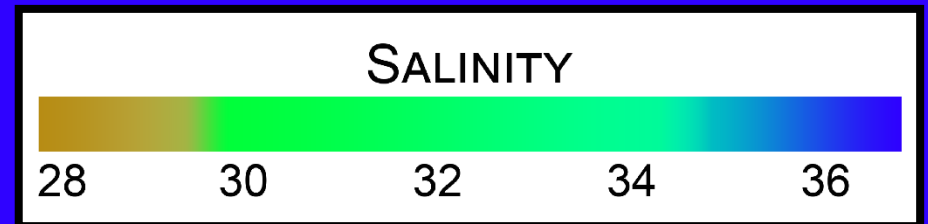
Nitrogen
Phosphorus
Silica



Coastal
Phytoplankton

Diatom Diazotroph
Associations

Trichodesmium



Amazon River Plume Carbon sequestration

Biological carbon dioxide drawdown ($\mu\text{mol C kg}^{-1}$)

20

29

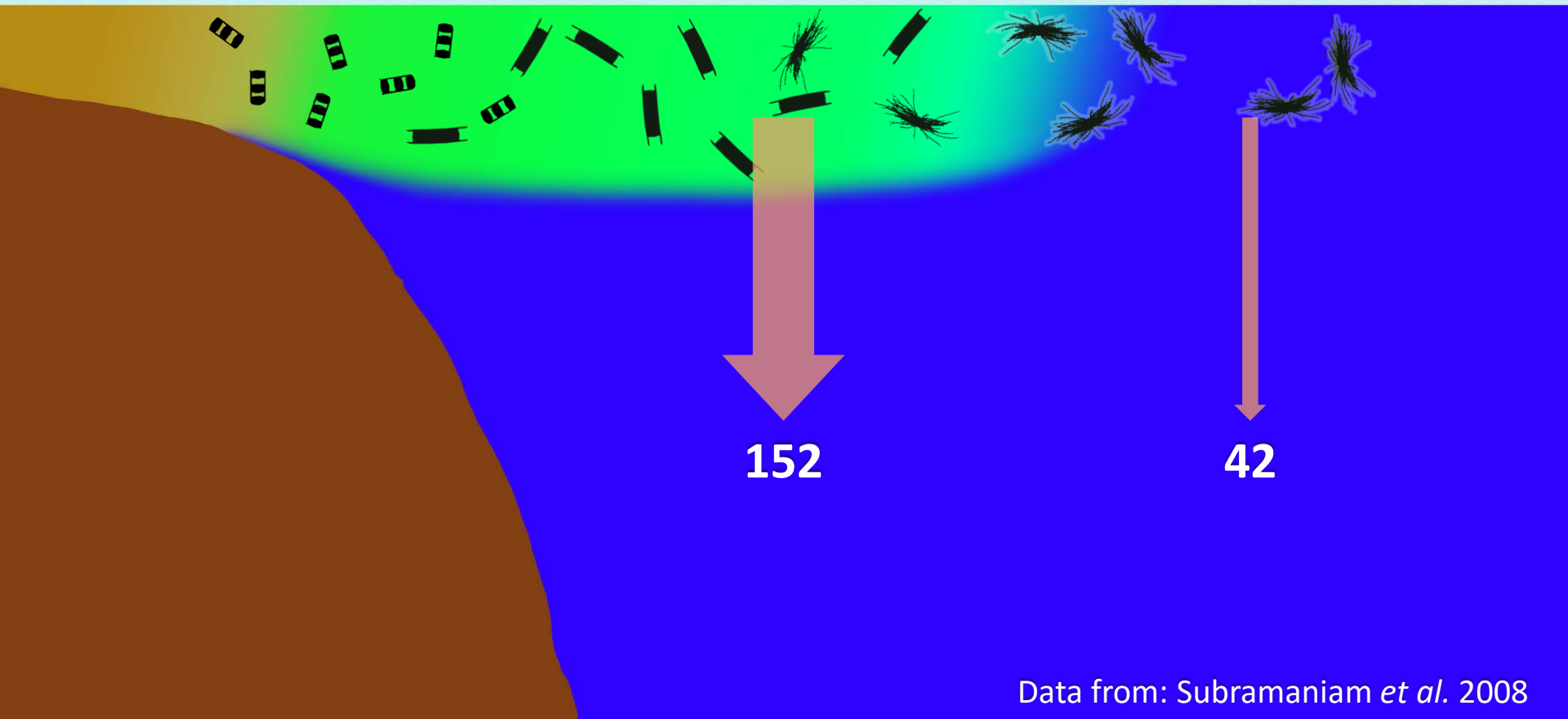
12

Diatoms:
Moderate DIC
Drawdown

Data from: Subramaniam *et al.* 2008

Amazon River Plume Carbon sequestration

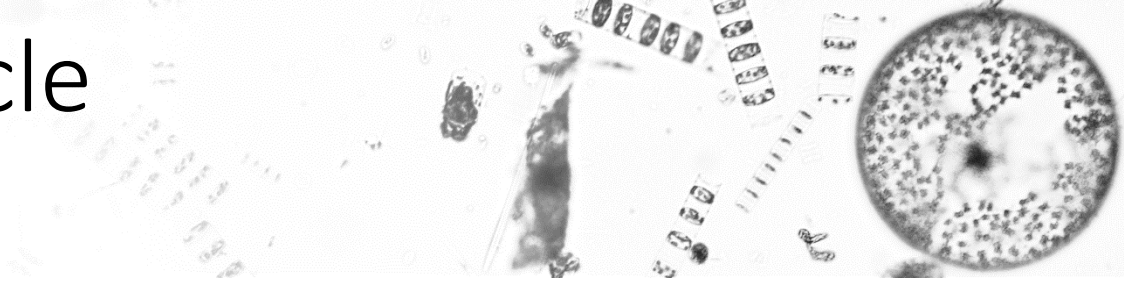
Sedimentation rates
mg C m⁻² d⁻¹



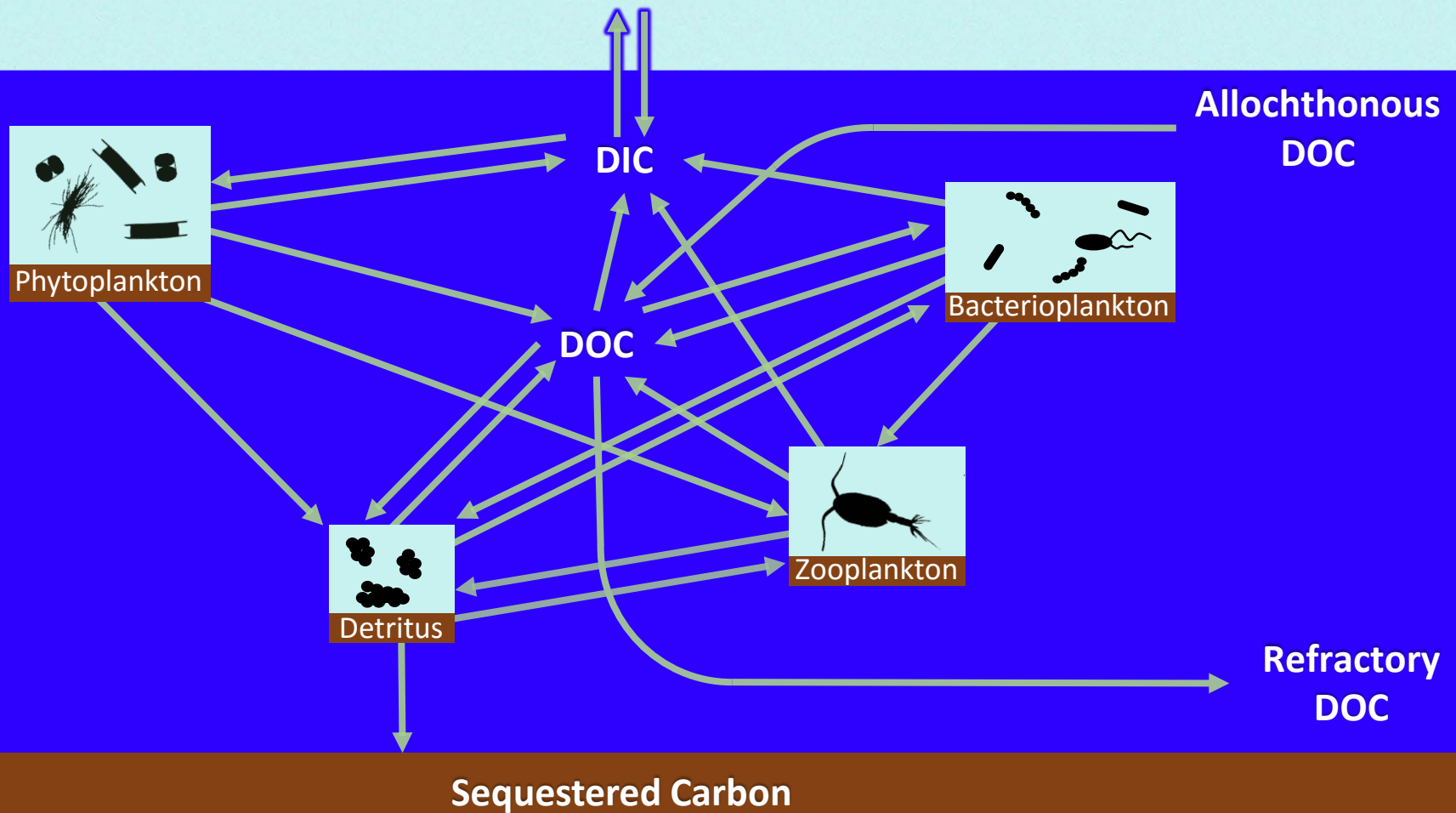
Data from: Subramaniam *et al.* 2008

Marine carbon cycle

My work

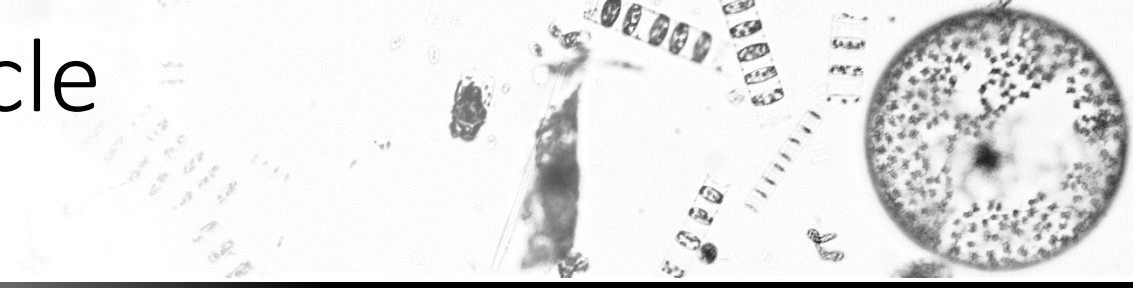


Atmospheric carbon dioxide

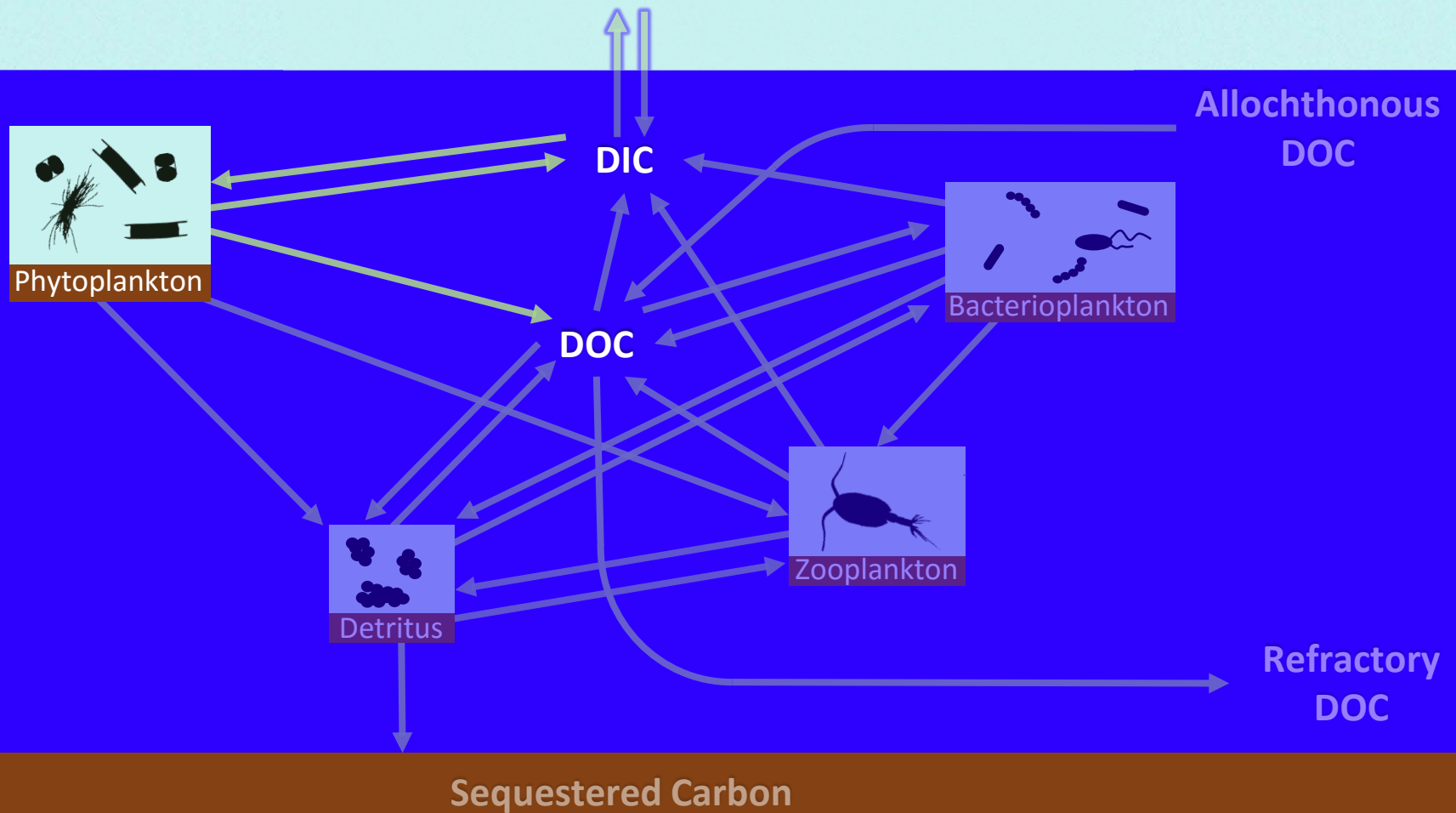


Marine carbon cycle

My work

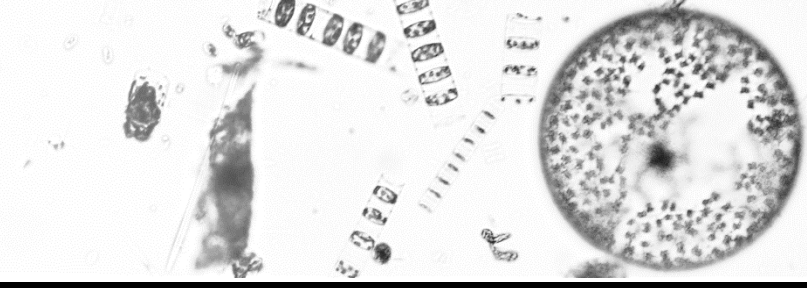


Atmospheric carbon dioxide



Marine carbon cycle

DOC from phytoplankton



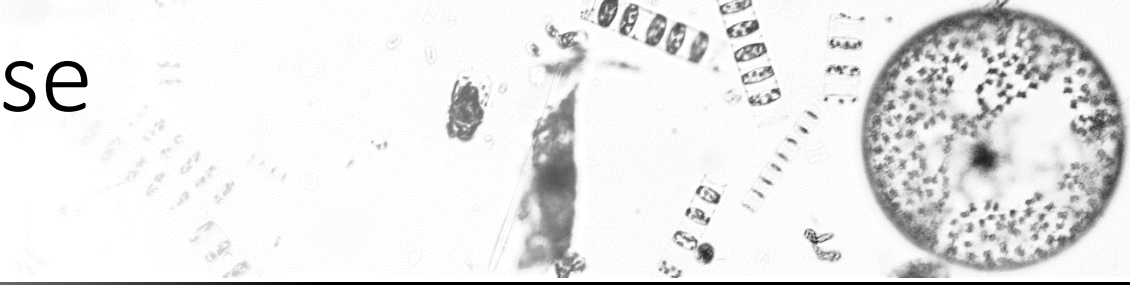
Healthy phytoplankton release DOC to the environment

Why?

Overflow or passive release models



Extracellular release by phytoplankton



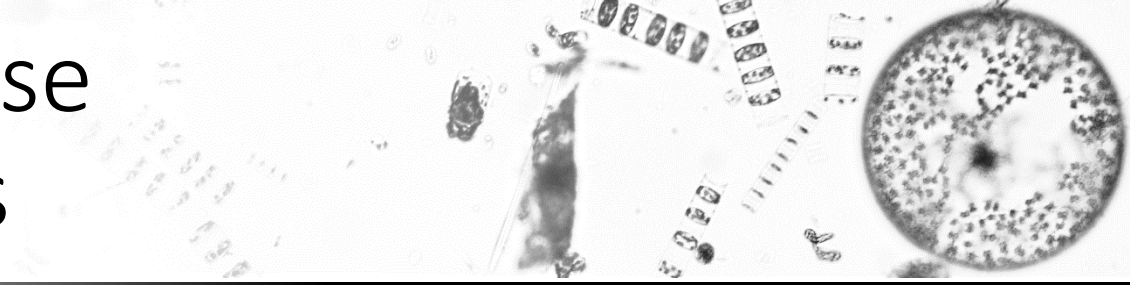
Passive release model

Constant diffusion
through the cellular
membrane

Overflow model

Extracellular release is a
physiological strategy for
environmental stresses.

Extracellular release Model predictions



Passive release model

Small phytoplankton
will have higher
release

Overflow model

Oligotrophic regions
have high release rates

Talk outline

A grayscale microscopic image showing biological tissue. On the right, there is a circular structure with a dense, granular interior and a darker central spot. To its left, there are elongated, segmented structures that appear to be part of a larger tissue or cellular structure.

Introductions

Objectives

Overall objectives

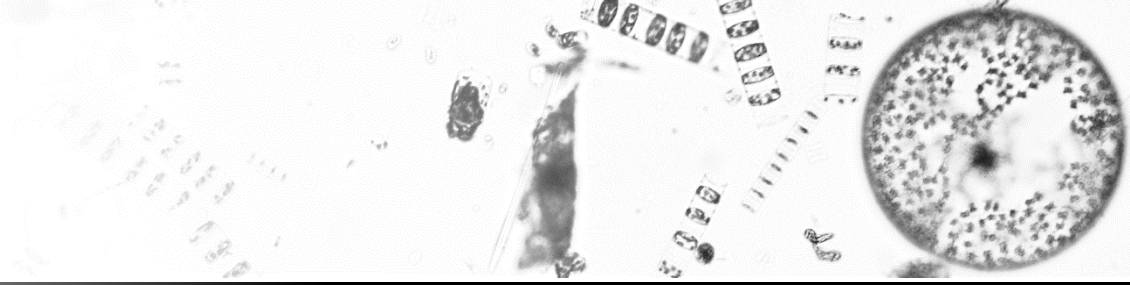


Predict extracellular release of DOC by parameters affected by the river water.

and

Evaluate the expectations of the two models in the Amazon River Plume.

Questions & Hypotheses



How does phytoplankton size affect DOC release?

The small size class will have higher relative extracellular release.

Do environmental gradients in in the Amazon River Plume predict extracellular release?

ER will rise as salinity increases and as nitrogen concentrations decrease.

Does extracellular release vary by phytoplankton assemblage in the plume?

The extracellular release will vary between the different communities.

Talk outline

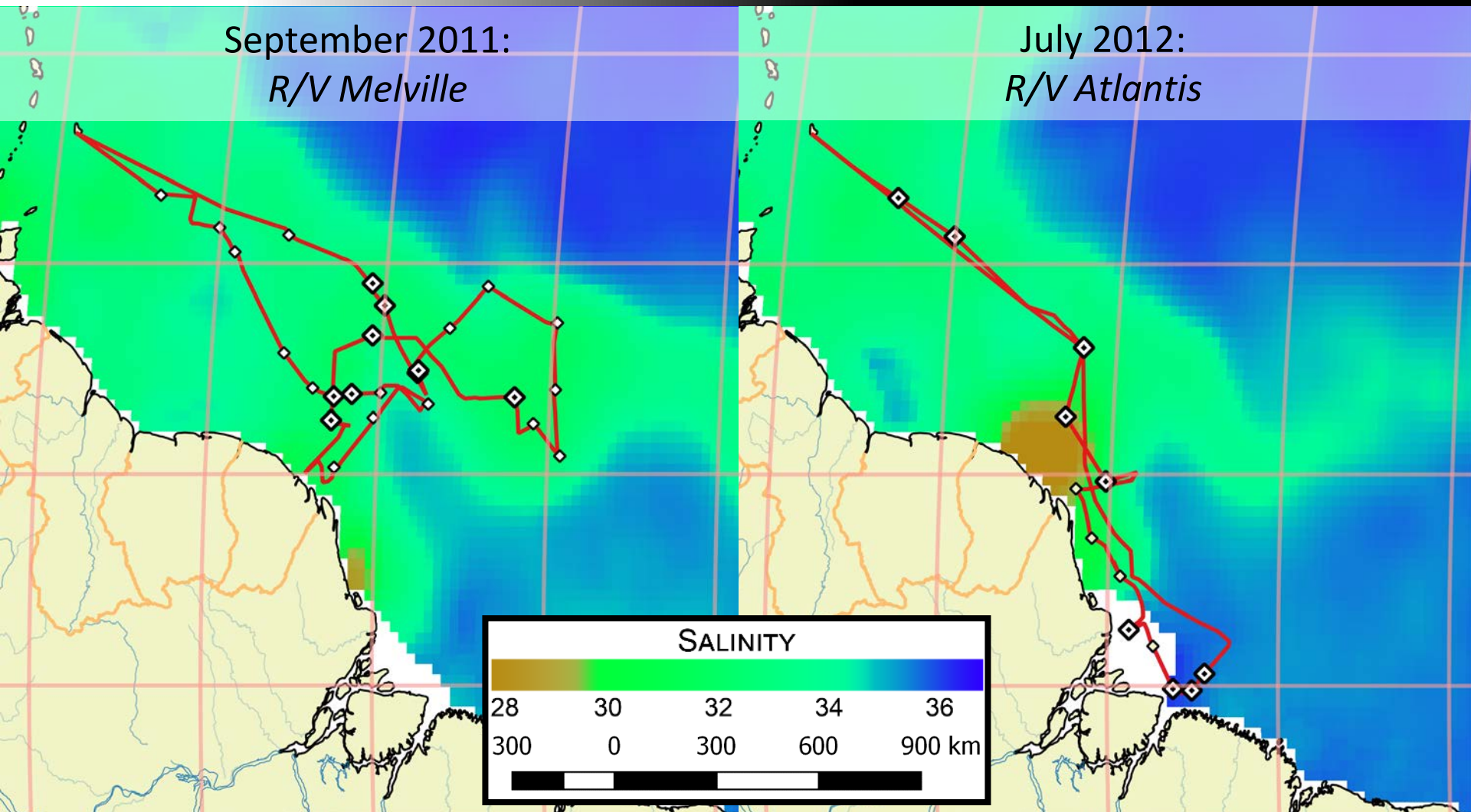
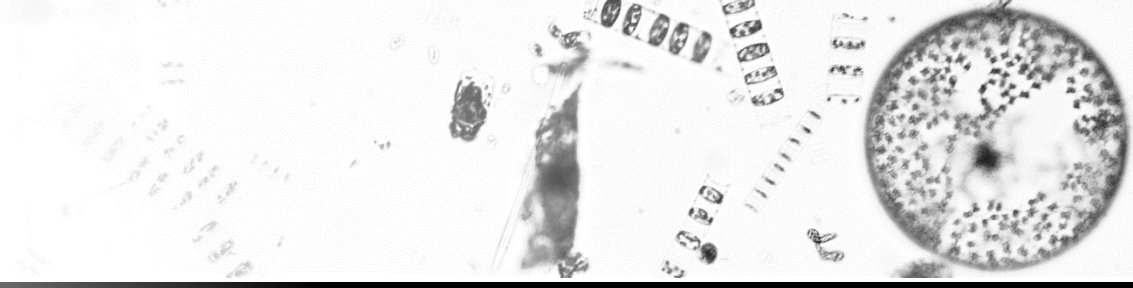
A grayscale microscopic image showing biological tissue. On the right, there is a circular structure with a dense, granular interior and a darker central spot. To its left, there are several elongated, parallel structures with a segmented or beaded appearance. The background is light and shows some faint, scattered cellular structures.

Introductions

Objectives

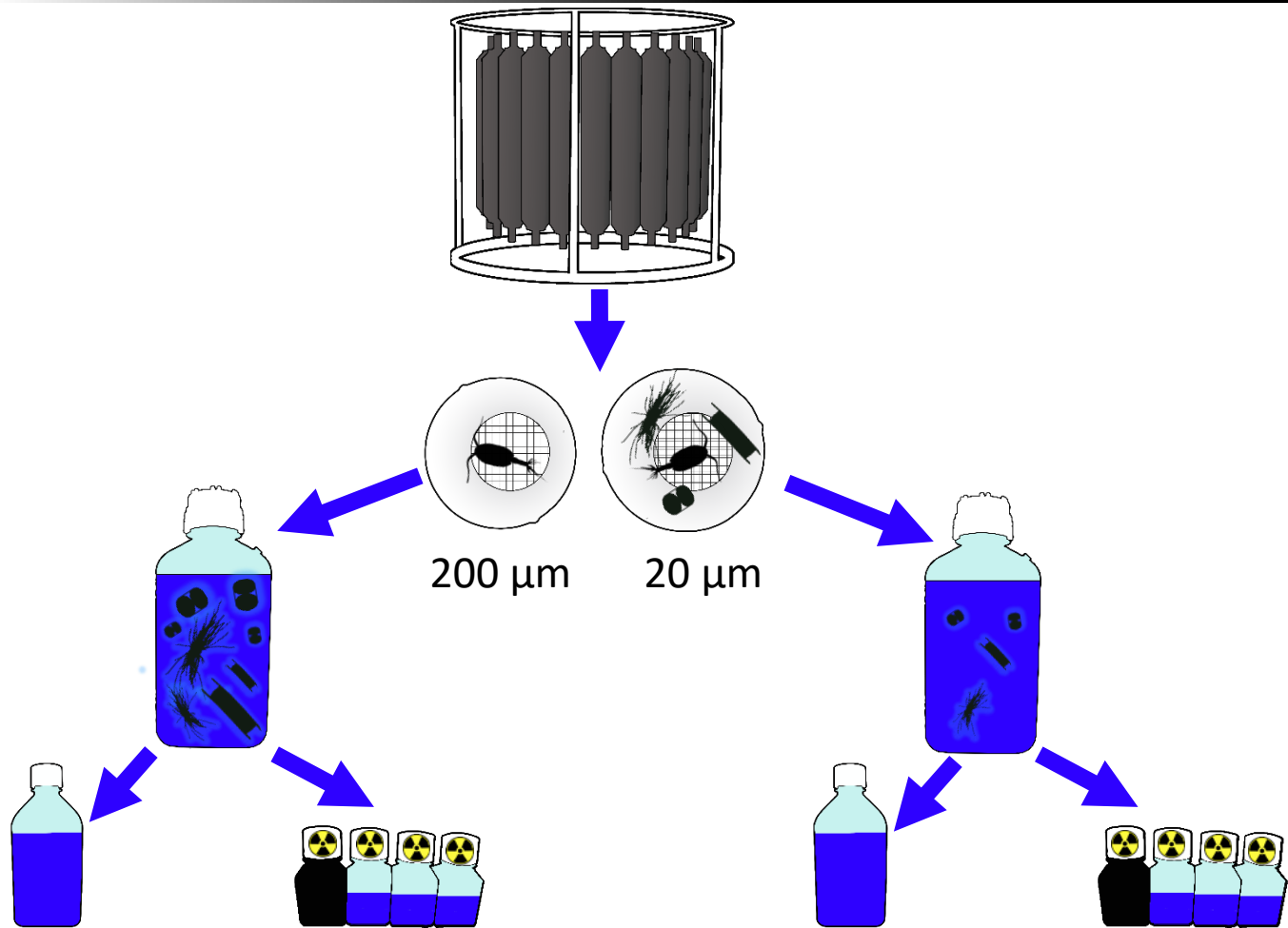
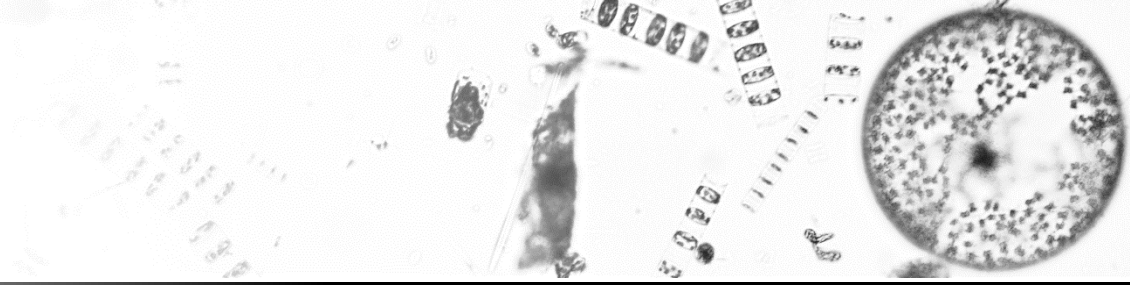
Methods

Methods study sites



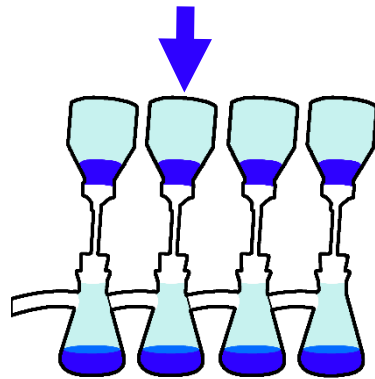
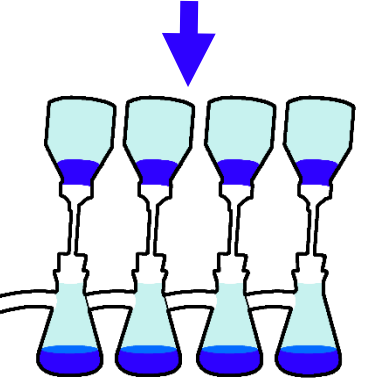
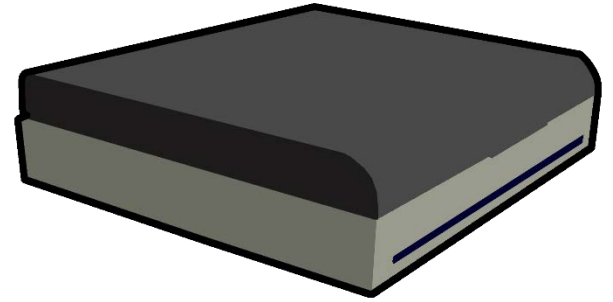
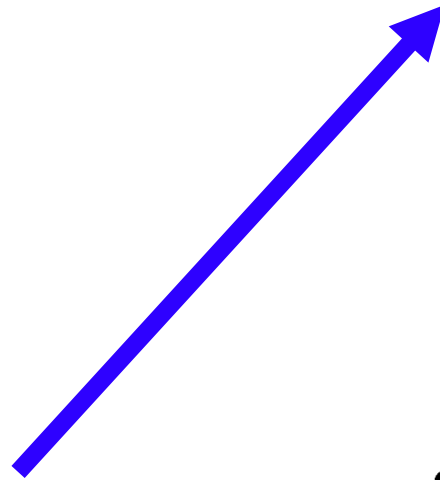
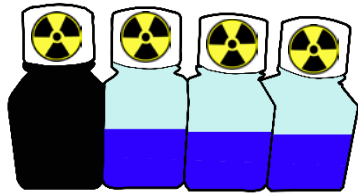
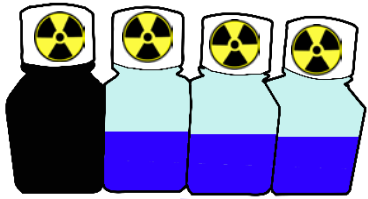
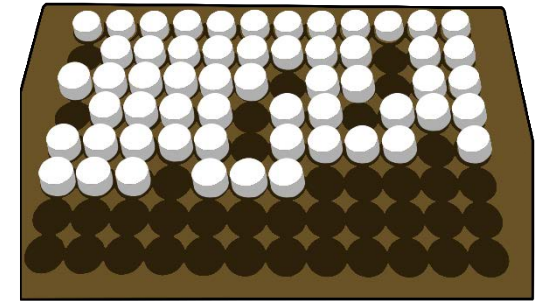
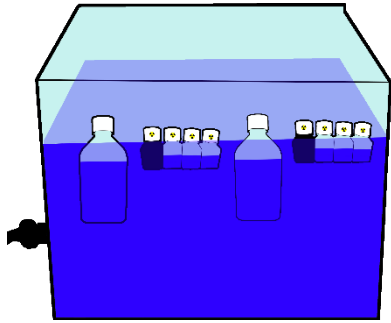
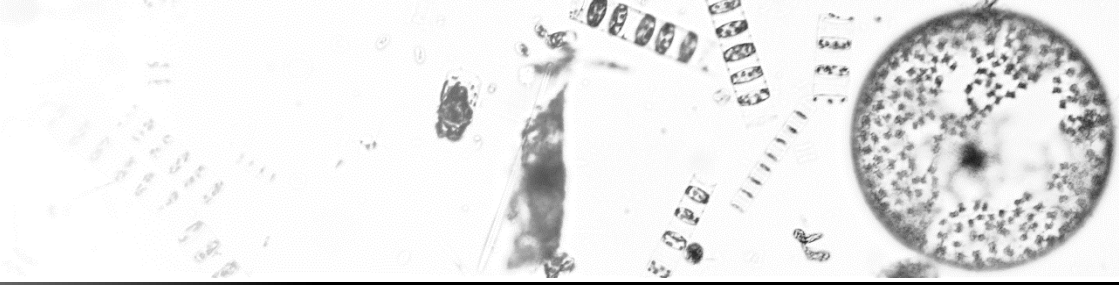
Methods

^{14}C labeling



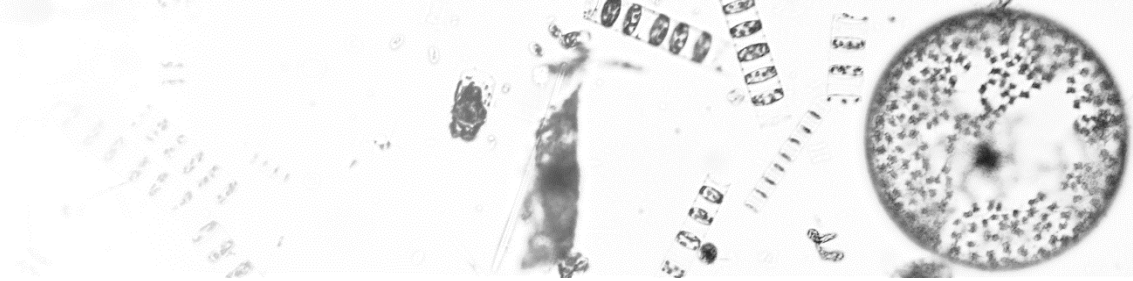
Methods

Reading activity



Methods

Calculations



Extracellular release (ER) [$\text{mg C m}^{-3} \text{ h}^{-1}$]=

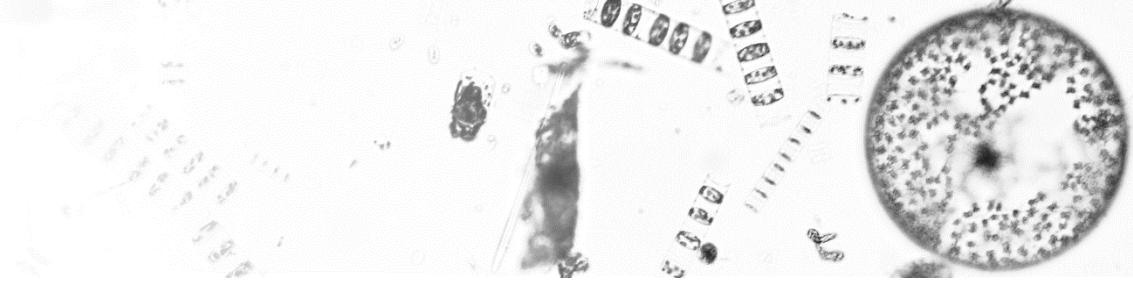
$$\frac{DPM_{\text{filtrate}} - DPM_d}{Vol_{\text{filtrate}}} * \frac{Vol_{t_0}}{DPM_{t_0}} * DIC * \frac{1.05}{24}$$

Particulate production (PP) [$\text{mg C m}^{-3} \text{ h}^{-1}$] =

$$\frac{DPM_{\text{filter}} - DPM_d}{Vol_{\text{filter}}} * \frac{Vol_{t_0}}{DPM_{t_0}} * DIC * \frac{1.05}{24}$$

Methods

Calculations



Percent extracellular release (PER) [%]=

$$\frac{ER}{ER+PP} * 100$$

$$\text{Chlorophyll normalized ER [mg C mg Chl}^{-1} \text{ h}^{-1}] = \frac{ER}{Chl a}$$

$$\text{Chlorophyll normalized PP [mg C mg Chl}^{-1} \text{ h}^{-1}] = \frac{PP}{Chl a}$$

Methods

Environmental variables



Environmental variables collected include:

Chlorophyll a

Taxa counts

Salinity

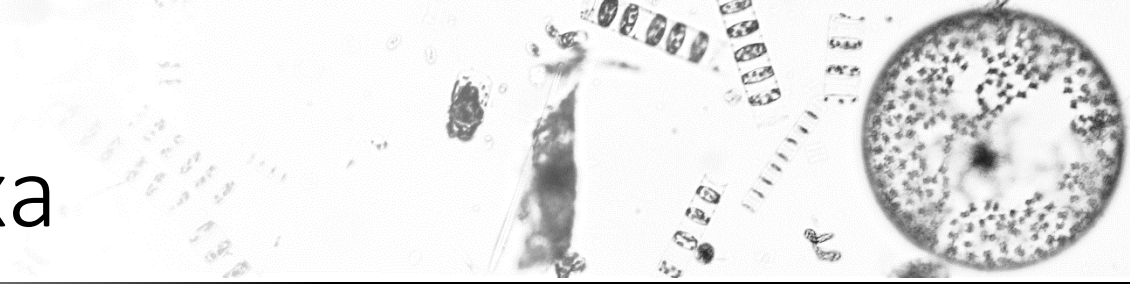
Light Attenuation

Nitrate, ammonium, silicate and phosphate

Total dissolved nitrogen

Methods

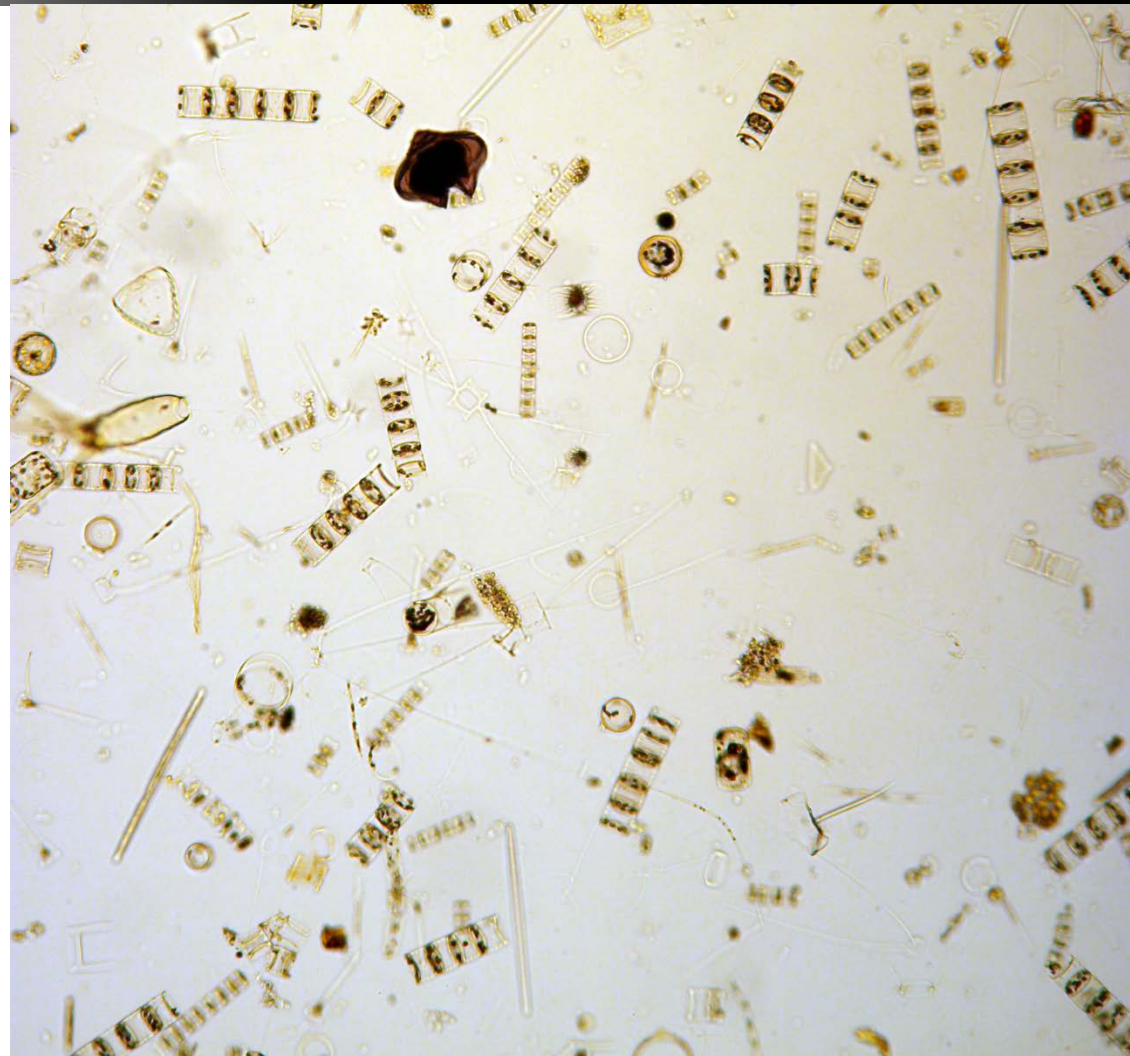
Phytoplankton taxa



Station cell counts

Assemblage
similarity

Station similarity
dendrogram



Talk outline

A grayscale microscopic image showing biological tissue. On the right, there is a circular structure with a dense, granular interior and a darker central spot. To its left, there are elongated, segmented structures that appear to be part of a larger tissue or cellular structure.

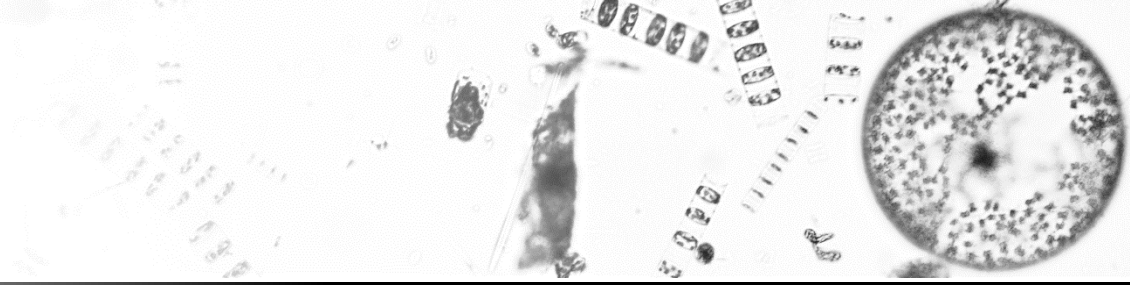
Introductions

Objectives

Methods

Results

Questions & Hypotheses

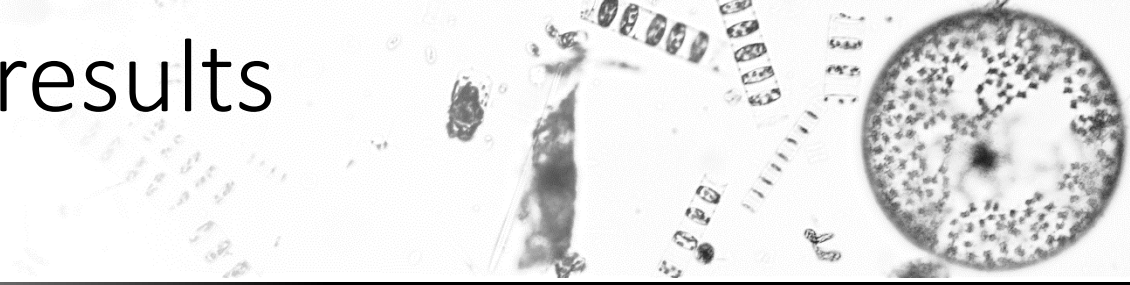


How does phytoplankton size affect DOC release?

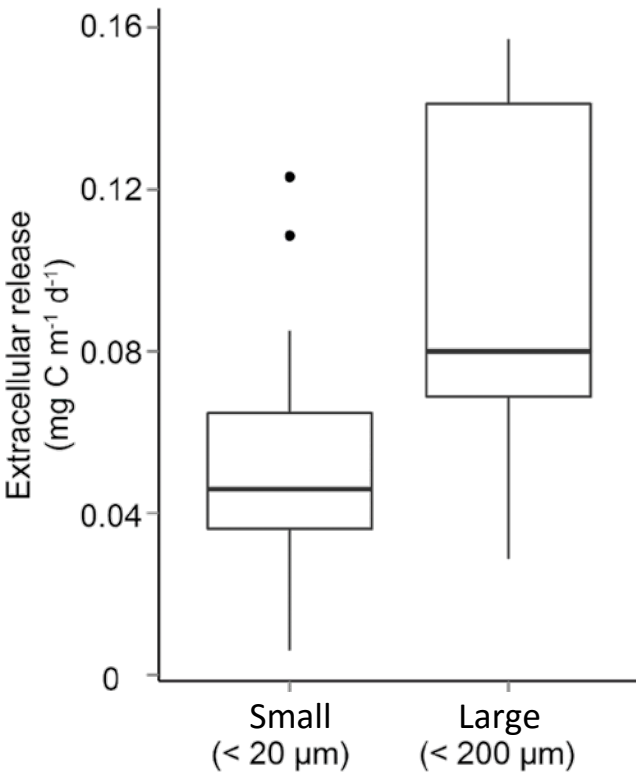
The small size class will have higher relative extracellular release.

Size fractionation results

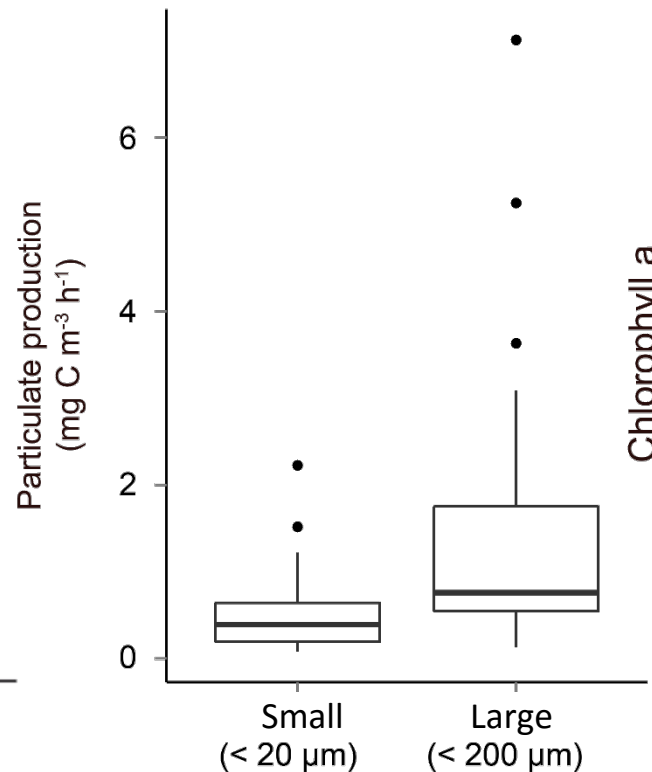
Chlorophyll a



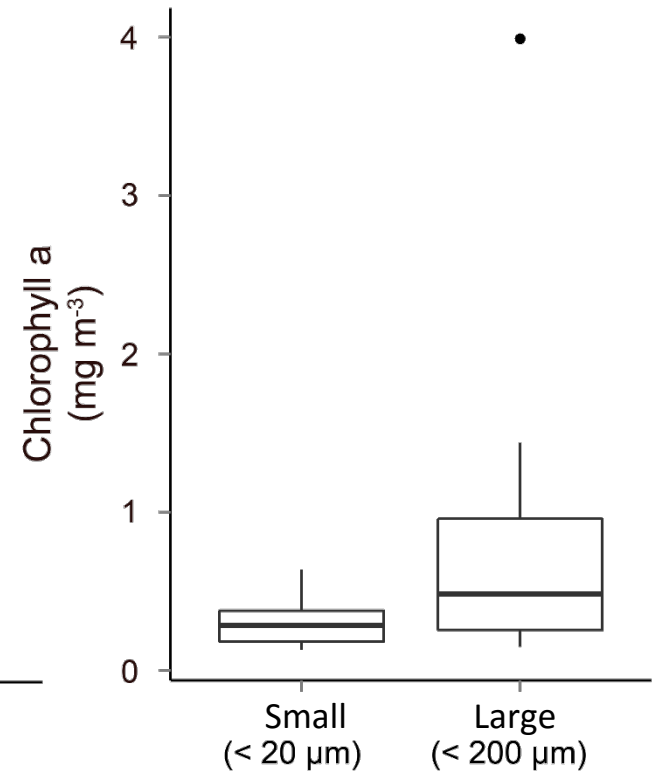
Extracellular Release (ER)



Particulate Production (PP)

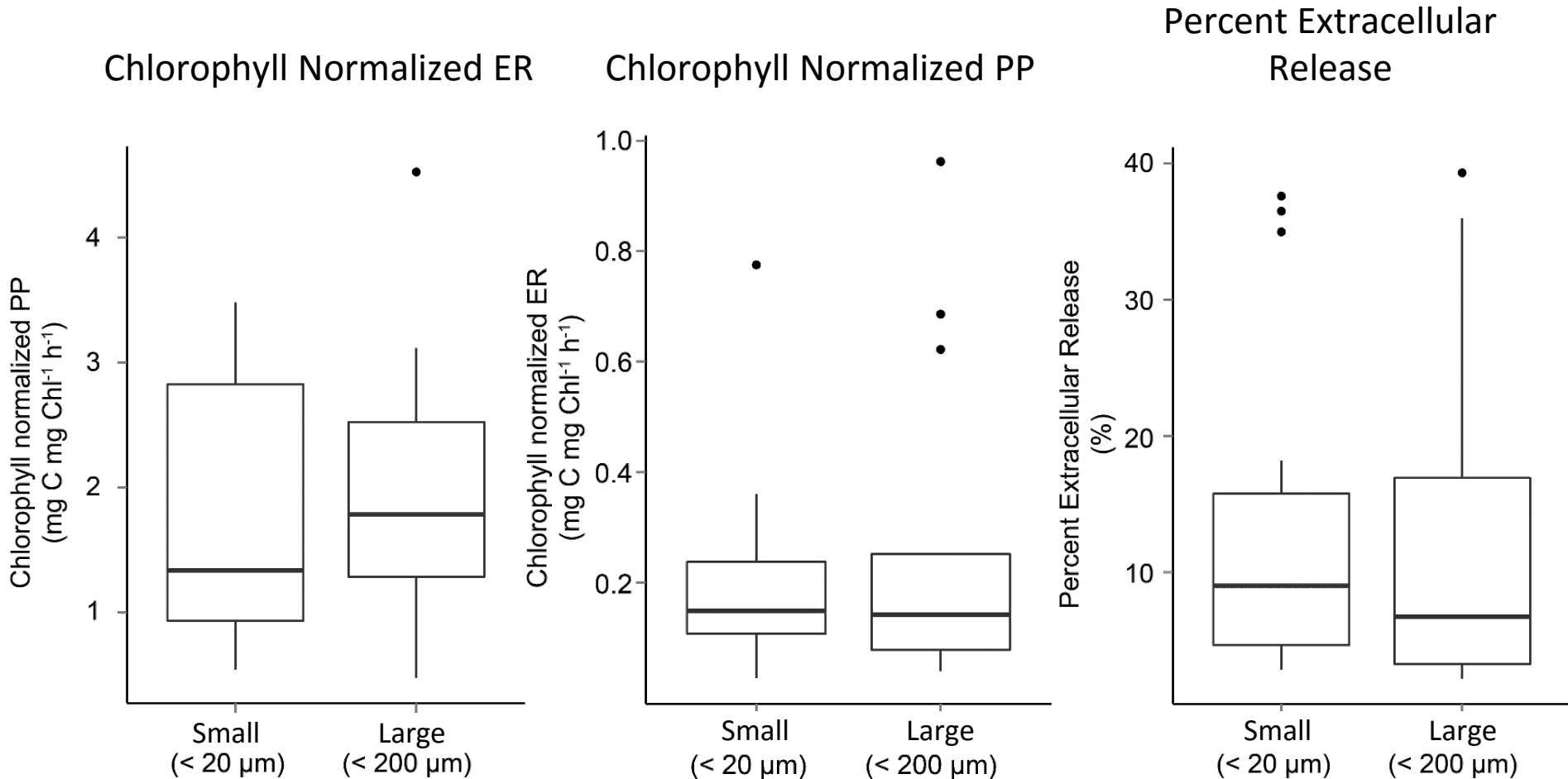
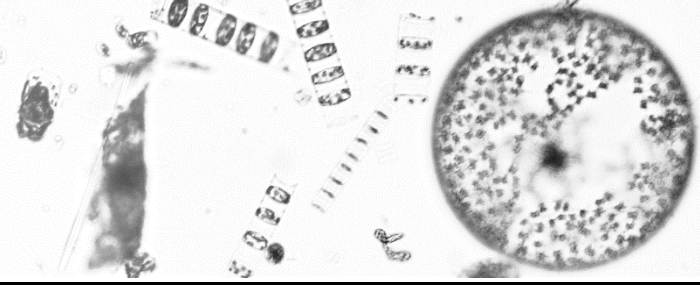


Chlorophyll a (Chl)



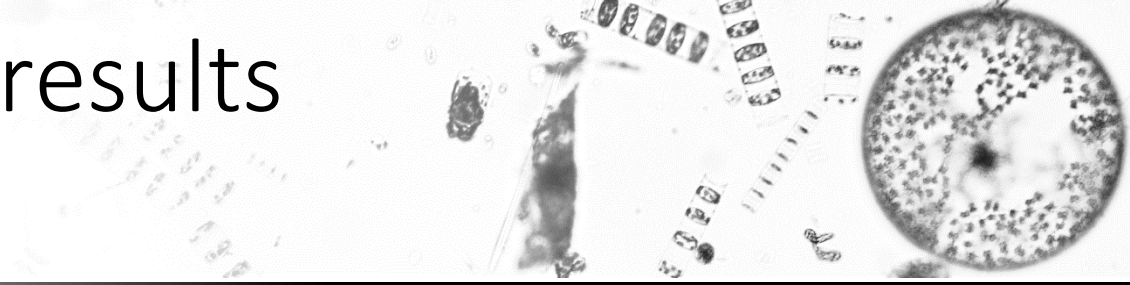
Size fractionation results

Normalized ER, PP, and PER

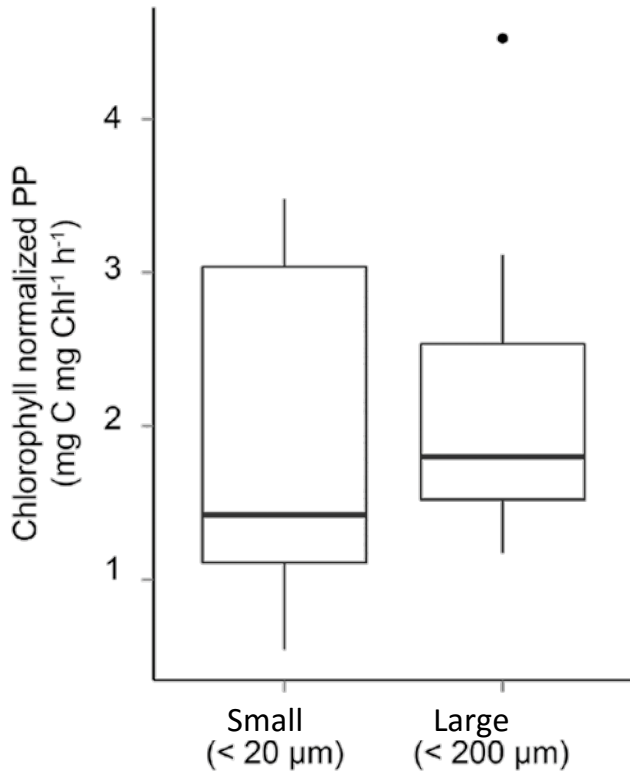


Size fractionation results

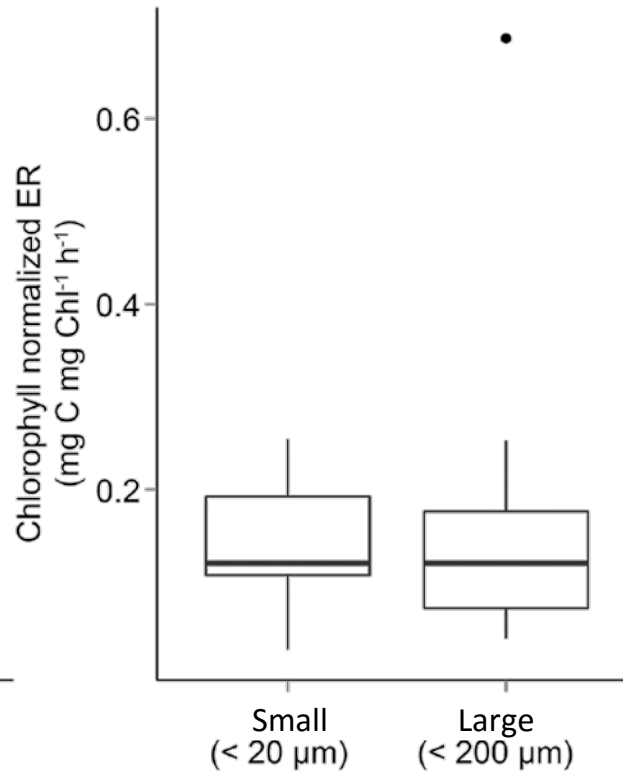
Outliers removed



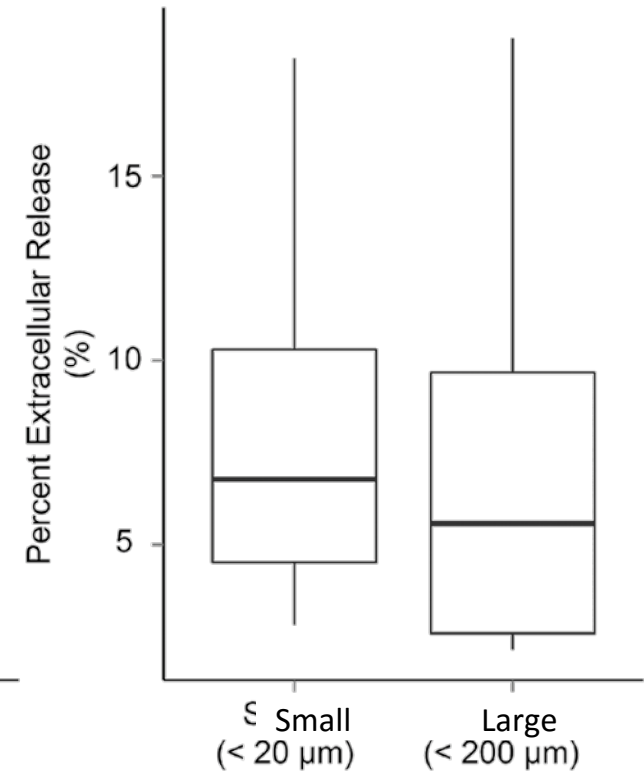
Chlorophyll Normalized ER
Outliers Removed



Chlorophyll Normalized PP
Outliers Removed



Percent Extracellular Release
Outliers Removed



Questions & Hypotheses



How does phytoplankton size affect DOC release?

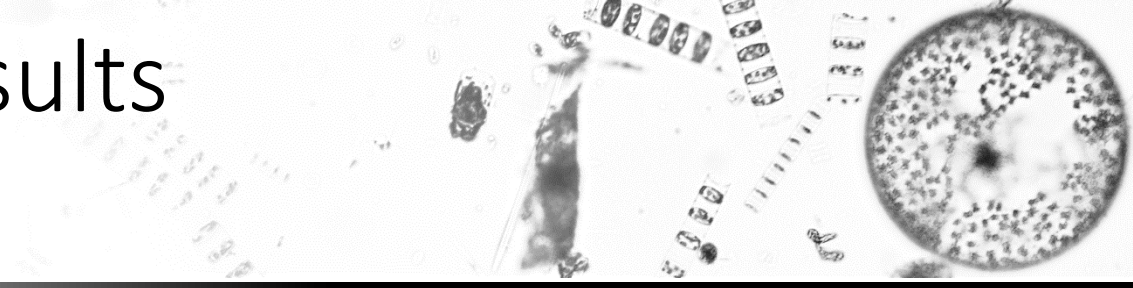
~~The small size class will have higher relative extracellular release.~~

Do environmental gradients in the Amazon River Plume predict extracellular release?

ER will rise as salinity increases, and as nitrogen concentrations decrease.

Environmental results

Variable selection



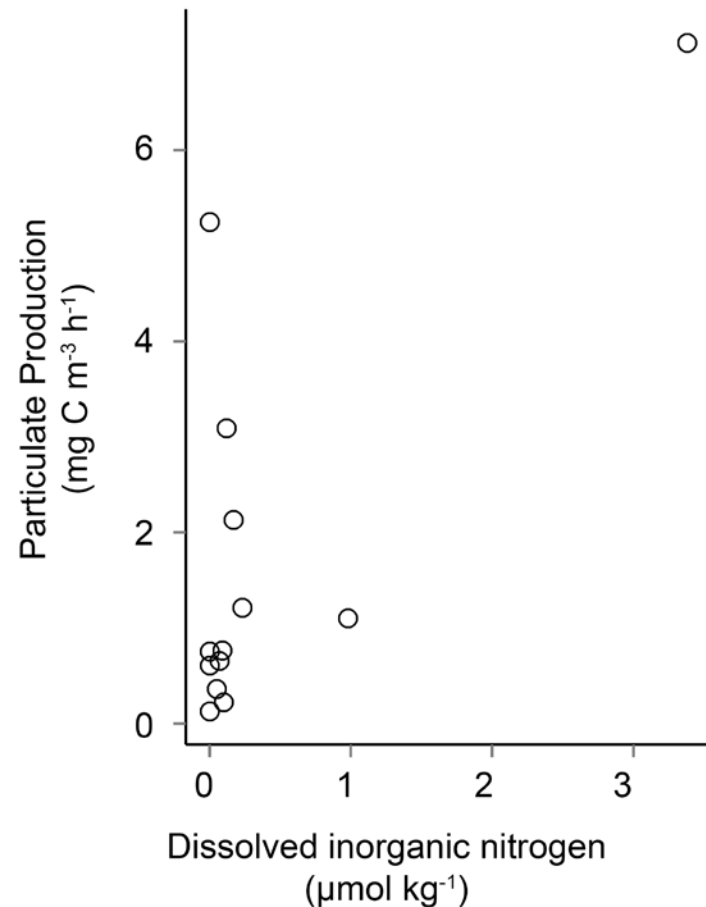
		Nutrients ($\mu\text{mol kg}^{-1}$)				Organic Matter ($\mu\text{mol kg}^{-1}$)					m^{-1}
	Salinity	TDN	DIC	PO_4	SiO_4	Chl a	POC	PON	DOC	DON	Atten
Salinity											
Total Dissolved Nitrogen	-0.30										
Dissolved Inorganic Nitrogen	-0.35	0.67*									
Phosphate	-0.73*	0.14	0.15								
Silicate	-0.91*	0.18	0.09	0.87*							
Chlorophyll a	-0.62*	0.65*	0.82*	0.48*	0.45*						
Particulate Organic Carbon	-0.52*	0.18	0.08	0.48*	0.59*	0.45*					
Particulate Organic Nitrogen	-0.54*	0.14	0.08	0.51*	0.62*	0.39*	0.97*				
Dissolved Organic Carbon	-0.32	0.29	0.36	0.35	0.29	0.40*	0.32	0.29			
Dissolved Organic Nitrogen	-0.19	0.91*	0.30	0.09	0.17	0.39*	0.18	0.14	0.17		
Attenuation	-0.29	-0.37	-0.23	0.55*	0.47*	0.20	0.58*	0.54*	0.26	-0.35	

Nitrogen as a nutrient in the Amazon River Plume?

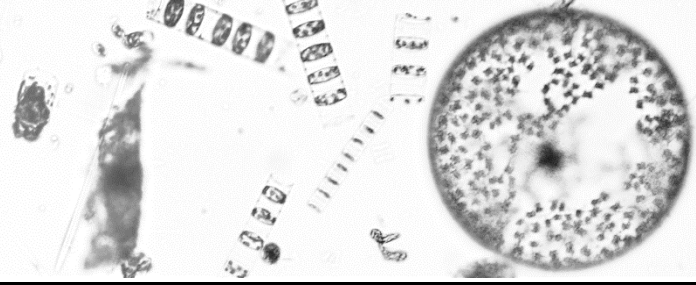
Dissolved inorganic nitrogen vs. total dissolved nitrogen

Why use total dissolved nitrogen?

Low dissolved inorganic nitrogen, even where primary production is high



Nitrogen as a nutrient in the Amazon River Plume?



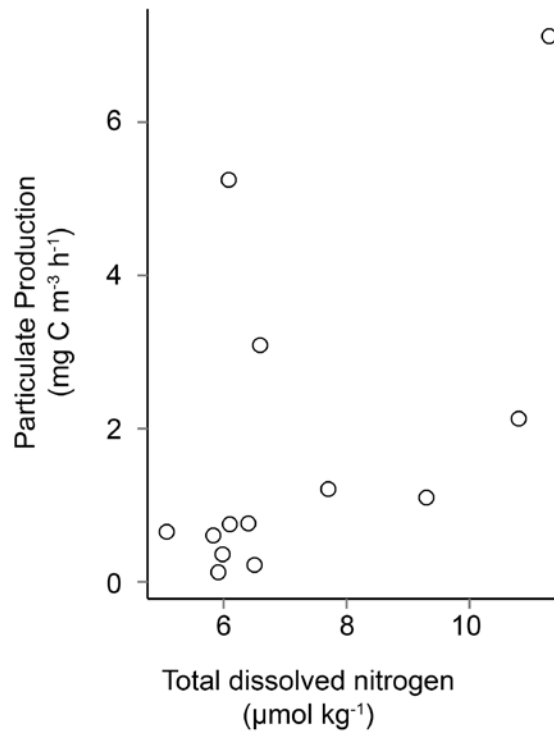
Why use total dissolved nitrogen?

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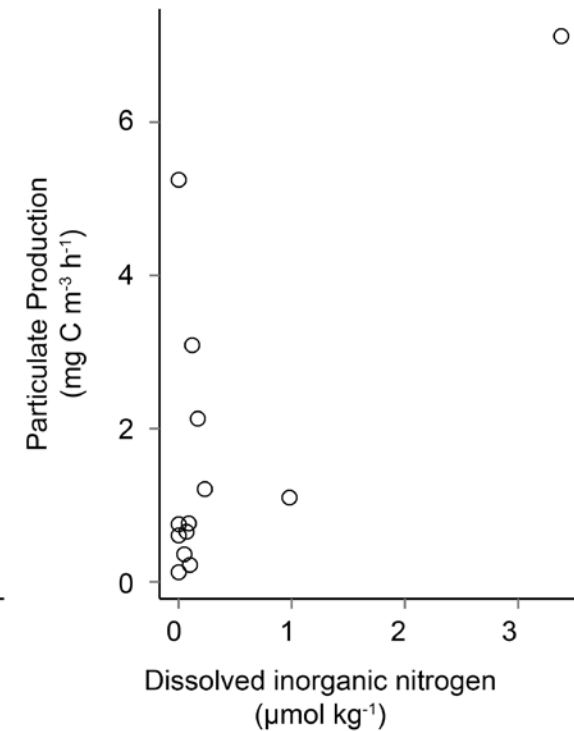
Many dissolved organic nitrogen species can be used as nutrients

Antia *et al.* 1991

Particulate production vs. total dissolved nitrogen

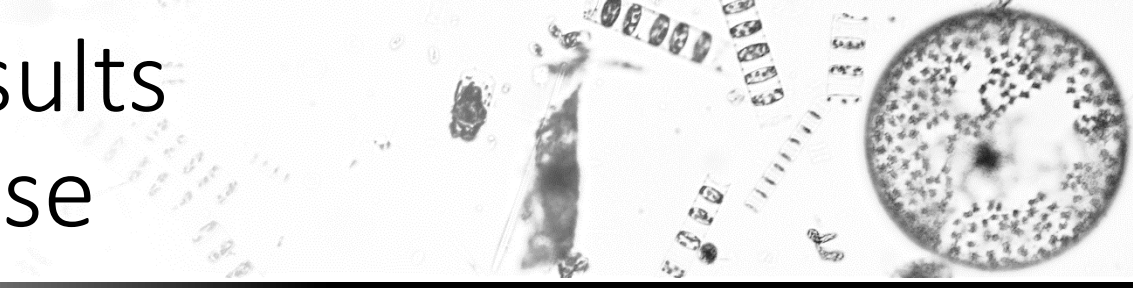


Dissolved inorganic nitrogen vs. total dissolved nitrogen



Environmental results

Extracellular release



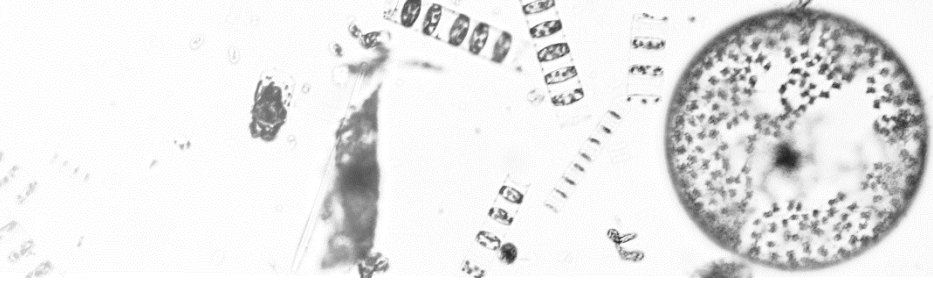
$$\ln(ER) = TDN + Salinity$$

$$\ln\left(\frac{ER}{Chl}\right) = TDN + Salinity$$

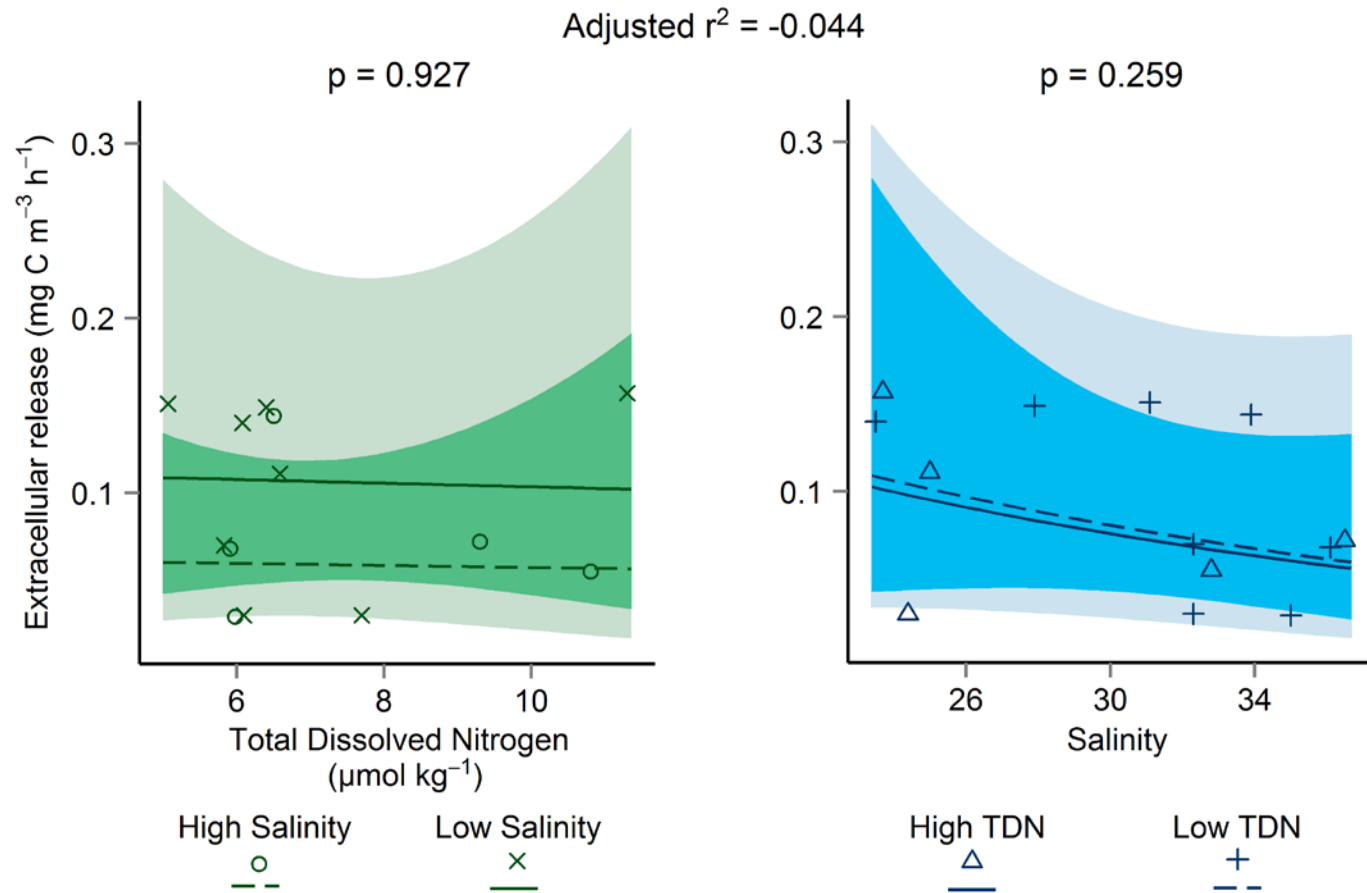
$$\ln\left(\frac{PER}{1 - PER}\right) = TDN + Salinity$$

Environmental results

Extracellular release

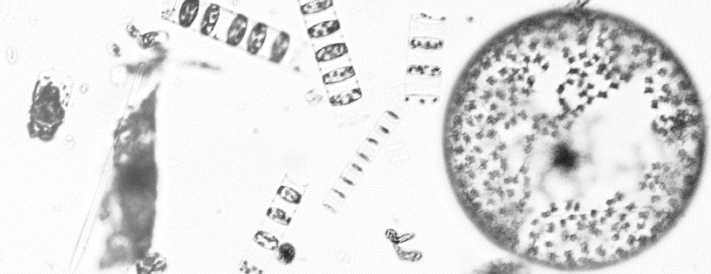


Extracellular DOC release vs. environmental parameters



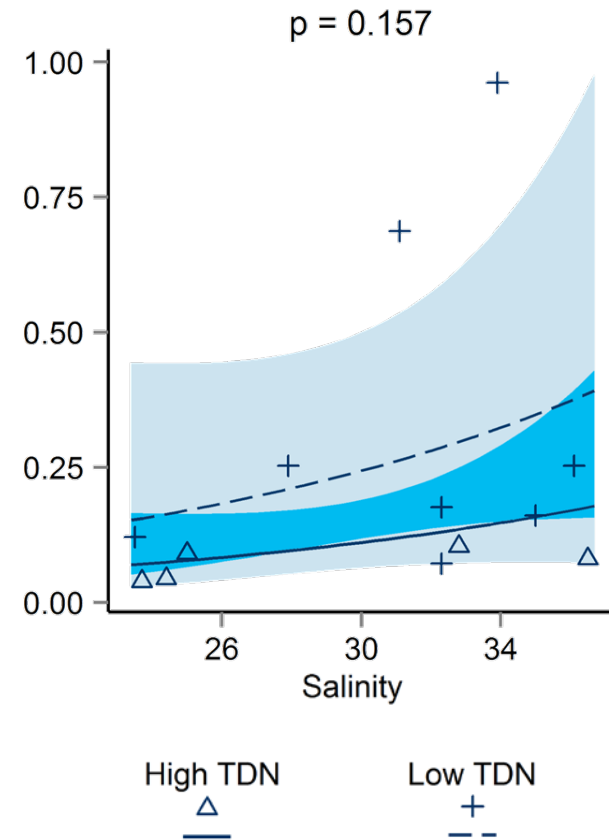
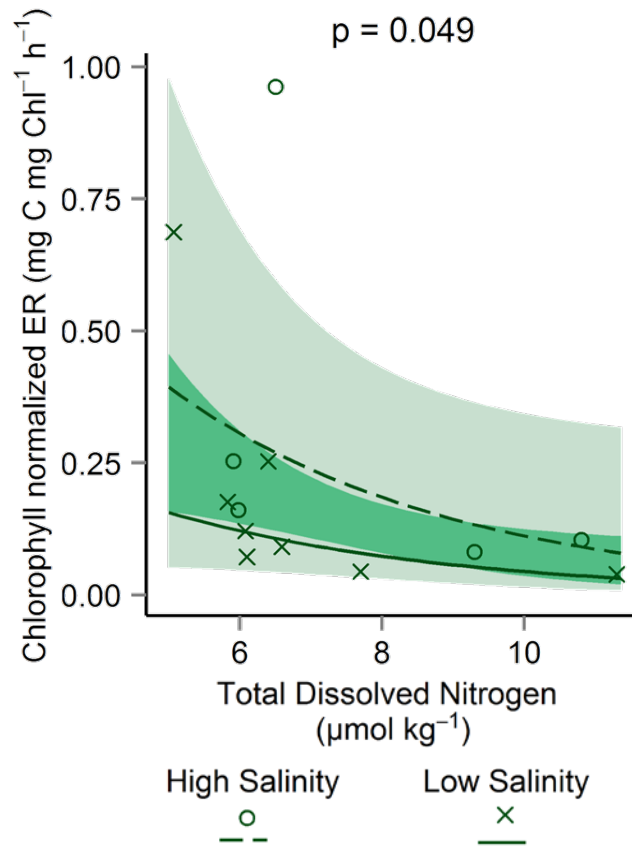
Environmental results

Chlorophyll Normalized ER



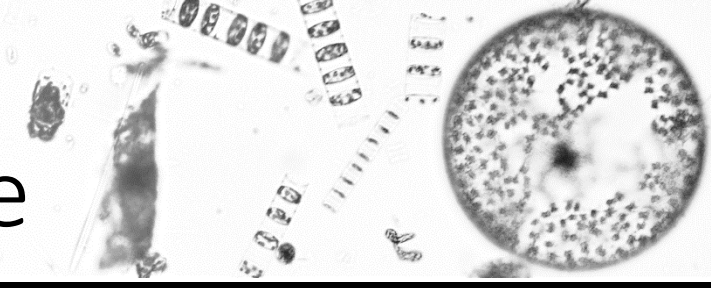
Chlorophyll normalized extracellular
DOC release vs. environmental parameters

Adjusted $r^2 = 0.355$



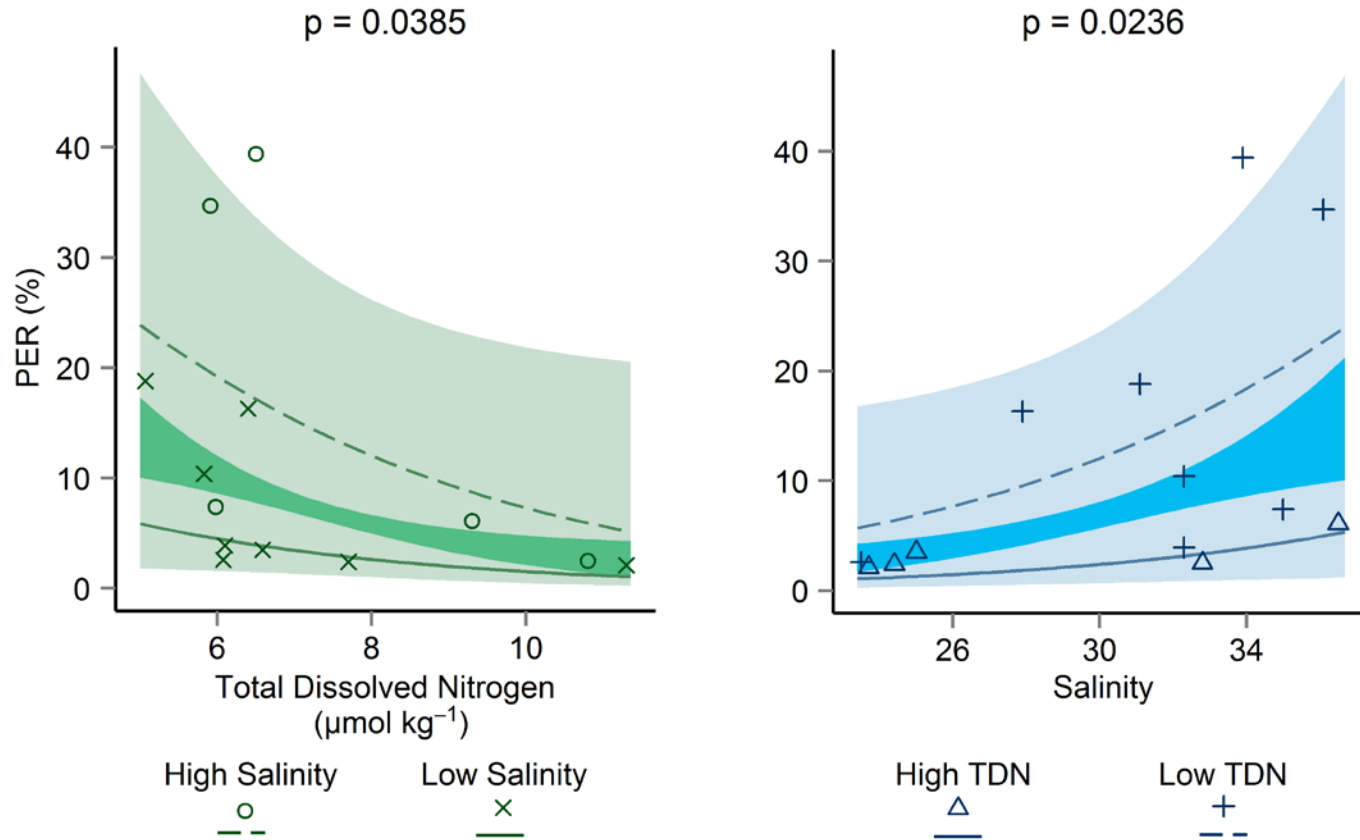
Environmental results

Percent extracellular release

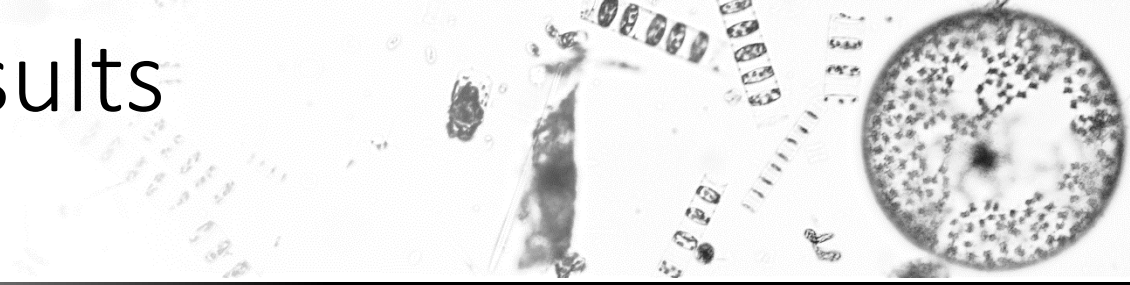


Percent extracellular release vs. environmental parameters

Adjusted $r^2 = 0.46$



Environmental results



Percent extracellular release is correlated with salinity.

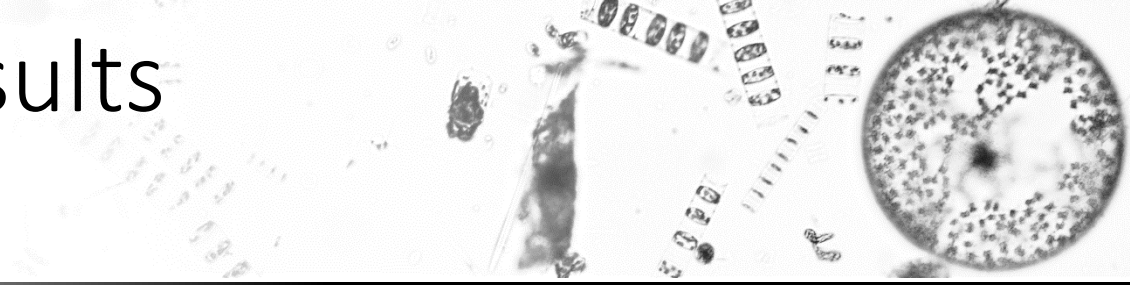
Why?

Low nutrients as plume and oceanic waters mix

or

Different phytoplankton in oceanic waters

Environmental results



Low nitrogen predicts high percent extracellular release and chlorophyll normalized ER.

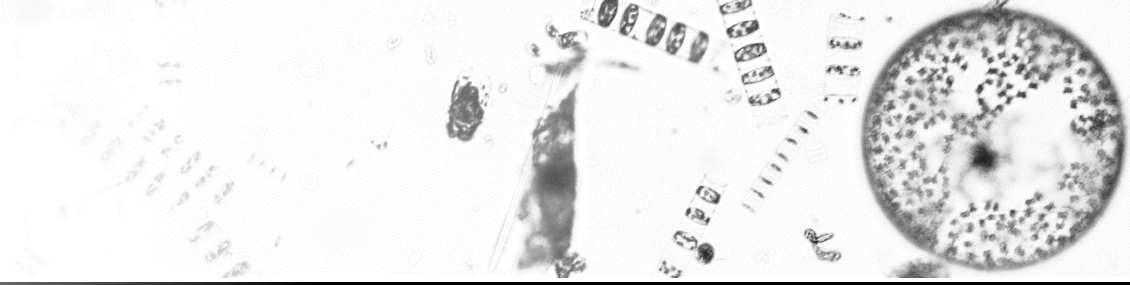
Why?

Nitrogen limitation/depletion

or

Shifting phytoplankton assemblages

Questions & Hypotheses



How does phytoplankton size affect DOC release?

~~The small size class will have higher relative extracellular release.~~

Do environmental gradients in the Amazon River Plume predict extracellular release?

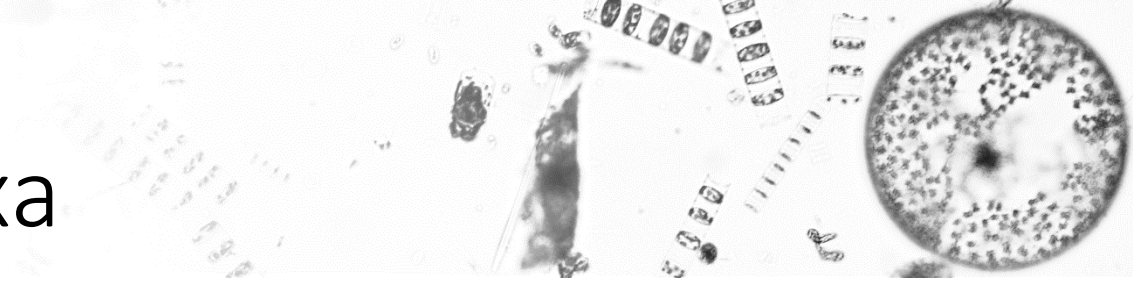
ER will rise as salinity increases, and as nitrogen concentrations decrease.

Does extracellular release vary by phytoplankton assemblage in the plume?

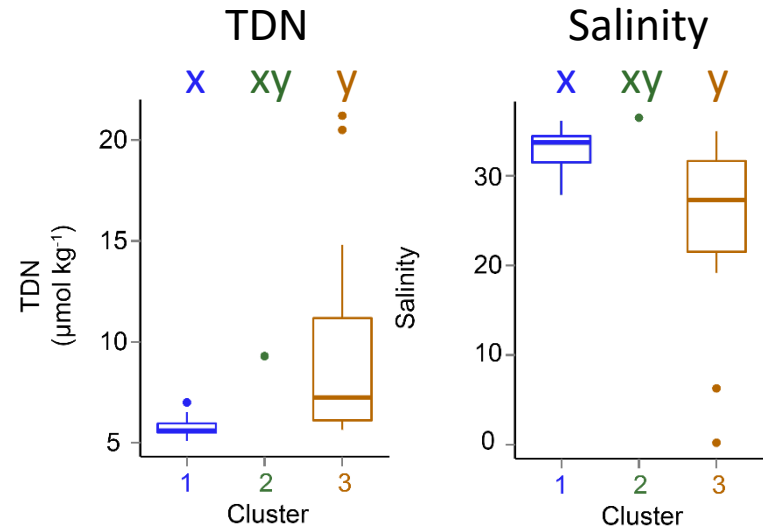
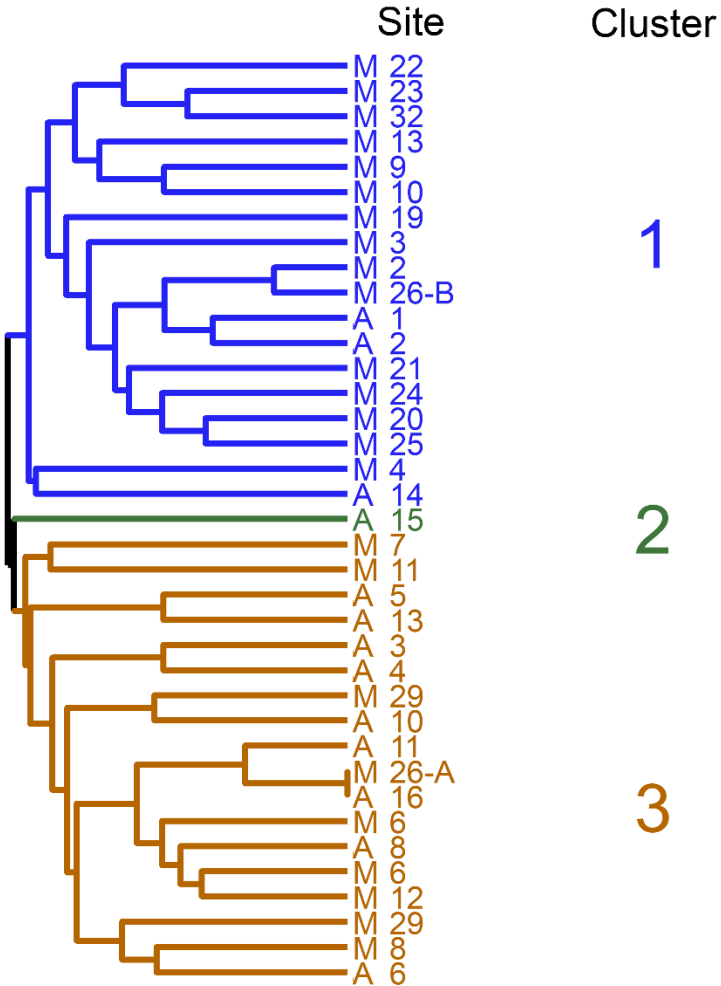
The extracellular release will vary between the different communities.

Results

Phytoplankton taxa

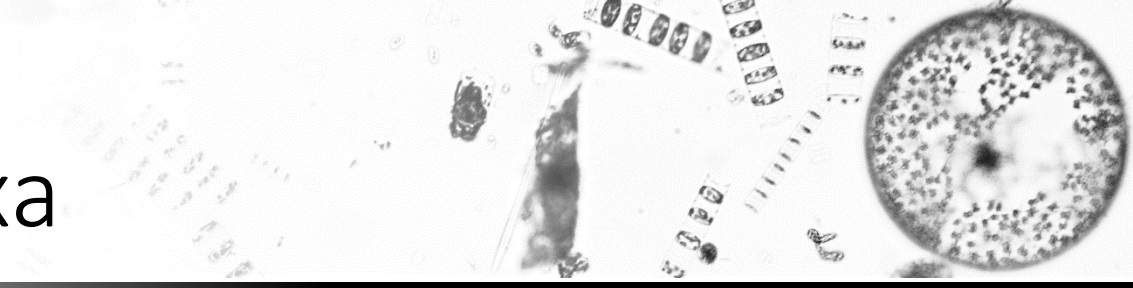


Taxa similarity by site

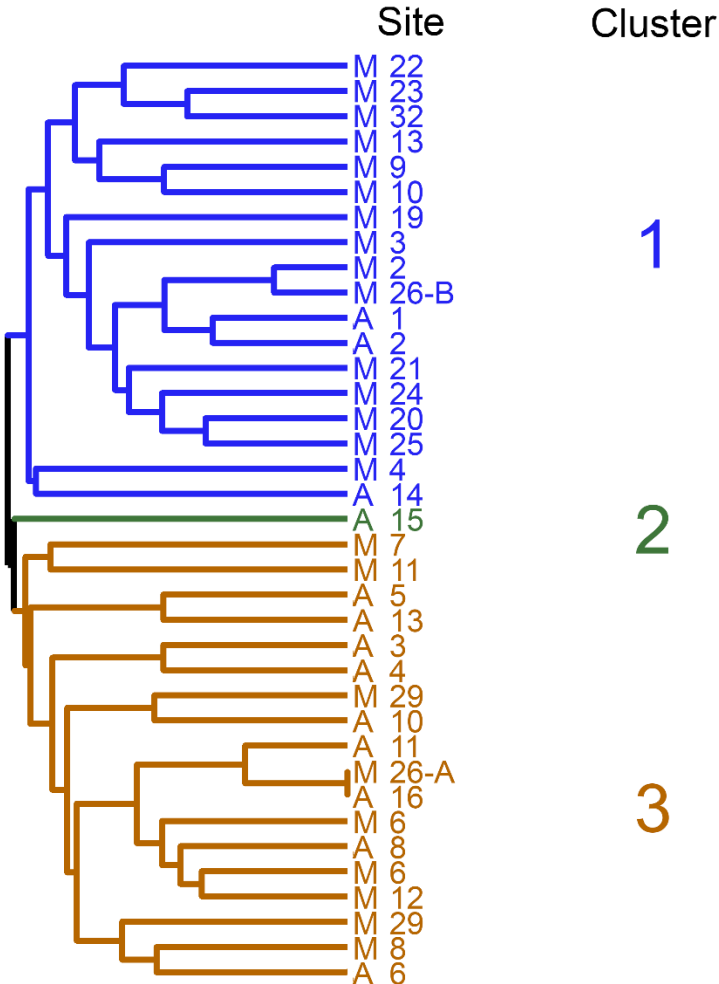


Results

Phytoplankton taxa



Taxa similarity by site



$$1 \quad IndVal_{ij} = A_{ij} * B_{ij}$$

Specificity:

Fidelity:

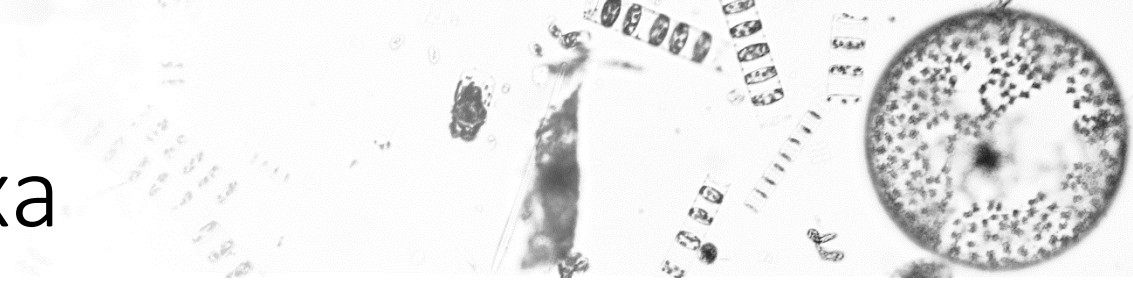
Proportion of each taxa in a given group

Proportion of stations in a group that contain a given taxa

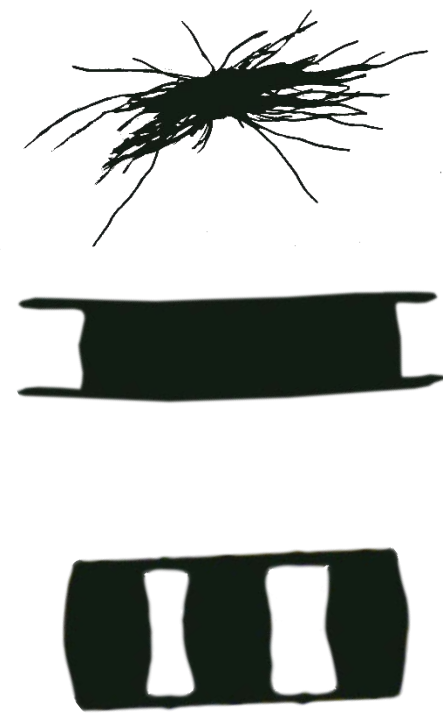
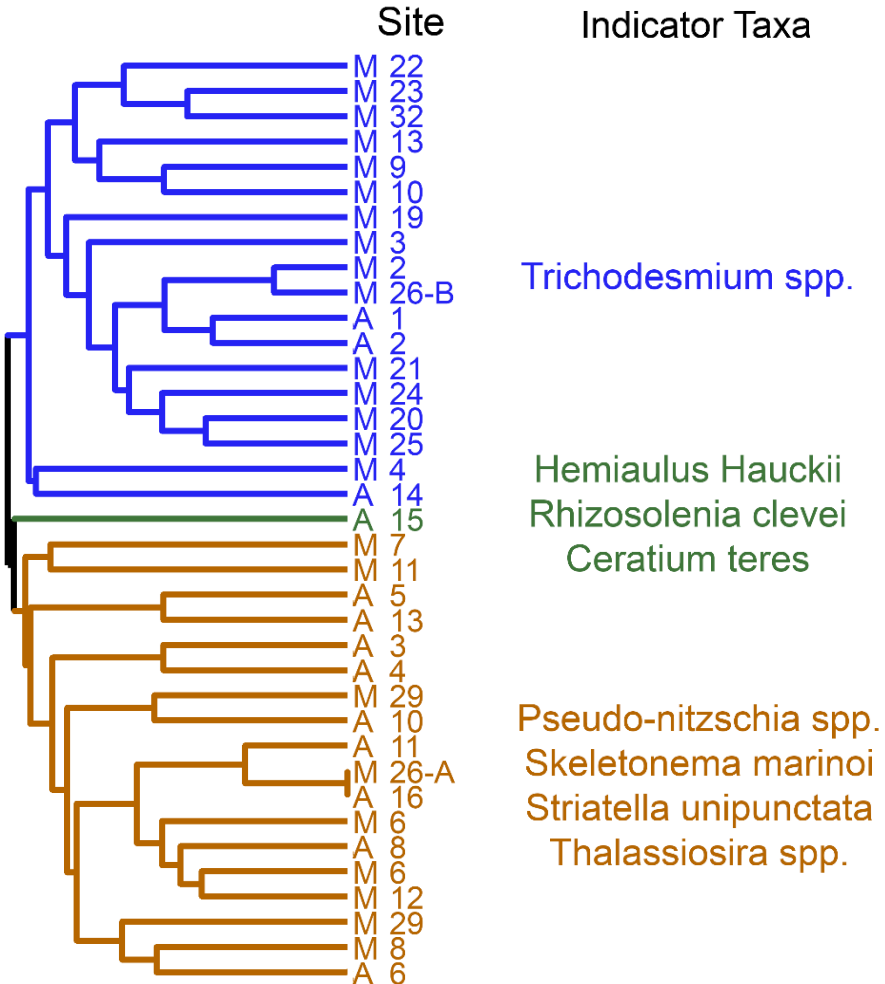
Dufre ne and Legendre, 1997

Results

Phytoplankton taxa

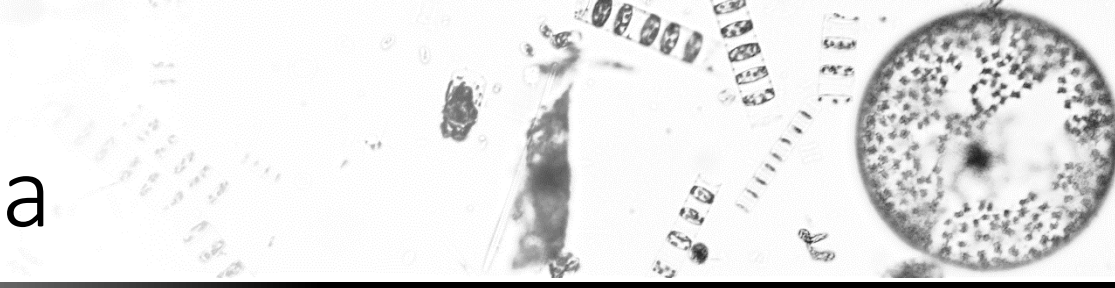


Taxa similarity by site

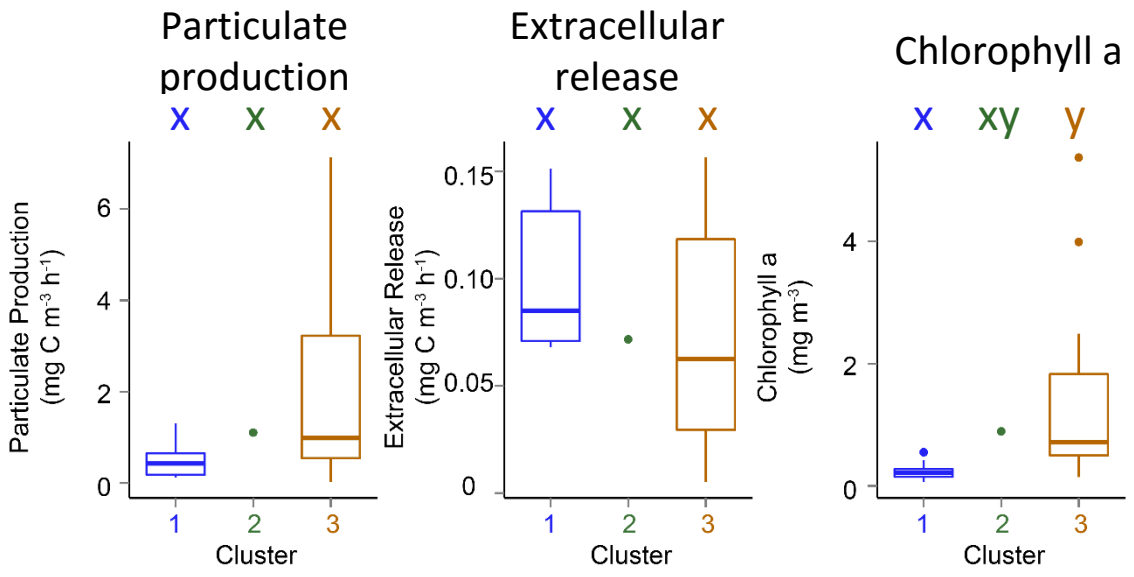
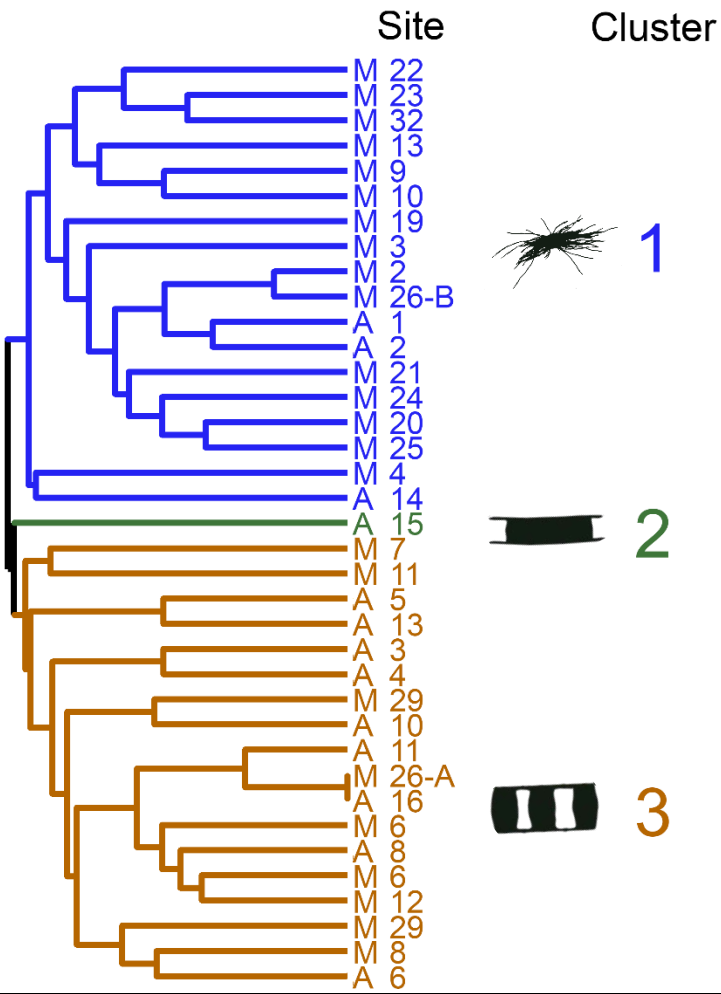


Results

Phytoplankton taxa



Taxa similarity by site

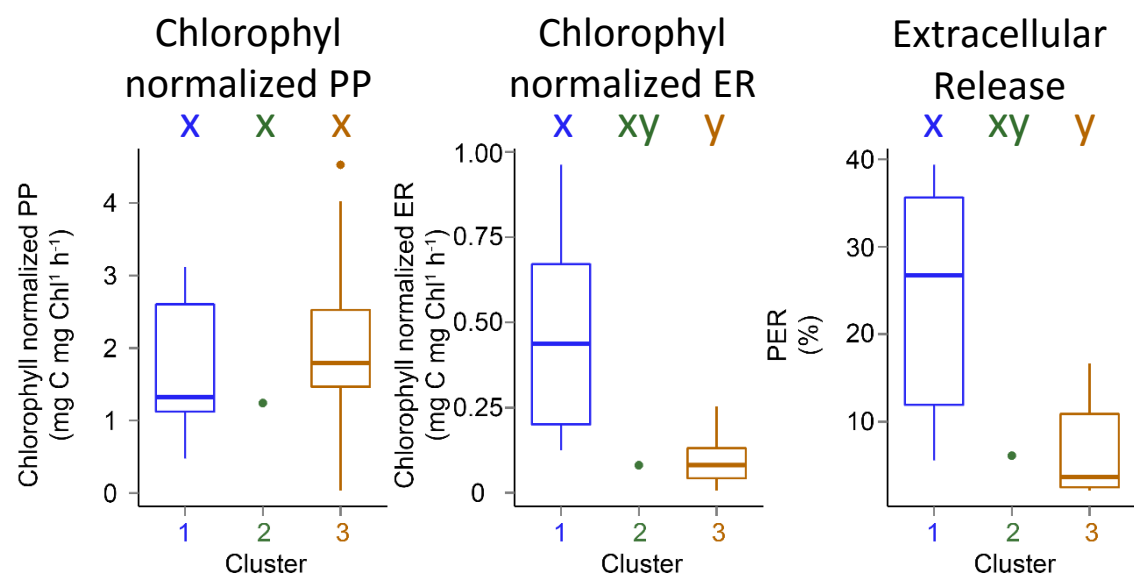
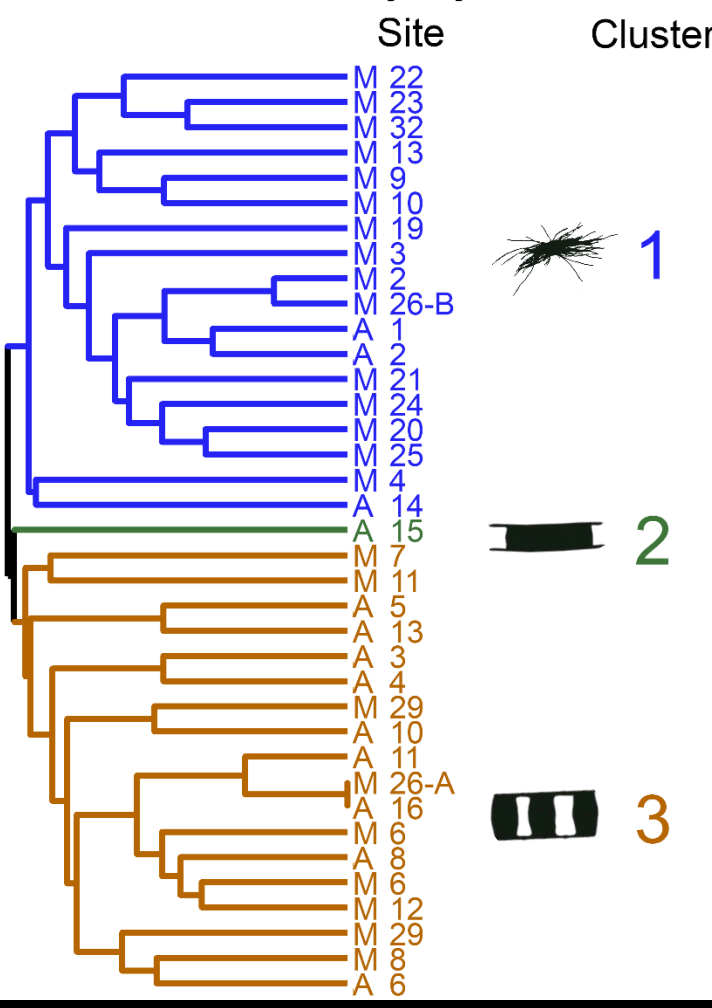


Results

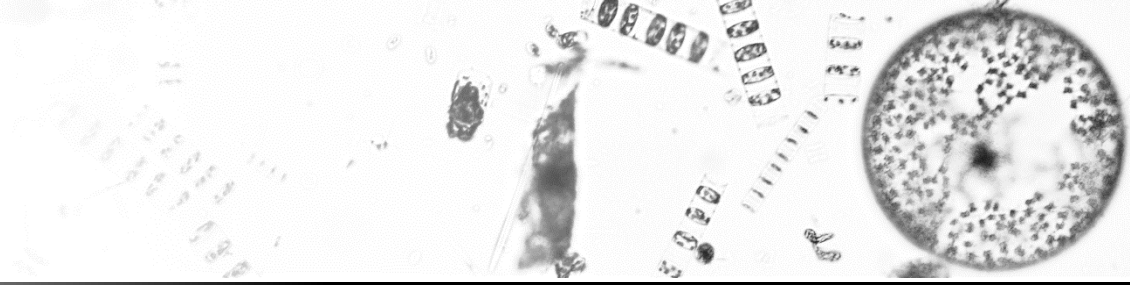
Phytoplankton taxa



Taxa similarity by site



Questions & Hypotheses



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ER will rise as salinity increases, and as nitrogen concentrations decrease.

Does extracellular release vary by phytoplankton assemblage in the plume?

The extracellular release will vary between the different communities.

Talk outline

A grayscale microscopic image showing biological tissue. On the right, there is a circular structure with a dense, granular interior and a darker central spot. To its left, there are elongated, segmented structures that appear to be part of a larger organism or tissue section.

Introductions

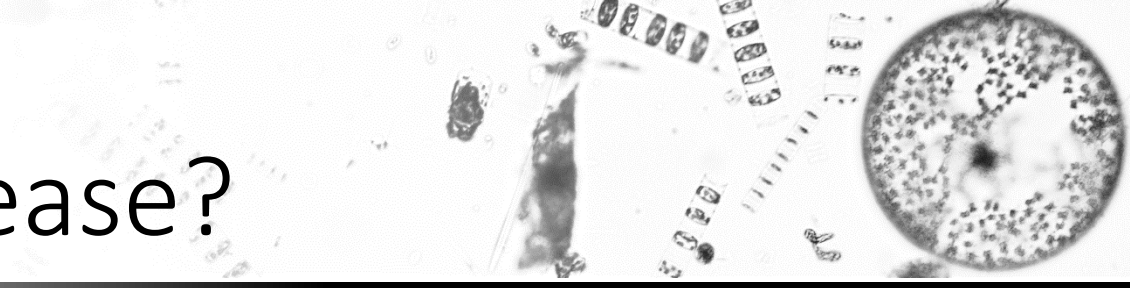
Objectives

Methods

Results

Conclusions

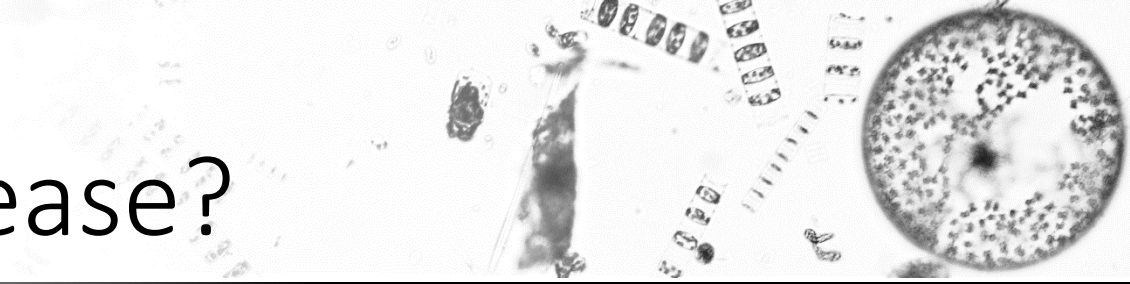
What drives
extracellular release?



Phytoplankton size

Nope!

What drives
extracellular release?



Environmental parameters

Extracellular release correlates with
nitrogen and salinity

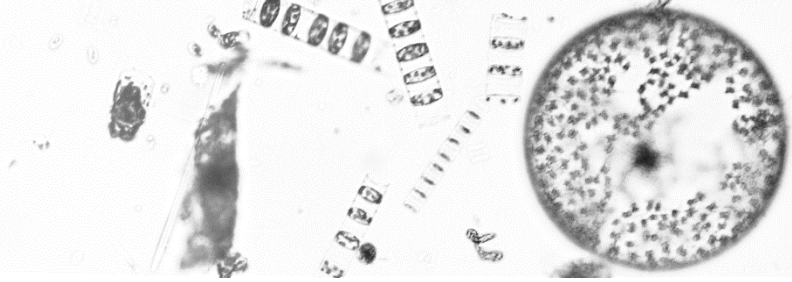
What drives
extracellular release?

Taxa Assemblage

The oceanic *Trichodesmium* stations had
high extracellular release

Stations with higher *Trichodesmium*
concentrations had higher release

Overall effects on the Amazon River Plume



High release in the oceanic region may change the overall sequestration by the plume.

Sedimentation rates may be underestimated

Rates based on DIC may be inaccurate

Take home messages

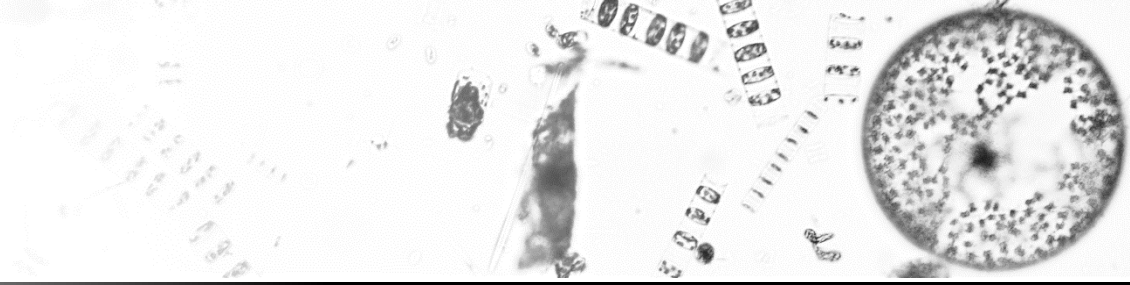


Extracellular release needs to be taken into account in the carbon cycle

Extracellular release in the Amazon River Plume can be predicted by the conditions affected by the river outflow

But those effects are secondary as taxa has a strong influence on release

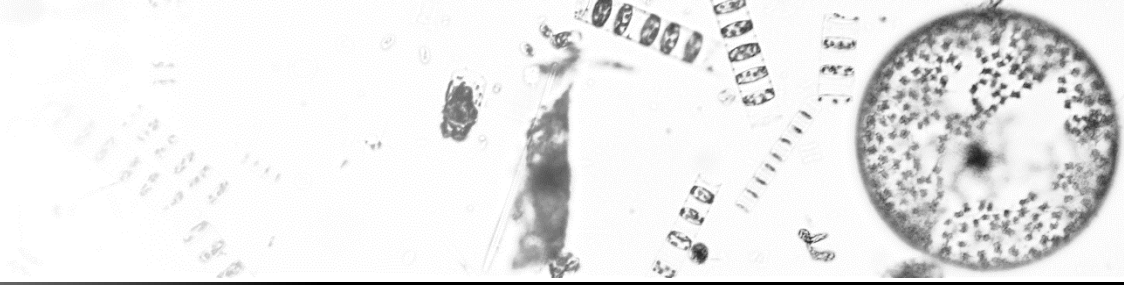
Next steps



Examine the potential sinks of the Dissolved organic carbon released in the system

Use nutrient amendments to further evaluate the role of nutrient concentrations on DOC release by the assemblages in the region

Thank you



Ed Carpenter



William Cochlan



Ina Benner

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Ned Antell, Gail Ashton, Sarah Blaser, Lina Ceballos, Anna Deck, Dick Dugdale, Anastasia Ennis, Toni Ignoffo, Chris Ikeda, Allison Johnson, Karen Kayfetz, Wim Kimmerer, Tomoko Komada, Jamie Lee, Calvin Lee, Nate Miller, Julien Modéran, Anne Slaughter, Joseph Spauldings, Jonathan Stillman, Shannon Strong, Frances Wilkerson, Charles Wingert

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Thank you

