A Phytoplankton Conceptual Diagram and Some Phytoplankton-Water Clarity Relationships

Claire Buchanan (ICPRB)

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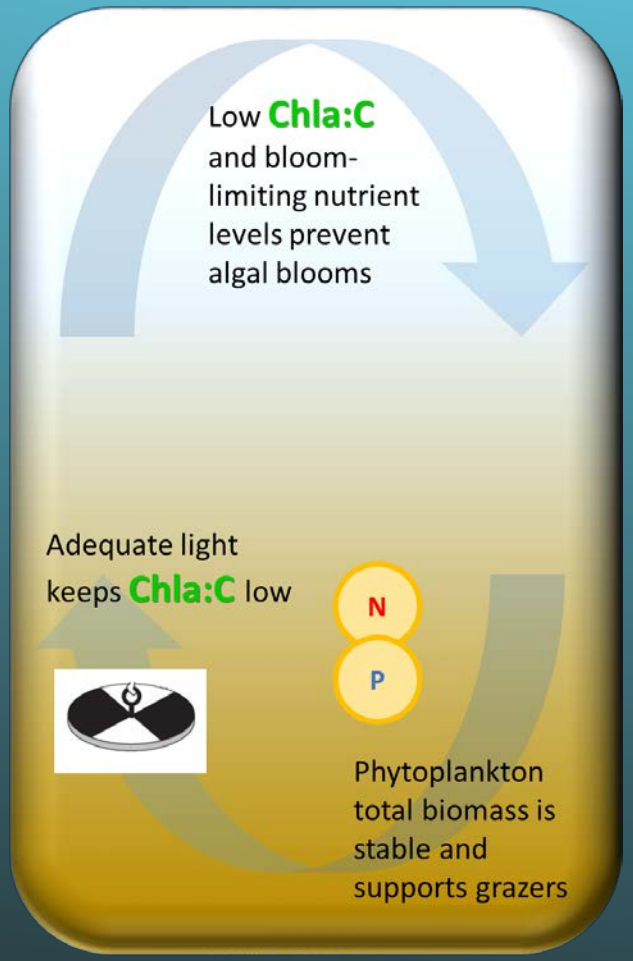
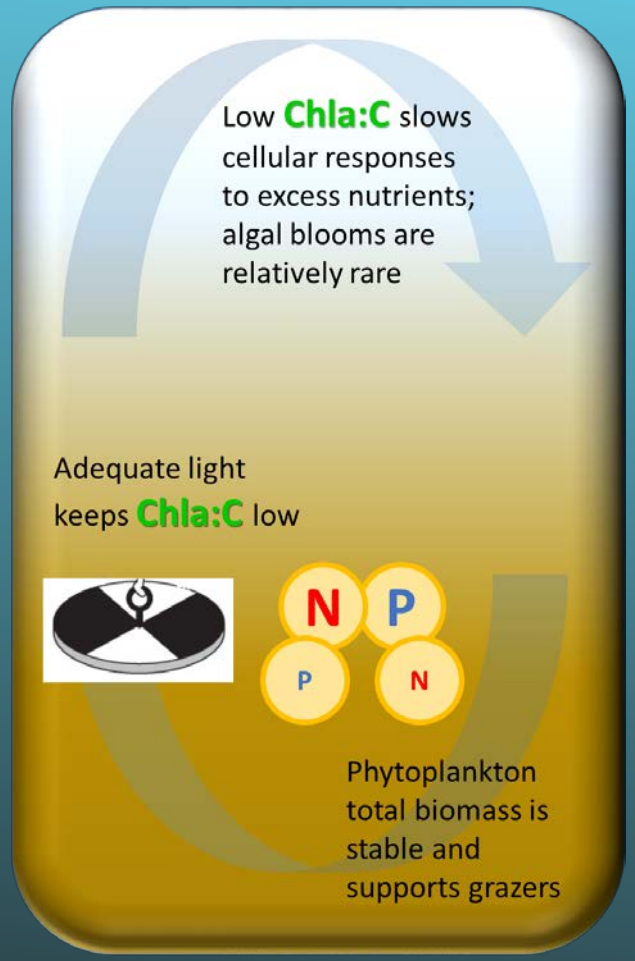
Water Clarity Workshop II

Phytoplankton Conceptual Diagram



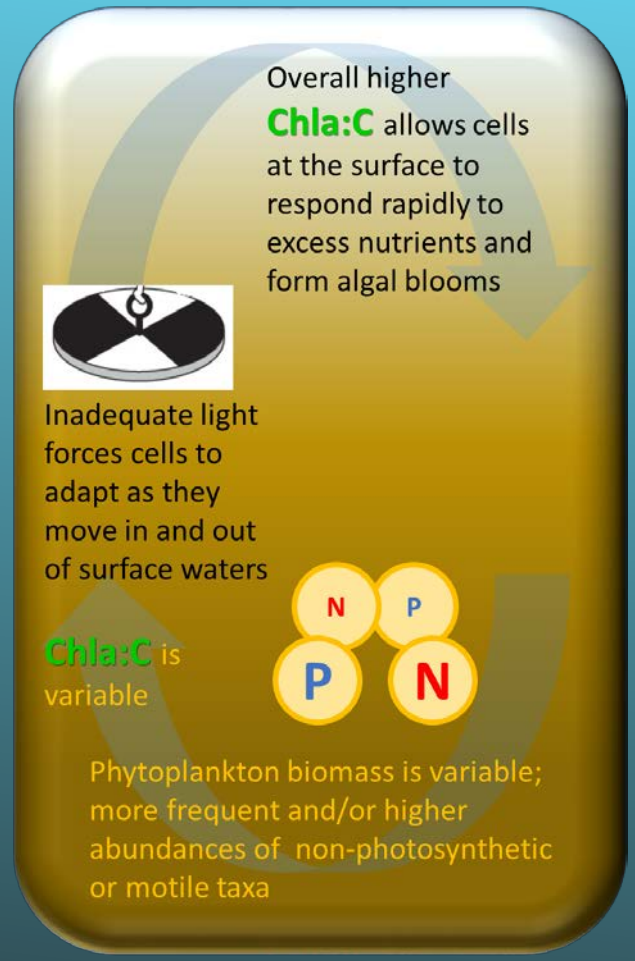
Reference

Adequate clarity *and* bloom-limiting DIN *and* bloom-limiting PO_4



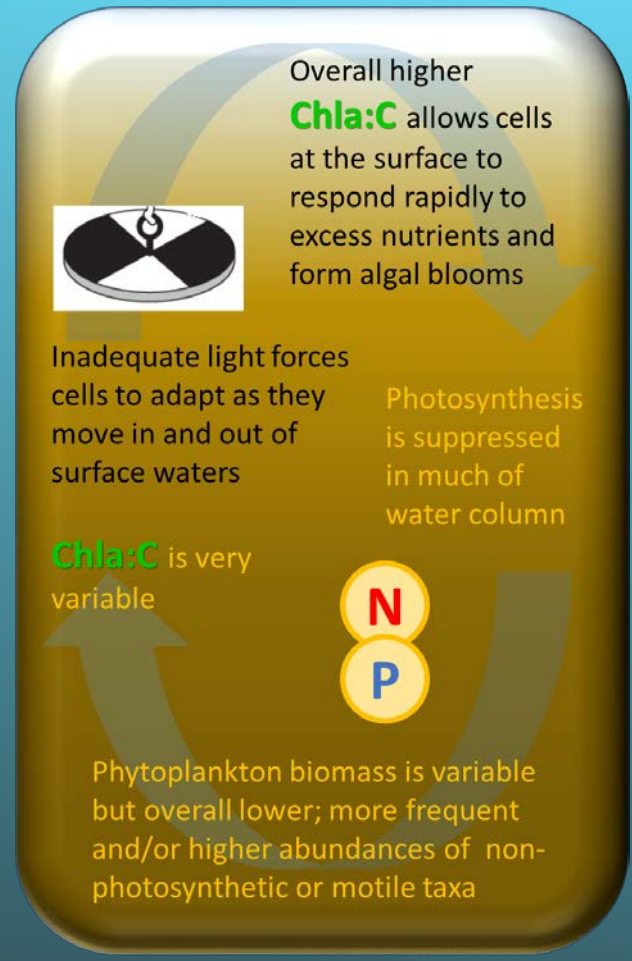
Mixed Better Light

Adequate clarity but DIN *and/or* PO_4 is excess



Mixed Poor Light

Inadequate clarity but DIN *and/or* PO_4 is bloom-limiting



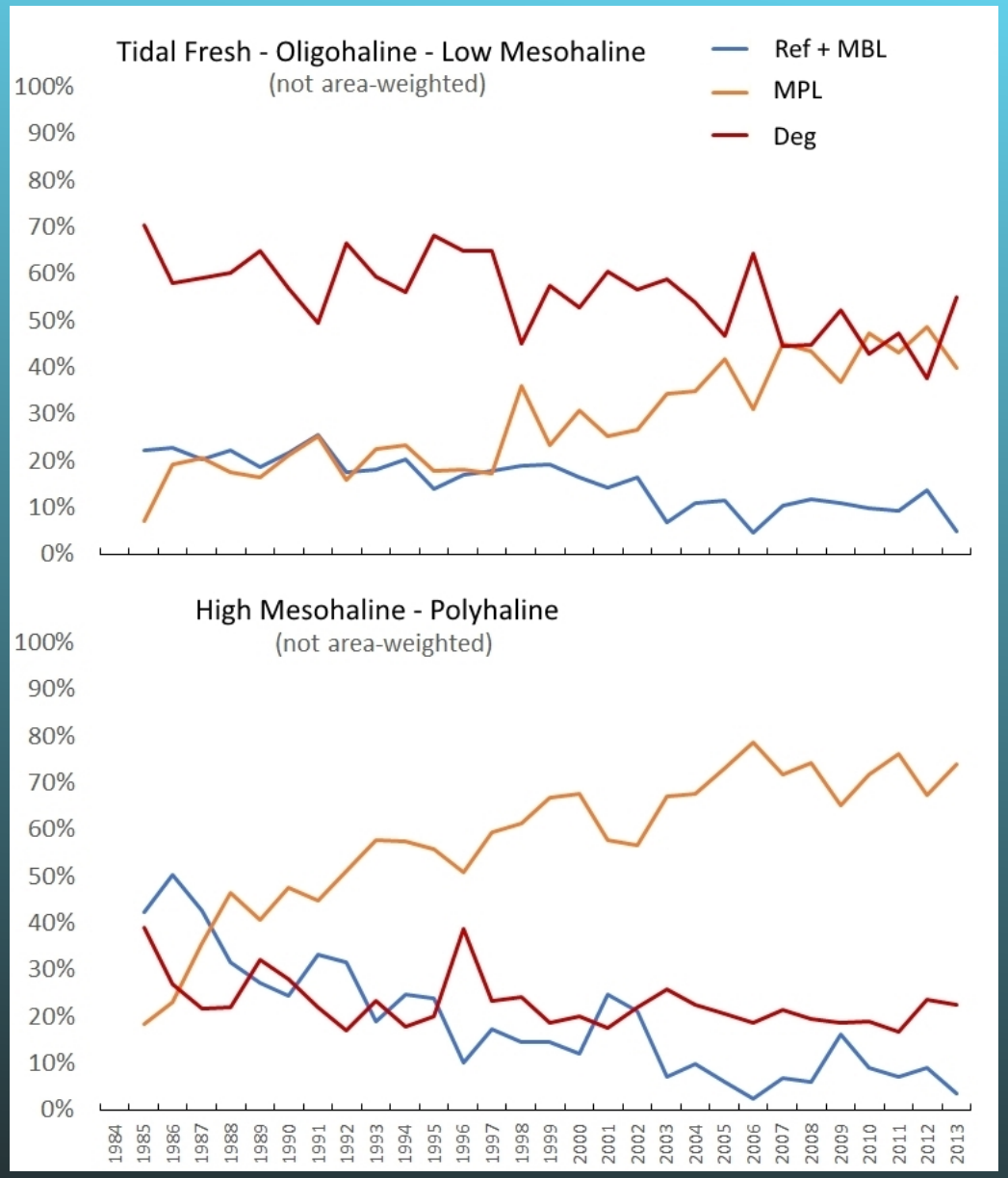
Degraded

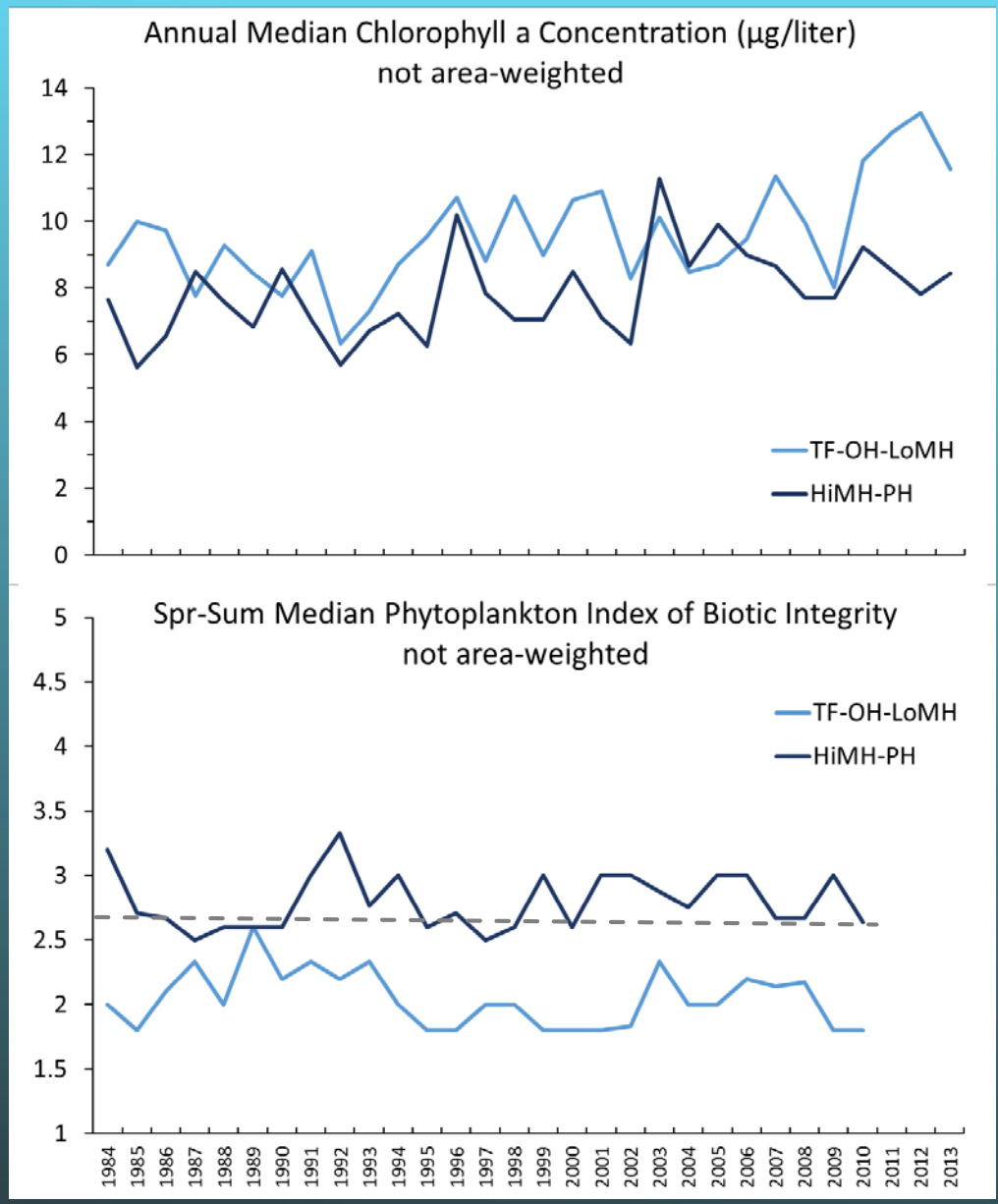
Inadequate clarity *and* excess DIN *and* excess PO_4

Phytoplankton Conceptual Diagram

Light Requirements (Secchi Depth, m)

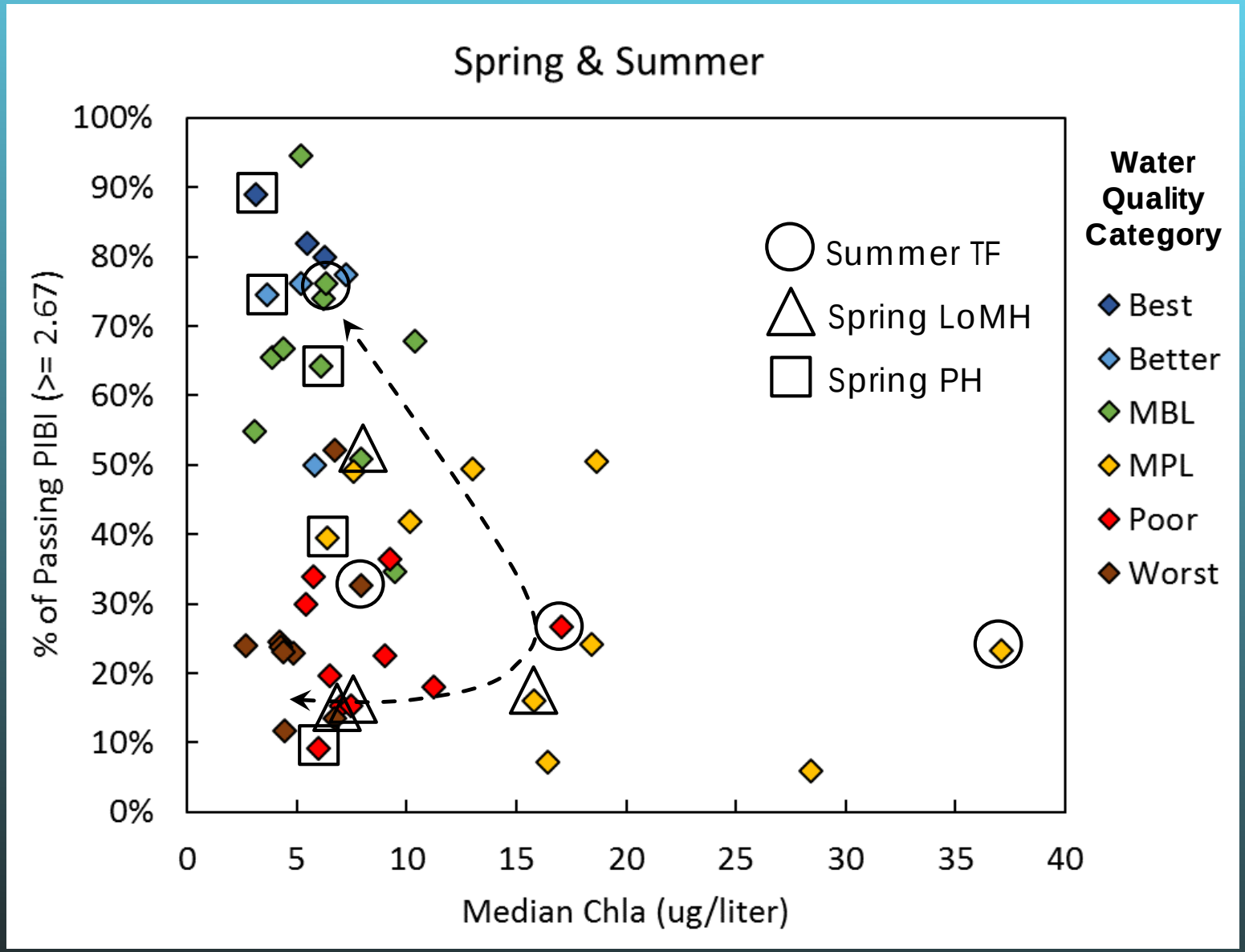
Salinity Zone	Phytoplankton (seasonal)	SAV (1m & 2m application depth)	
Tidal Fresh	0.7 – 0.9	0.7	1.4
Oligohaline	0.7 – 0.9	0.7	1.4
Low Mesohaline	1.2 – 1.4	1.0	1.9
High Mesohaline	1.4 – 2.0	1.0	1.9
Polyhaline	1.6 – 2.1	1.0	1.9





PIBI correctly ID's REF and DEG 70% - 84%

Phytoplankton Recovery (Degradation) Trajectory?



Water Clarity ←→ Phytoplankton

Photosynthesis requires photons

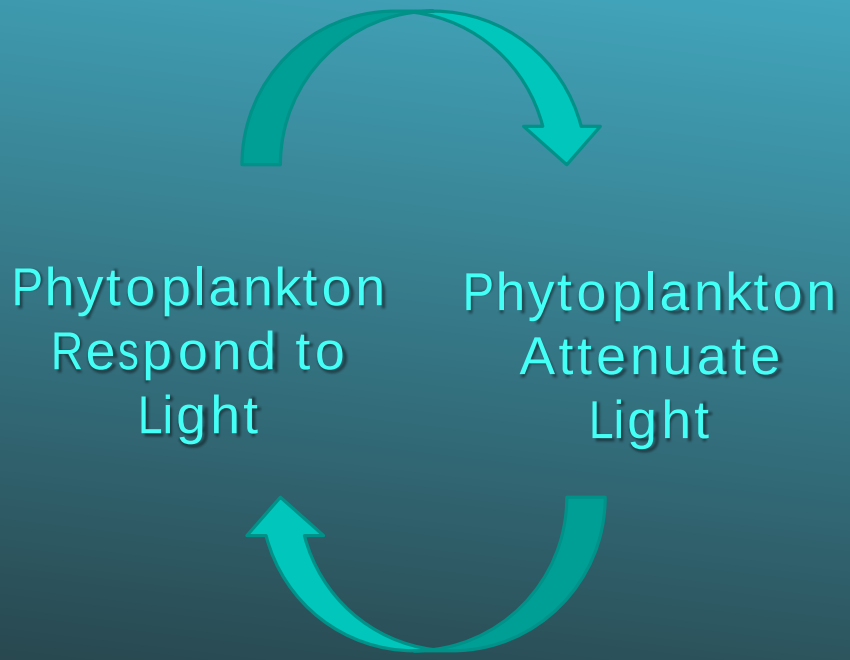
↕

Phytoplankton cells adjust photopigment levels to capture sufficient photons

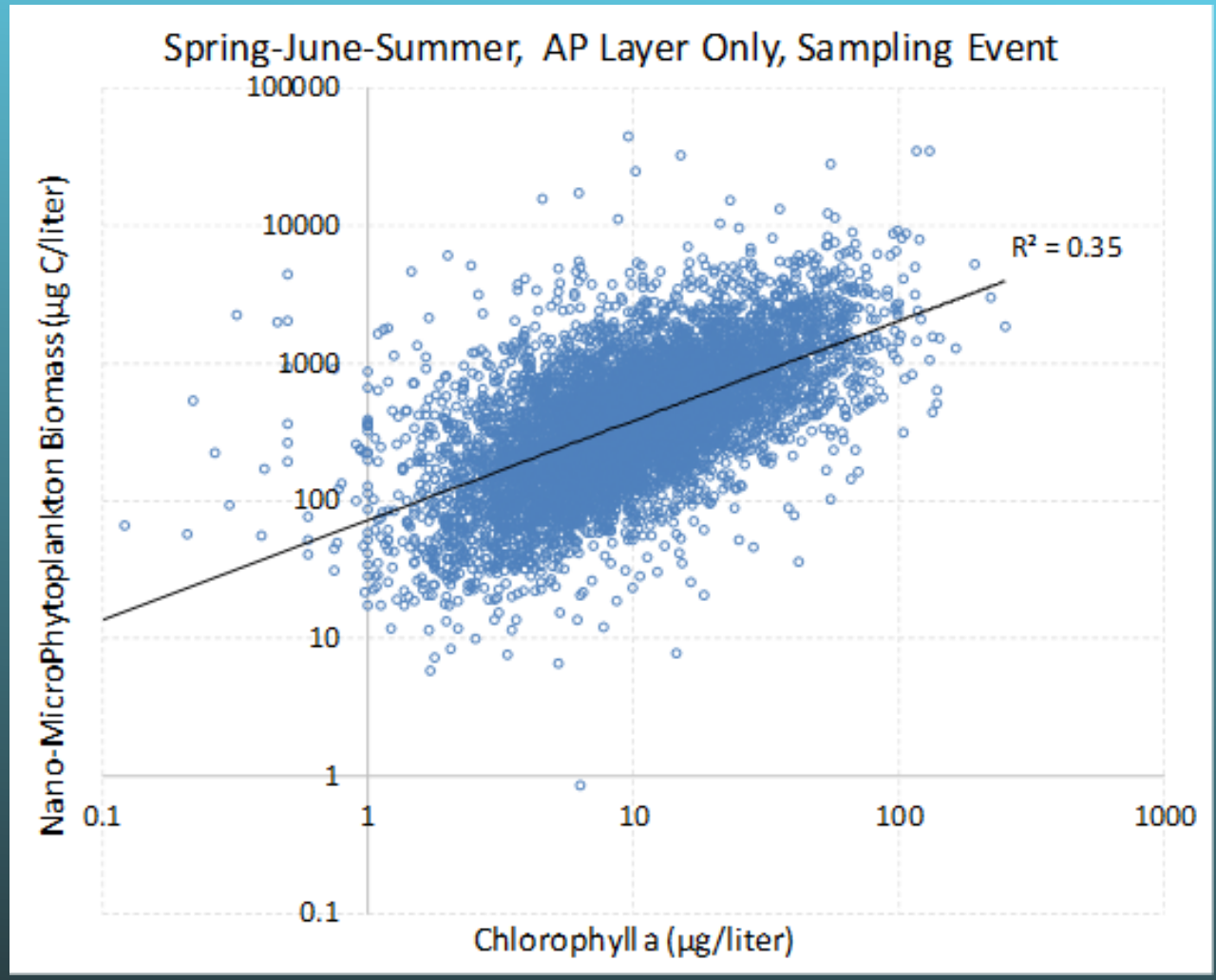
↕

Cells adapt or die in poor light environments

- Mixotrophy
- Buoyancy/motility



Phytoplankton Chlorophyll as a Surrogate for Biomass

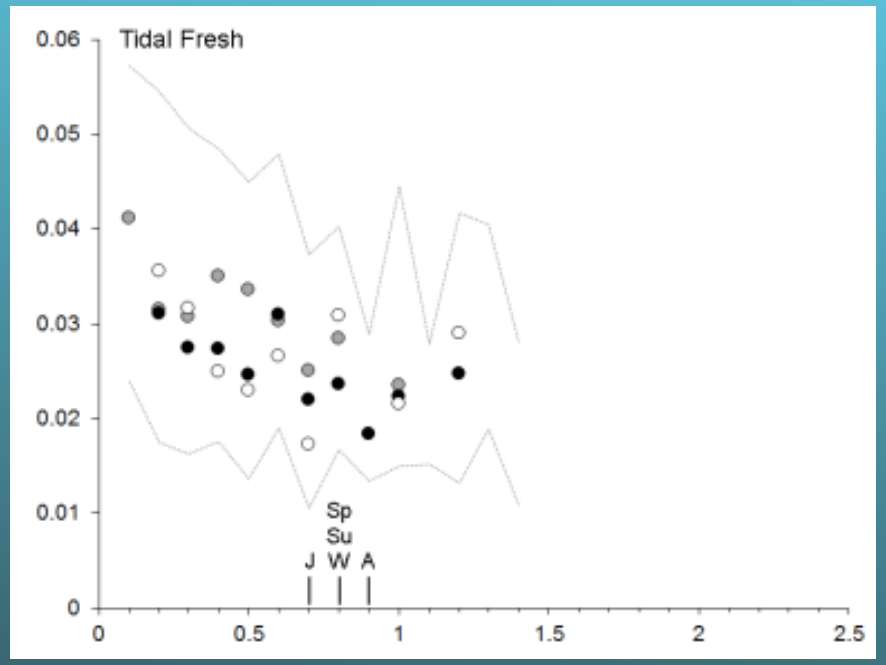


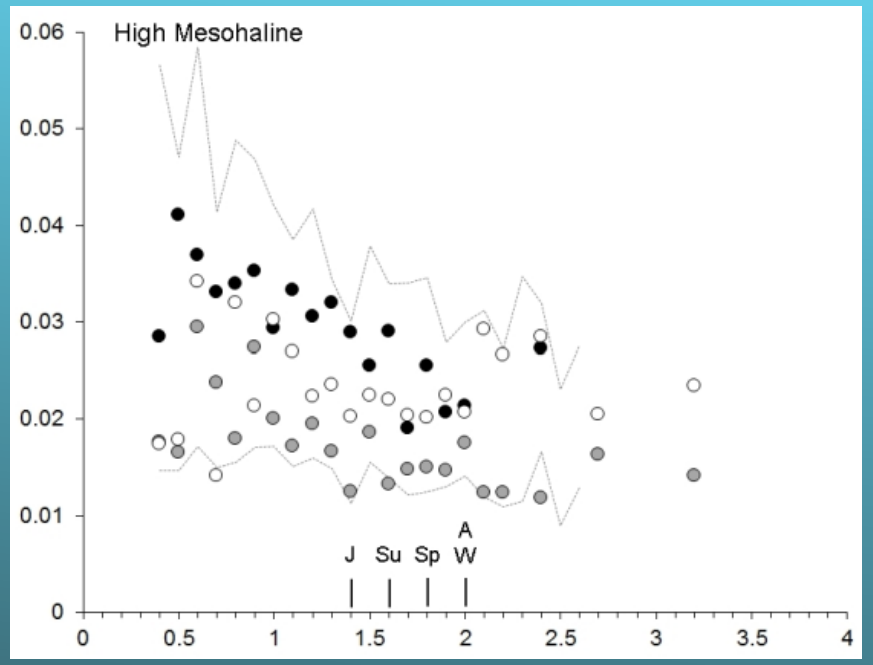
...not so good!

Cell Adaptation in Low Light

Chla : PhytoC

- Spring
- Summer
- Autumn-Winter
- 25th – 75th %ile





Secchi Depth (m) →

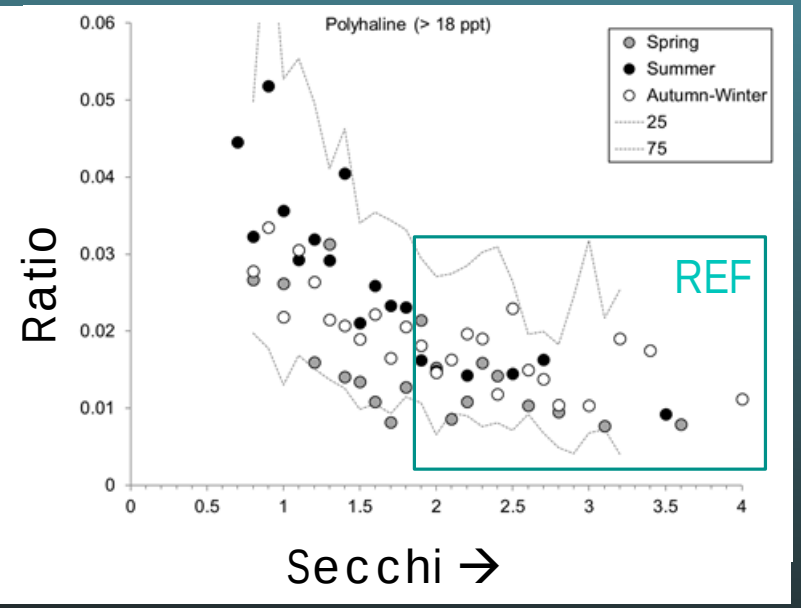
$$\text{Chla : PhytoC} = \frac{\text{Chlorophyll } a \text{ (µg/liter)}}{\text{Total Nano-Micro-Phytoplankton Biomass (µg C/liter)}}$$

$$\text{Pheo : PhytoC} = \frac{\text{Pheophytin (µg/liter)}}{\text{Total Nano-Micro-Phytoplankton Biomass (µg C/liter)}}$$

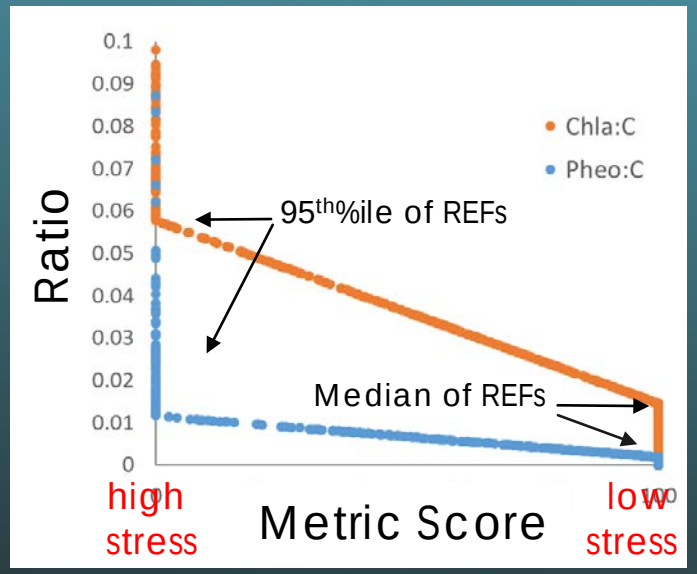
Cell Adaptation to Low Light

Indicator of low-light stress

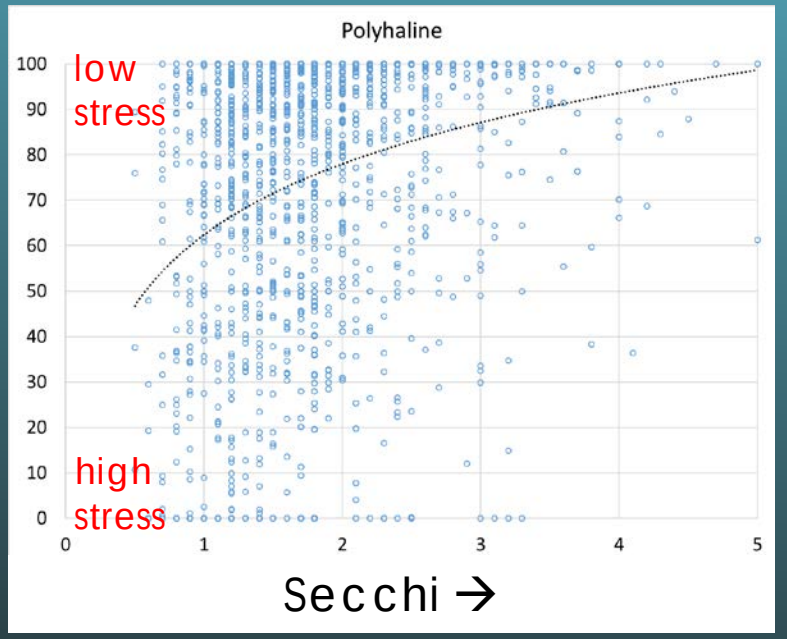
Ratios vs Secchi depth

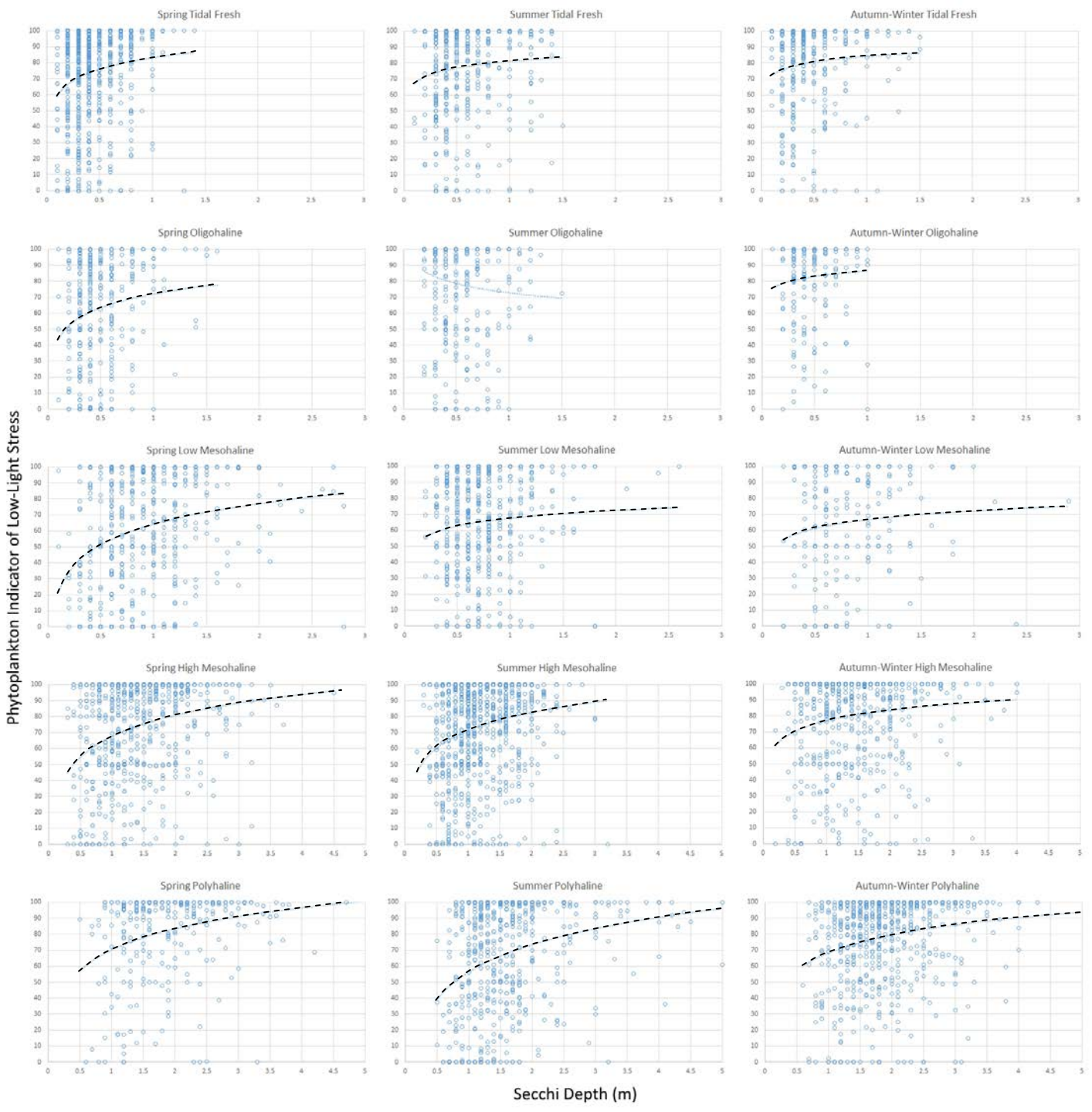


Ratios converted to unitless scores and averaged



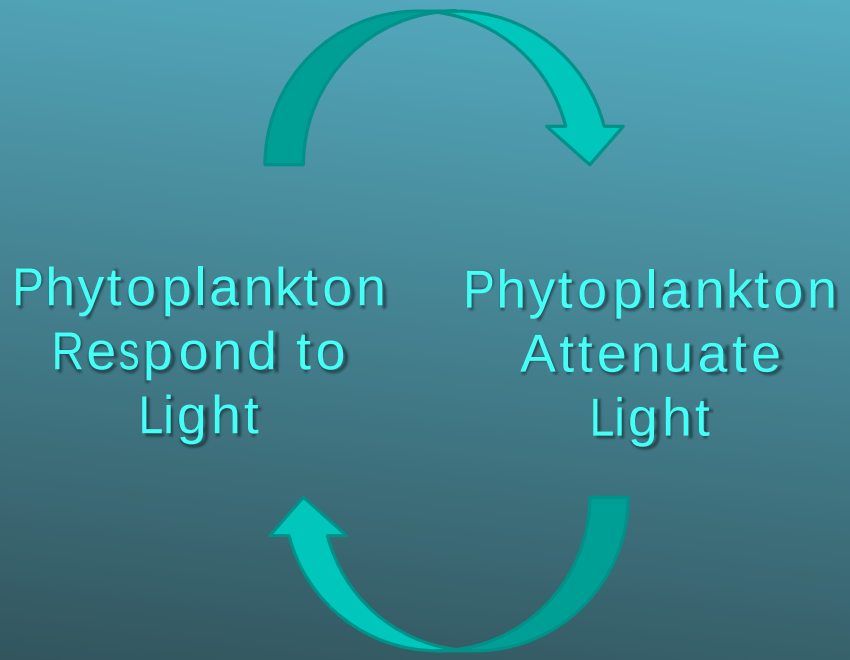
Indicator score vs Secchi depth





As Secchi depth improves, variability in cellular photopigment levels decreases and stress due to low-light conditions is minimized

Phytoplankton ←→ Water Clarity



Phytoplankton attenuate light in several ways

↕

Living cells leak DOM – leak faster if stressed by

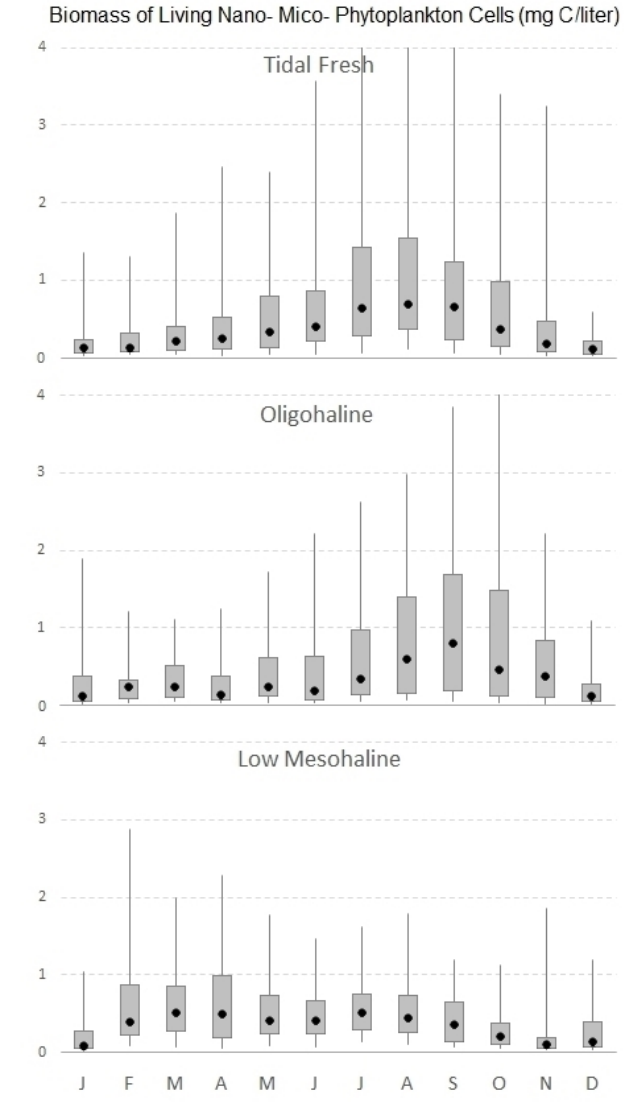
- Low light levels
- High cell densities
- Viruses & parasitic fungi
- Grazers
- Salinity

↕

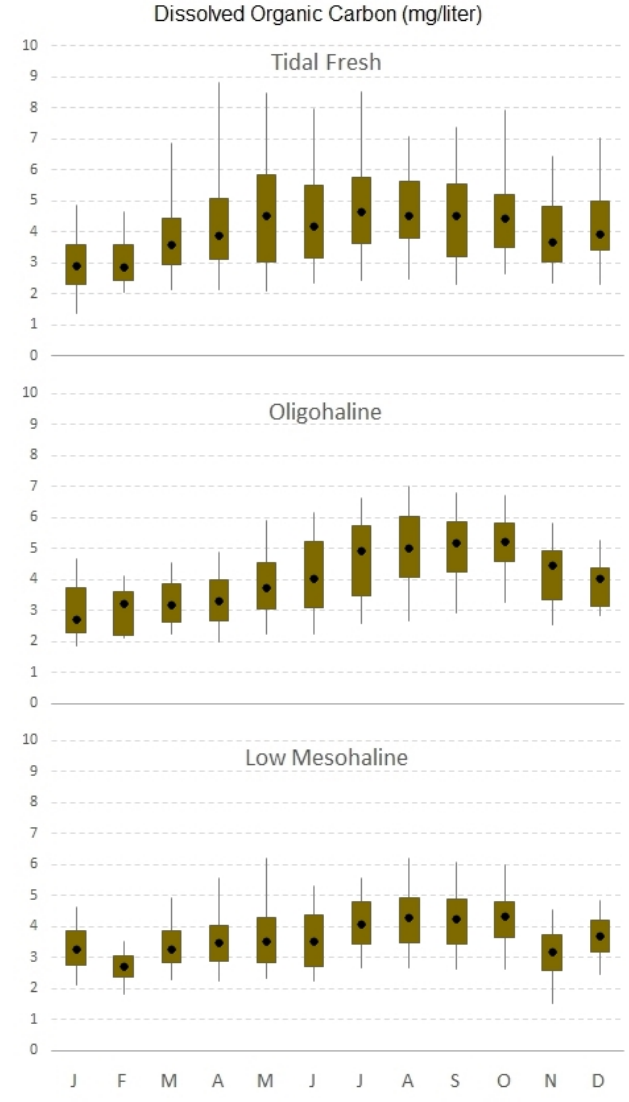
Living cell structure is one component of TSS and mostly scatters light

Phytoplankton Biomass and DOC

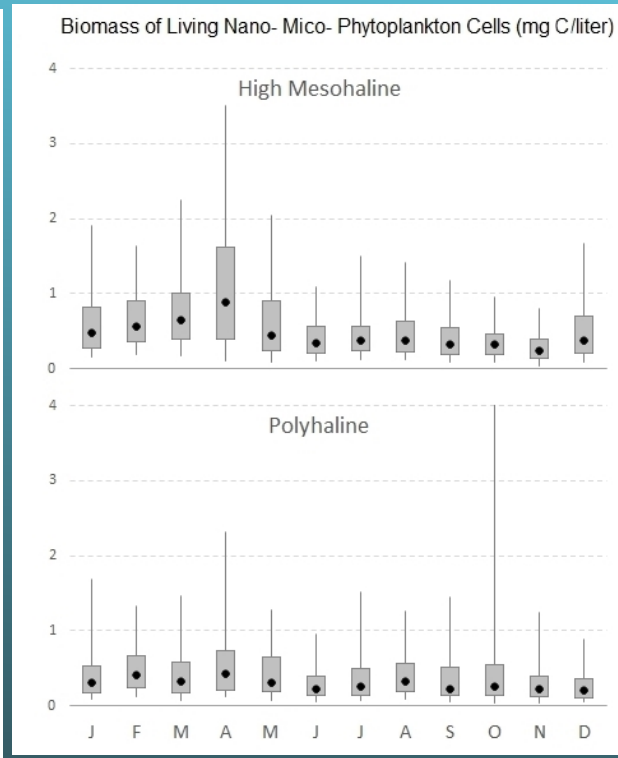
Biomass



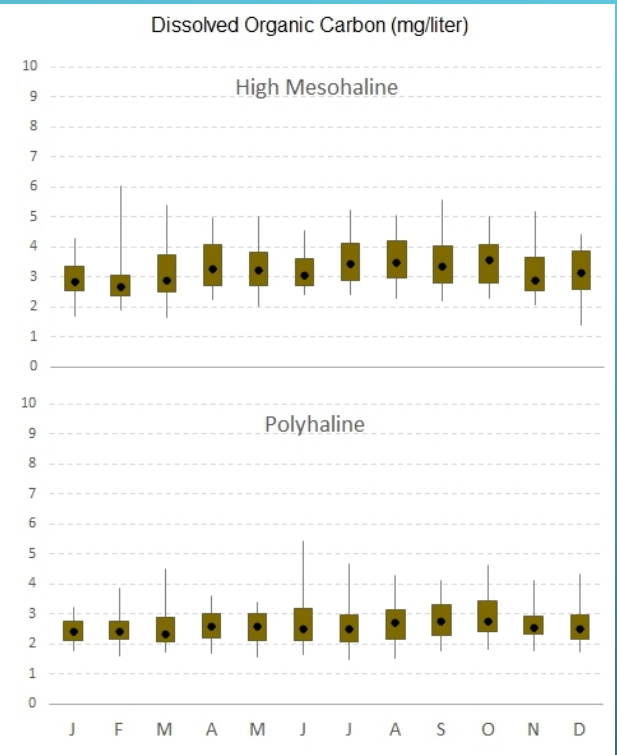
DOC



Biomass



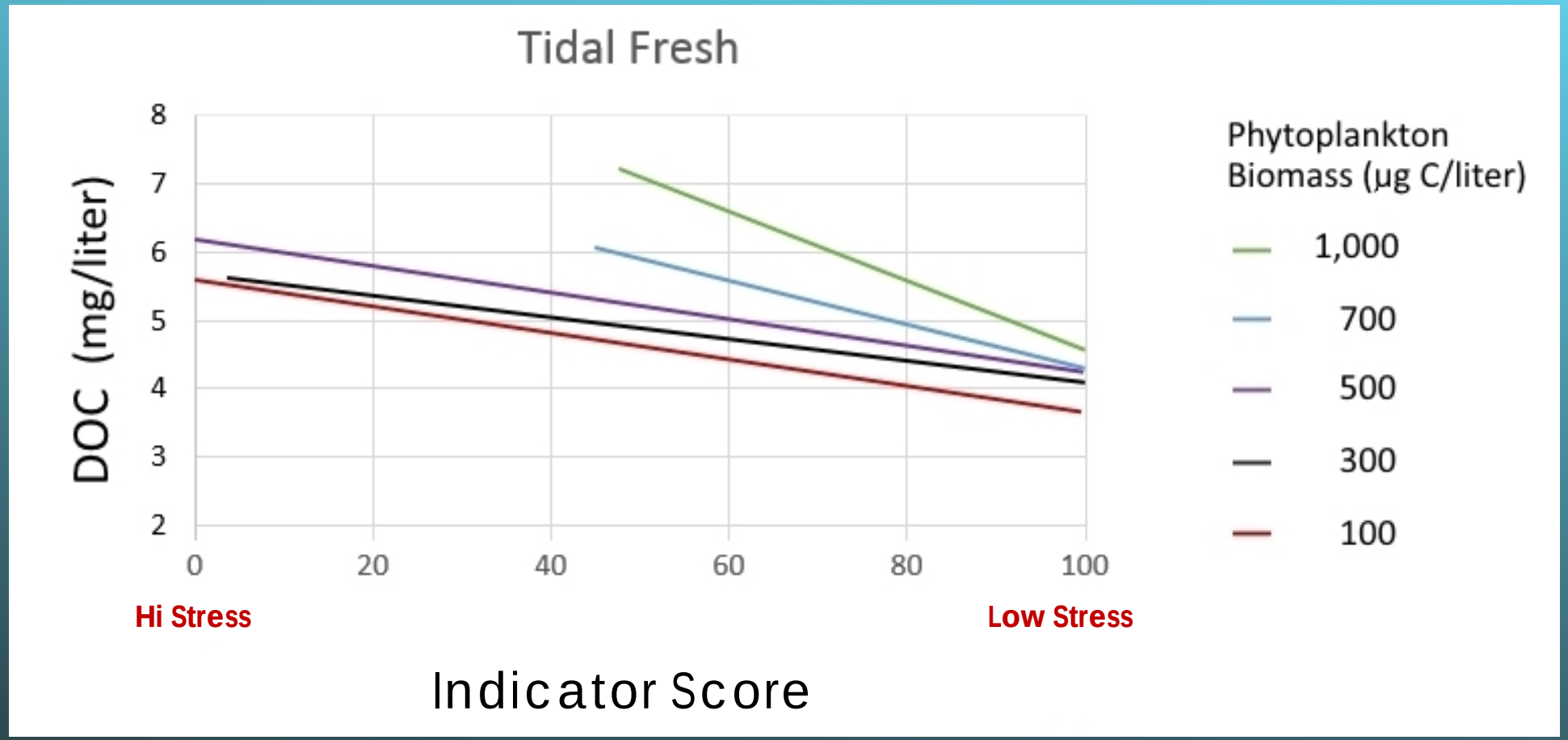
DOC



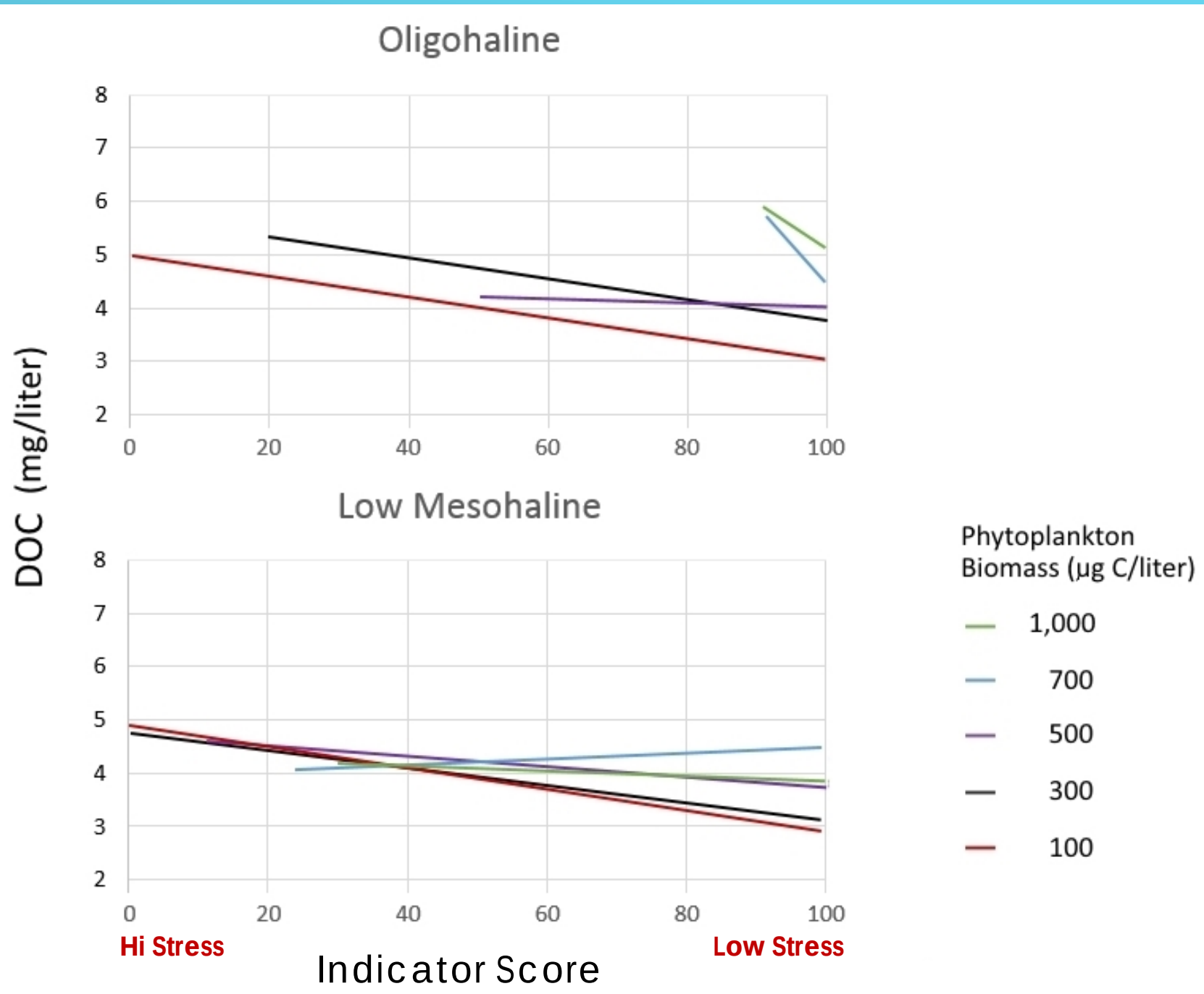
CBP data, 1985 – 2010

DOC paired with biomass at phytoplankton monitoring stations only

Relationship of Low-Light Stress Indicator to DOC

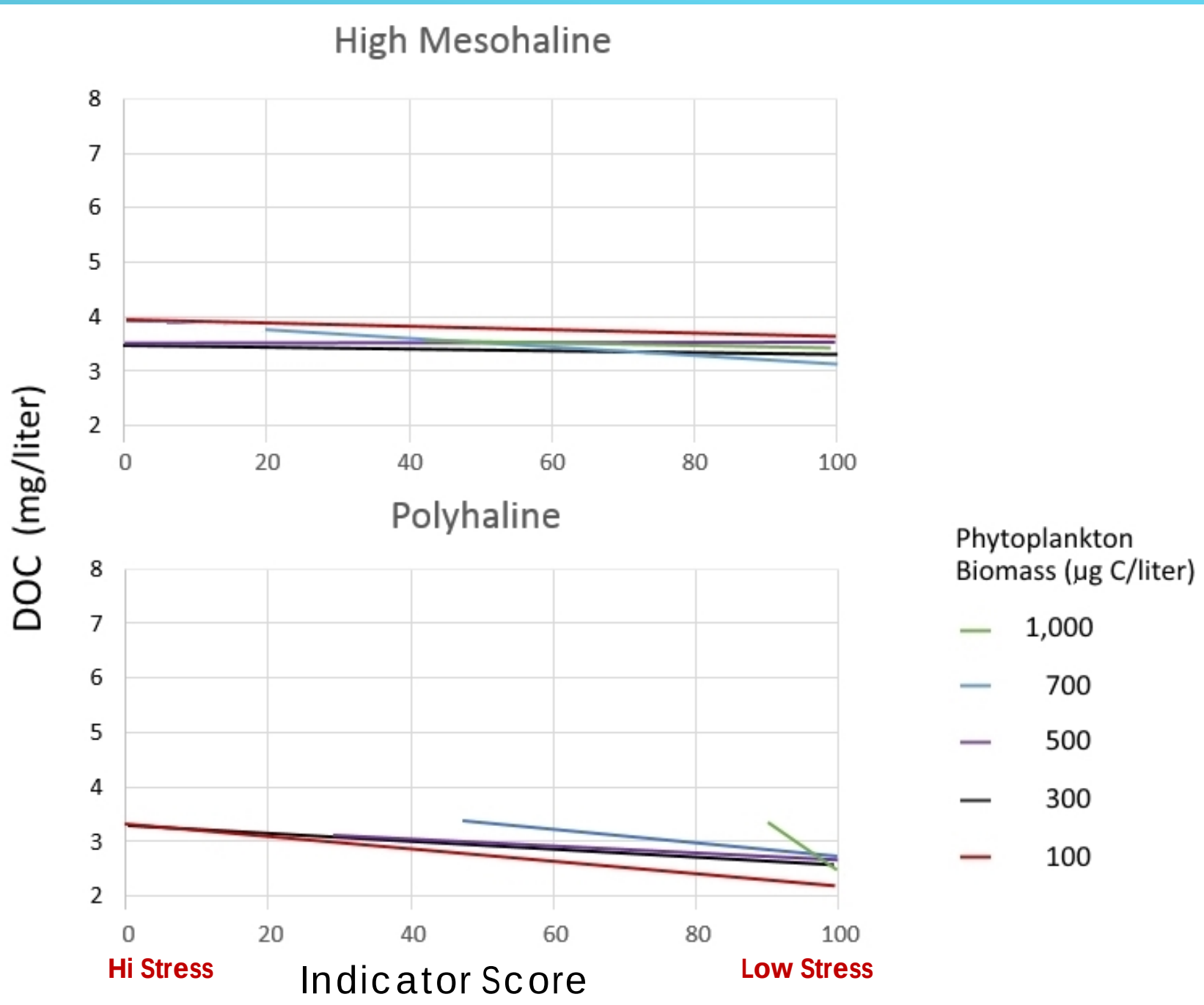


- For a given stress level, higher phytoplankton biomass ⇔ higher ambient DOC
- For a given biomass level, stressed cells ⇔ higher ambient DOC



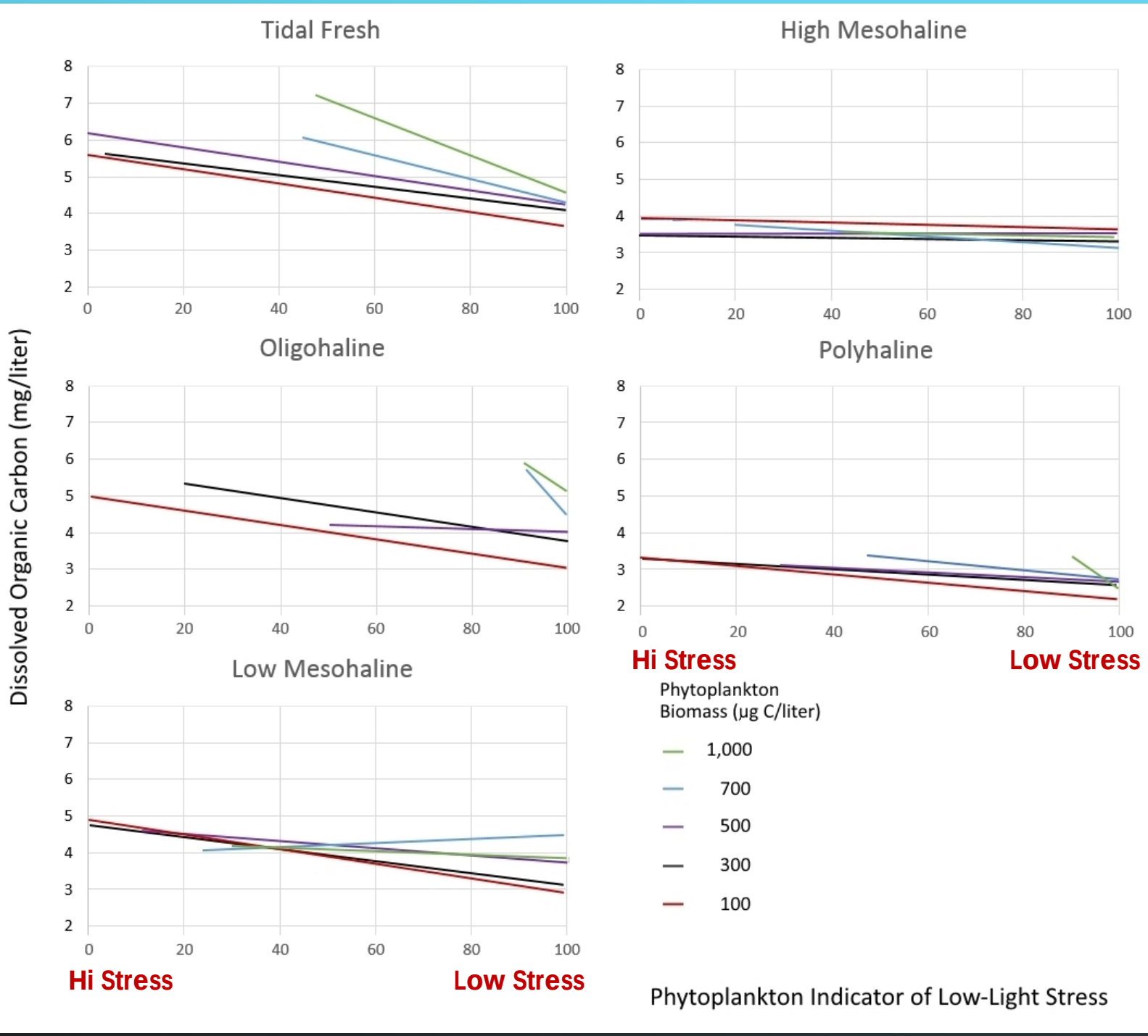
Oligohaline & Low Mesohaline

- For lower biomasses, stressed cells ⇔ higher ambient DOC
- For a given stress level, higher phytoplankton biomass ⇔ higher ambient DOC



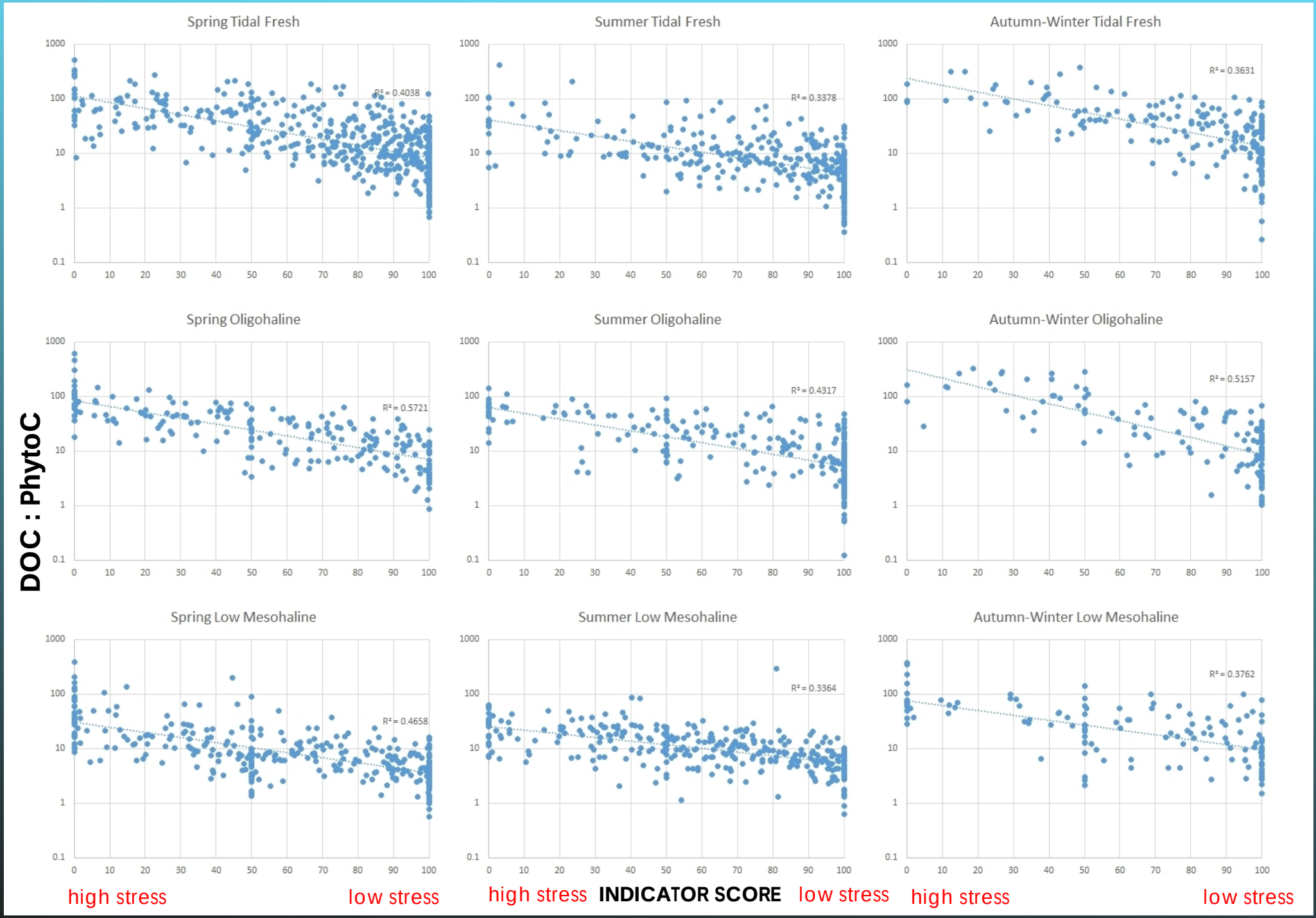
Hi Mesohaline & Polyhaline

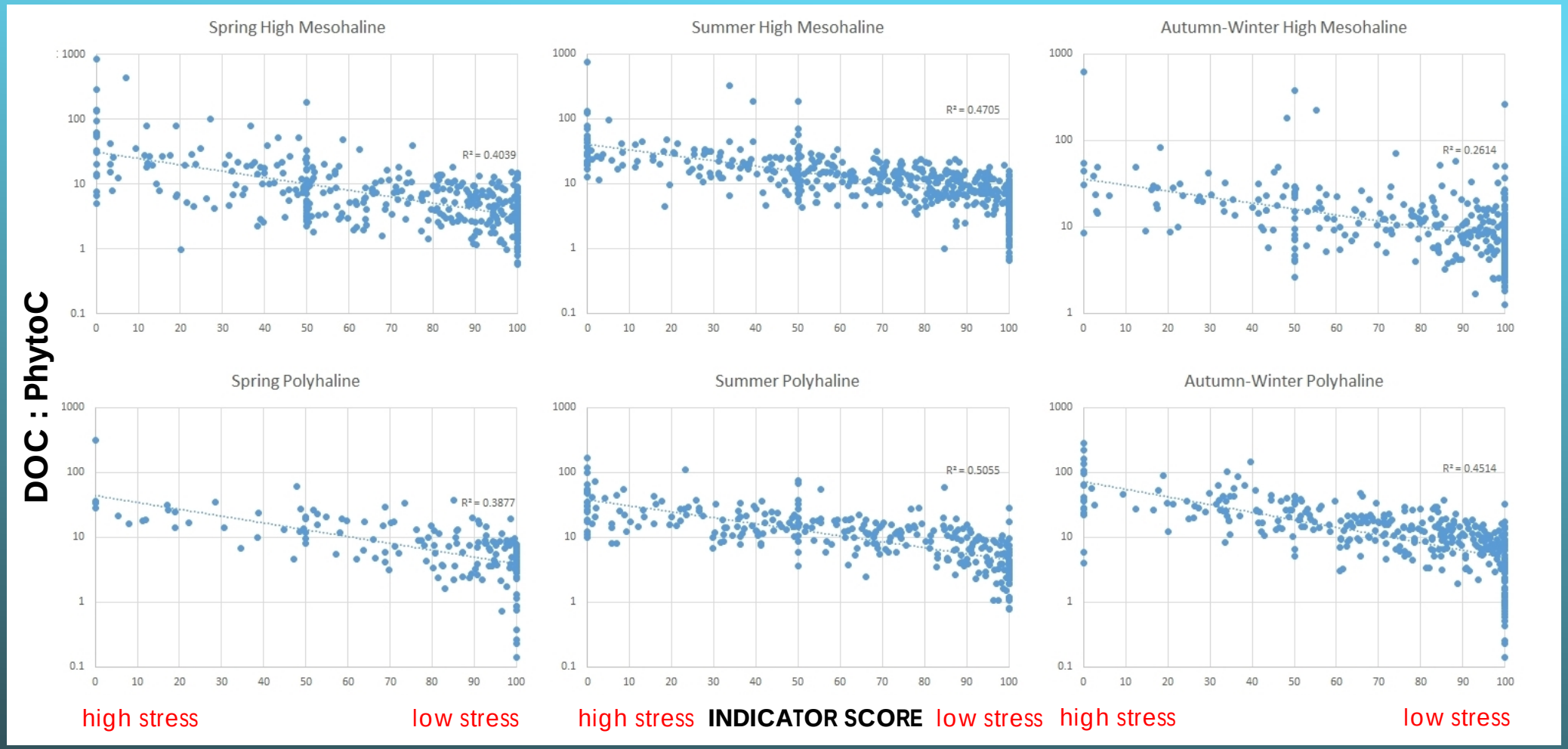
- Decreasing stress is associated with a *smaller drop* in ambient DOC
- Large blooms don't increase DOC as much (but large blooms are rarer here)



Different slopes in TF-OH-LoMH and HiMH-PH caused by changes in:

- Taxa?
- Non-living factors that attenuate light?
- Rates of vertical mixing?
- Other?
- **All of the above?**

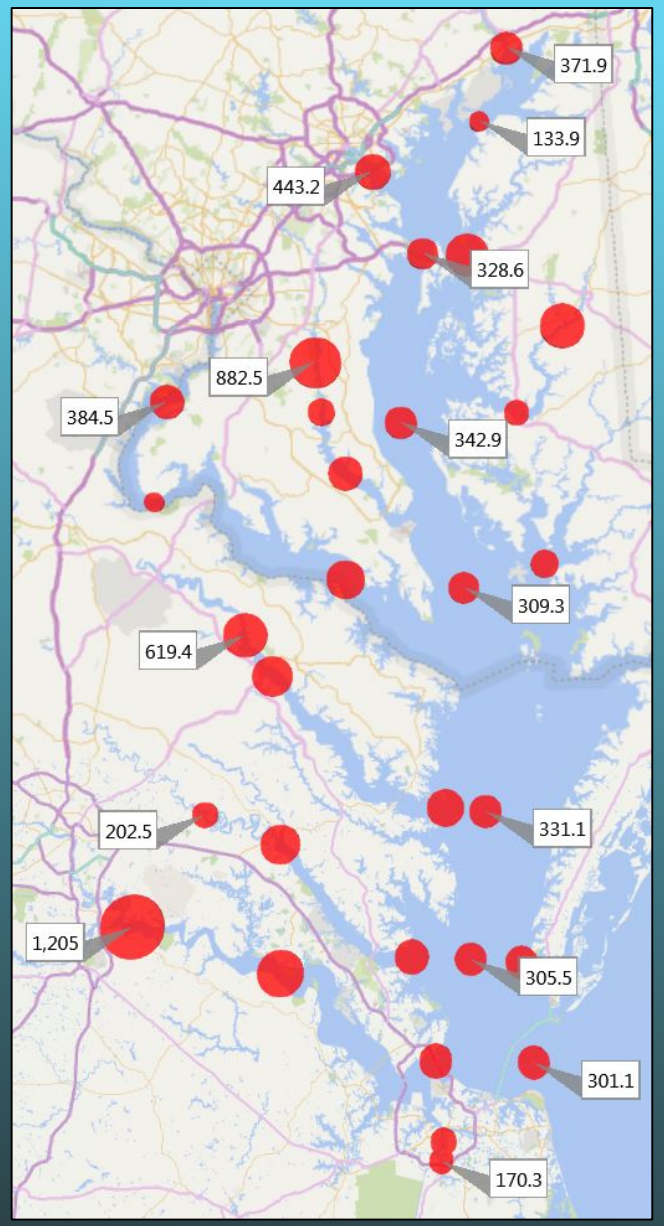

Spring Tidal Fresh
R² = 0.4038
Summer Tidal Fresh
R² = 0.3378
Autumn-Winter Tidal Fresh
R² = 0.3631
Spring Oligohaline
R² = 0.5721
Summer Oligohaline
R² = 0.4317
Autumn-Winter Oligohaline
R² = 0.5157
Spring Low Mesohaline
R² = 0.4658
Summer Low Mesohaline
R² = 0.3364
Autumn-Winter Low Mesohaline
R² = 0.3762
DOC : PhytoC
high stress
low stress
high stress
INDICATOR SCORE
low stress
high stress
low stress
TF
OH
LoMH



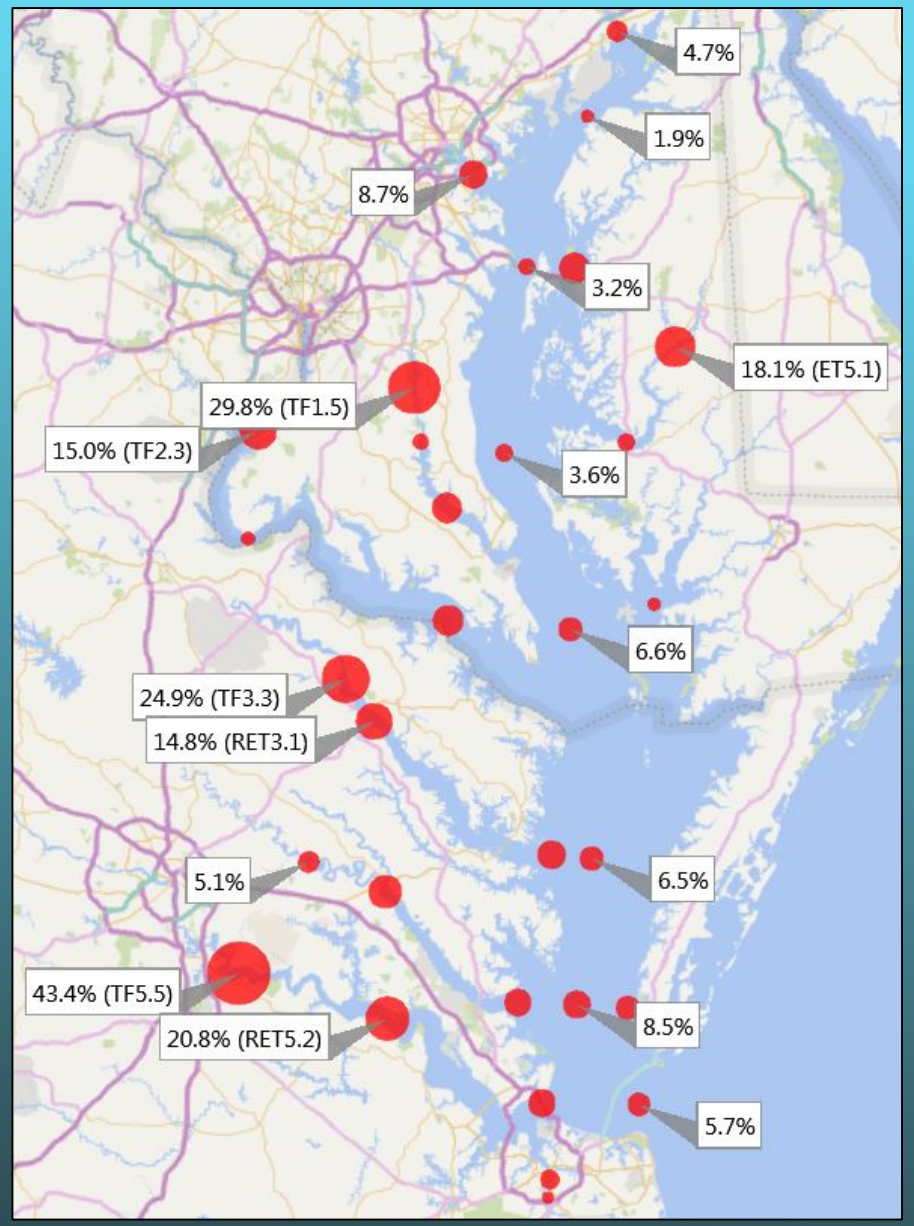
Geometric Mean DOC:PhytoC			
	Hi Stress	Low Stress	% Drop
F	77.19	4.75	-94%
O	74.34	4.87	-93%
LoM	41.01	4.27	-90%
HiM	47.30	4.72	-90%
P	41.67	2.41	-94%

Cells leak (exude) proportionally more DOC when stressed by low-light conditions

Higher phytoplankton biomass = greater amount of DOC exuded



Station median phytoplankton biomass (µg C/liter)



% biomass exceedances of 1,500 µg C/liter (blooms)

Phytoplankton exude:

- Glycolic acid
- Carbohydrates
- Polysaccharides
- Amino acids
- Peptides
- Organic phosphates
- Volatile compounds
- Enzymes
- Vitamins
- Hormonal substances
- Toxins
- Allelochemicals that inhibit photosynthesis in competing taxa

Many are small, labile, low-molecular-weight compounds

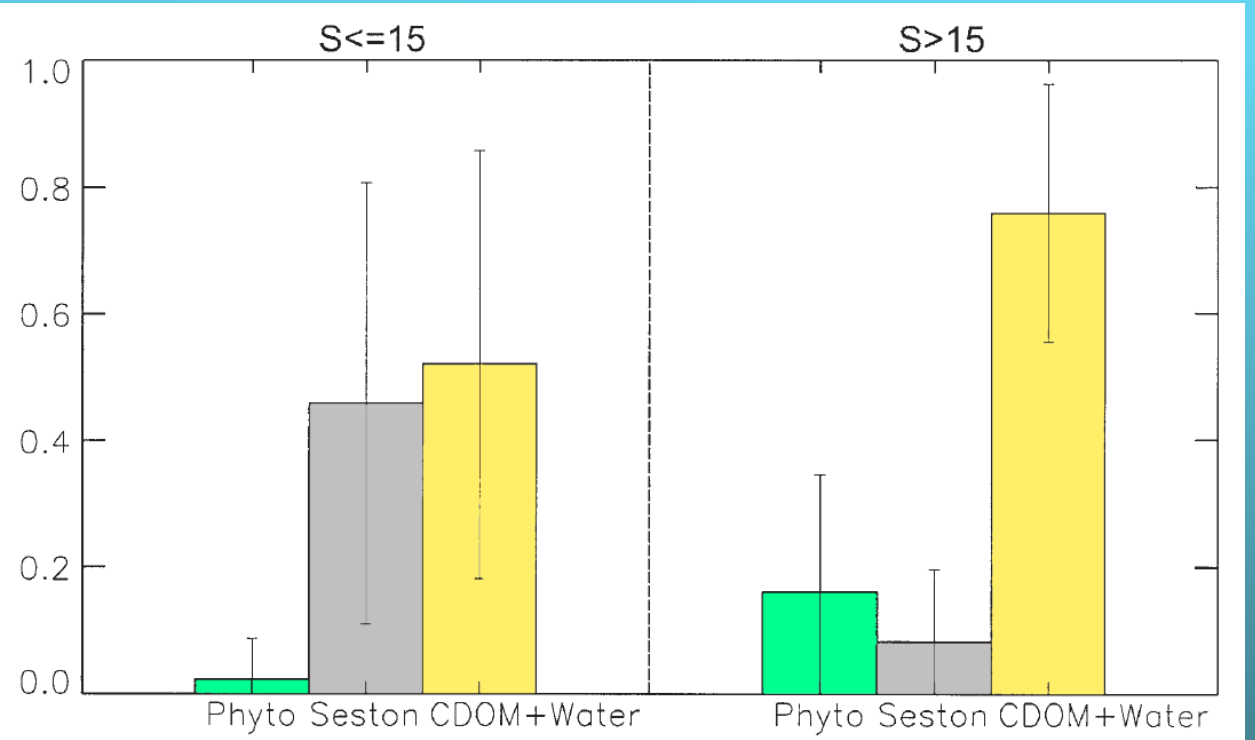
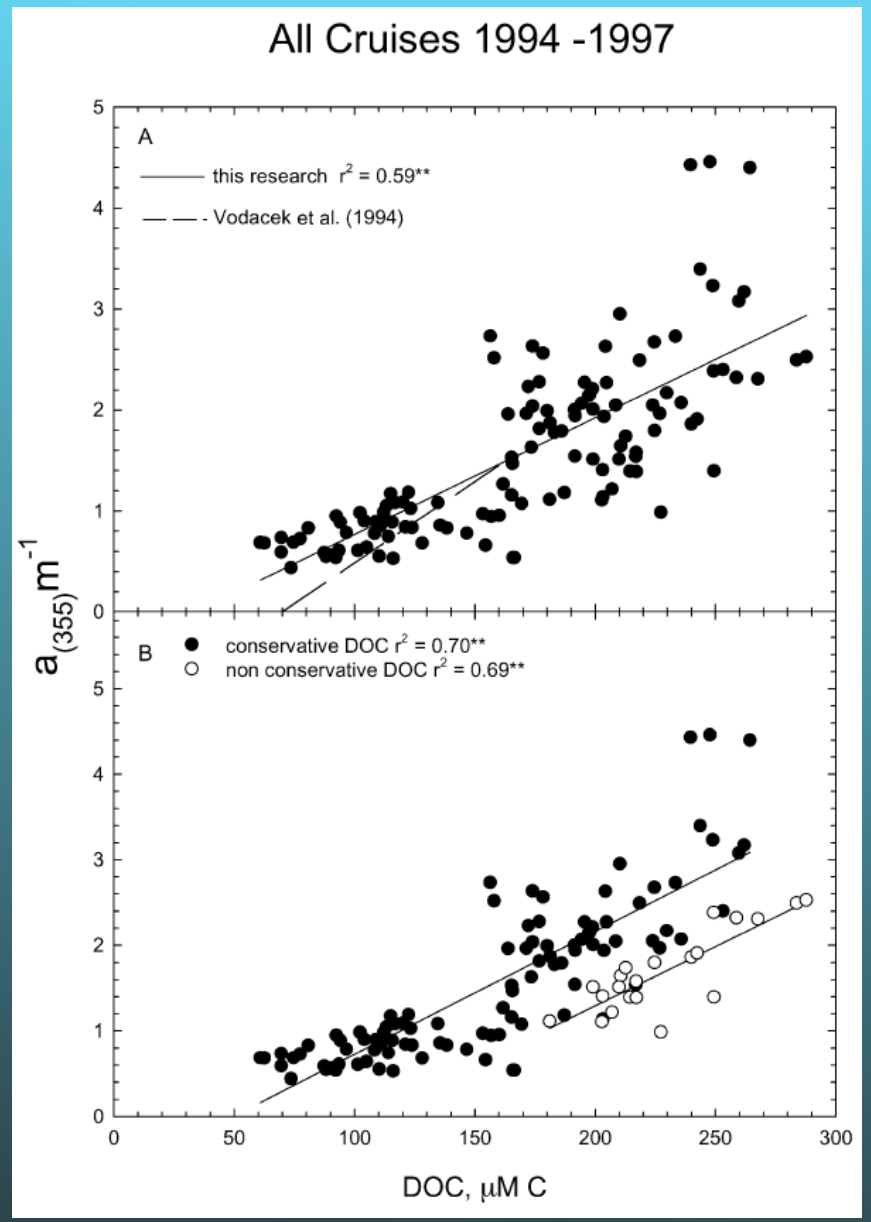


Fig. 6. The contributions of water plus dissolved organic matter ($K_w' + K_s[SAL]$), phytoplankton ($K_c[CHL] + K_t[Phy]$), and seston ($K_t[TSS - Phy]$) to the total light attenuation coefficient for all data points used in the regression model.

Xu et al. (2005) – non-spectral empirical model of light attenuation in Chesapeake Bay

Rochelle-Newall and Fisher (2002) – measured CDOM, DOC, and Chla in Bay mainstem cruises

- Overall, DOC and CDOM correlate (others have found this relationship too)
- CDOM behaves ‘conservatively’ (like salinity)
  → large, high-molecular-weight, refractory
- Increased production of non-chromophoric DOC occurs in Chla max of Bay
- No clear relationship between Chla and CDOM
- Concluded there were two or more sources of CDOM to Bay



CDOM (absorption at 355 nm)

DOC

Possible Phytoplankton Role in Light Attenuation

- CDOM and suspended sediments are most responsible for light attenuation in Bay mainstem (e.g., Xu et al. 2005)
- Microbial processing of detritus (multiple sources) generates much of CDOM in Bay mainstem (e.g., Rochelle-Newall & Fisher 2002)

6. Die-offs of these phytoplankton & bacteria are a large source of autochthonous detritus

5. Largest biomasses of phytoplankton & bacteria presently occur in tributaries (not upper Bay)

4. Exuded DOC contains relatively little CDOM but inputs copious amounts bacterial substrate; bacterial biomass increases and produces CDOM

3. Cells leak (exude) proportionally more DOC when stressed by poor light

2. Phytoplankton increase cellular concentrations of photopigments to compensate; boom-bust growth cycles occur if waters are also nutrient-rich

1. Non-living suspended solids create poor light conditions; impede photosynthesis in open water

- Phytoplankton are a *controllable* internal source of DOC and can influence CDOM concentrations in open waters

Caption: Always bring lights — that's one lesson Nick Caloyianis learned from decades of filming and photographing underwater life in the Chesapeake Bay. His photographs document the loss of natural light in the estuary. In 2008 (above top) he worked with multiple lights as he tried to film oyster restoration on Dominion Reef in the mainstem Bay. Back in 1979 (above bottom), he had plenty of light to photograph his partner, Clarita Berger, as she took pictures of the grassbeds of the Choptank River. Credits: Michael Eversmier, Aqua Ventures, inc. (left) and Nick Caloyianis (right). Fincham, M. 2008 "Naturalist at Bay: A Winter's Tale" Chesapeake Quarterly vol. 7 no. 4

Extra Slides

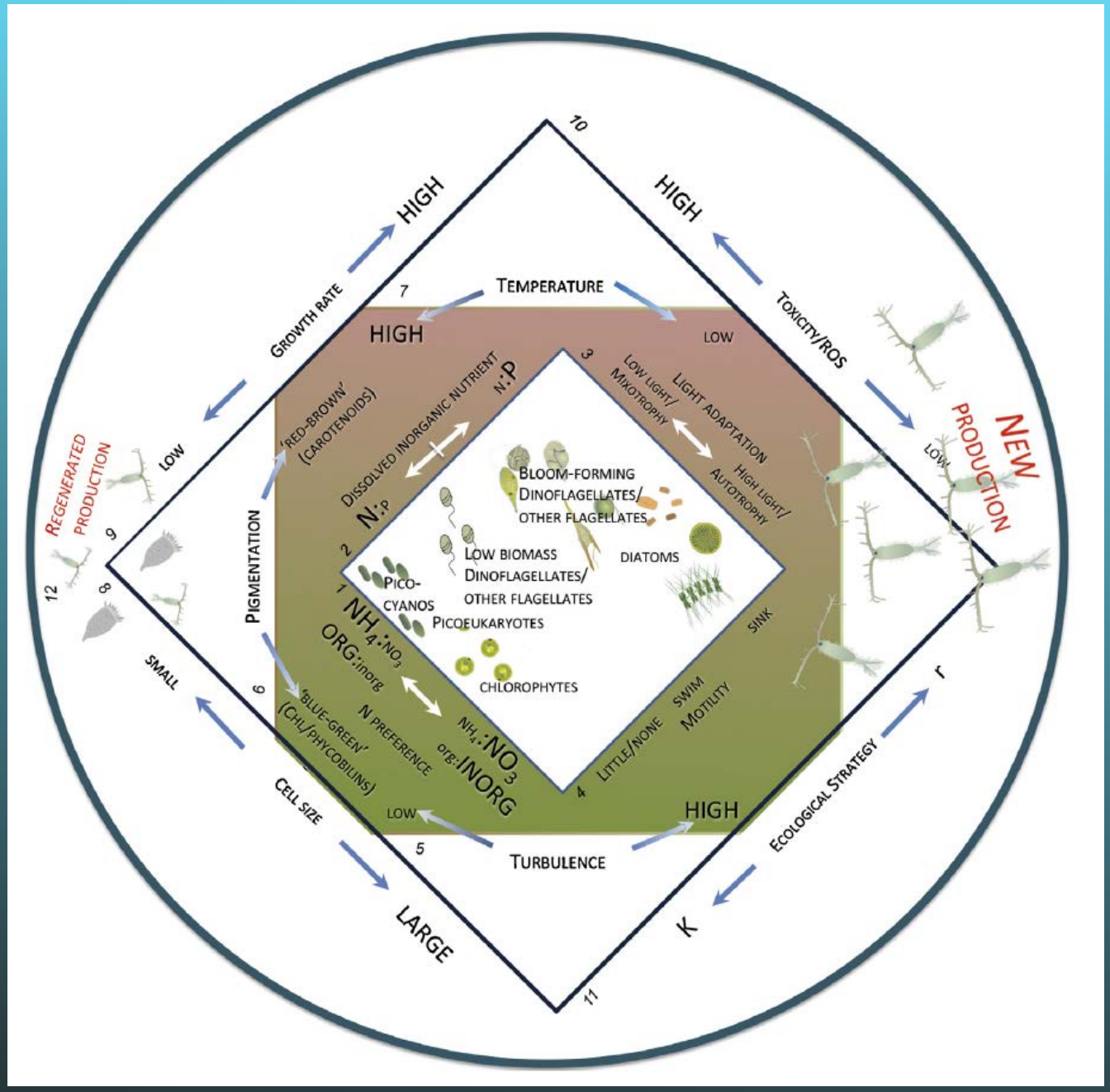
		Buchanan et al. 2005			Revised thresholds (2016)		
Secchi Depth (meters)							
		worst	poor|better	best	worst	poor|better	best
Season	Salinity	<	≤ >	>	<	≤ >	>
Spring	F	0.7	0.9	1.1	0.6	0.8	1.1
	O	0.5	0.7	1.1	0.7	0.8	1.0
	LoMH	1.35	1.8	2.25	1.2	1.4	1.7
	HiMH	1.35	1.8	2.25	1.5	1.8	2.0
	P	1.6	2.15	2.55	1.7	2.1	2.6
June	F				0.6	0.7	0.8
	O				0.6	0.7	0.8
	LoMH				1.0	1.2	1.5
	HiMH				1.1	1.4	1.7
	P				1.3	1.6	1.8
Summer	F	0.6	0.8	1.0	0.6	0.8	1.1
	O	0.55	0.6	0.7	0.6	0.8	1.0
	LoMH	1.2	1.45	1.7	0.9	1.2	1.4
	HiMH	1.2	1.45	1.7	1.4	1.6	1.8
	P	1.55	1.85	2.35	1.5	1.8	2.1
Autumn	F	0.7	0.9	1.2	0.7	0.9	1.2
	O	0.4	0.5	0.7	0.6	0.8	1
	LoMH	1.7	2.0	2.2	1.1	1.2	1.5
	HiMH	1.7	2.0	2.2	1.6	2.0	2.3
	P	1.7	2.1	3.5	1.7	2.0	2.5
Winter	F	0.5	0.6	0.9	0.6	0.8	1.1
	O	0.5	0.6	0.9	0.6	0.9	1.0
	LoMH	1.4	1.8	2.2	1.2	1.4	1.7
	HiMH	1.4	1.8	2.2	1.5	2.0	2.2
	P	1.8	2.3	2.7	1.7	2.1	2.5
DIN (mg/liter)							
		worst	poor|better	best	worst	poor|better	best
		>	> ≤	<	>	> ≤	≤
All Seasons	All Salinities	various	0.07	0.03	0.35	0.07	0.03
PO_4 (mg/liter)							
		worst	poor|better	best	worst	poor|better	best
		>	> ≤	<	>	> ≤	≤
All Seasons	All Salinities	various	0.007	0.003*	0.035	0.007	0.003

Thresholds used to separate Secchi depth, dissolved inorganic nitrogen (DIN), and ortho-phosphate (PO_4) into four classes: worst, poor, better, and best. Buchanan *et al.* (2005) did not include June thresholds and did not have different thresholds for low and high mesohaline salinities. Seasons: Spring, March – May; Summer, July – September; Autumn, October – November; Winter, December – February. Salinity zones: tidal fresh (F), <0.5‰; oligohaline (O), >0.5 – 5.0‰; low mesohaline (LoMH), >5.0 – 10‰; high mesohaline, (HiMH), >10 – 18‰; polyhaline (P), >18.0‰. *The mesohaline PO_4 threshold in Buchanan *et al.* (2005) was 0.002 mg/liter. See text for further details.

Patricia Glibert. (2016) in Harmful Algae. Phytoplankton mandala

12 dimensions

Each axis depicts a phytoplankton functional type



Keller & Hood (2011) model of DOC sources at CB3.3C (Low Mesohaline)

"…phytoplankton exudation was the dominant source of DOC, averaging 63% of total DOC production throughout the year [at CB3.3C]…"

Flowing in to CB3.3C		**CB3.3C**
		phyto exudation, mortality
19%	Labile	40%
30%	Semi-labile	59%
51%	Refractory	1%
		sloppy feeding
	Labile	53%
	Semi-labile	45%
	Refractory	2%
		detritus decay
	Labile	50%
	Semi-labile	49%
	Refractory	1%