Thresholds of Adverse Effect of Macroalgae on Estuarine Intertidal Flats:

Findings of Studies Supporting an Estuarine Macroalgal Nutrient Numeric Endpoint

A Webinar Sponsored By The California Water Quality Monitoring Collaboration Network

October 31, 2012
9:30-11:30

State Water Resources Control Board is Developing Nutrient Objectives

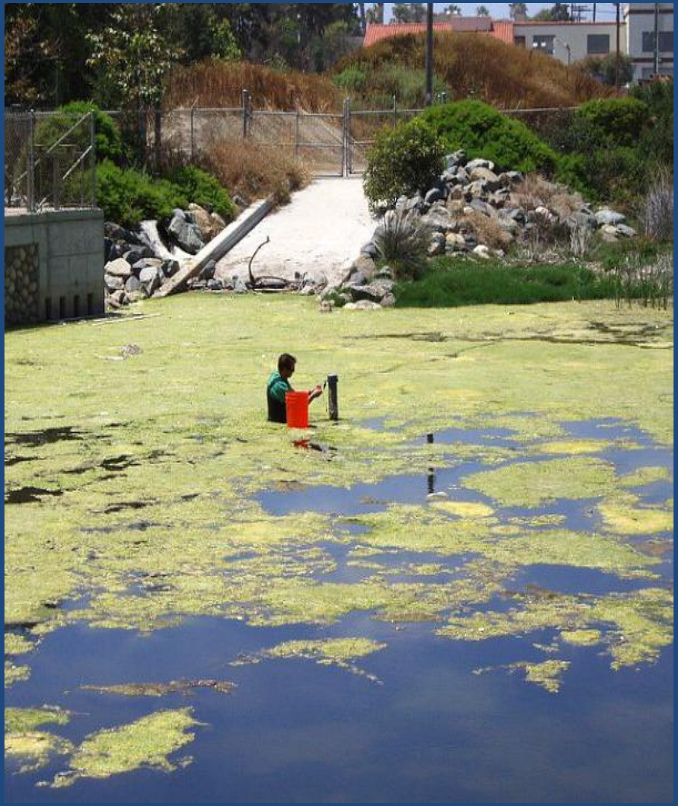
- Freshwater (lakes and streams)
  - Work initiated in 2000
  - Technical work complete
  - Policy under development
- Estuaries
  - Work initiated in 2008
  - Scientific studies are being conducted to support decision-making
- Today's presentation presents a component of science supporting nutrient objective development in estuaries

Overview of Presentations

- State Water Board's conceptual approach to nutrient objectives (Martha Sutula, SCCWRP)
  - Need for numeric endpoints for macroalgae
- Why macroalgae? (Peggy Fong, UCLA)
  - Ecology of macroalgal blooms in estuaries
- Effects of macroalgal blooms on benthic infauna– results of field experiments (Lauri Green, Harbor Branch Oceanographic Institute)
- Effects of macroalgal blooms on benthic habitat quality- results of a sediment profile imagery survey (Martha Sutula, SCCWRP)
- Synthesis and next steps (Martha Sutula, SCCWRP)

Approach to Setting Nutrient Objectives Distinct From That Used For Traditional Contaminants

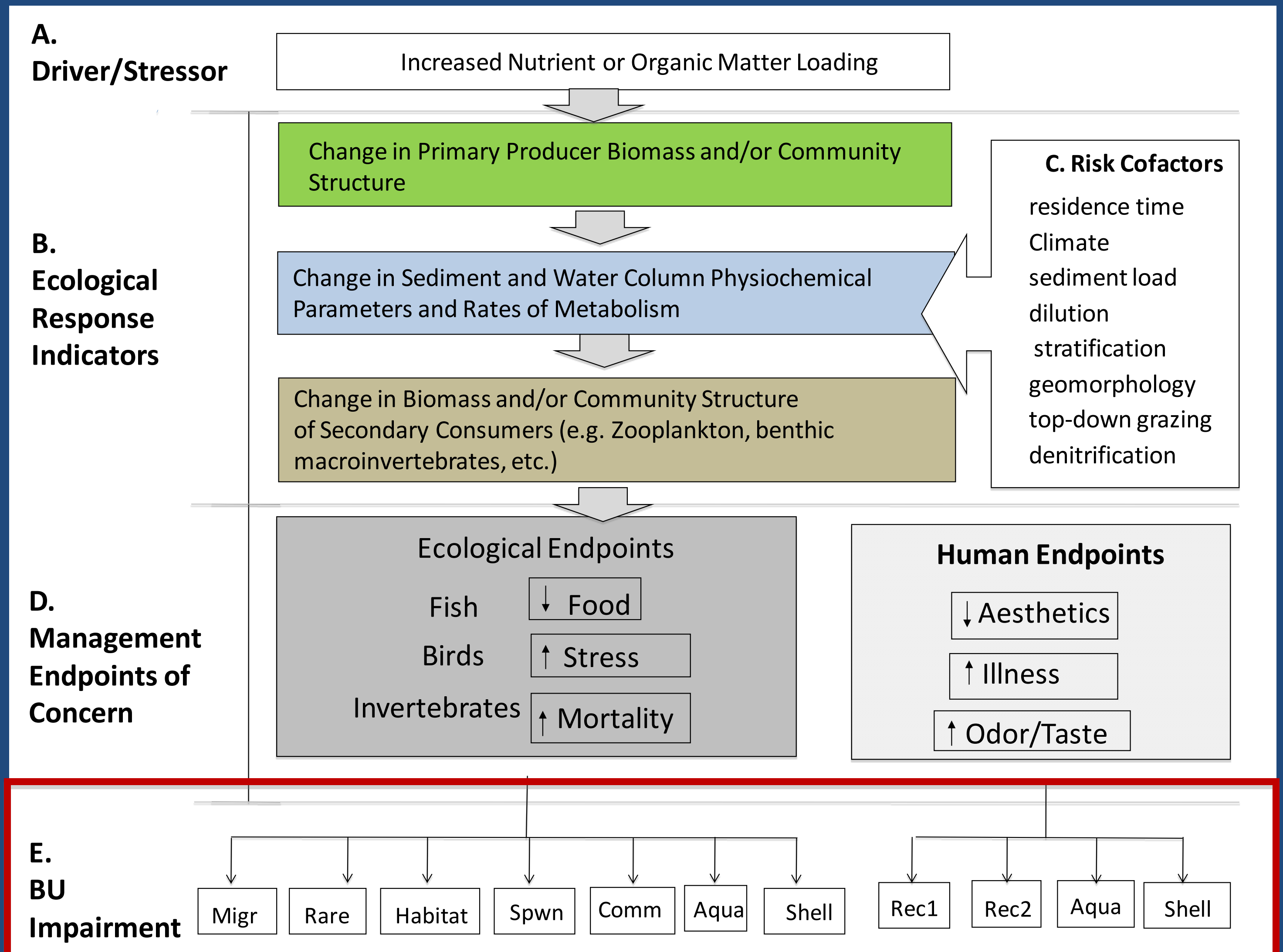
- Nutrients are required to support life
  - How much is too much?
- Toxicity rarely endpoint of interest
  - Effects occur at much lower levels
- Using ambient nutrients to diagnose effects can often give a false-negative or false-positive
  - Need a different approach



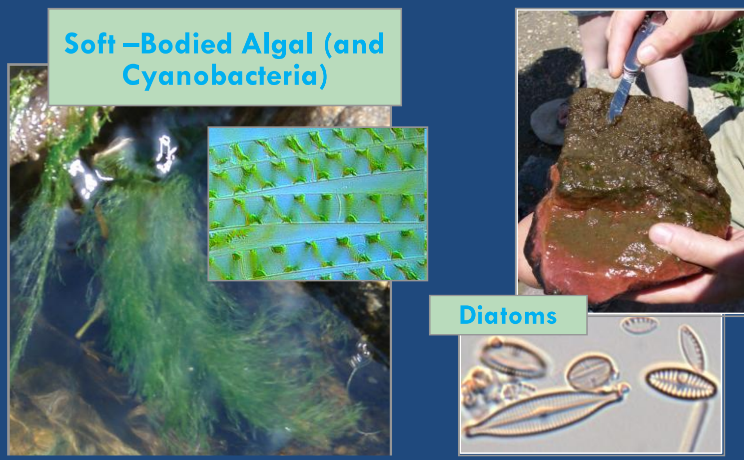
Tenets of California's Approach to Nutrient Objectives

- Narrative objective, with numeric guidance
  - Guidance coined as " Nutrient Numeric Endpoint or NNE"
- Diagnosis based on <u>response indicators</u> = <u>NNE assessment framework</u>
  - Assessing eutrophication et al. adverse effects of nutrients
  - <u>Multiple lines of evidence </u>for more robust diagnosis
- Models to link response indicators to nutrients et al. factors (e.g. hydrology, climate, etc.)
  - Can be empirical or dynamic simulation models

Ecological Responses Are More Strongly Linked to Beneficial Uses Than Nutrients Alone



Application of the NNE In Streams: Example of Endpoints for Benthic Algal Biomass

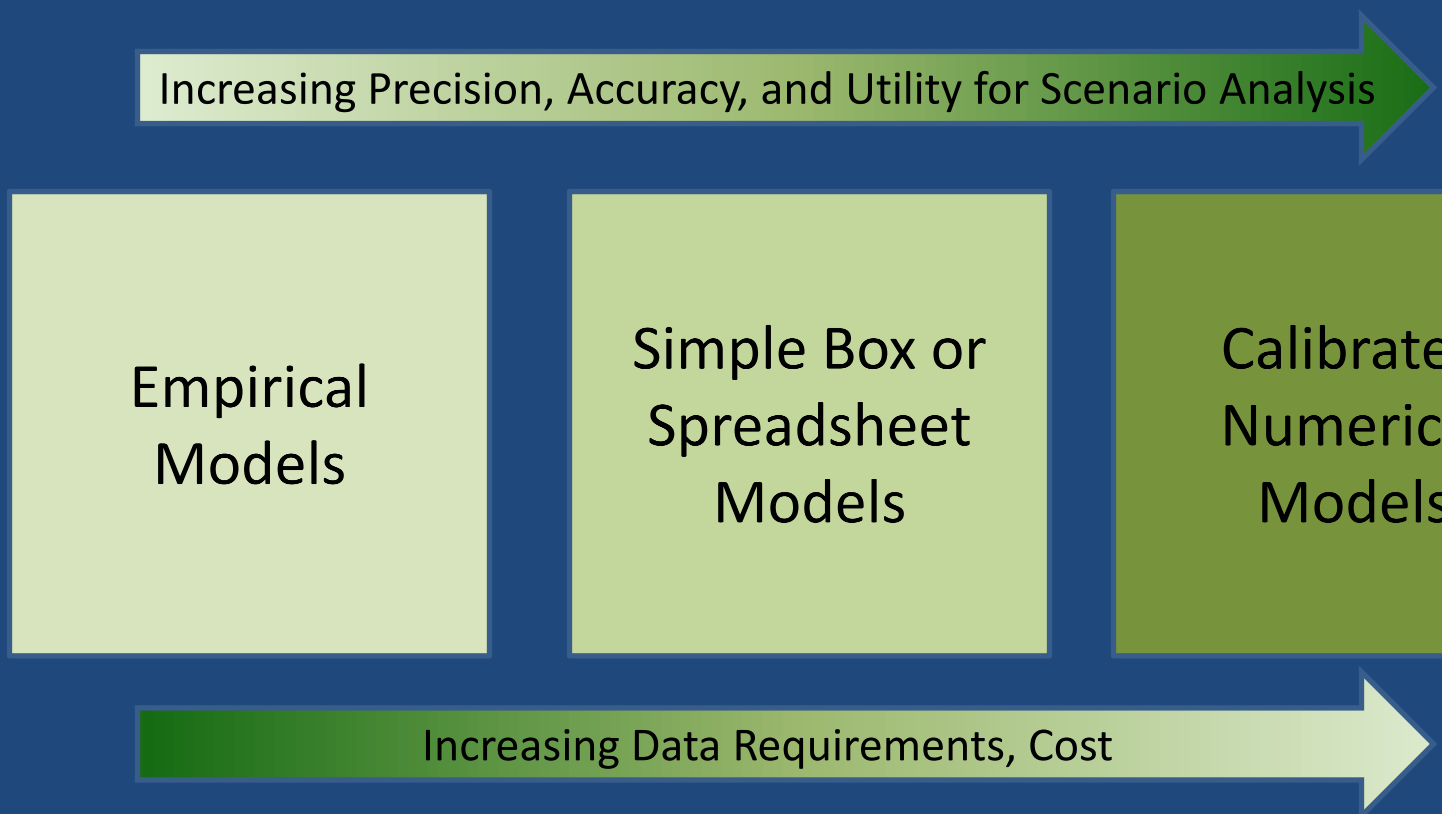


Benthic Algal Biomass
+
pH
+
Dissolved Oxygen

Benthic Algal Biomass Thresholds (mg chl a m^{-2})	Beneficial Use					
	COLD	WARM	REC-1 &-2	MUN	SPWN	MIGR
BURC I/II	100	150	Same as WARM/COLD	100	100	Not Defined
BURC II/III	150	200		150	150	

Assess Eutrophication, Manage Nutrients

- **Use models to convert response thresholds into nutrient goals**
  - Key to how we protect beneficial uses

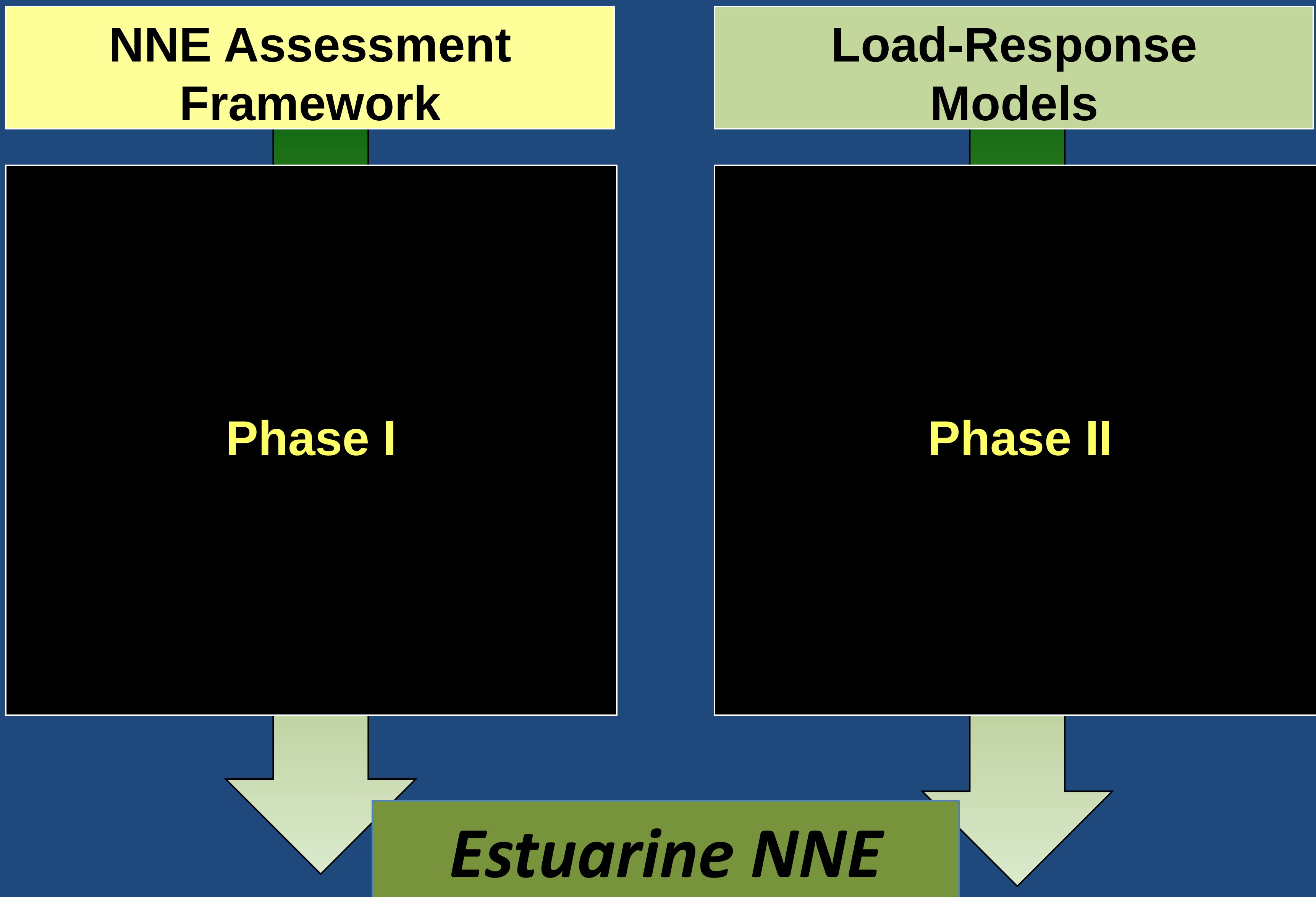


Conceptually Application of NNE Same Across Waterbody Type

Indicators, thresholds and appropriate models differ:

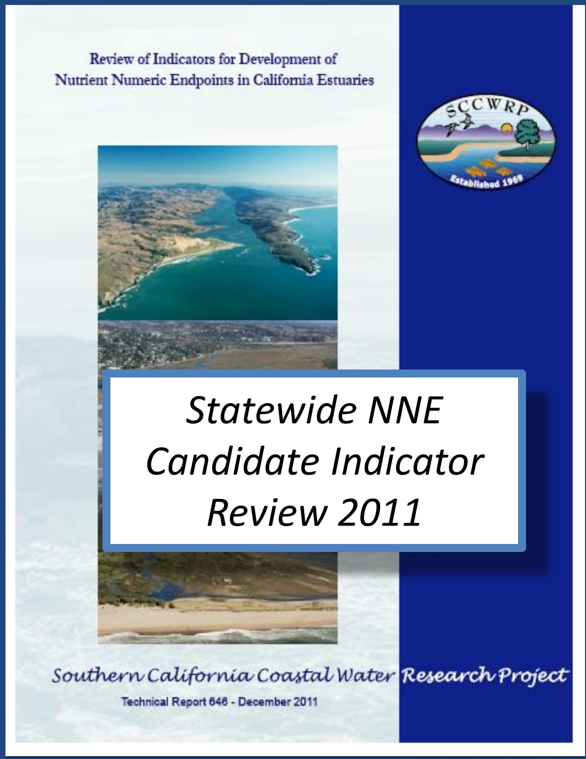
- Streams
- Lakes
- Estuaries

Estuarine NNE Workplan: Phasing



Evaluation of Candidate Estuarine NNE Indicators

- **Evaluated candidate indicators vis-à-vis review criteria**
  - Clear link to beneficial uses
  - Can build model to link to nutrients
  - Scientifically sound & practical measure
  - Reliably use to diagnose eutrophication (signal: noise acceptable)
- **Reviewed studies to establish thresholds**
  - Identifies data gaps and next steps
- **Chapter authored by Fong, Green and Kennison on macroalgae**



Estuarine Classification

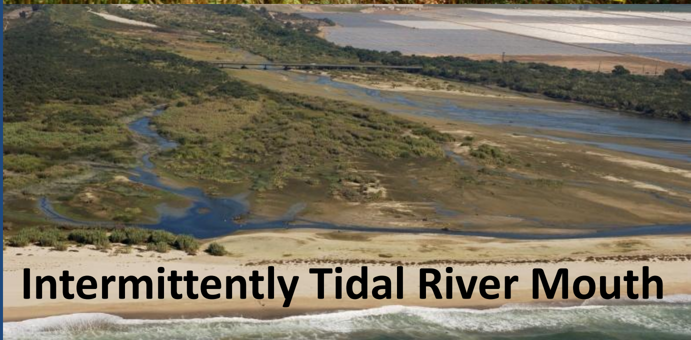
Geoform	Tidal Regime	No.
Enclosed Bay	Perennial	30
Lagoon	Perennial	15
	Intermittent	33
	Ephemeral	46
River mouth	Perennial	11
	Intermittent	270
Total		405

BAR-BUILT ESTUARIES

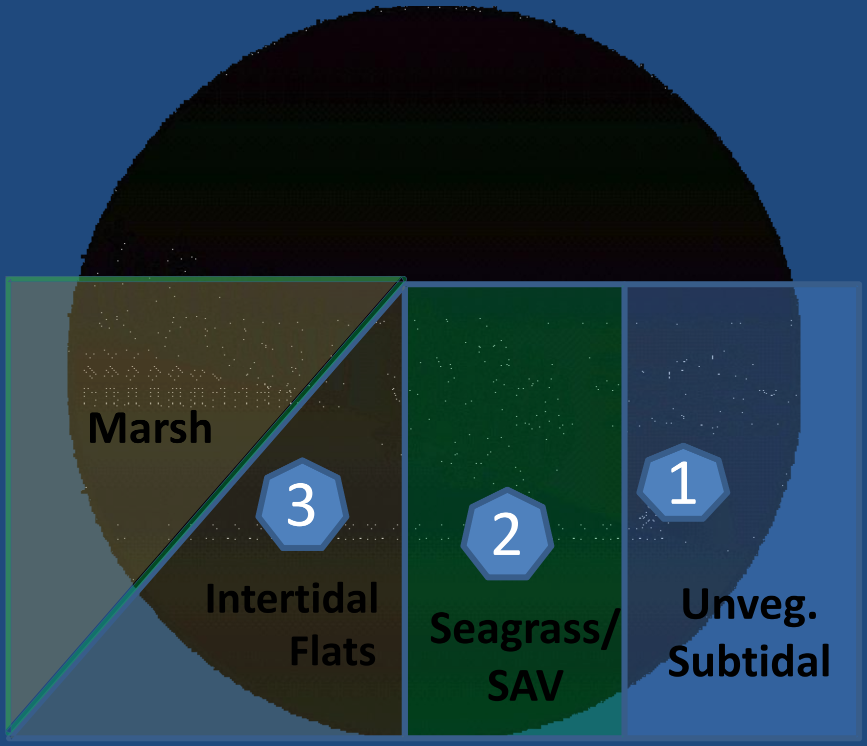

Perennially Tidal Enclosed Bay


Intermittently Tidal Lagoon


Ephemerally Tidal Lagoon


Intermittently Tidal River Mouth

Habitat Types Considered in Estuarine NNE Framework



Include:

- Intertidal flats
- Seagrass et al. submerged aquatic vegetation
- Unvegetated subtidal

Exclude:

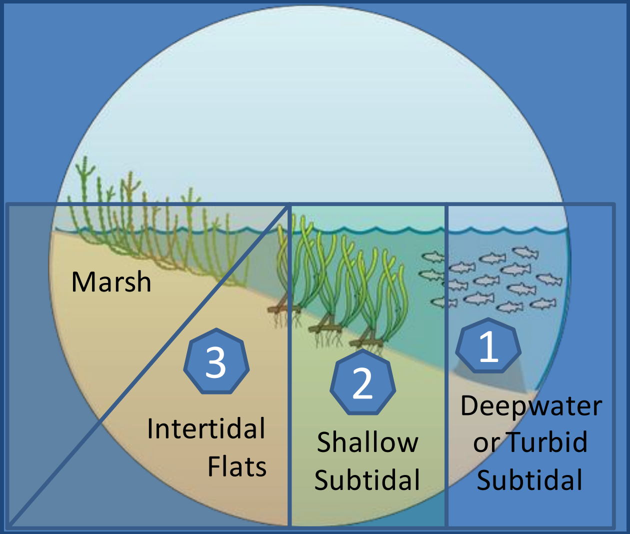
- Emergent marsh

Recommended Indicators

All Subtidal	Intertidal Flats and Shallow Subtidal	Seagrass
Dissolved oxygen Phytoplankton Biomass and Assemblage HAB cell counts & toxin conc. -- Cyanobacteria Macroalgal biomass/cover	Macroalgal biomass/cover	Phytoplankton Biomass Macroalgal Biomass and Cover Light attenuation Epiphyte load

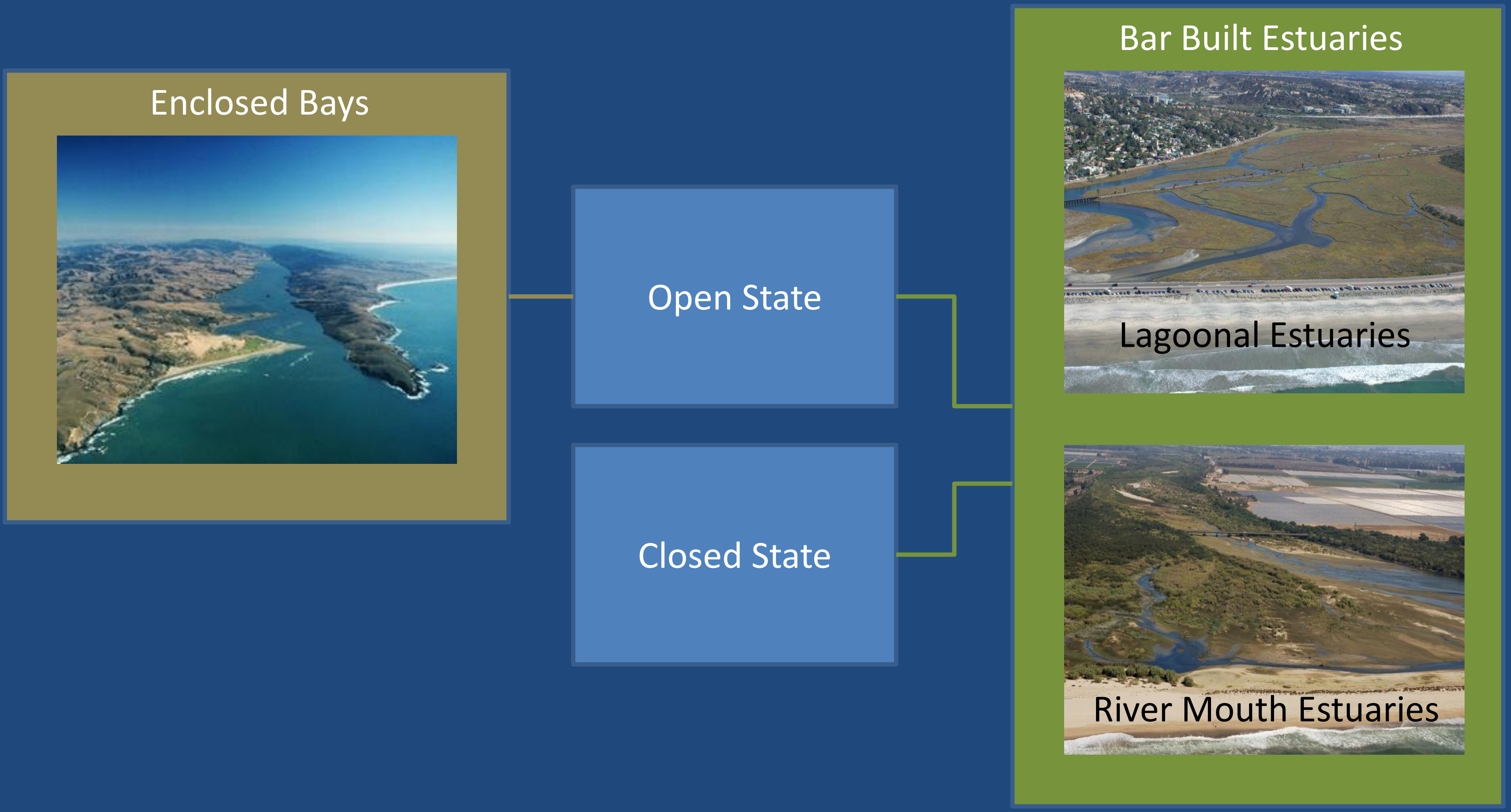
In Bar-Built Estuaries, Inlet Status Controls Dominant Primary Producers

Benthic diatoms and macroalgae on intertidal flat in "open" state

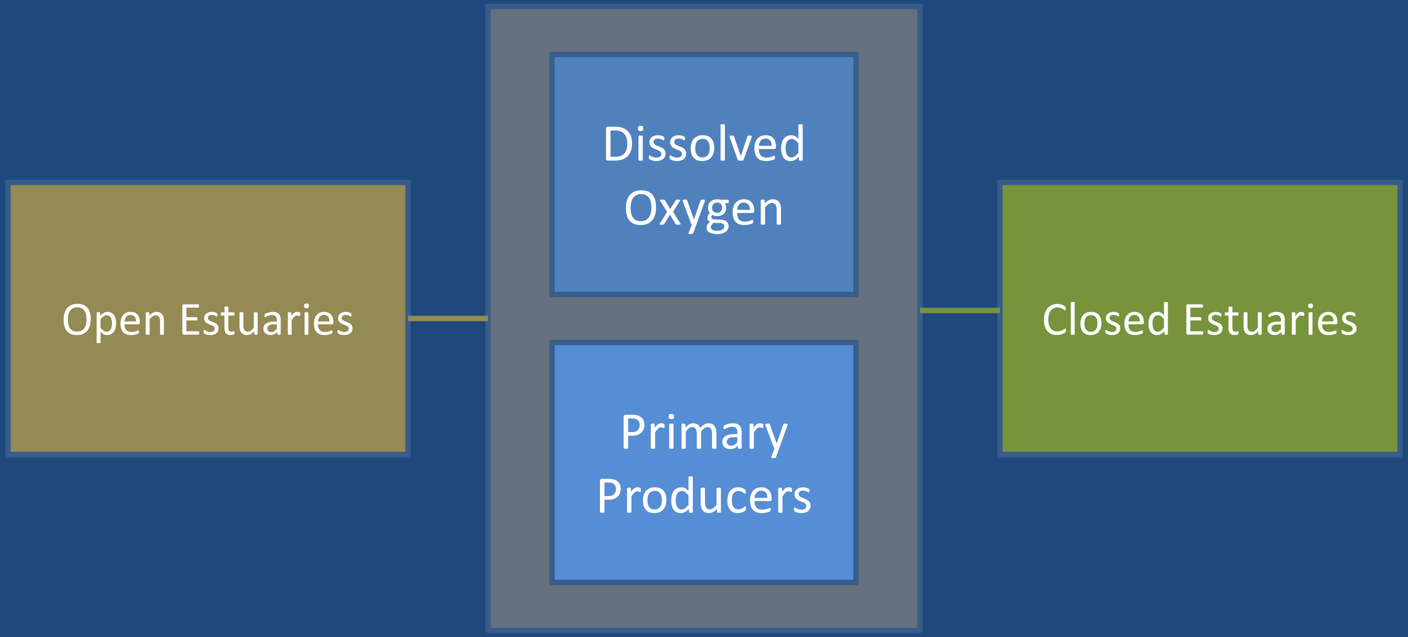


Floating macroalgae, submerged aquatic vegetation & phytoplankton in "closed" state

NNE Assessment Framework: Simplified Classification

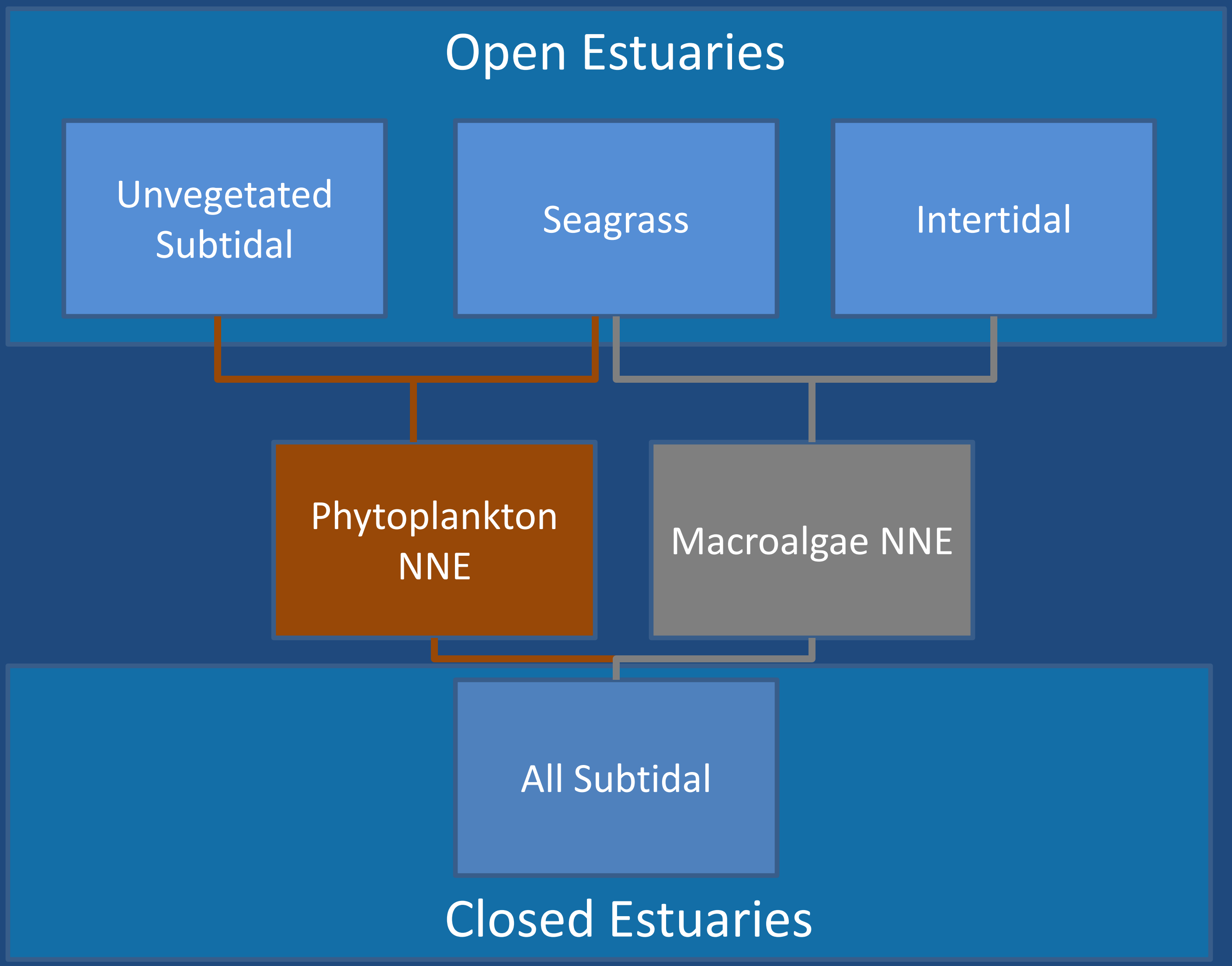


Estuarine NNE Assessment Framework

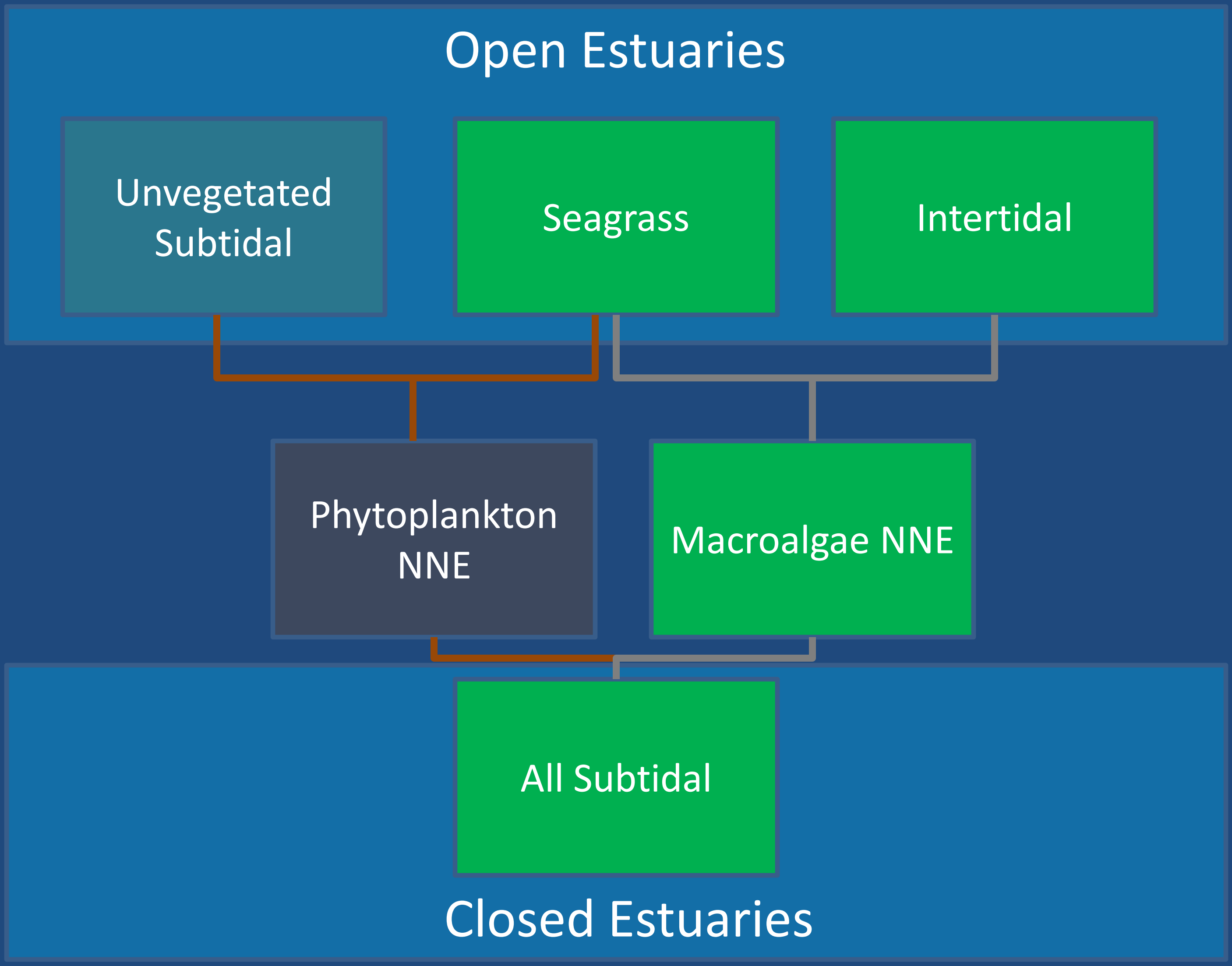


- Same Indicators in “open” versus “closed” estuaries
- But ….different assessment frameworks
  - —Thresholds
  - —Guidance for how to measure and how to use data to make an assessment

Estuarine NNE Assessment Framework: Primary Producers



Estuarine NNE Assessment Framework: Primary Producers



Studies Supporting Macroalgal Numeric Endpoints

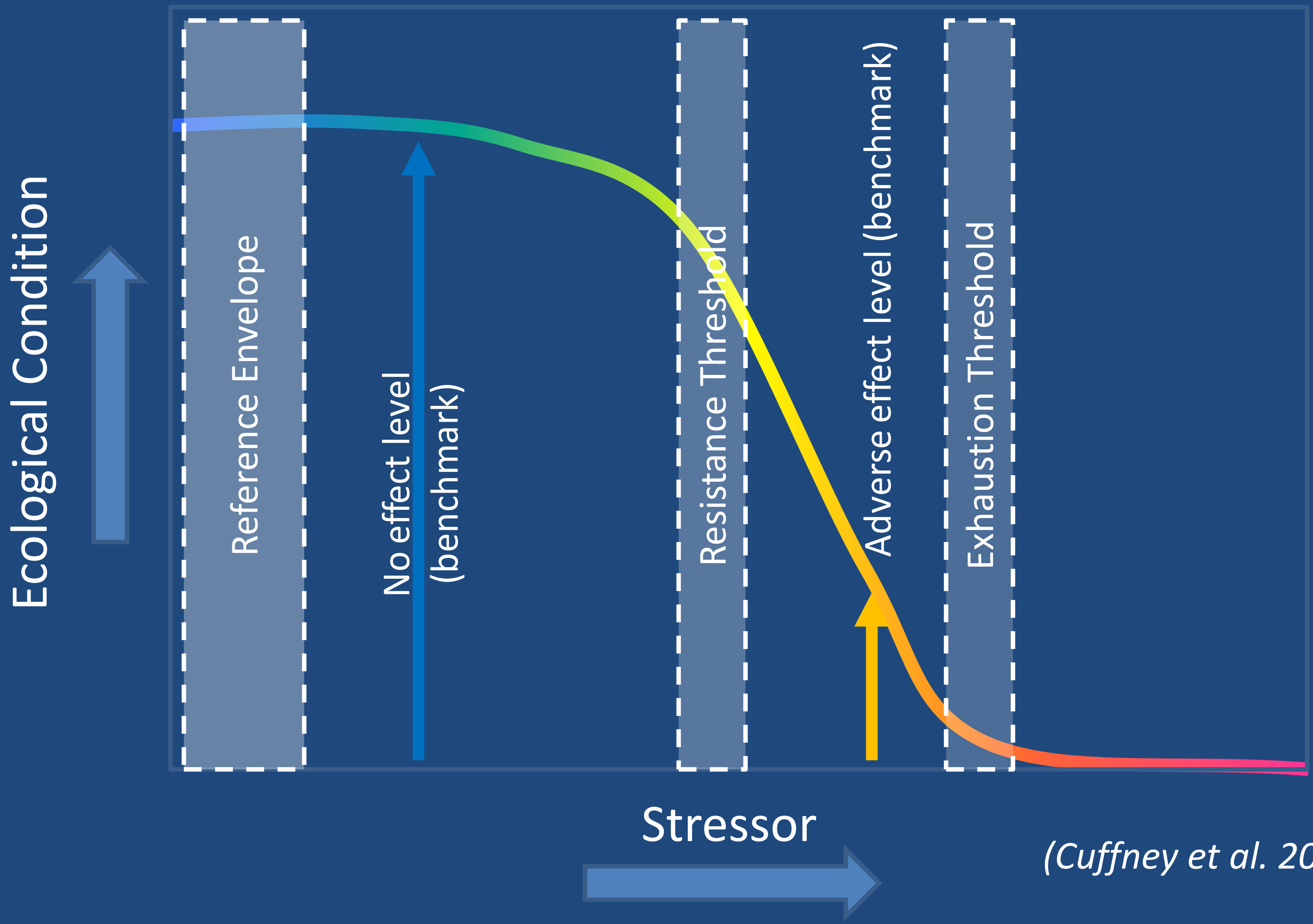
"Open Estuaries"

- Field experiments and survey of effects of macroalgae on intertidal and shallow subtidal habitat- Complete
- Field experiments and survey of effects of macroalgae on seagrass habitats- Work in progress

Closed Estuaries

- Field survey documenting natural background abundances of macroalgae and phytoplankton in "closed" estuaries- Begin in 2013

Defining Terms: Thresholds vs. Benchmarks



(Cuffney et al. 2010)

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- State Water Board's conceptual approach to nutrient objectives (Martha Sutula, SCCWRP)
  - Need for numeric endpoints for macroalgae
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Basic Ecology of Ephemeral Macroalgae

- A little taxonomy and ecology

  -macroalgae come in 3 flavors:

  green, red, and brown

  -support vital ecological functions in all aquatic systems

- Macroalgae have extremely diverse morphologies:

  -blooms species have simple thalli (body/form)

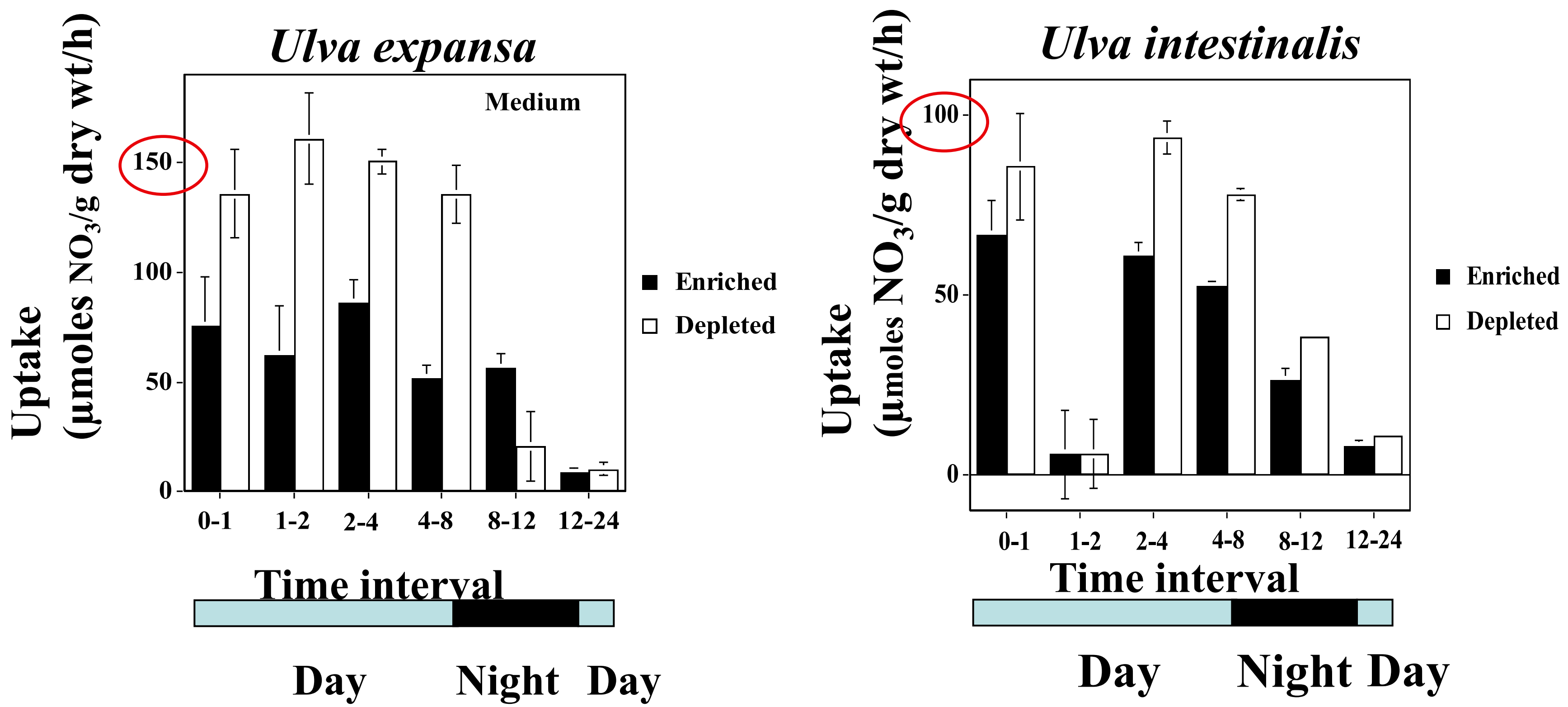
  -often undergo changes in habitat usage through different life stages

Macroalgae are Found in Many Estuarine Habitat Types

- Surface of mudflats (intertidal)
- As epiphytes on seagrass (shallow subtidal)
- Floating mats (deeper brackish lakes and deepwater enclosed bays)

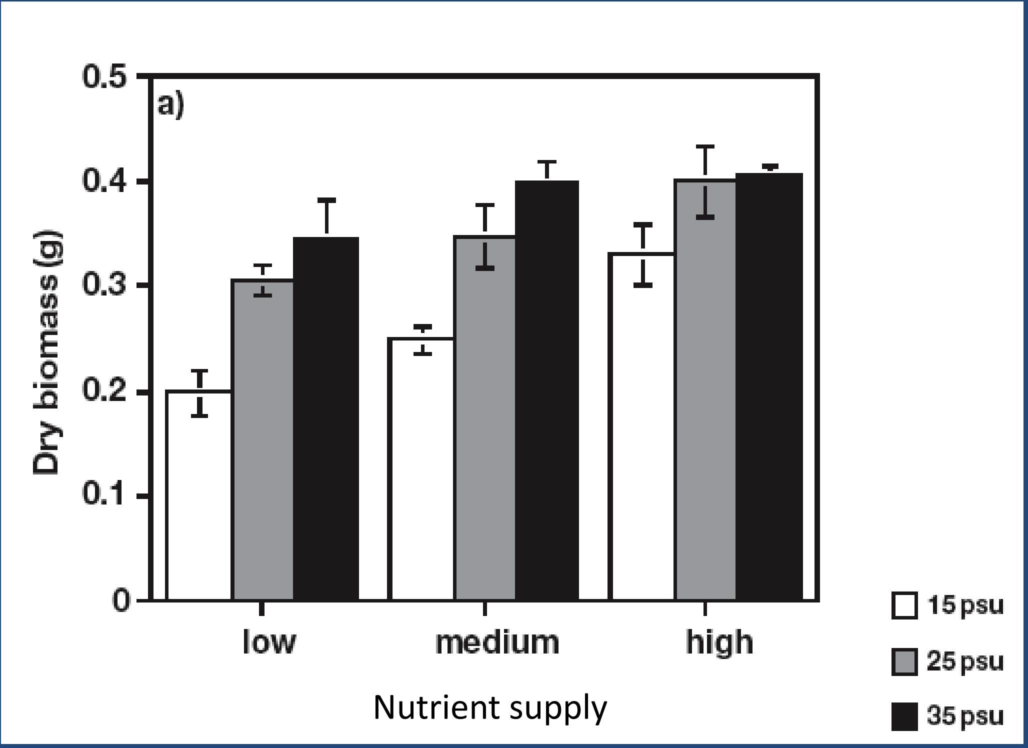


Rapid nutrient uptake abilities produce rapid growth



Kennsion, Kamer , and Fong 2011
Journal of Phycology 47: 483-494

High nitrogen supply enhances tolerance to extremes: nutrients ameliorate negative effects of low salinity

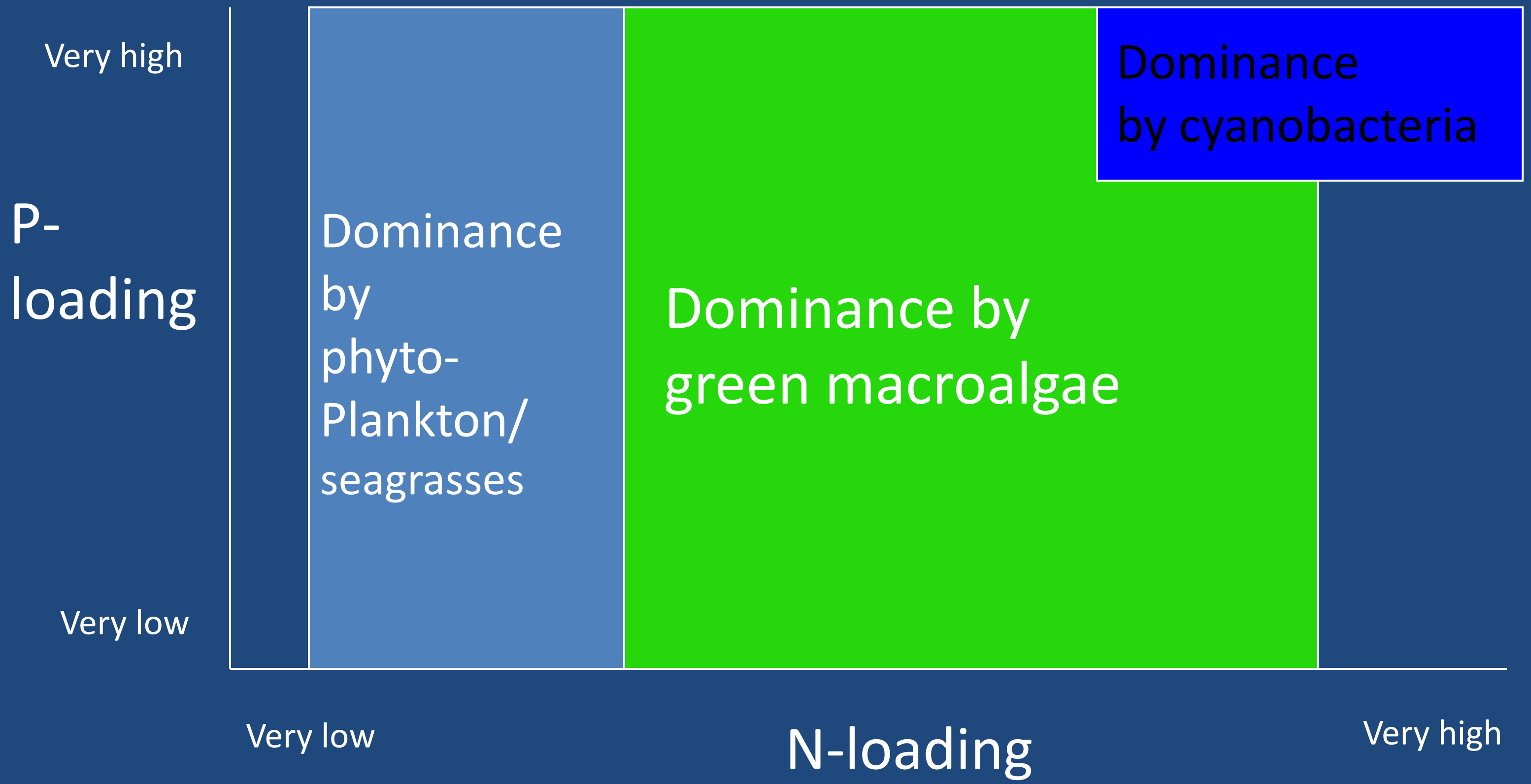


Kamer and Fong 2001
Marine Ecology Progress Series 218: 87-93

Result: ubiquitous in shallow estuaries, prolific in nutrient-rich estuaries

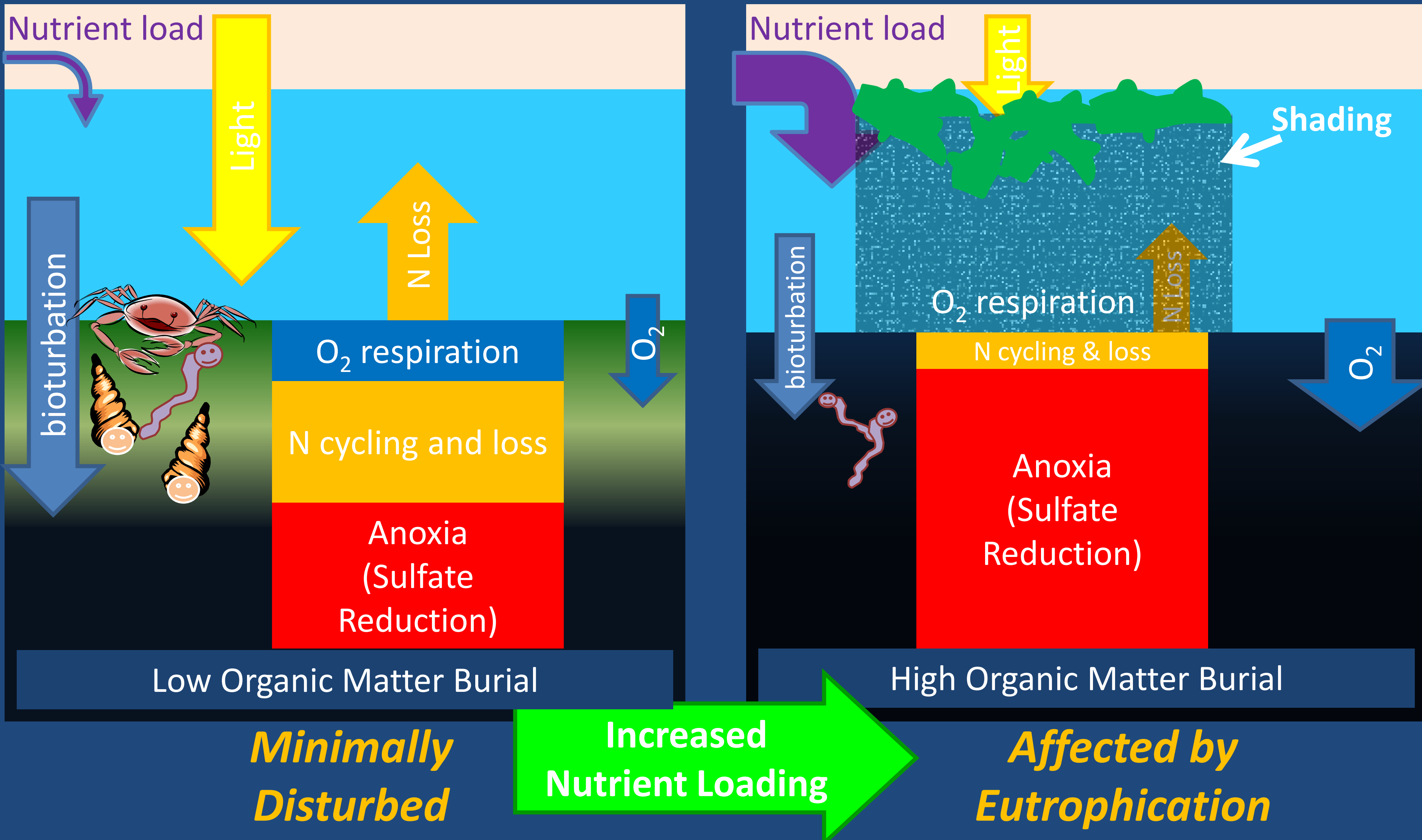
Excessive Nutrients Causes Shifts in Dominant Primary Producers

Increased N-loading shifts from microphytobenthos, phytoplankton, or seagrass to macroalgae to cyanobacteria domination



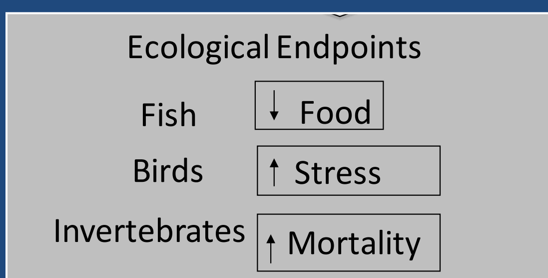
Fong, Zedler and Donohoe 1993
Limnology and Oceanography 38: 906-923

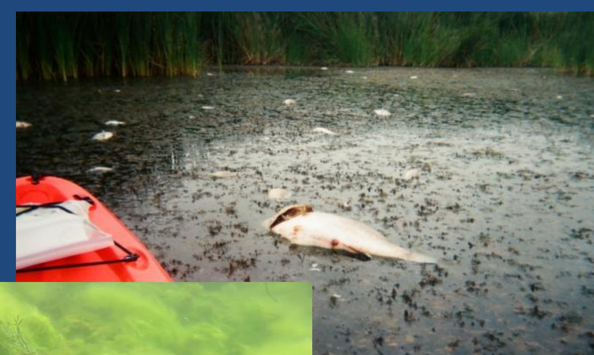
Conceptual Model of Effects of Macroalgae



Effects on Management Endpoints of Concern

- Poor surface water quality (strong diel DO fluctuations and hypoxia, increased bacterial growth)
- Poor benthic habitat quality (Increased sediment organic matter accumulation, sediment anoxia, increased pore water sulfide, ammonia, etc.)
- Changes in food web (shifts in food supply for upper trophic levels)
- Loss of critical habitat for fisheries, birds, esp. T&E species





Lots of Literature on Effects of Macroalgae, But..

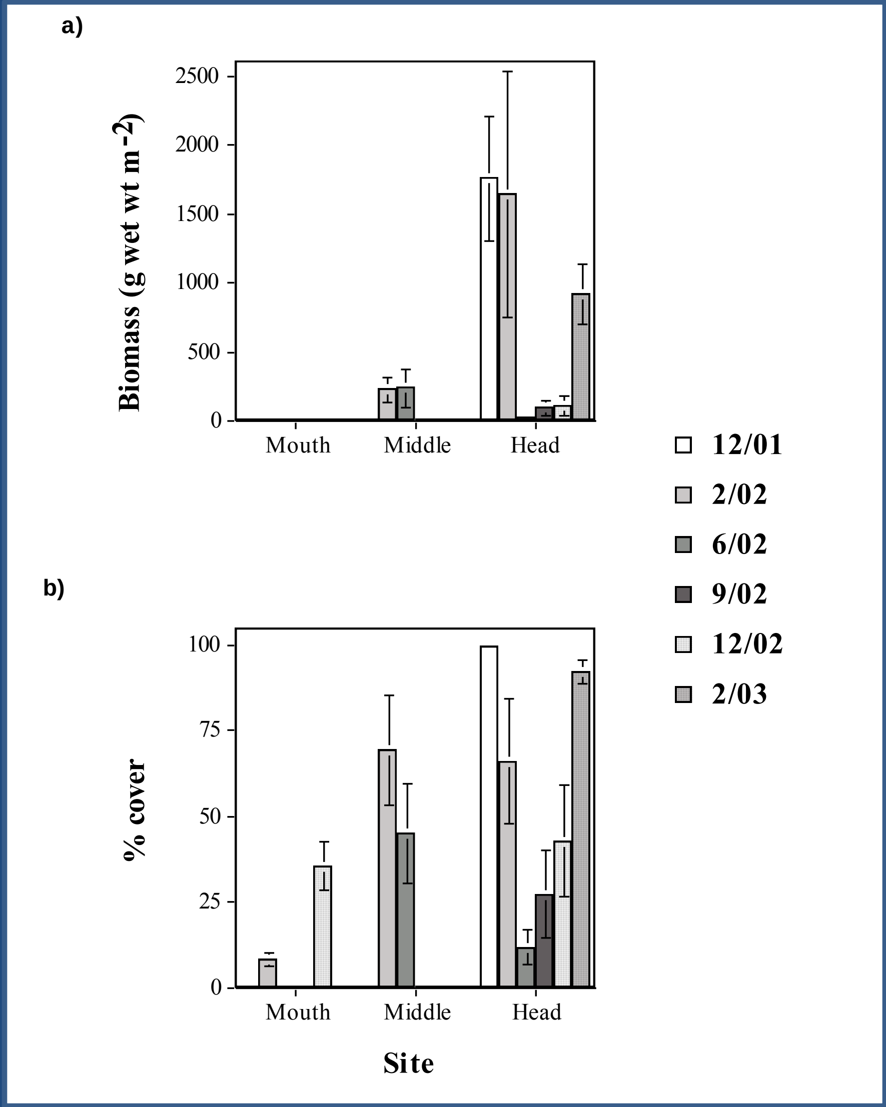
- Little literature characterizing the “dose-response” that would be valuable for endpoint selection

Does Macroalgae Have A Predictive Relationship with Nutrients?

- Yes - best example is Waquoit Bay (MA)
  - Total nutrient loads predict algal biomass in 3 sub-basins with differing loads
  - But the relationship is complex (easiest where river sources are dominant)

- Co-factors play a large role in regulating response to nutrients

Temporal and Spatial Variability of Blooms in Estuaries Can be High

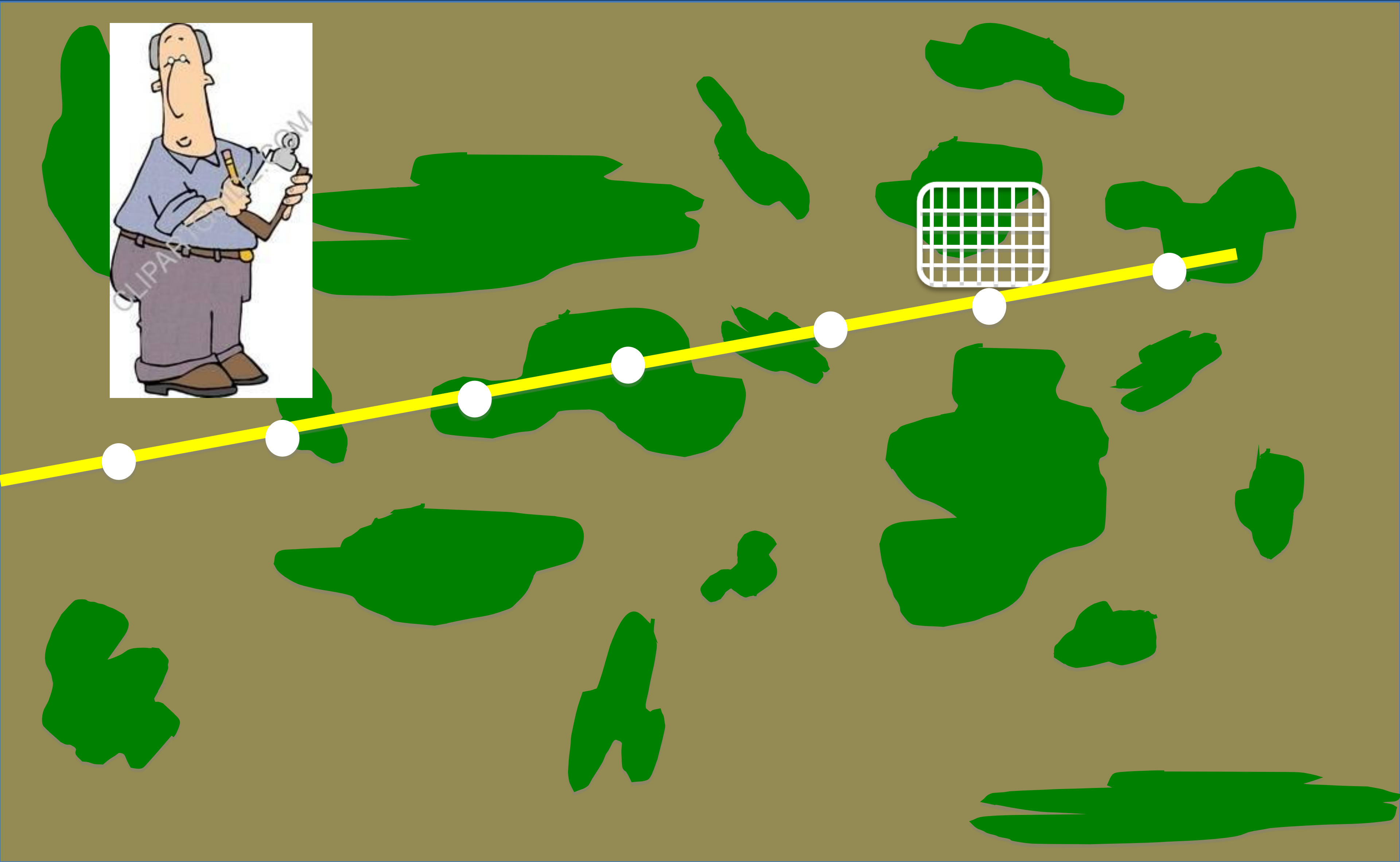


An example from Carpinteria Marsh

More algae near river inflow

In some years, blooms coincide with winter fertilization of strawberry fields

Abundance is Typically Measured Using Transects To Estimate Biomass and %Cover



A Primer On Macroalgae: Summary

- Macroalgae are a natural and beneficial part of estuaries
- Flavors of macroalgae – red, brown and green
- Rapid uptake abilities, plasticity in growth form, combined with tolerance to environmental extremes makes them prolific in anthropogenically disturbed systems
- Macroalgae outcompete other primary producers as nutrient loads increase
- Well documented relationship with nutrient loads
- Spatially and temporally variable
  - Typically measured by estimating biomass and % cover

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Field Experiments-Overview

- Why do we focus on macrobenthos as management endpoint of concern?
- What information can previous studies provide?
  - Green (2011) experiments in Mugu Lagoon
- NNE field experiments
  - Methods
  - Results
  - Relevance to synthesis of information on thresholds

Why Study the Response of Infauna and Epifauna?

Important to food web support & Biogeochemical cycling

Importance of Macrofaunal Functional Groups

Suspension and Surface Deposit Feeders, Herbivores:

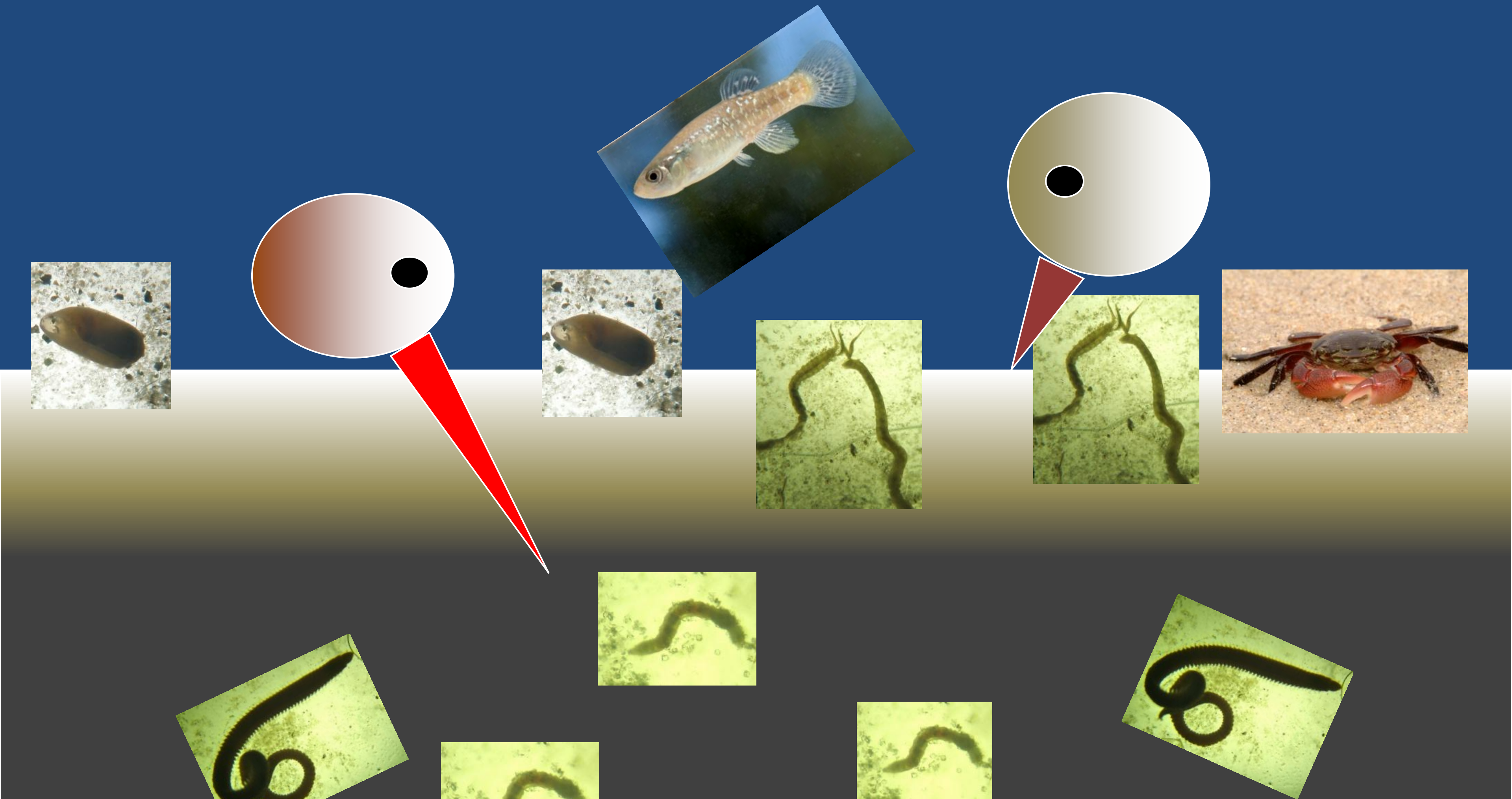
- Graze on phytoplankton, microphytobenthos, macroalgae, detritus == bottom of the food chain
- Important prey for birds, fish and crustaceans
- Burrowing and irrigating increase oxygen penetration and enhance nitrogen removal

Suspension Feeders

Surface Deposit Feeders

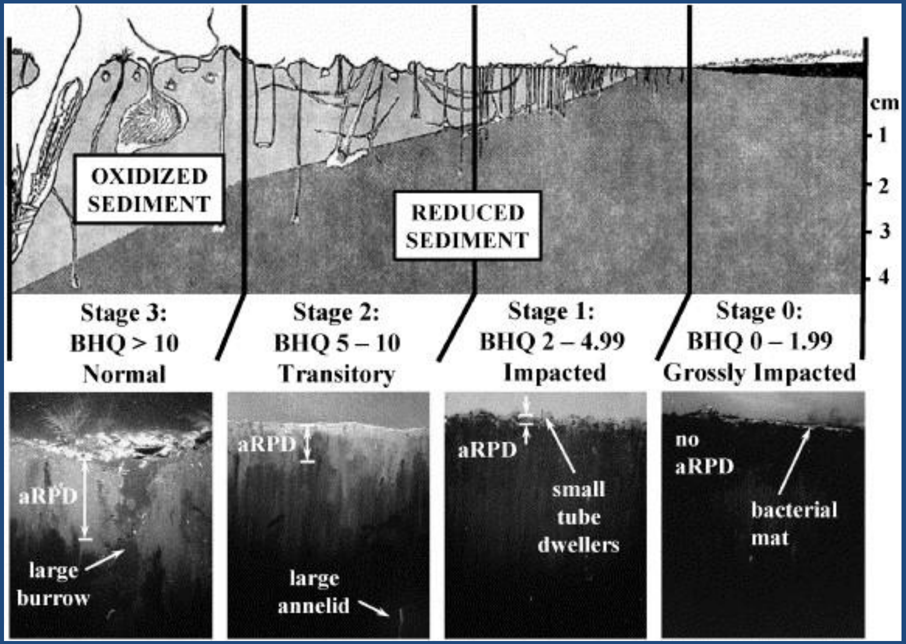
Herbivores

Surface Deposit Feeders Are More Accessible to Birds & Fish Than Subsurface Deposit Feeders



Macrobenthos Are Part of Feedback Loop that Control Depth of Oxygen Penetration in Sediments

- Diverse macrobenthos mix sediment, increasing depth of oxygen penetration
- High organic matter loading reduces sediment redox potential
- Sulfate reduction shallows, causing high pore water sulfide
- Sulfide is toxic to many benthic organisms

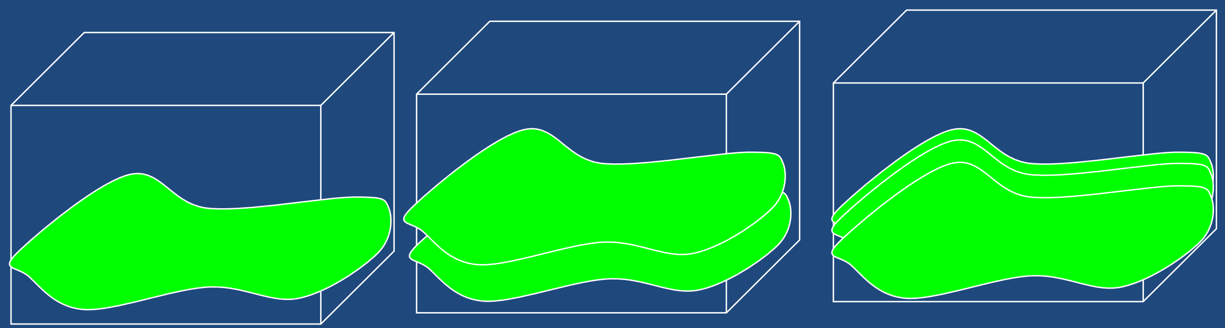


Previous Studies

- Previous studies showed a negative effect of macroalgae on benthic invertebrates (e.g. Hull 1987).
  - Methods tended to be a single application of macroalgae (Hull 1987), a single treatment (Cummins et al 2004) or field surveys (Jones and Pinn 2006).
  - Effects based on multiple treatments and continuous application (and monitored by frequent sampling) were lacking.
- Green (2011) first field experiment with tight control on dose and duration

Initial Experiment Consisted of 3 Treatments Maintained for 8 Weeks (Green 2011)

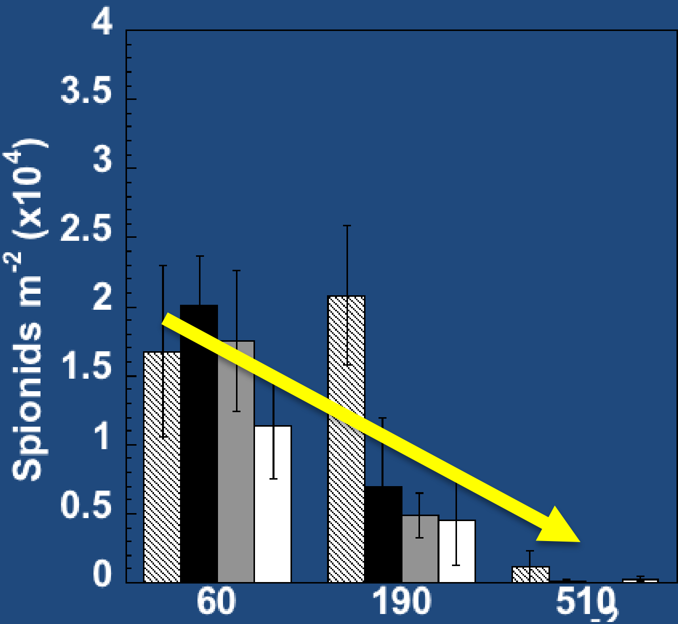
~0-60 g dw m^{-2} ~190 g dw m^{-2} 510 g dw m^{-2}



Sampling Protocol

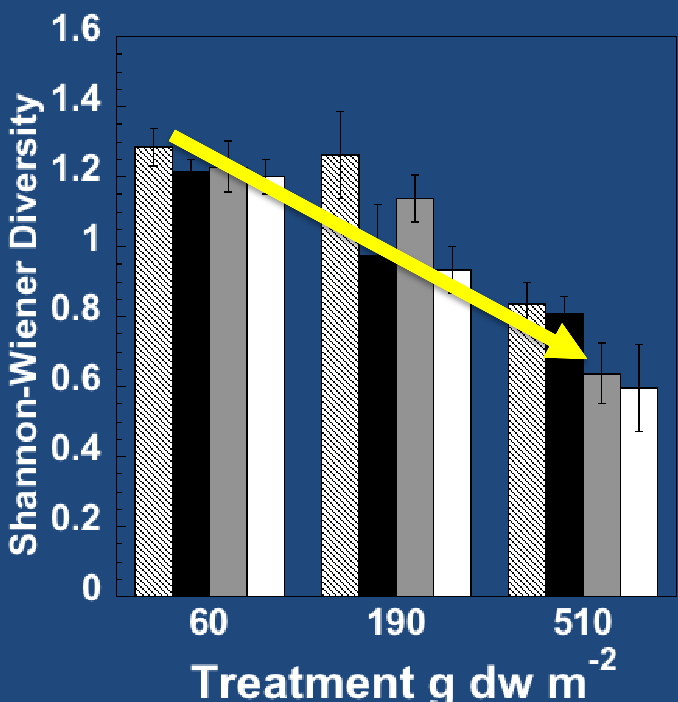
- Sampled infauna initially, then every two weeks for 8 weeks
  - Documented change in macrobenthic species diversity and abundance

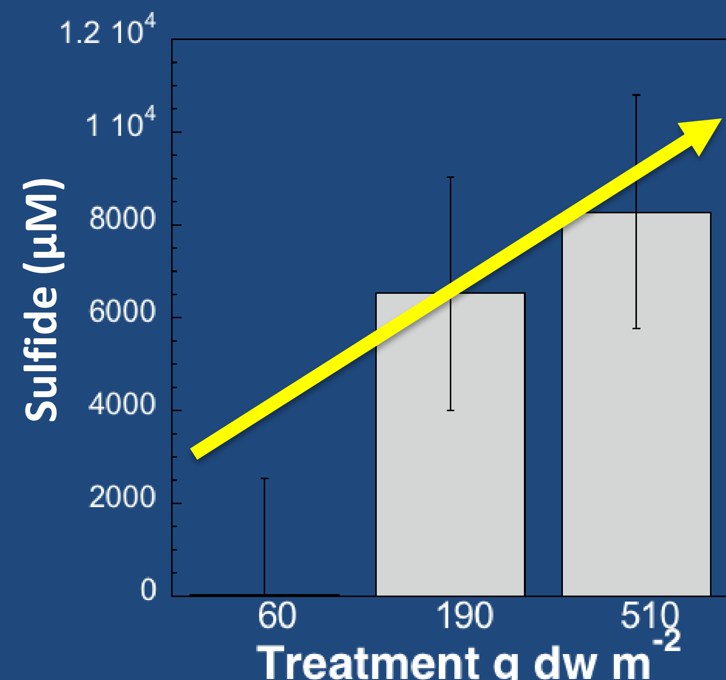
- Week 6-8 deployed “peepers” to measure pore water sulfide and ammonium



Findings:

- 190 g treatment: significant negative effect on diversity, decrease in surface deposit feeders
- Level associated with high pore water sulfide
- Control had no observed effect



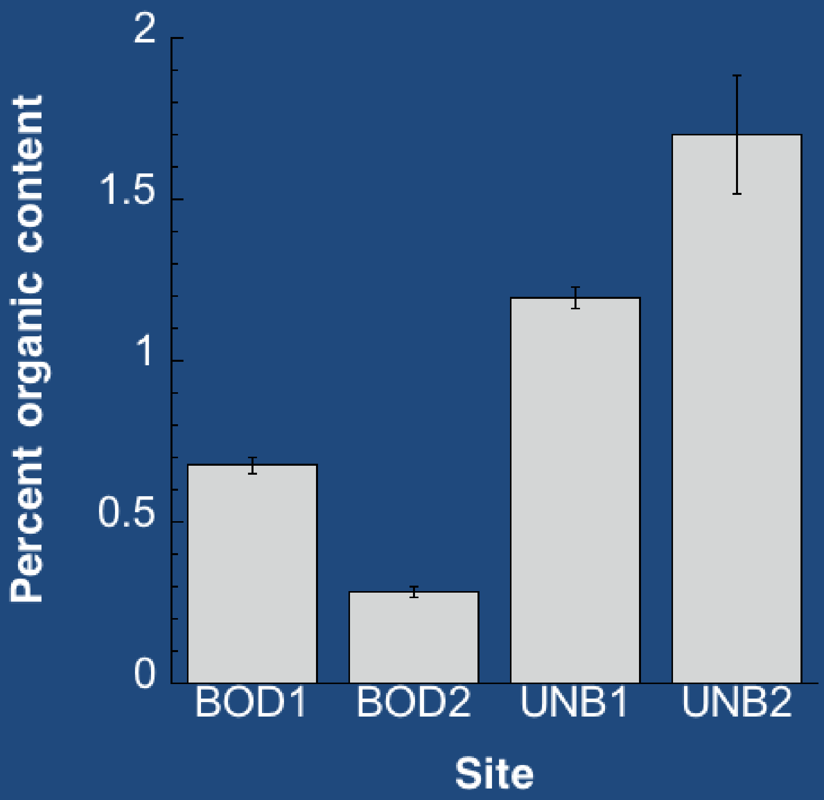


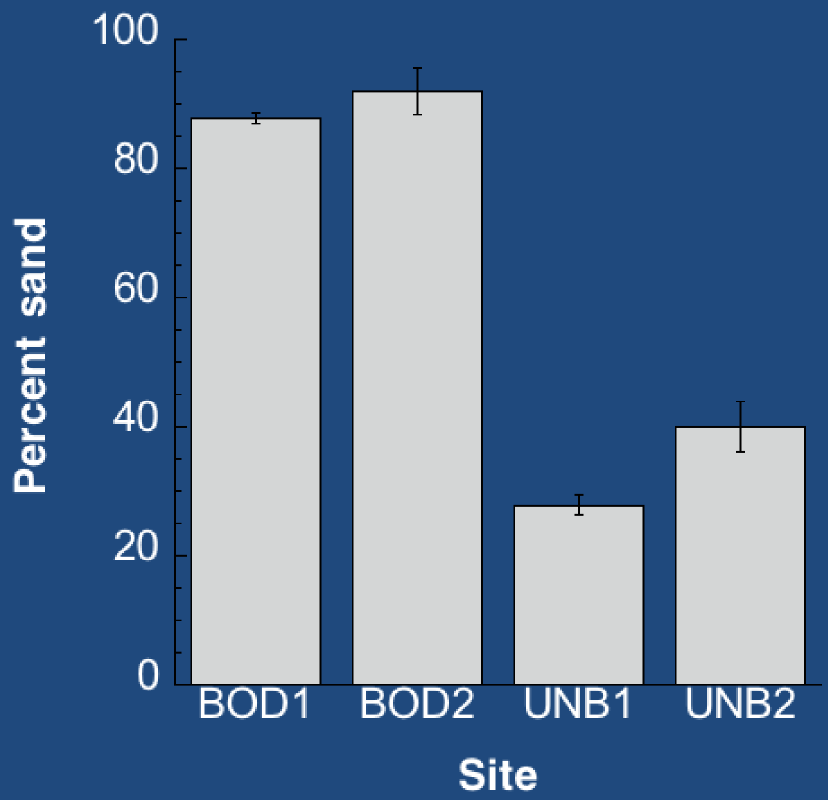
Estuaries Differ With Respect to:

- Climate
- Hydrology
- Sediment organic matter and grain size
- Benthic community

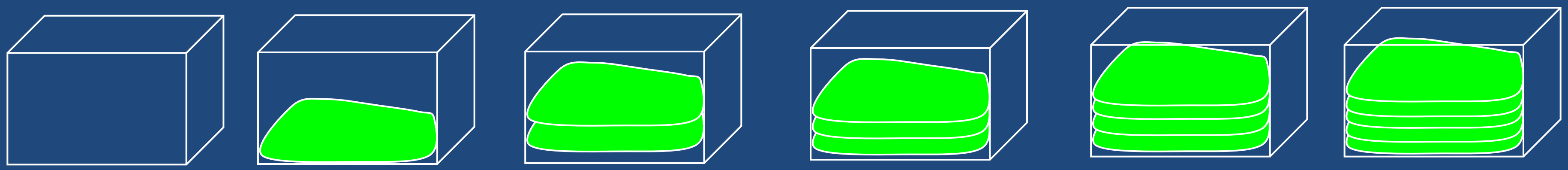
Are Benchmarks the Same Despite Differences Between Estuaries (and the Sites Within Estuaries)?

Bodega Bay Has Higher Sand Content, Lower Organic Matter than Upper Newport Bay





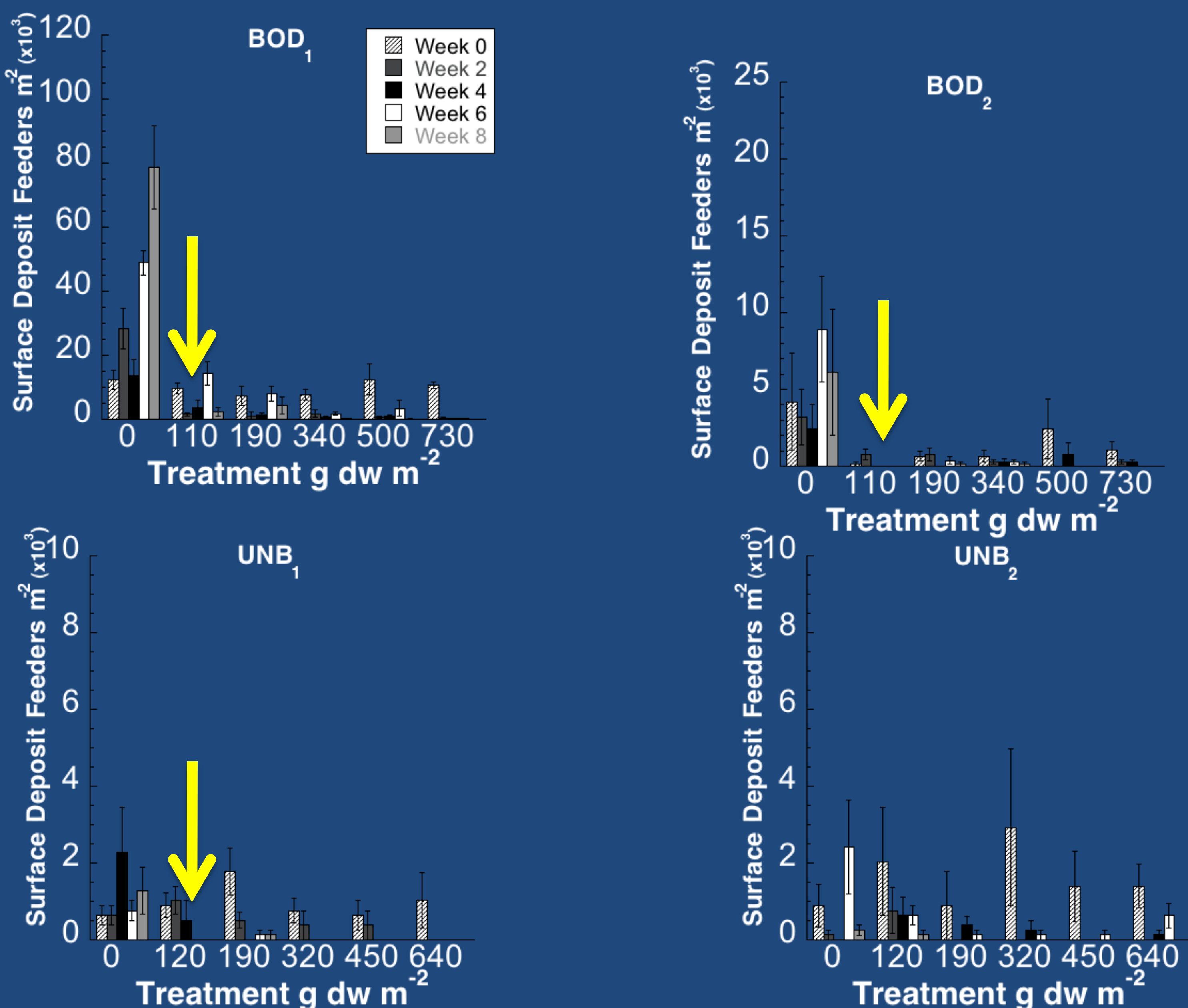
Broader Treatment Range, Similar Sampling Protocol to Earlier Experiment



0 100-120 190 315-340 440-500 510-730

Sampled infauna & epifauna initially and every two weeks for eight weeks

Surface Deposit Feeders Declined at 110-120 g dw m^{-2}

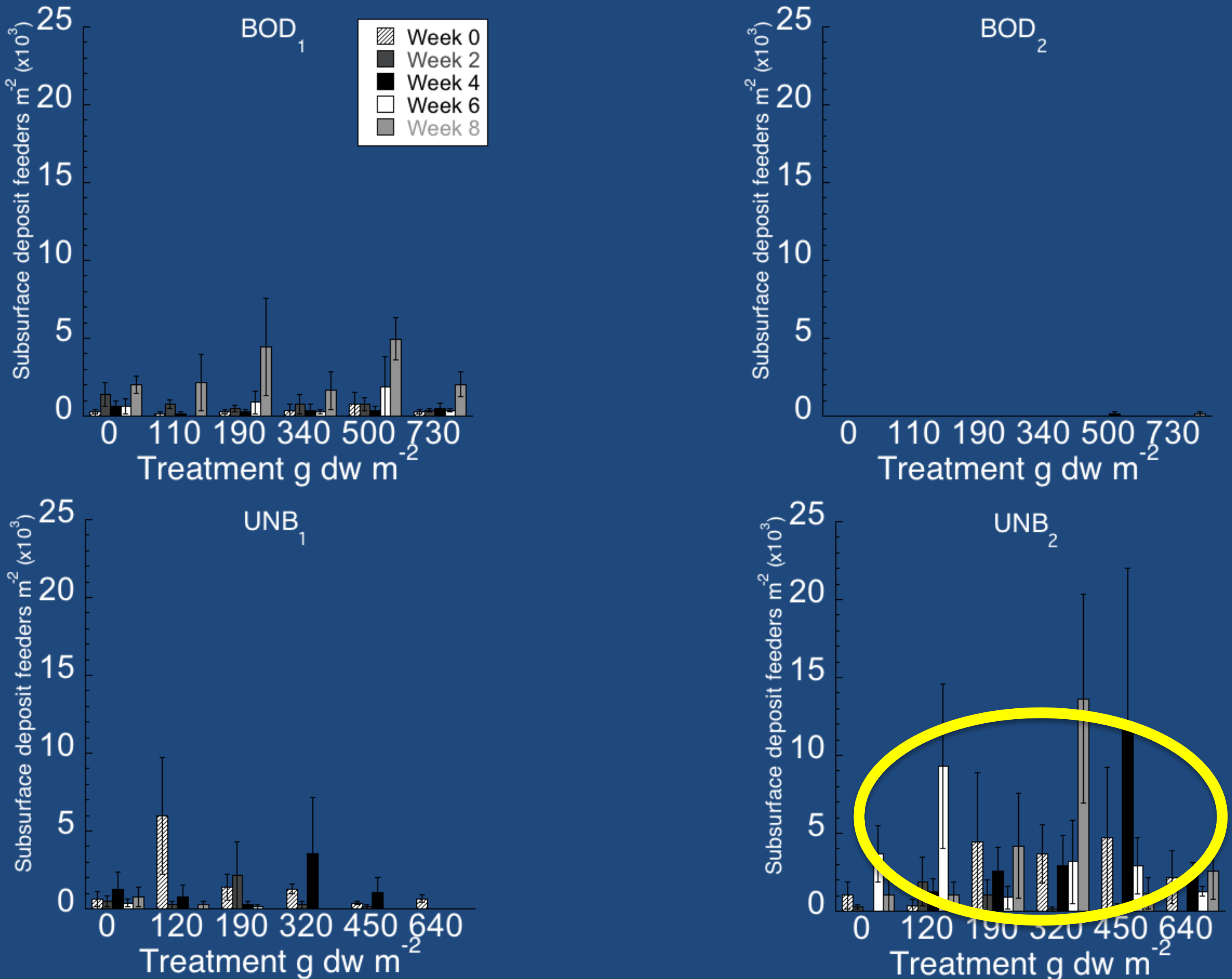


Similar Patterns Were Found With Diversity, Herbivores and Suspension Feeders

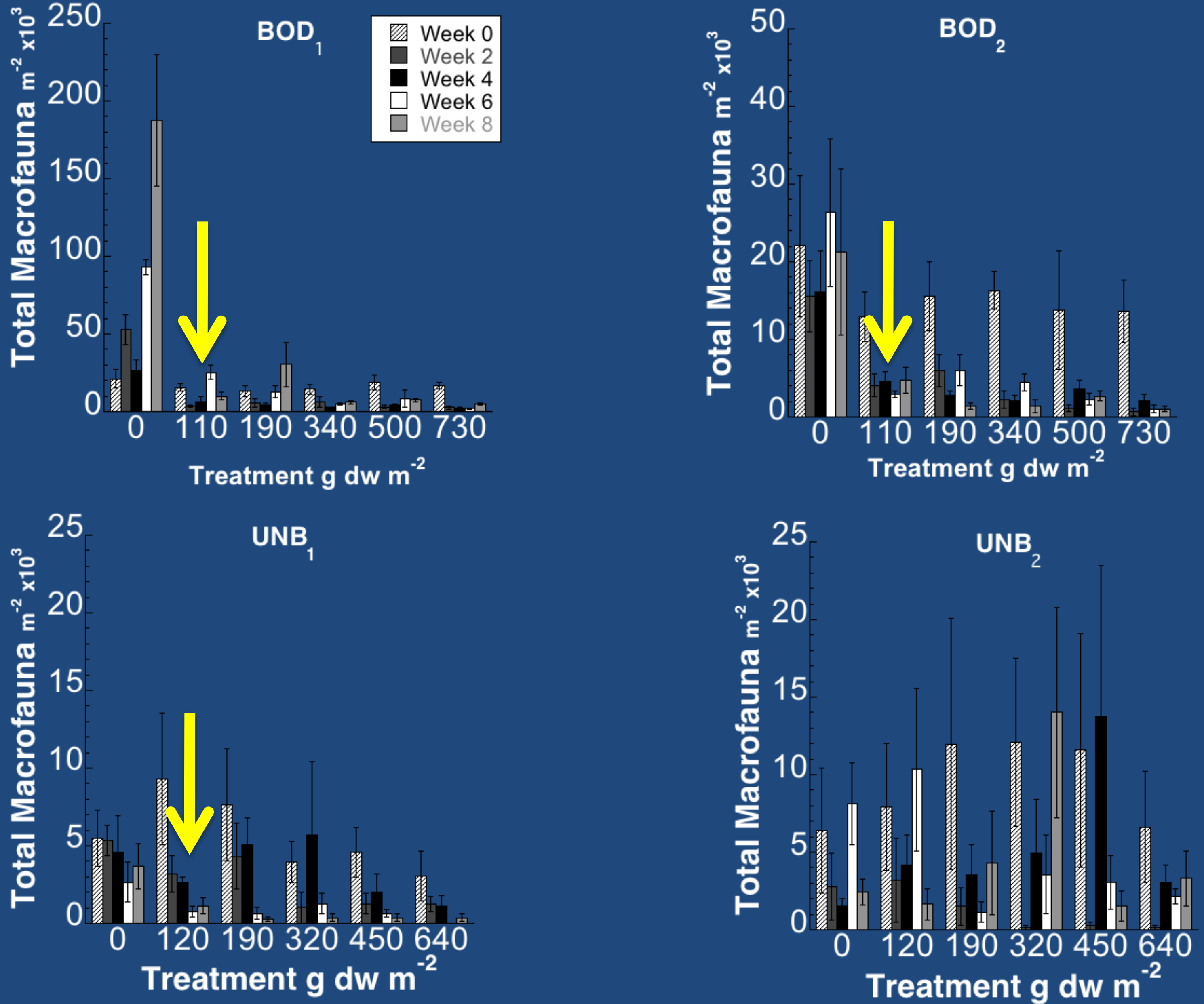
What makes UNB_2 less responsive to macroalgae?

One explanation is the composition of the benthic community

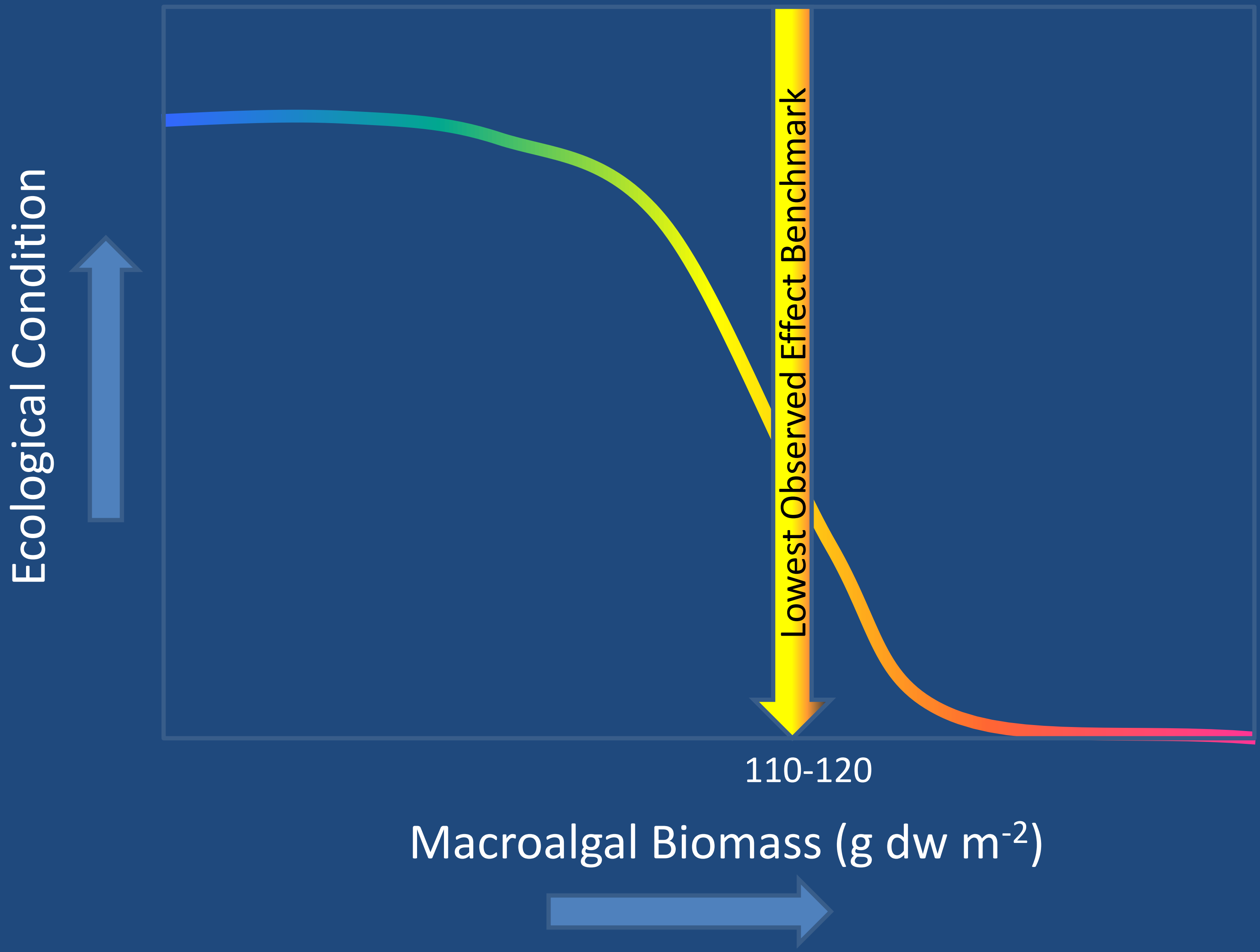
Subsurface Deposit Feeders Increased at 110 g dw m^{-2} or Greater



Total Infauna Increased at Some Sites, Due to Increase in Subsurface Deposit Feeders



Study Establishes Lowest Observed Effect Benchmark



Summary of Field Experiment Findings

- Strong negative effects on infauna and epifauna at ~ **100-120 g dw m^{-2}**
- Rapid response by benthic community within 2-4 weeks of treatment
- Similar benchmark for two very different estuaries
- High abundances of subsurface deposit feeders (UNB_2) may indicate a disturbed state not strongly affected by added eutrophic stress

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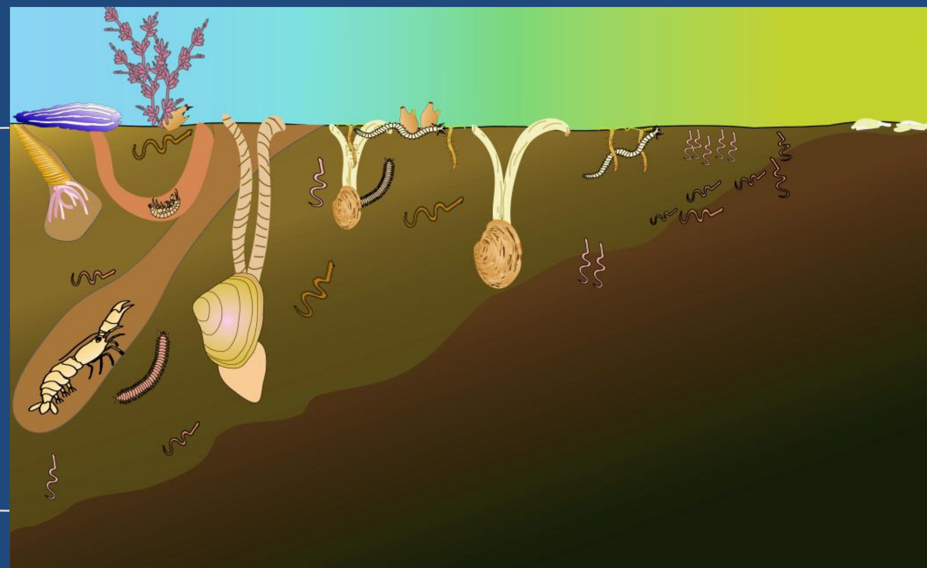
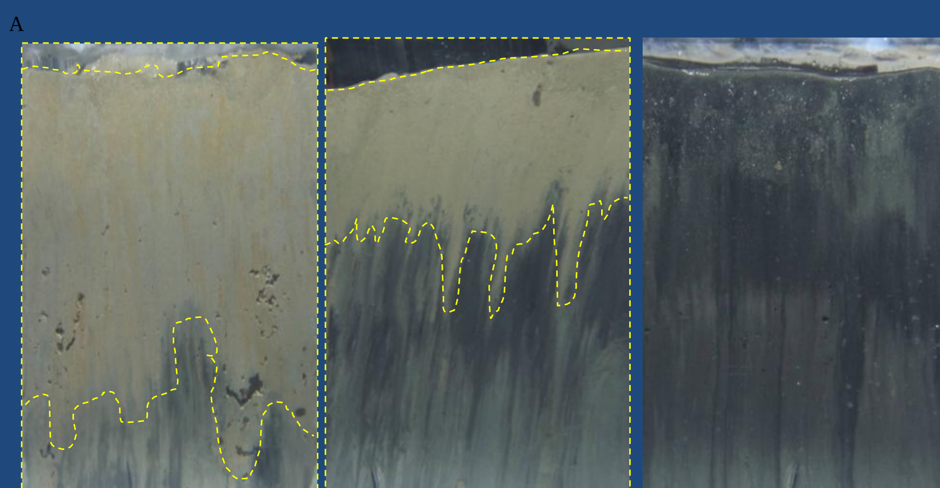
How Do We Extrapolate These Findings Across Estuaries?



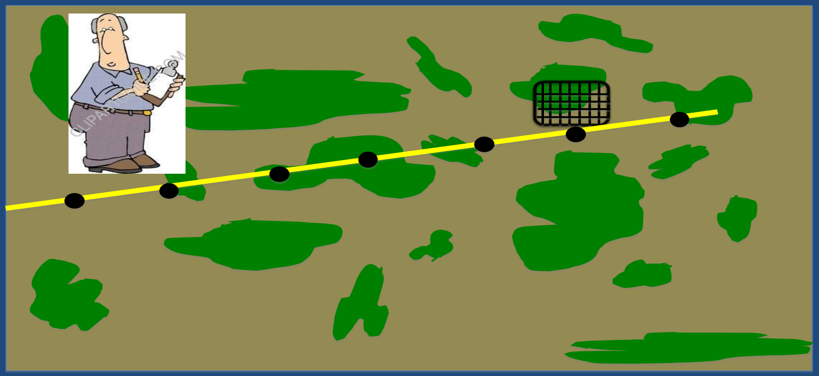
Depth to apparent redox potential discontinuity (aRPD)



Sediment Profile Imagery (Rhoads and Cande, 1971

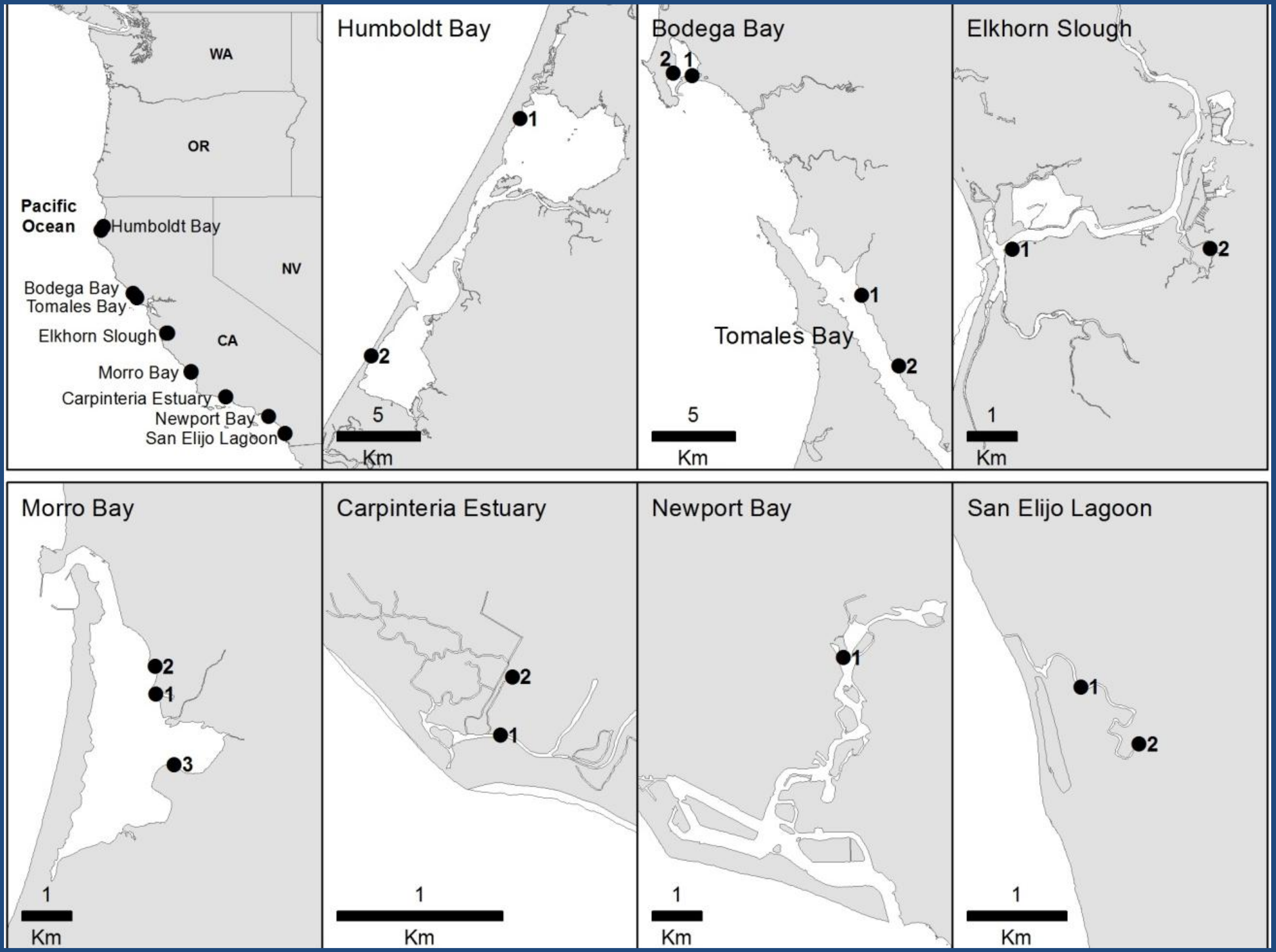
Sediment Profile Imagery Survey: Approach

- Survey of 16 sites in 8 estuaries
- At each sites, measured suite of parameters in 20 plots along a transect
  - Macroalgal biomass and % cover
  - Sediment %OC, %N, % fines
  - aRDP from sediment profile imagery

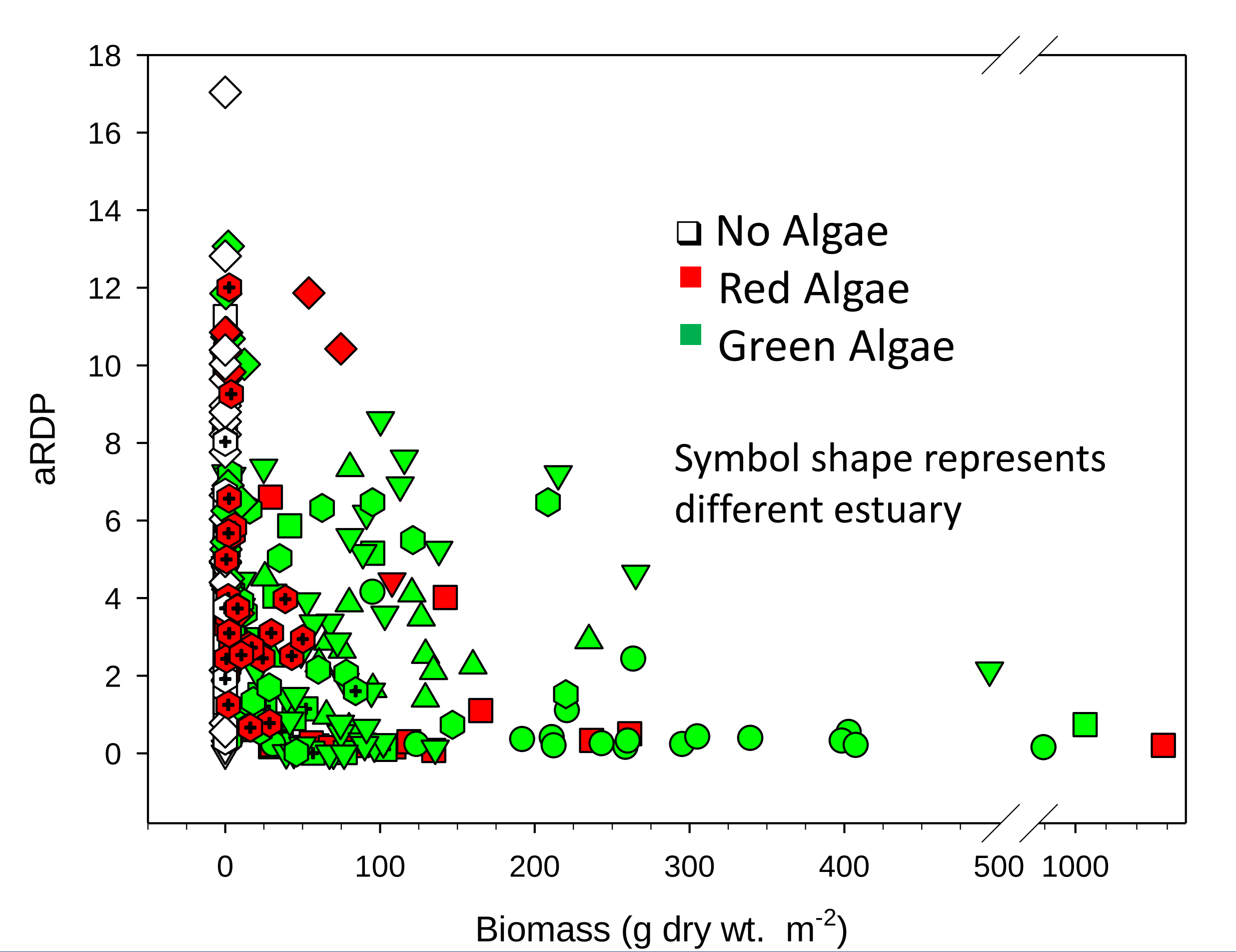


Sutula et al. (submitted to Estuaries and Coasts)

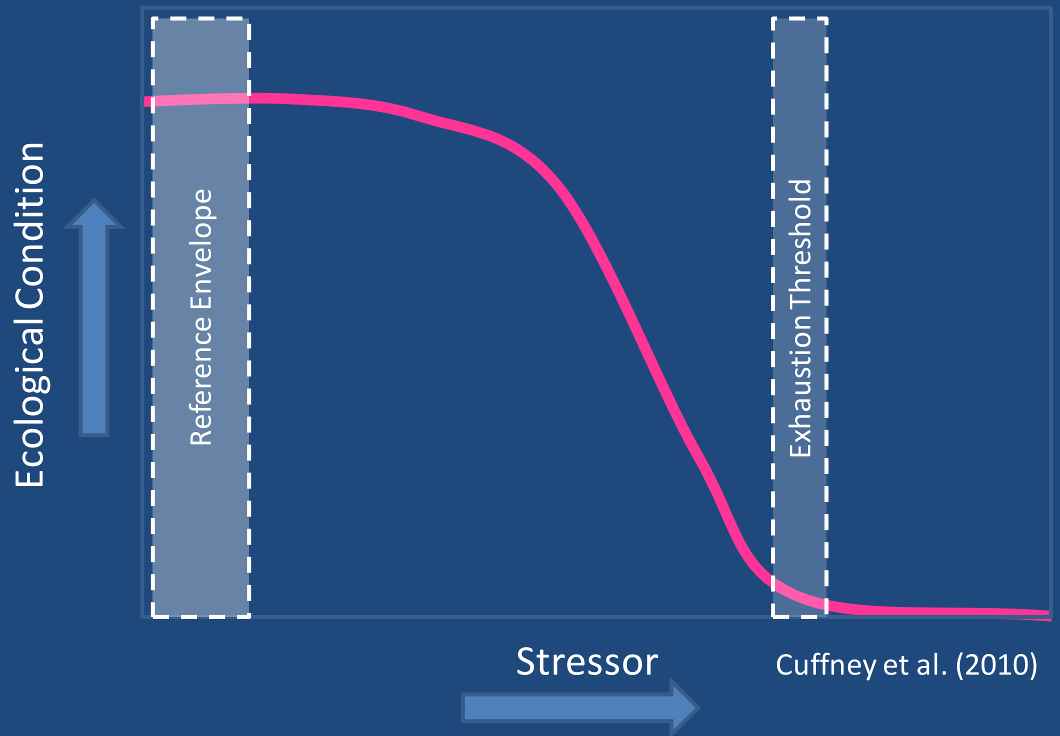
Eight Estuaries Captured Diversity of California Estuaries



Data Illustrate That Lots of Factors Control aRDP, But That Macroalgae At Some Point Override Other Factors

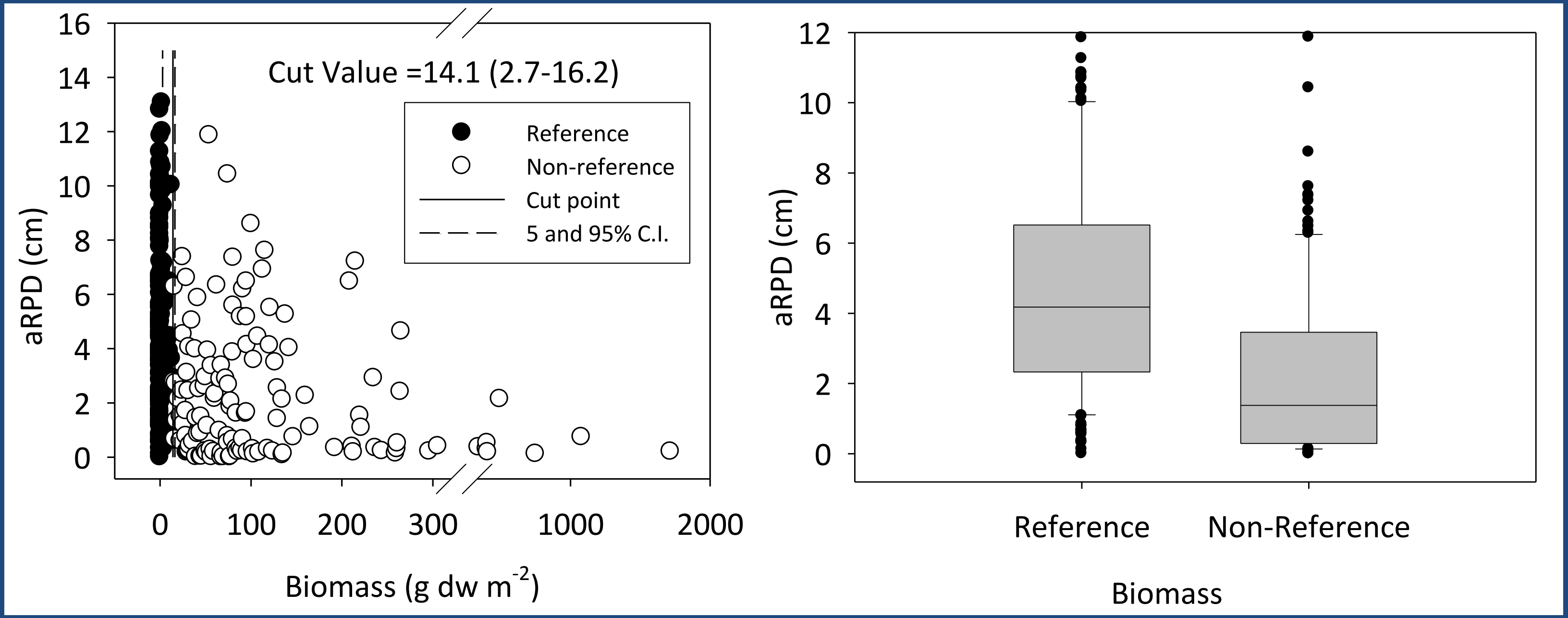


Used Statistical Modeling Approaches Can Identify Two Types of Thresholds

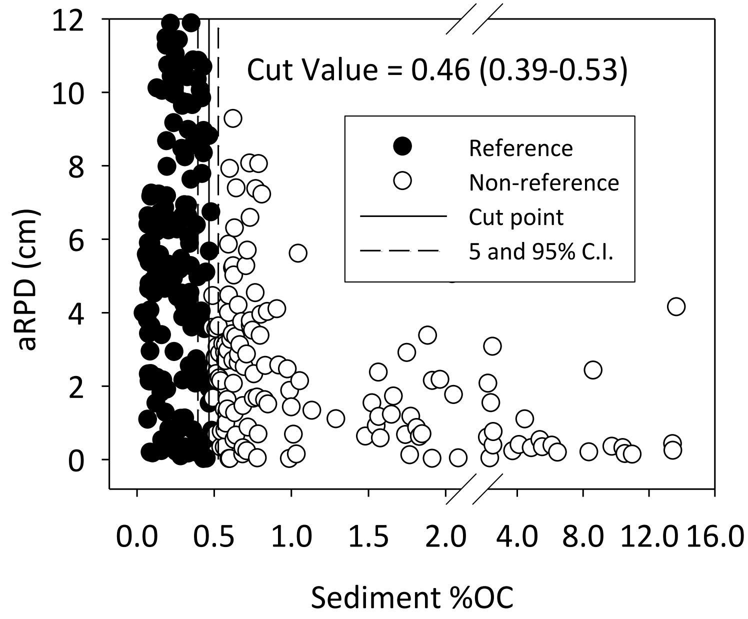


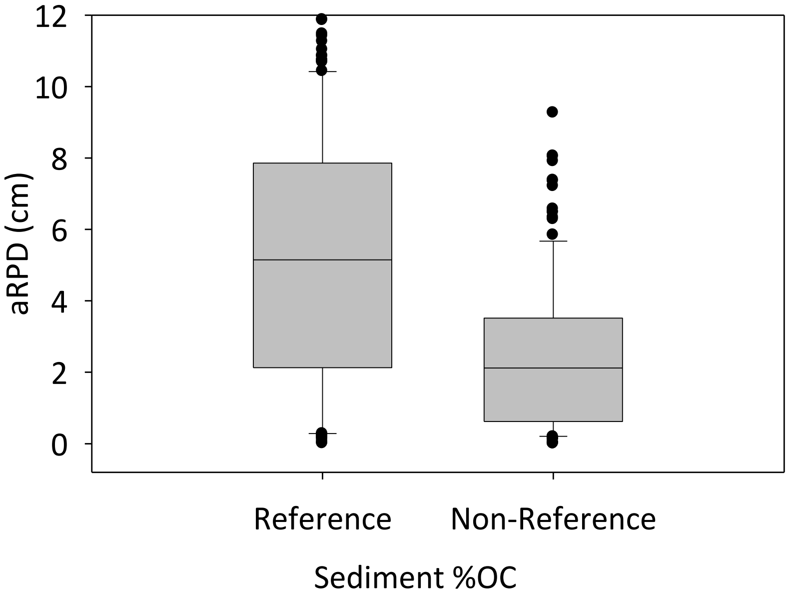
- Classification and Regression Tree Analysis (CART) to identify "step thresholds" = reference/non-reference population
- Piecewise regression to identify slope thresholds = exhaustion threshold

Macroalgal Biomass of 2-16 g dw m^{-2} Defined as a Reference Envelope Based on aRPD



0.4-0.5% OC Defined as a Reference Envelope Based on aRPD

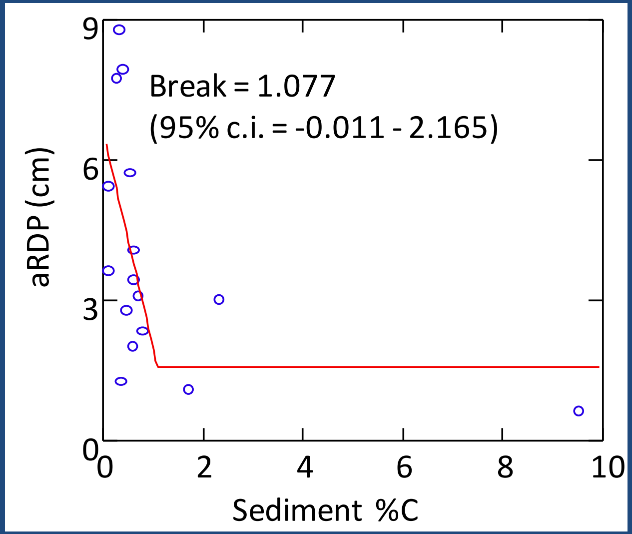




Biomass of 175-190 g dw m^{-2}, 1.1%OC Defined as a Exhaustion Threshold Based on Site-Averaged Data

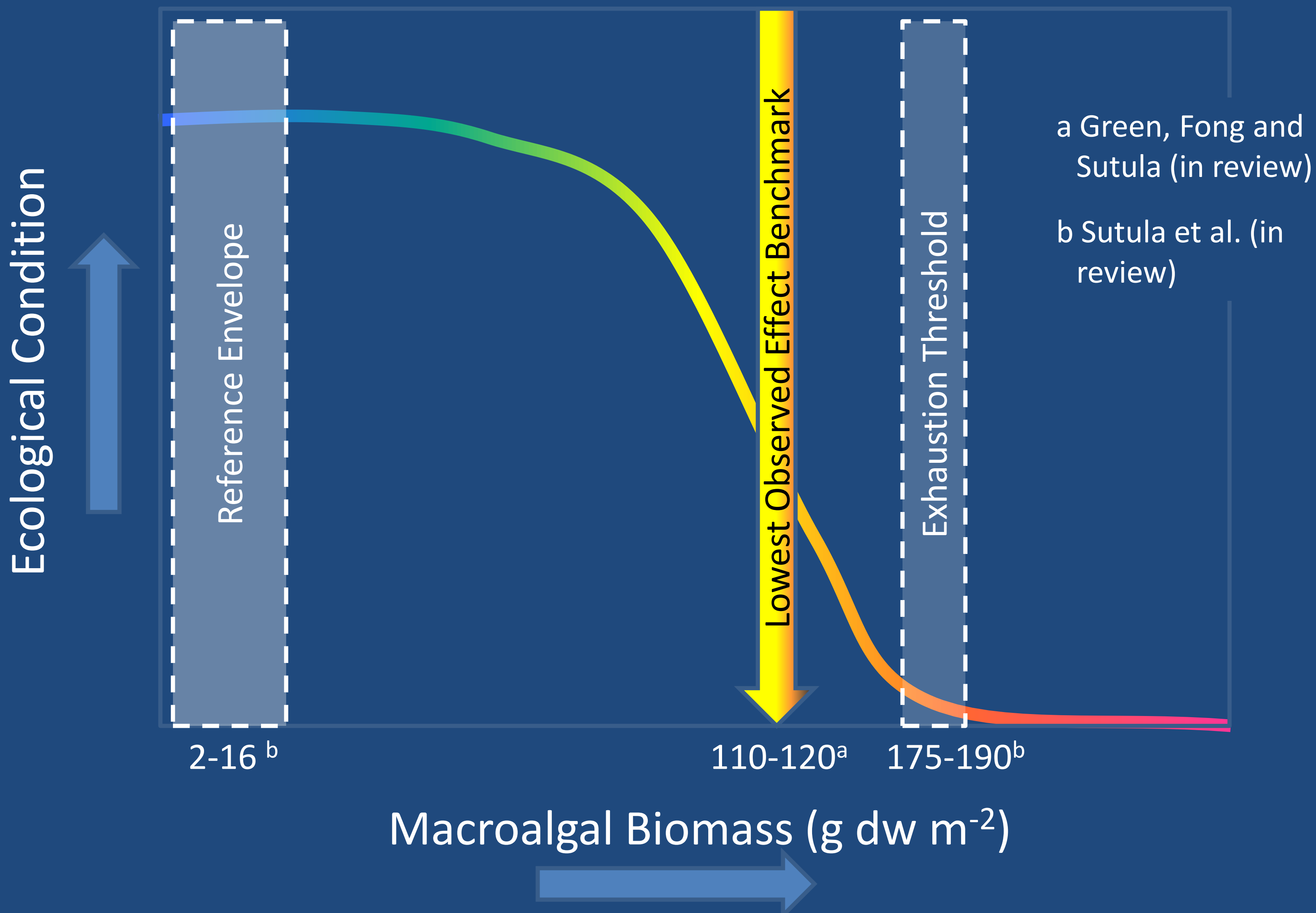
Fit method	Y-inter-cept	Slope	X-Intercept Parameter Estimates (Bootstrap 95% C.I.)		
			Median	5th	95th
Least squares	4.5	-0.013	318.6	175.8	358.8
Robust regression	3.9	-0.011	318.0	189.4	358.7

Slope only (no break) model best fit for Macroalgal Biomass

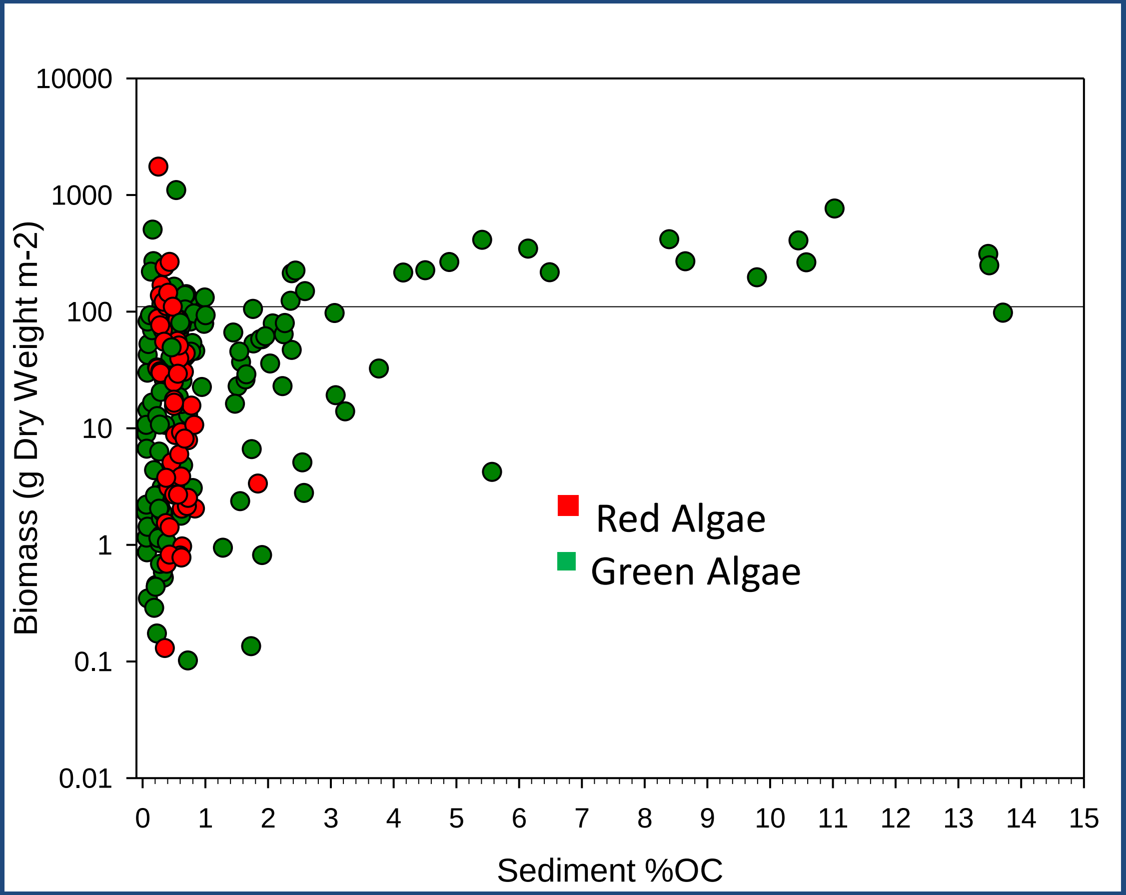


Slope + break model best fit for Sediment %OC

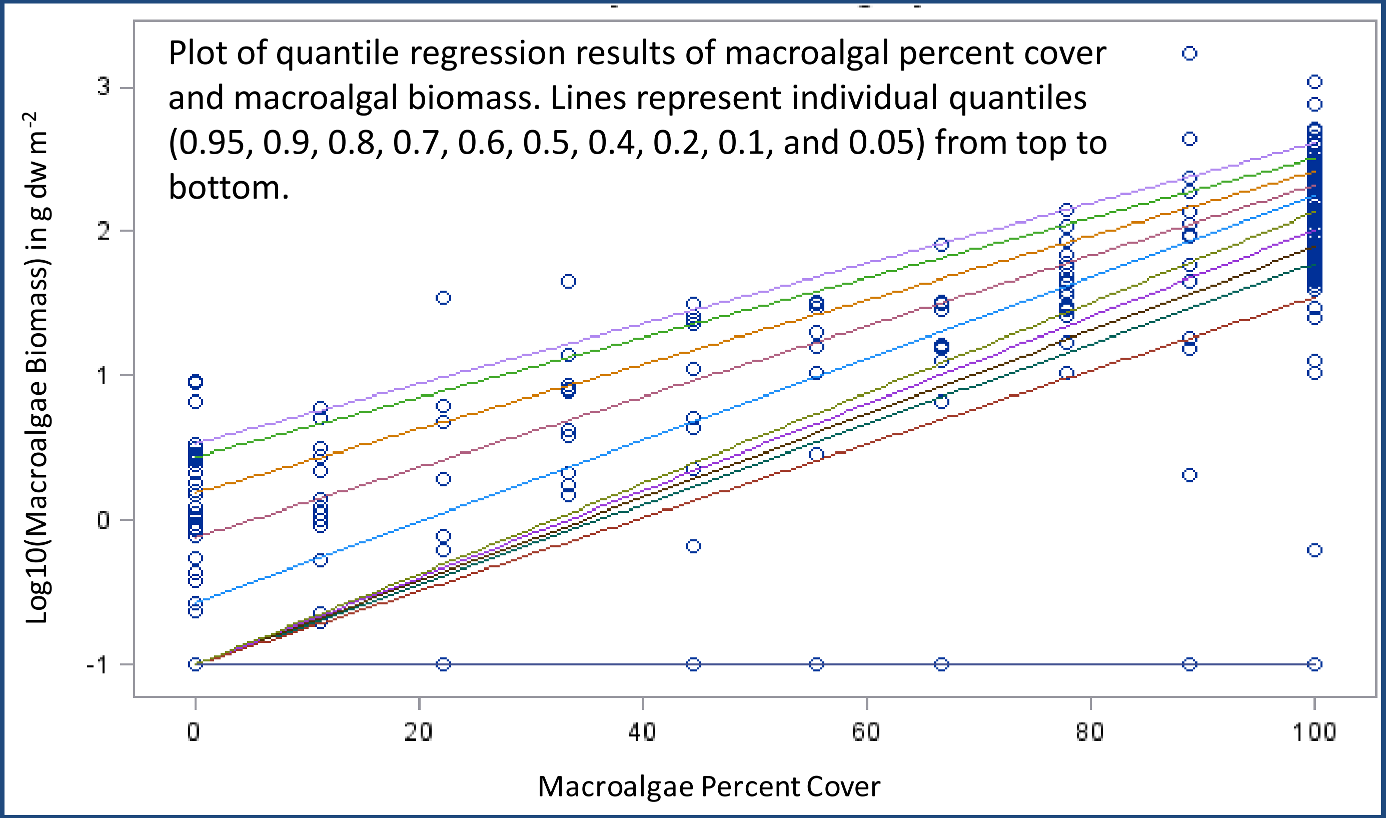
Study Establishes Reference Envelope and Exhaustion Thresholds for Macroalgae, Supports Pelletier et al (2011) Findings for %OC Thresholds



Strong Feedback Loop Between Macroalgal Biomass and Sediment Organic Matter Content



% Cover Has No Relationship with aRDP
……But May Have Potential As Screening Variable



< 30% cover, only 5% of plots exceeded a biomass of 14 g dw m^{-2}

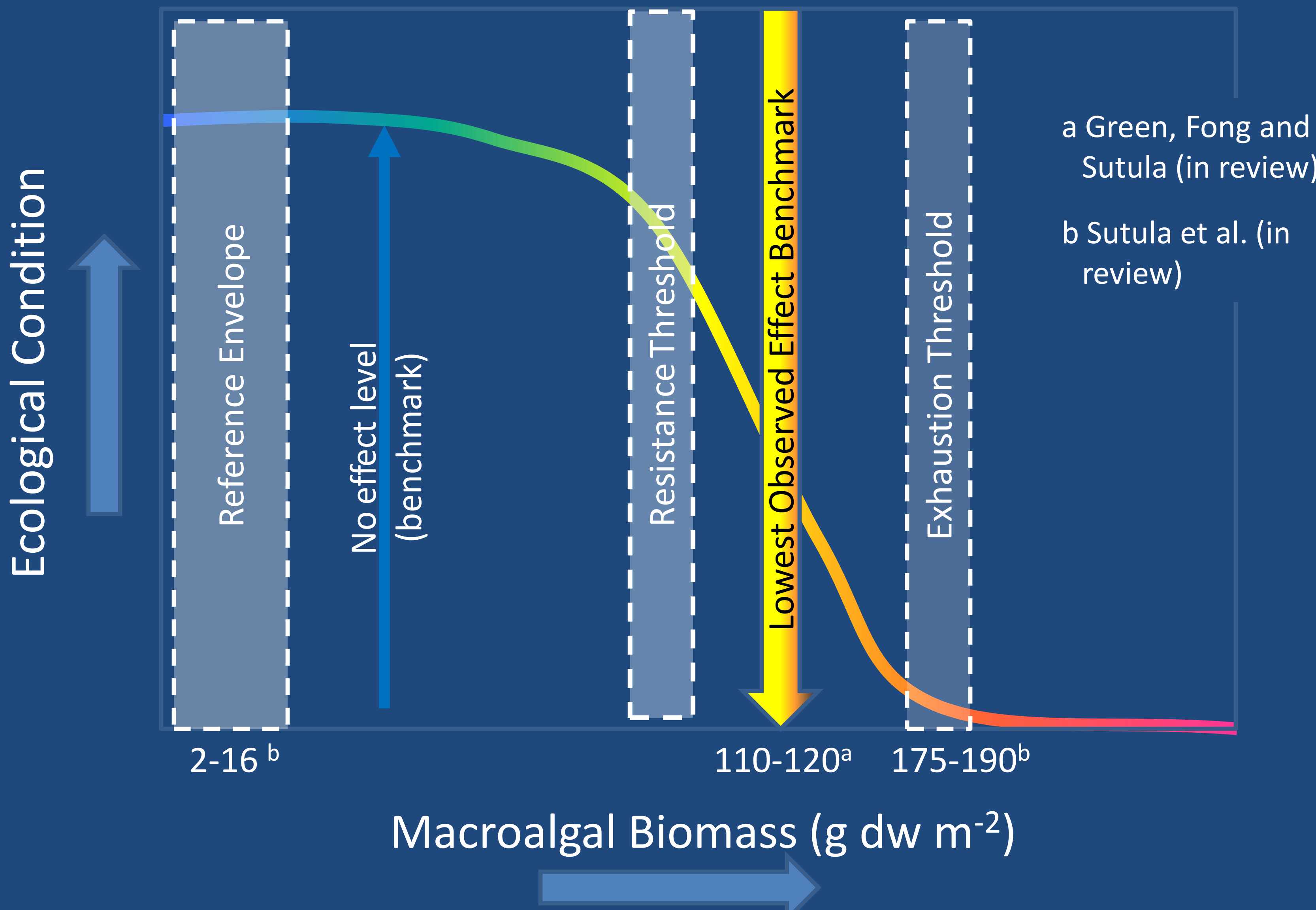
Sediment Profile Imagery Survey: Findings

- Study established reference envelope and exhaustion thresholds for macroalgal biomass and sediment %OC
  - Reference envelope of 2-16 g dw macroalgal biomass m^{-2} and 0.4-0.5% OC
  - Resistance threshold of 175-190 g dw macroalgal biomass m^{-2} and 1.1%OC
- Strong relationship between sediment %OC and macroalgae indicative of feedback loop
- No relationship between aRDP and cover, but may be possible to use % cover as a screening tool

Overview of Presentations

- State Water Board's conceptual approach to nutrient objectives (Martha Sutula, SCCWRP)
  - Need for numeric endpoints for macroalgae
- Why macroalgae? (Peggy Fong, UCLA)
  - A Primer on ecology of macroalgal blooms in estuaries
- Effects of macroalgal blooms on benthic infauna– results of field experiments (Lauri Green, Harbor Branch Oceanographic Institute)
- Effects of macroalgal blooms on benthic habitat quality- results of a sediment profile imagery survey (Martha Sutula, SCCWRP)
- Synthesis and next steps (Martha Sutula)

Synthesis of Thresholds: NNE Studies Do Not Inform No Effect Level and Resistance Threshold



Can Other Studies Fill In Gaps in Thresholds?

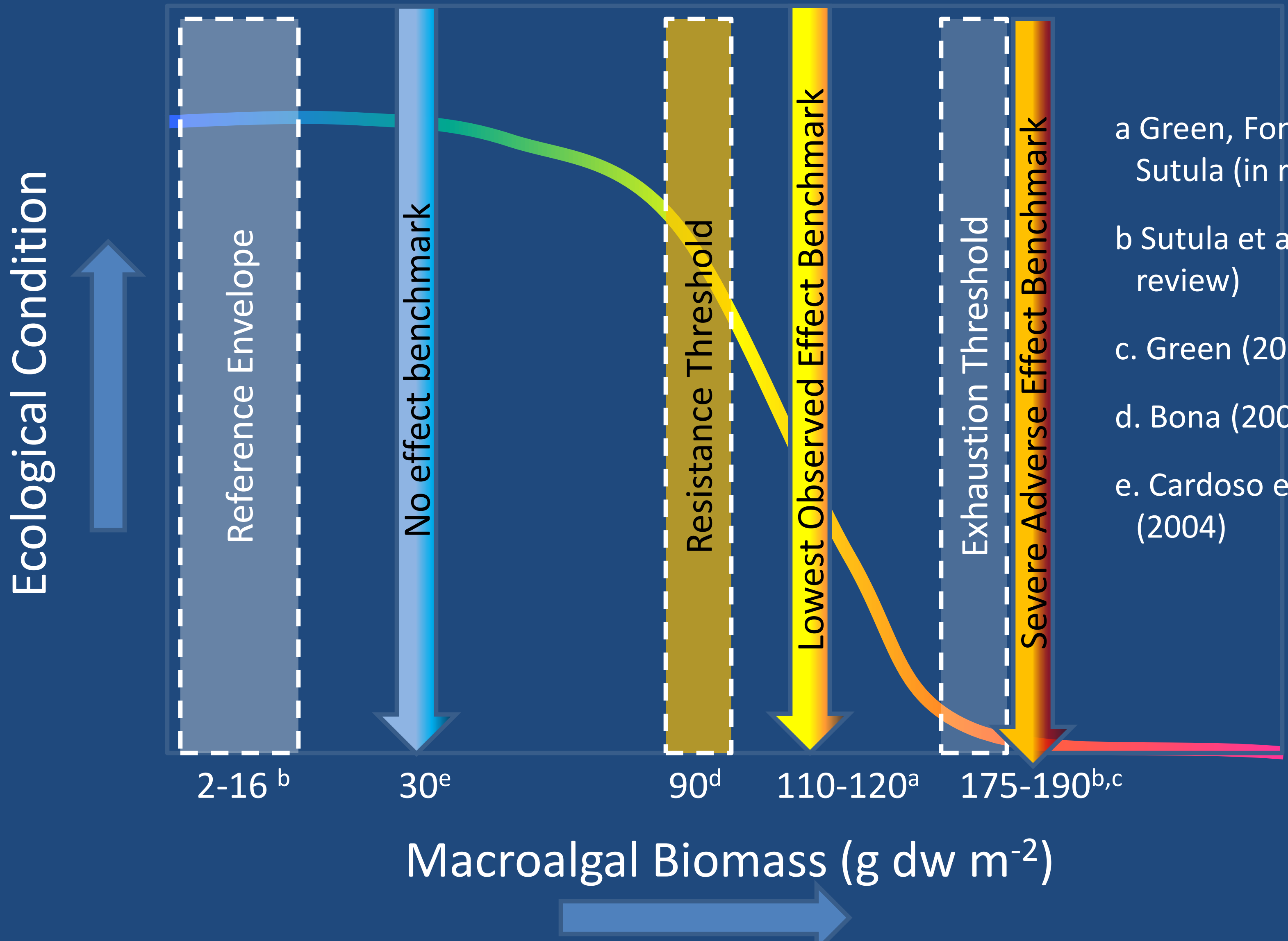
High Confidence

Moderate Confidence

Low Confidence

- Green (2011)- Field experiment, continuous application
  - High pore water sulfide, severe effects benchmark of 190 g dw m^{-2}
- Bona (2006)- Field survey with benthic camera, single estuary
  - Loss of Stage III benthic colonizers at 90 d dw m^{-2}
- Cardoso et al. (2004)- Field experiment, single application
  - No adverse effect at 30 g dw m^{-2}
- Green (2011) – Field experiment, continuous application
  - Control = algal removal (biomass varied from 0-60 g dw m^{-2})
  - No effect found, but biomass not constant

Other Studies Can Shed Light on Information Gaps, Policy Decision on What to Use



a Green, Fong and Sutula (in review)

b Sutula et al. (in review)

c. Green (2011)

d. Bona (2006)

e. Cardoso et al. (2004)

Next Steps: Develop Macroalgal Assessment Framework to Support NNE

Example: Proposed Macroalgal Assessment Framework from European Union Water Framework Directive (Scanlan et al. 2007)

Biomass (g dw m^{-2})	Percent Cover				
	<5%	5% to 15%	15% to 25%	25% to 75%	> 75 %
> 400	Moderate	Low	Very Low	Very Low	Very Low
130 to 400	Moderate	Moderate	Low	Very Low	Very Low
70 to 130	Good	Moderate	Moderate	Low	Low
10 to 70	High	Good	Good	Moderate	Low
< 10	High	Good	Good	Moderate	Moderate

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- Taxonomic Quality Assurance: Tony Phillips

References Cited

Bona, F. (2006) Effect of seaweed proliferation on benthic habitat quality assessed by Sediment Profile Imaging. *Journal of Marine Systems,* **62,** 142-151.

Cardoso, P. G., M. A. Pardal, D. Raffaelli, A. Baeta, and J. C. Marques. 2004. Macroinvertebrate response to different species of macroalgal mats and the role of disturbance history. Journal of Experimental Marine Biology and Ecology 308:207-220.

Cuffney, T.F., Brightbill, R.A., May, J.T. & Waite, I.R. (2010) Responses of benthic macroinvertebrates to environmental changes associated with urbanization in nine metropolitan ares. *Ecological Applications,* **20,** 1384-1401.

Green, L. (2011) Macroalgal mats control trophic structure and shorebird foraging behavior in a southern California estuary. Ph.D. Dissertation, University of California, Los Angeles.

Green, Sutula, and Fong (in review). How much is too much? Identifying benchmarks of adverse effects of macroalgae on the macrobenthic community in estuarine intertidal flats. Submitted to Journal of Applied Ecology (http://californiaestuarinenneproject.shutterfly.com/)

McLaughlin K., M. Sutula, L. Busse, S. Anderson, J. Crooks, R. Dagit, D. Gibson, K. Johnston, N. Nezlin, L. Stratton. 2012. Southern California Bight 2008 Regional Monitoring Program: Estuarine Eutrophication Assessment. Southern California Coastal Water Research Project. Costa Mesa, CA. www.sccwrp.org/Documents/BightDocuments/Bight08Documents.aspx

Sutula, Green, Cichetti, Detenbeck, and Fong (in review). Thresholds of Adverse Effects of Macroalgal Abundance and Sediment Organic Matter on Benthic Habitat Quality in Estuarine Intertidal Flats (http://californiaestuarinenneproject.shutterfly.com/

Sutula M. 2011. Review of Indicators for Development of Nutrient Numeric Endpoints in California Estuaries. 2011. M Sutula. Technical Report 646. Southern California Coastal Water Research Project. Costa Mesa, CA. http://www.sccwrp.org/Documents/TechnicalReports.aspx

Comments? Questions?

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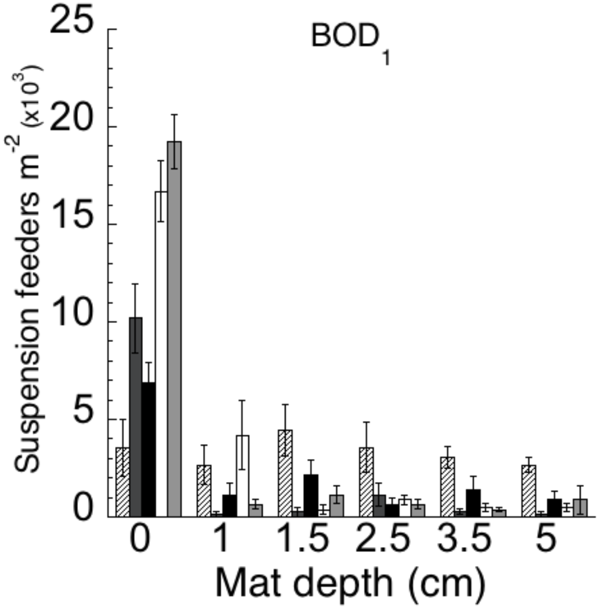
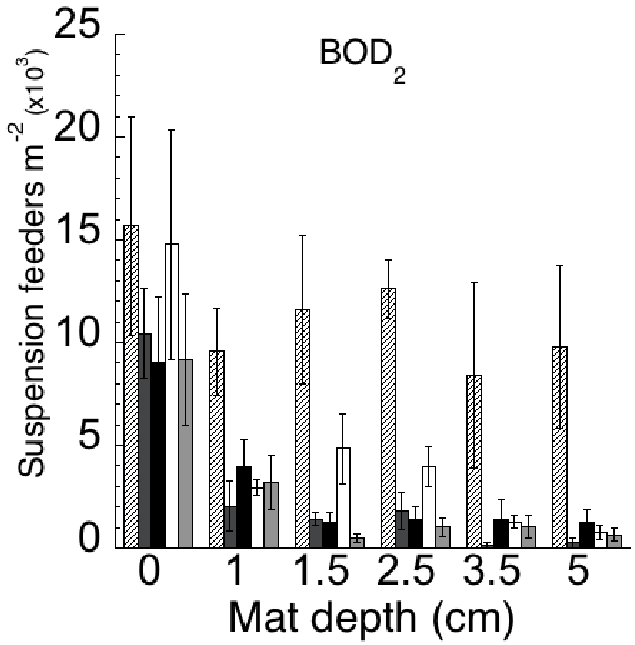
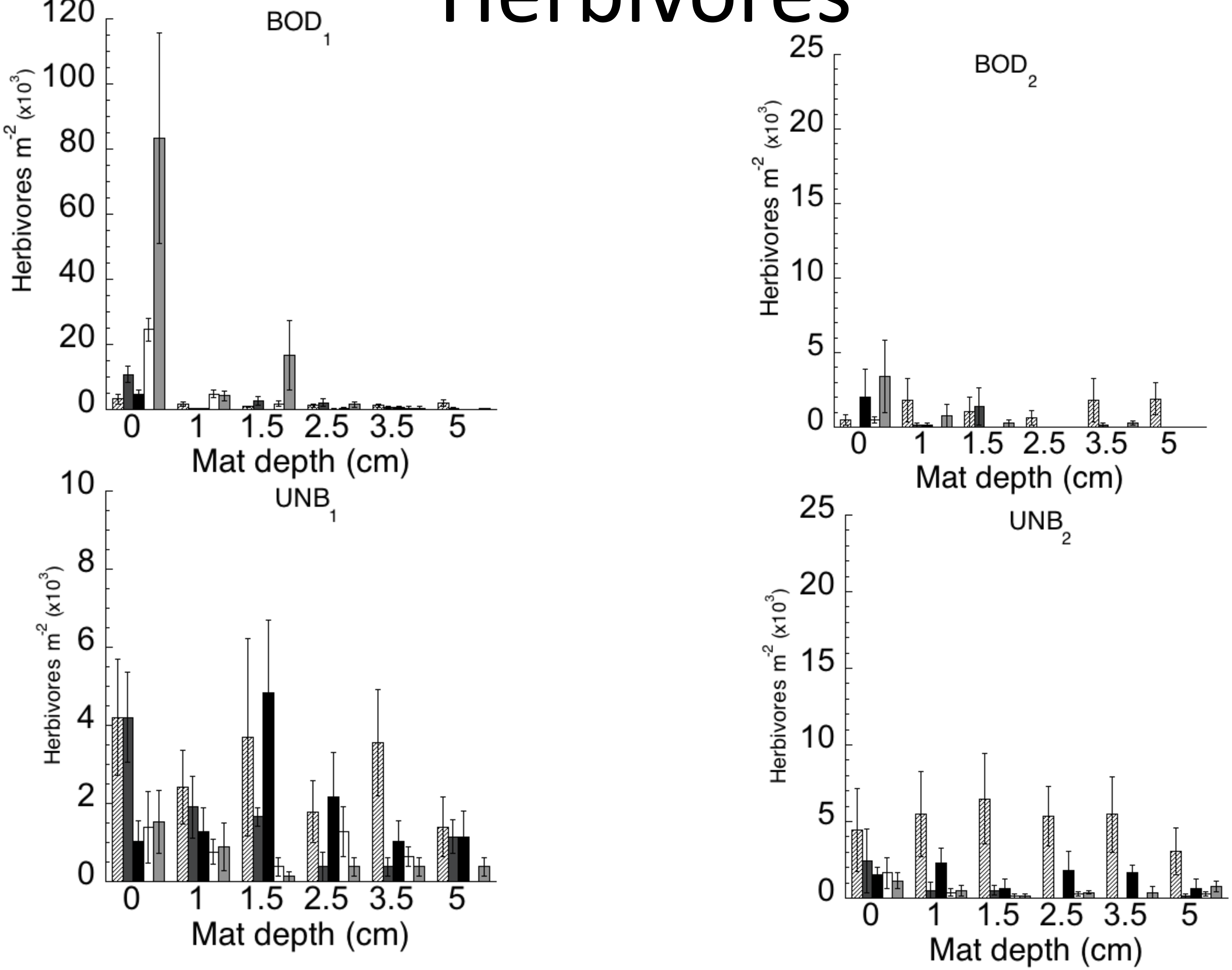
Suspension feeders

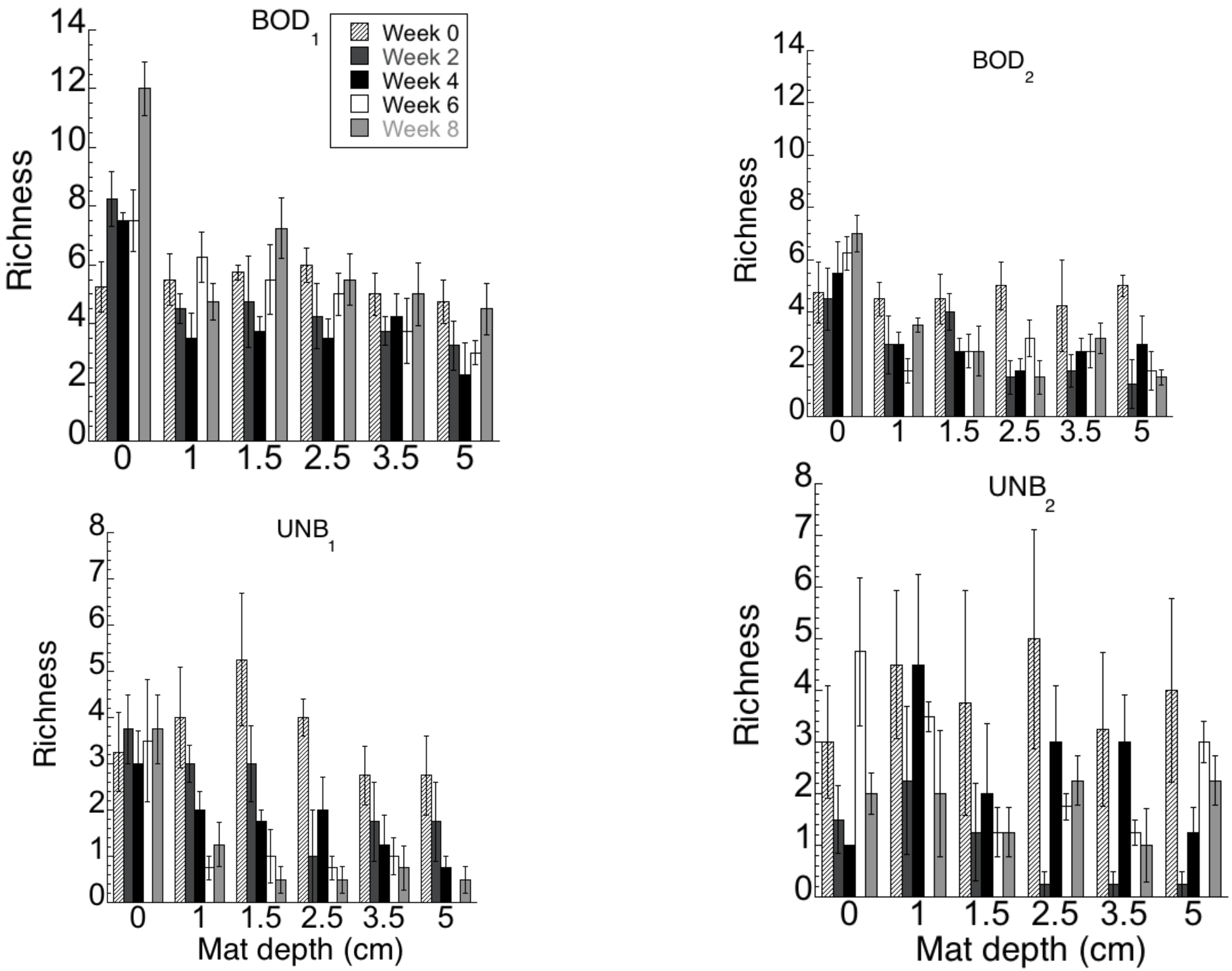




Herbivores


BOD1
Herbivores m-2 (x10^3)
120
100
80
60
40
20
0
0
1
1.5
2.5
3.5
5
Mat depth (cm)
BOD2
25
20
15
10
5
0
UNB1
10
8
6
4
2
0
UNB2
25
20
15
10
5
0

Richness



BOD1
Week 0
Week 2
Week 4
Week 6
Week 8
Richness
14
12
10
8
6
4
2
0
0
1
1.5
2.5
3.5
5
BOD2
UNB1
UNB2
Mat depth (cm)