Review of BEC
From a Biological Modeler's Perspective

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NWRI Panel for SCCWRP's Coupled ROMS-BEC Model
Technical Session 4: Technical Input
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Background

Why is NOAA-Fisheries is interested in BEC?

- Interest in
  - Subsurface O_2 measurements (fish)
  - pH (to a lesser degree)

Background

My Professional Experience:

- Have followed BEC model progress as a NOAA SWFSC representative since 2019
- Part of JGOFS HNLC program: origin of BEC: Moore et al. 2002 and 2004
- PISCES member: Early development of similar NEMURO model
- Led the CalCOFI State of the California Current report
- Co-lead the NOAA California Current Integrated Ecosystem Assessment (CCIEA) Status Report

Review of BEC

- **Some parts of BEC work quite well:**
    - Biogeochemistry of how O_2 and pH are handled is excellent
    - Useful for academic purposes
- **Concerns:**
    - Overall: Model is not ready for operational mode for management purposes
        - ***Model structure of the NPZ components***
        - Secondary concerns:
            - Parameter values
            - Sensitivity analysis

The BEC Paradigm

NH_4 from outfalls

Diatoms uptake these nutrients and grow

NO_3 from upwelling

seafloor

The BEC Paradigm

- Diatoms are heavy (big silica shell) so they sink fairly fast when they die
- Fecal pellets also sink rapidly

seafloor

The BEC Paradigm

Diatoms die, sink, use up oxygen and produce CO_2 at depth which causes a reduction in pH

seafloor

Important Missing Component of BEC:

Dinoflagellates!!!

Diatoms take up these nutrients, and grow

NH_4 from outfalls

seafloor

NO_3 from upwelling

Important Missing Component of BEC:

Dinoflagellates!!!

- Dinos are an important class of phytoplankton in the Bight (up to 40-60% of cell numbers, seasonally)
- Larger, but not as much total carbon as diatoms
- DON'T have a silica shell (so they don't sink like diatoms)
- Preferentially uptake NH_4 over NO_3 (possibly outcompete diatoms for this resource)
- Are likely "first responders" to sudden NH_4 increases (e.g., from a wastewater outfall)
- Can include important HAB species
- Have different growth and uptake dynamics than other categories of phytoplankton
- Explicitly excluded from BEC model

So, what if…?

Dinoflagellates are the ones responding to NH_4 inputs?

Diatoms uptake these nutrients and grow

NH_4 from outfalls

NO_3 from upwelling

So, what if…?

Dinoflagellates are the ones responding to NH_4 inputs?

Diatoms uptake these nutrients and grow

NH_4 from outfalls

Less sinking

NO_3 from upwelling

So, what if...?

Dinoflagellates are the ones responding to NH_4 inputs?

Diatoms uptake these nutrients and grow

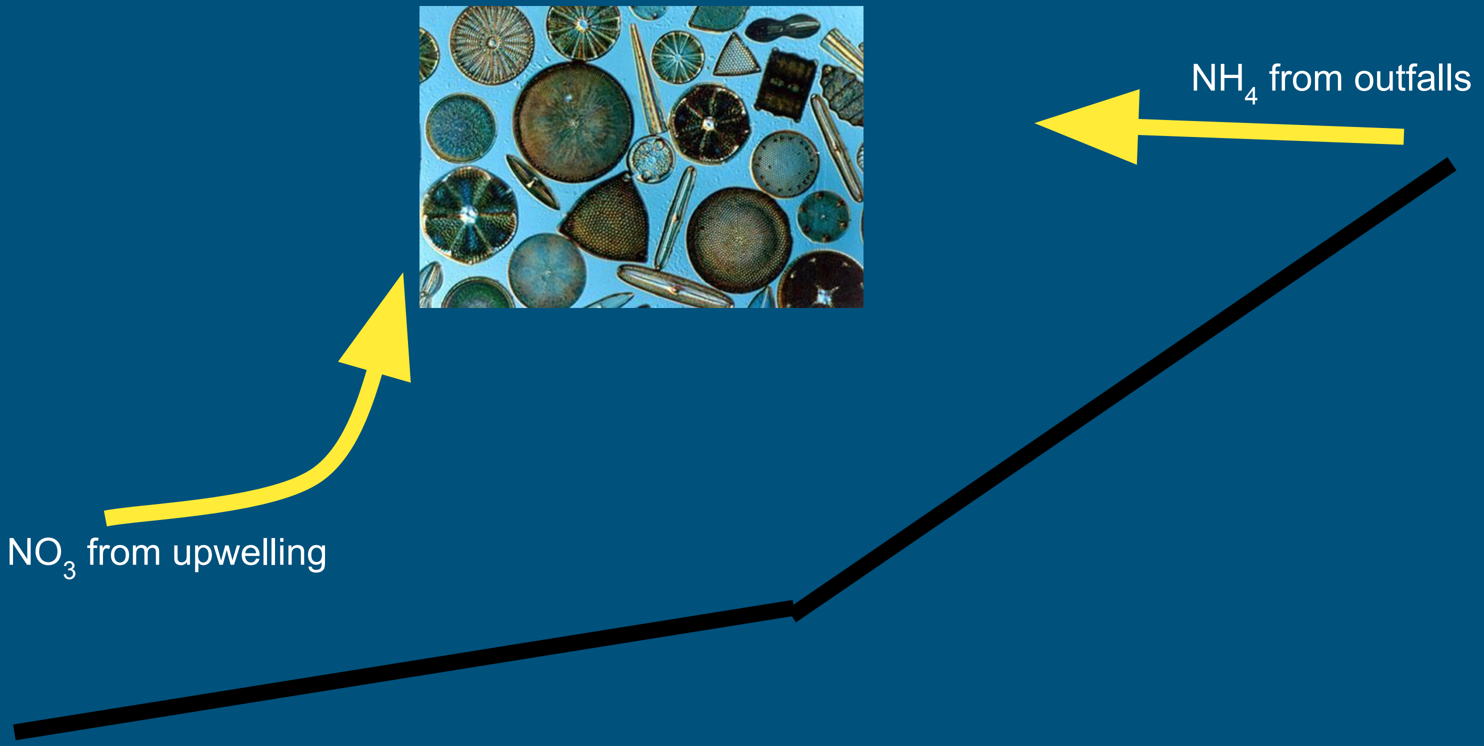
NH_4 from outfalls

NO_3 from upwelling

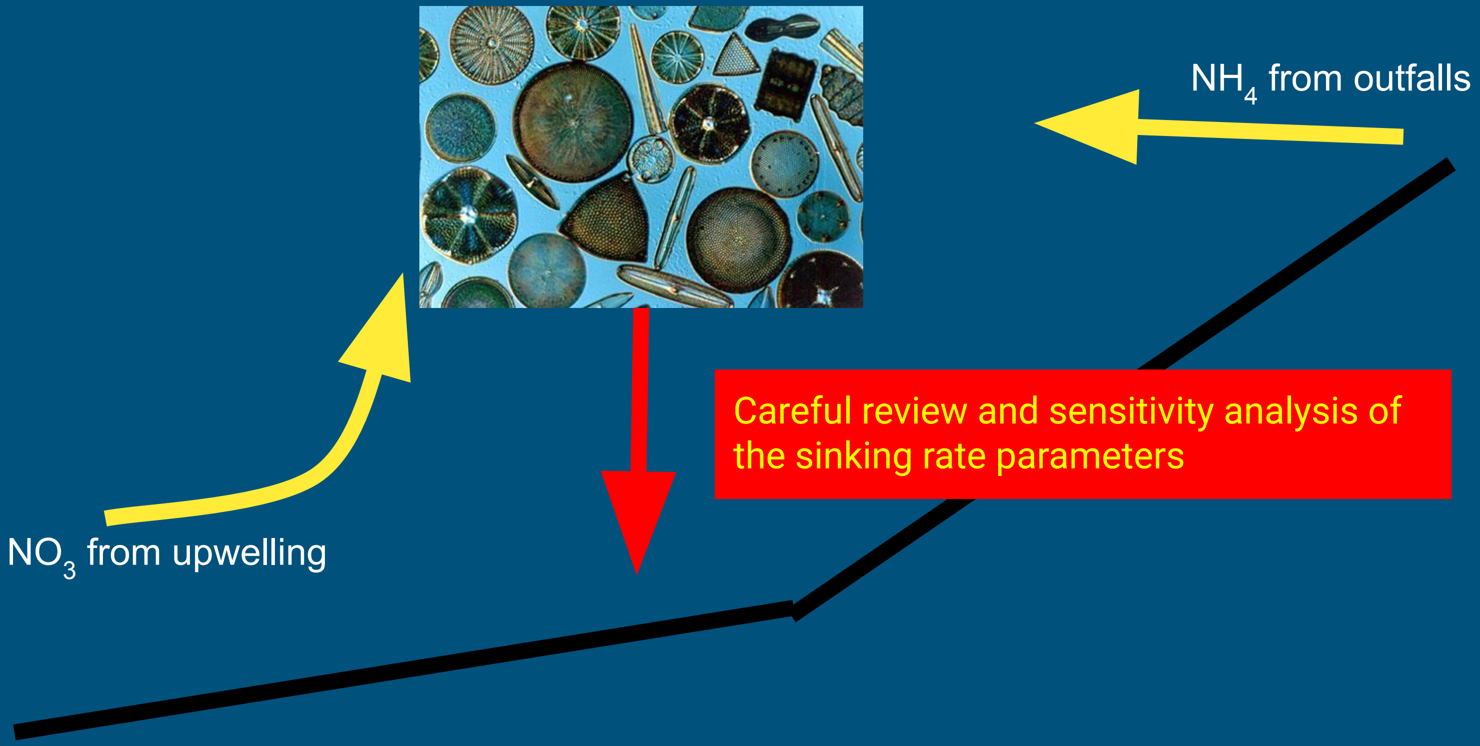
Less sinking

Nothing dying at depth, so less O_2 and pH reduction

The BEC Paradigm: How to Address this Issue Using the Current Model As-Is?



The BEC Paradigm: How to Address this Issue Using the Current Model As-Is?



The BEC Paradigm: How to Address this Issue Using the Current Model As-Is?

NH_4 from outfalls

NO_3 from upwelling

Careful review and sensitivity analysis of the sinking rate parameters

NOTE: The current BEC parameters being applied to the SCB for phytoplankton growth are the same as the early 2000's version used to model the Equatorial Pacific

The BEC Paradigm: How to Address this Issue Using the Current Model As-Is?

NH_4 from outfalls

NO_3 from upwelling

Careful review and sensitivity analysis of the remineralization rate parameters

The BEC Paradigm: How to Address this Issue?

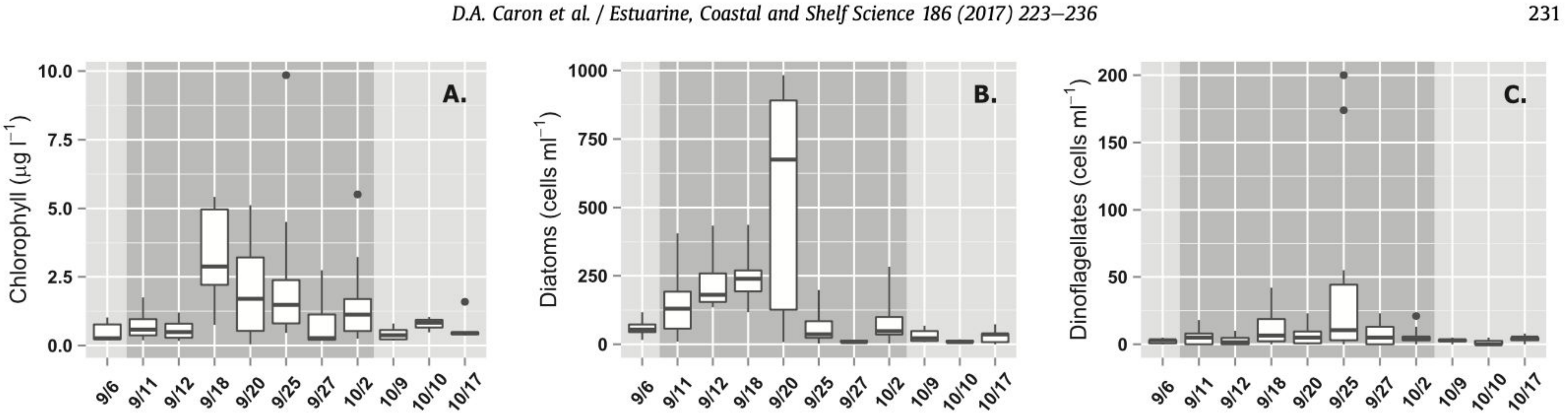
Reparameterize the nitrogen fixer group to a dinoflagellate group
→N_2 fixers are relatively unimportant in the CCS

NH_4 from outfalls

NO_3 from upwelling

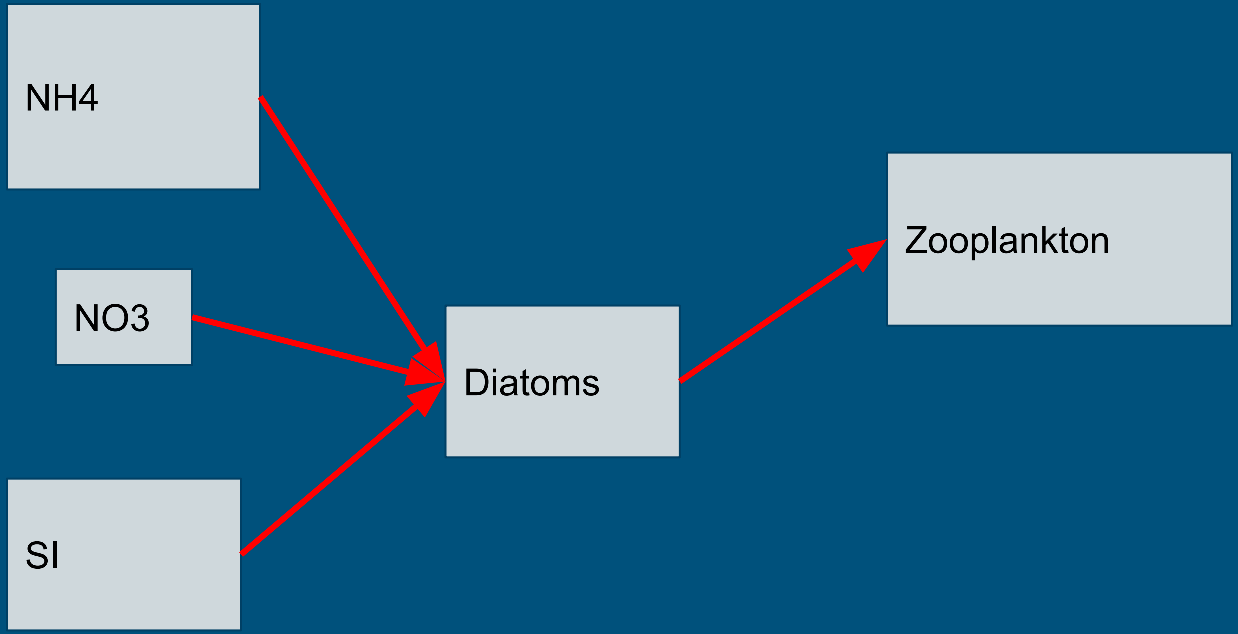
Caron et al. 2017: Estuarine, Coastal and Shelf Science, Volume 186, Part B

3 week diversion at OC sanitation in Sept.-Oct 2012 (non upwelling season): chl levels similar or less than peak spring bloom. Diatoms -> Dinos -> BACTERIA!?!



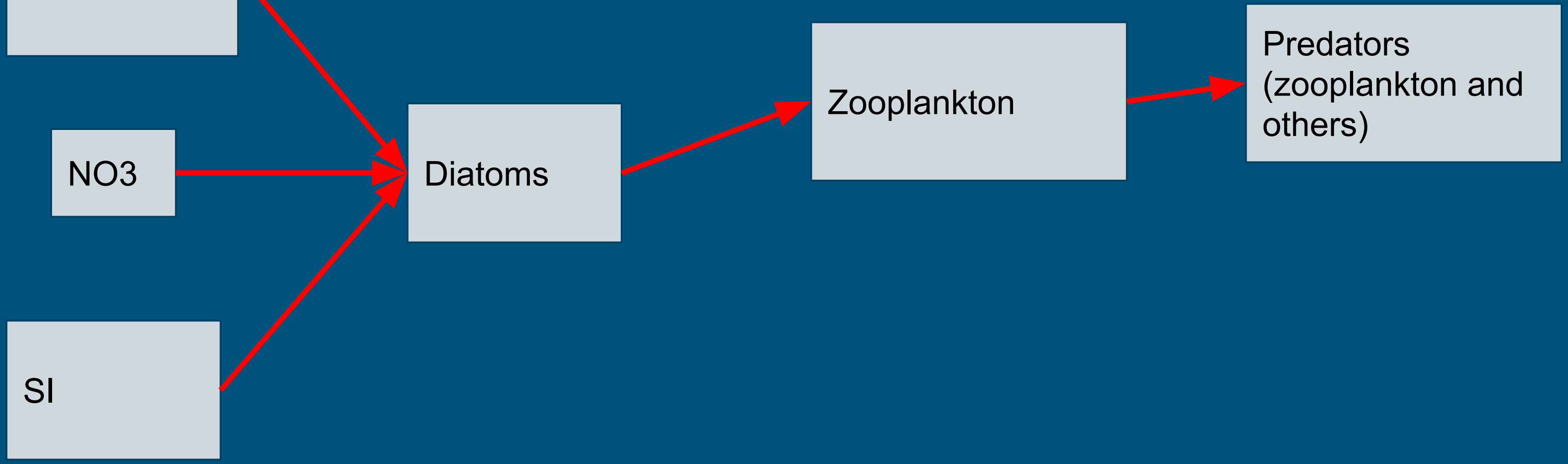
"Surprisingly, the overall increase in phytoplankton biomass during the 3-week diversion was minor, although shifts in taxonomic composition did occur" -Caron et al.

Second Major Concern: Grazing Formulation



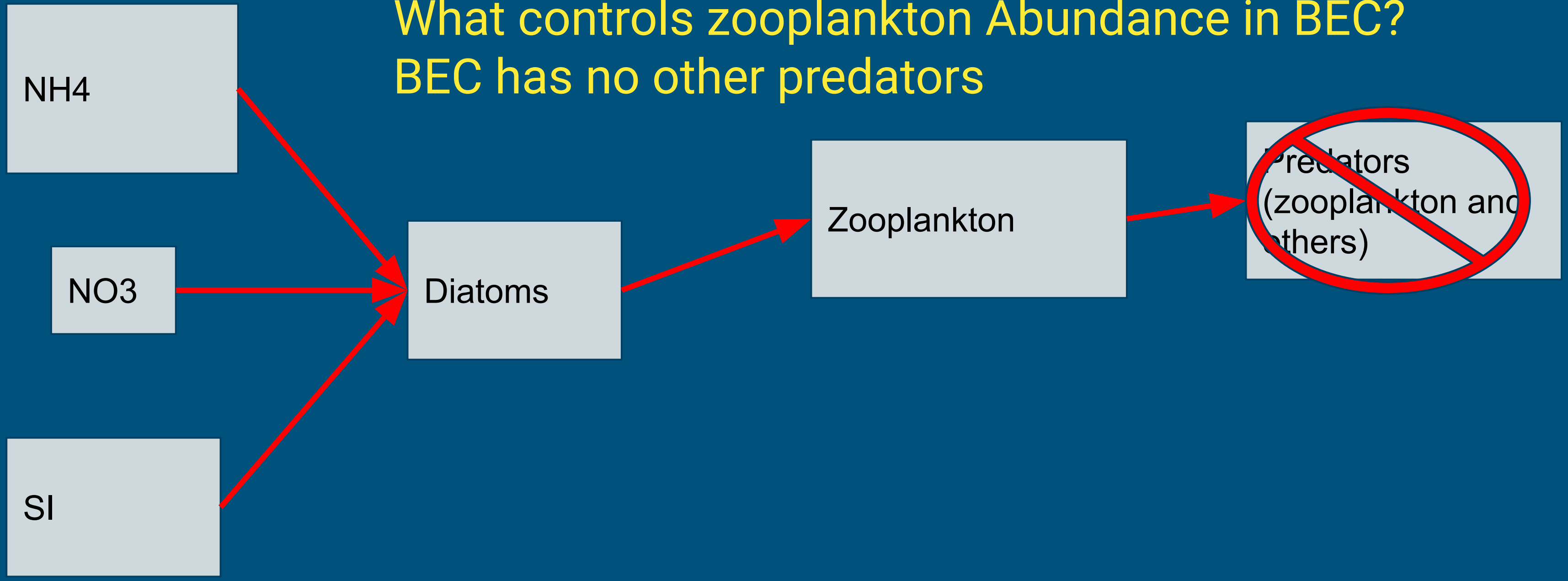
Second Major Concern: Grazing Formulation

What controls zooplankton Abundance?
Normally, it's predators and "natural death"



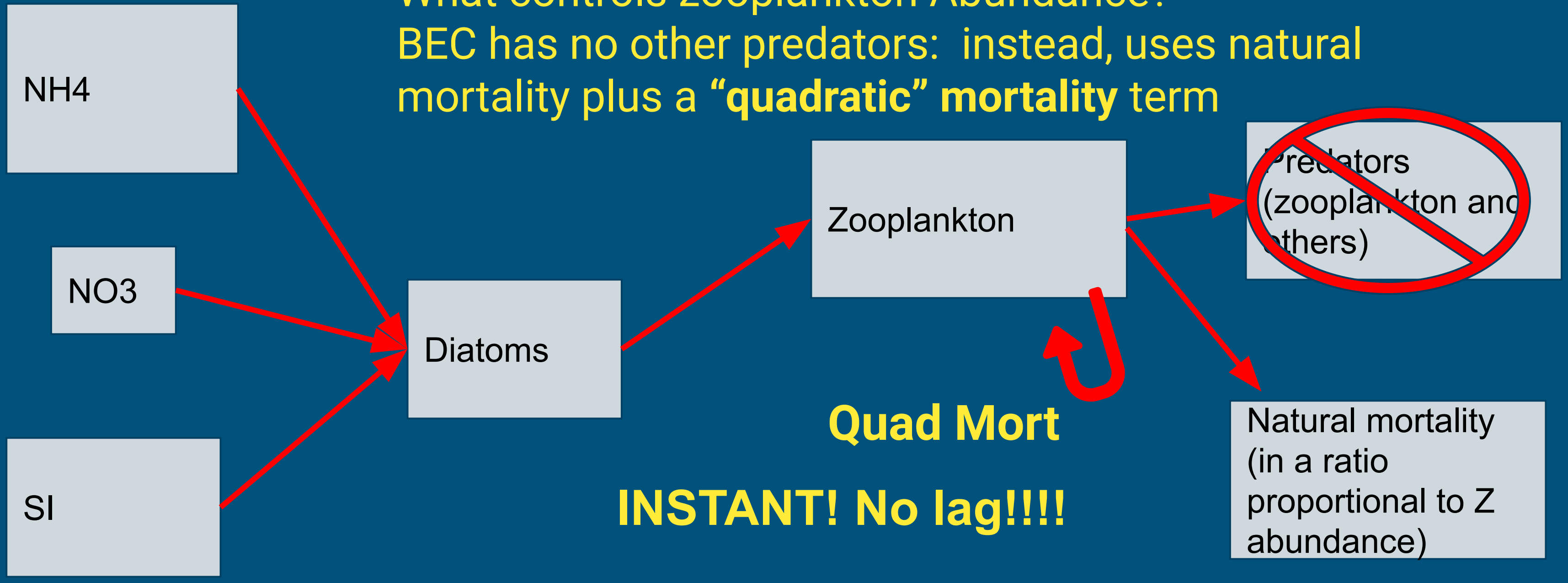
Second Major Concern: Grazing Formulation

What controls zooplankton Abundance in BEC?
BEC has no other predators



Second Major Concern: Grazing Formulation

What controls zooplankton Abundance?
BEC has no other predators: instead, uses natural mortality plus a “**quadratic**” **mortality** term

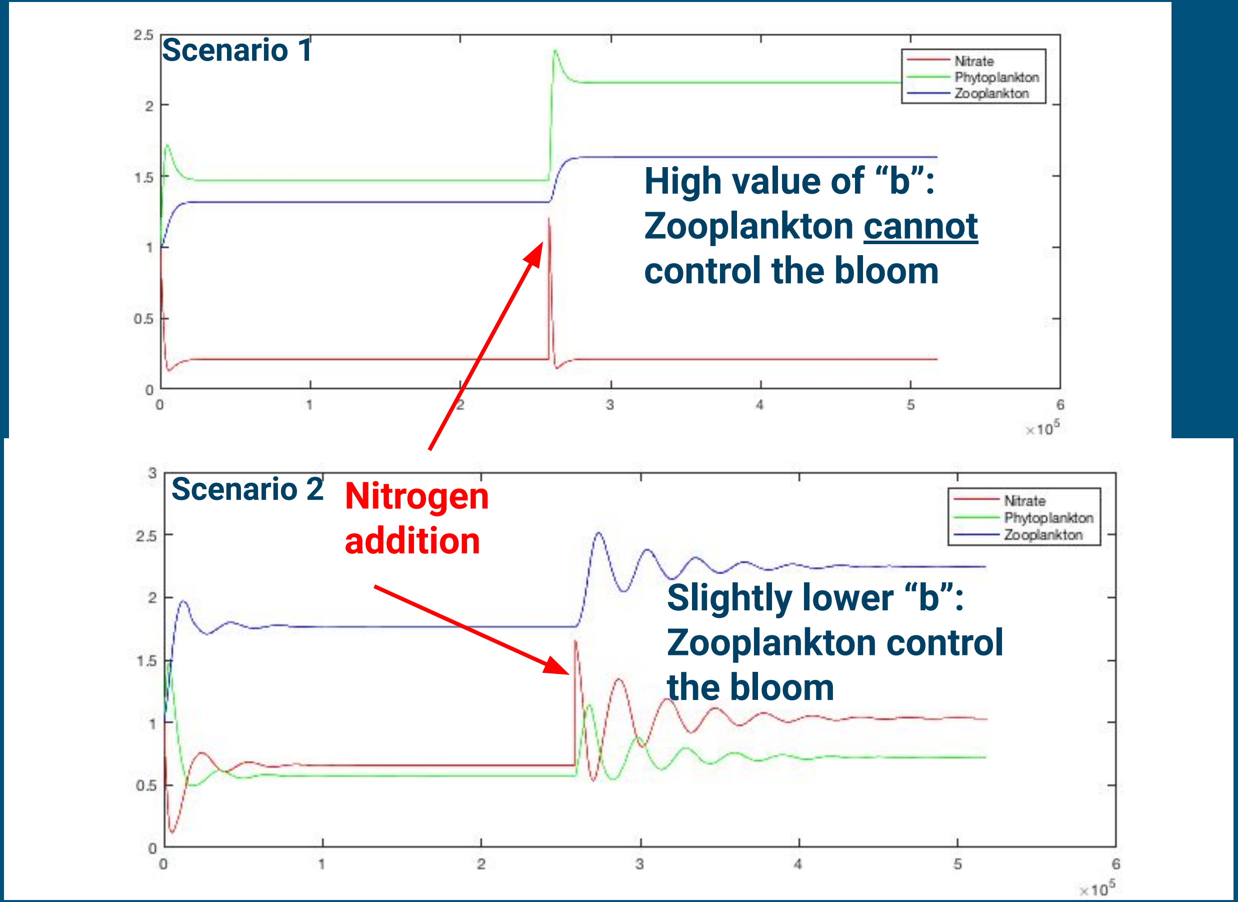


Quadratic mortality assumes zooplankton “feed” on themselves, but do not grow

Second Major Concern: Grazing Formulation

Quadratic Mortality:

- **Death = Z*a + b*Z^2**
- In the second scenario (lower panel), a very short bloom is eventually controlled by the zooplankton, implying less total phytoplankton biomass accumulation, and resulting sinking and changes in O_2 and pH at depth.
- "b" was lowered by about 20% in this comparison



Unintended Consequences of Quadratic Mortality in NPZ Models

If it's so bad, why do scientists use this equation in the first place?

1. Edwards and Yool, 2000 "The role of higher predation in plankton population models" describes the problems and caveats of this equation. This is a well-known issue to ecosystem modelers.
2. It provides model stability
3. It provides a shortcut for density-dependent mortality of the zooplankton when you have not included a higher trophic level to graze on them
   a. Works ok when there aren't strong perturbations to the underlying nutrient inputs, (e.g. see analysis in Friedrichs et al., shows a direct example of this for BEC)

Recommendation: Conduct a broader sensitivity analysis of the impact of "b" on the model results, *particularly in seasonal changes*

Overview of concerns:

1. **Model should incorporate dinoflagellates**
2. **More work on model sensitivity to grazing formulation needs to be conducted**
3. **Results of sensitivity analysis need not be published, but needs to be made available; both the methods and results (tables?)**
4. **Clear listing of (all) the current model equations behind recent papers**
    a. Is there still depth limited grazing?
    b. What is the T_{ref} function for temperature adjustment? (P growth?)
    c. List the “tweaks” used to turn an HNLC model into a coastal eutrophic model

Some Notes on Additional BEC Sensitivity Analyses:

1. No need to look at all 90 parameters, just the top ~10 previously identified as most influential on model outcome: growth and grazing rate control parameters, sinking, etc.
2. No need for multi-year runs, could be a single year
3. Could be just parts of the model, perhaps not even coupled to the physics in some cases
4. Could start with a “0D” or “1D” model run
5. For previous and any new runs, look at how different outputs are affected:
   a. NPP, not just yearly, but need to look at seasonal and even daily of base vs adjusted runs

      Ex: a 10% difference in annual PP may not seem like much, but if it's 40% higher during spring and 30% lower during summer, this IS a big difference!

   b. Should look at amounts of relative contributions from different “boxes” e.g. the relative NPZ biomass contributions.
   c. Should look at O_2 and other parameters, also on seasonal/daily timescale
   d. Should also look at “achieved” or “measured” rates (the rate you’d calculate after all adjustments due to temperature etc.) for phyto/zooplankton growth/death
   e. Suggested amounts to adjust are ±10 and ±25% within “real-life” range, if known.

References of Interest

The problems with quadratic grazing: Edwards, AM and Yool, A. 2000. “The role of higher predation in plankton population models”. J. Plankton Res., 22 (6).

Follow up recommendations: Rohr, T et al. 2022. “Recommendations for the Formulation of Grazing in Marine Biogeochemical and Ecosystem Models.” Progress in Oceanography 208: 102878.

The importance of dinoflagellates in the CCS: Venrick, EL. 2015. “Phytoplankton Species in the California Current System off Southern California: The Spatial Dimensions”. CalCOFI Rep., Vol 56: 17.

BEC (aka “Model 24”) led to unrealistic blooms when applied to a eutrophic system: Friedrichs, MAM. et al. 2009. “Assessing the Uncertainties of Model Estimates of Primary Productivity in the Tropical Pacific Ocean.” Journal of Marine Systems 76 (1–2): 113–33.

Original model with identical parameters to current BEC: Moore, JK et al 2002. “An Intermediate Complexity Marine Ecosystem Model for the Global Domain.” Deep Sea Research Part II: Topical Studies in Oceanography, The US JGOFS Synthesis and Modeling Project: Phase 1, 49 (1): 403–62.

Current BEC model with most recently published parameters/equations: Deutsch et al. 2021. “Biogeochemical Variability in the California Current System.” Progress in Oceanography 196: 102565.

Example of nutrient addition due to outfall overflow which led to no bloom: Caron, DA et al. 2017. “Response of Phytoplankton and Bacterial Biomass during a Wastewater Effluent Diversion into Nearshore Coastal Waters.” Estuarine, Coastal and Shelf Science 186: 223–36.

Example of a PUBLISHED sensitivity analysis: Yoshie, N et al. 2007. "Parameter sensitivity study of the NEMURO lower trophic level marine ecosystem model." Ecological Modelling 202, no. 1-2: 26-37.

Additional References

Examples of Sensitivity Analyses in NPZ models:

Fasham, MJR et al. 1990. “A Nitrogen-Based Model of Plankton Dynamics in the Oceanic Mixed Layer.” Journal of Marine Research 48 (3): 591–639.

Fennel, K et al. 2001. “Testing a Marine Ecosystem Model: Sensitivity Analysis and Parameter Optimization.” Journal of Marine Systems 28 (1): 45–63.

Mateus, MD and G Franz. 2015. “Sensitivity Analysis in a Complex Marine Ecological Model.” Water 7 (5): 2060–81.

Schartau, M et al 2017. “Reviews and Syntheses: Parameter Identification in Marine Planktonic Ecosystem Modelling.” Biogeosciences 14 (6): 1647–1701.

Thank you

Auxillary slides

BEC Parameterization Comparisons: 2002 HNLC vs 2021 CCS

Large Phytoplankton growth rate is the same in both models.

2002 HNLC

Appendix A. Model notation, parameter values, and equations

Biological parameters

PCref	3.0*+	maximum phytoplankton C–specific growth rate (per day) (GD98)
PCref_dz	0.4*	maximum diazotroph C-specific growth rate (per day)
z_umax	3.24*	maximum zooplankton growth rate when grazing small phytoplankton
lz_umax	2.16*	maximum zooplankton growth rate when grazing diatoms
d_umax	1.40*	maximum zooplankton growth rate when grazing large detritus
dz_umax	0.2*	maximum zooplankton growth rate when grazing diazotrophs
sp_mort	0.1	small phytoplankton non-grazing mortality (per day)
sp_mort2	2.0	small phytoplankton quadratic mortality/aggregation rate coeff.
lp_mort	0.1	large phytoplankton non-grazing mortality (per day)

2021 CCS

713 **5.2 Ecosystem parameters**

Parameters	Description	Values	Units
Model grid			
Δz	Model layer thickness	variable	meters
k_ρ	Index of model vertical level at tracer points	1-60	no units
Carbon			
PC^{sp}_{ref}	max phyto C-specific growth rate at Tref (GD98) for small phytoplankton	3.0	1/d
PC^{diat}_{ref}	max phyto C-specific growth rate at Tref (GD98) for diatoms	3.0	1/d

Some Notes on Additional BEC Sensitivity Analyses:

Table 1. BEC parameters that are candidates for sensitivity analyses

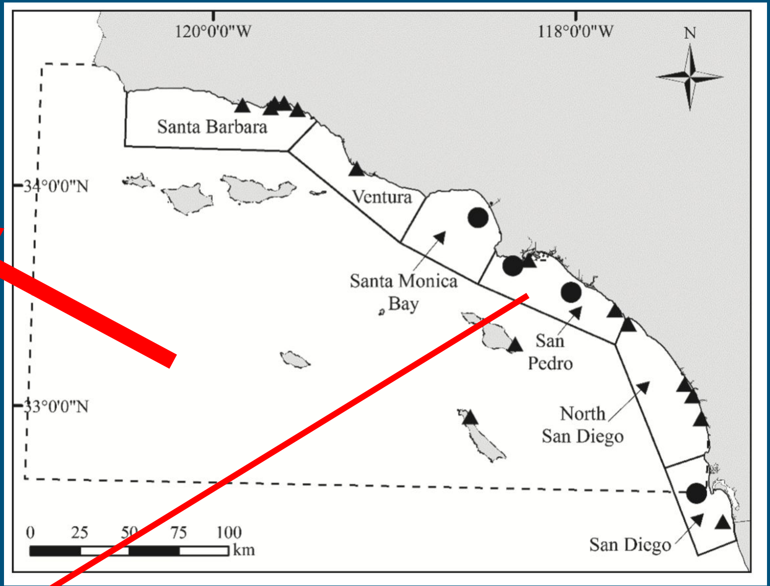
Priority Ranking	Parameter to Test	Parameter Description	Parameter	Parameter Value	Parameter Units
1	Maximum growth rate of large phytoplankton group (i.e., diatoms)	max phyto C-specific growth rate at Tref (GD98) for diatoms	PC_{ref}^{diat}	3	/day
2	Grazer population size	zooplankton quadratic mortality	λ_{zoo}^{mort}	0.42	/ mmol C m^3 day
3	Zooplankton maximum grazing rates on large phytoplankton (diatoms)	maximum grazing loss for diatoms	$J_{diat}^{g,max}$	1.95	/day
4	Grazer natural mortality rate	Zooplankton linear mortality	λ_{zoo}^{mort}	0.08	/day
5	Limits grazing once grazers reach a certain population size	grazing coefficient, used in density dependent grazing modification	β_{z}^{grz}	1.05	C /m^3
6	Carbon fluxes of large phytoplankton from the photic zone, i.e., remineralization rate of dead diatoms	Maximum aggregation rate for diatoms	$\tau_{diat}^{agg,max}$	0.75	/day
7	Small phytoplankton growth	max phyto C-specific growth rate at Tref (GD98) for small phytoplankton	PC_{ref}^{sp}	3	/day
8	Zooplankton maximum grazing rates on small phytoplankton	maximum grazing loss for small phytoplankton	$J_{sp}^{g,max}$	2.5	/day
9	Carbon fluxes of small phytoplankton from the photic zone, i.e., remineralization rate of dead small phytoplankton	Maximum aggregation rate for small phytoplankton	$\tau_{sp}^{agg,max}$	0.75	/day

Relative nutrient input amounts: Howard et al. 2014

Table 3. Annual nitrogen loads for each nutrient source and constituent. All loads are 10^6 kg N yr^{-1}. The form of nitrogen expressed as a percentage of total nitrogen for each source is given in parentheses.

	Total N	Nitrate + nitrite	Ammonium	Organic N
Upwelling	750	740 (98.7)	10 (1.3)	na*
Effluent	48	3.4 (7.0)	44 (92.0)	0.5 (1.0)
Riverine runoff†	10	3.5 (34.0)	0.6 (6.0)	6.2 (60.0)

If you use the whole region, ratio is 20:1 upwelling:anthro



Its only when you use arbitrarily small regions that you get ratios more like 2:1

Table 5. Annual total nitrogen flux for each subregion (10^2 kg N km^{-2} yr^{-1}).

Source	Santa Barbara	Ventura	Santa Monica Bay	San Pedro	North San Diego	San Diego
Upwelling	−210	−1071	102	238	367	24
Effluent	1.6	5.1	99	121	14	74
Riverine runoff*	0.7	4.1	1.4	12	6	60
Atmospheric deposition	4.3	4.3	8.7	8.7	4.7	4.7
Total N	−203	−1057	211	380	392	163

* Data for January through October 2010.

These arbitrarily small subregions do not adequately capture the residence times/mixing rates of this region (~1.5 d)