Modeling the impacts of water quality on SAV and other living resources in the tidal Chesapeake Bay

Bio-optics, Biogeochemistry & SAV Distribution

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Hydrodynamics

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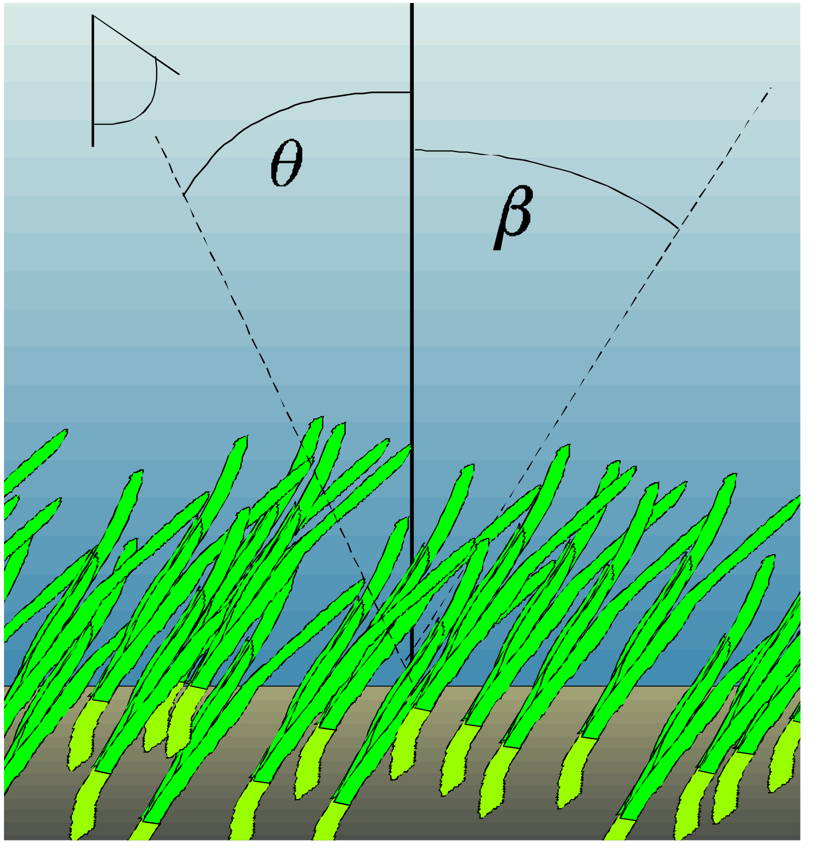
The Bio-Optical Model: *GrassLight*

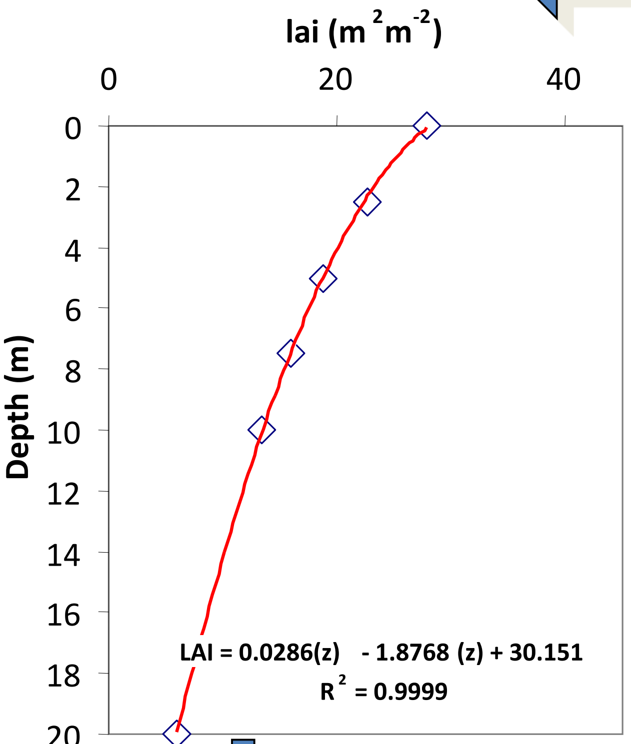
- Vertically structured radiative transfer model
- Simulates attenuation of spectral irradiance by
  - Pure water
  - Suspended and dissolved constituents
    - CDOM
    - Phytoplankton (Chl *a*)
    - Other suspended particulates
  - Submerged vegetation canopy
    - Shoot density
    - Biomass distribution
    - Leaf orientation
  - SAV photosynthesis and whole plant carbon balance



GrassLight Ver 2.11
Available from: rzimmerm@odu.edu

Predicting SAV Distributions:

Leaf Area Index as Function of Depth



Photosynthesis: Light & CO_2 Model

CO_2 dependence of P_m

$$P_m = 82 \cdot e^{(-0.53 \cdot pH)}$$

Absorptance:

$$A(\lambda) = 1 - R - \exp[a(\lambda) - a(750)]$$

Quantum Efficiency:

$$\alpha(\lambda) = \phi_{max} A(\lambda)$$

Instantaneous Photosynthesis

$$P(h,\lambda) = \int_h B(h) \cdot P_m \cdot \left[1 - \exp\left(\frac{\alpha(\lambda)E(h,\lambda)}{P_m}\right)\right]$$

Daily Production Integral:

$$\iint_{t,h} P(\lambda) = \int_h B(h) \cdot D \cdot P_m \cdot \left[1 - \exp\left(-\frac{0.67\alpha(\lambda)E(h,\lambda)}{P_m}\right)\right]$$

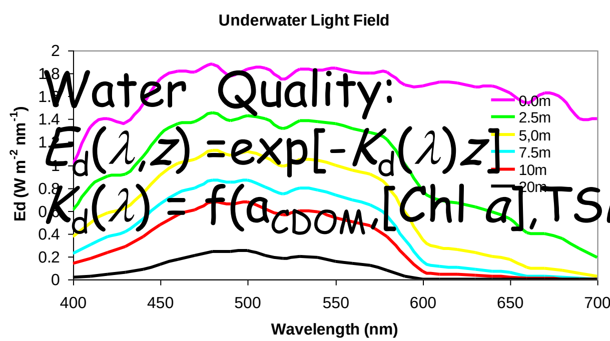
Determine maximum sustainable density at P:R=1

Result: Density and Leaf Area Index Estimate

$[CO_2]$

Temperature

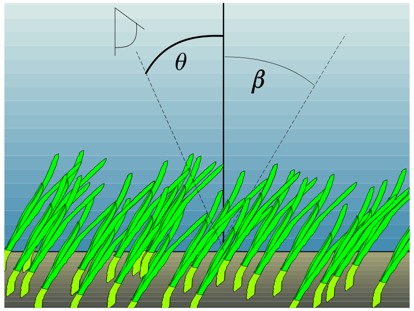
$\boldsymbol{E}$**(h,λ)**

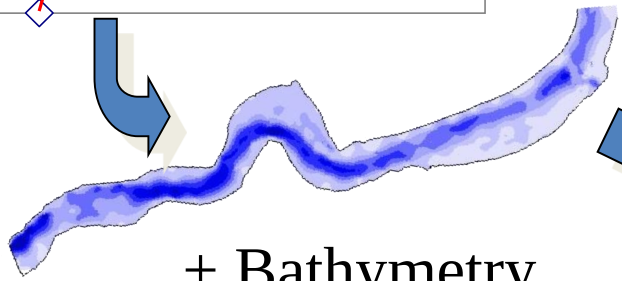


Water Quality:

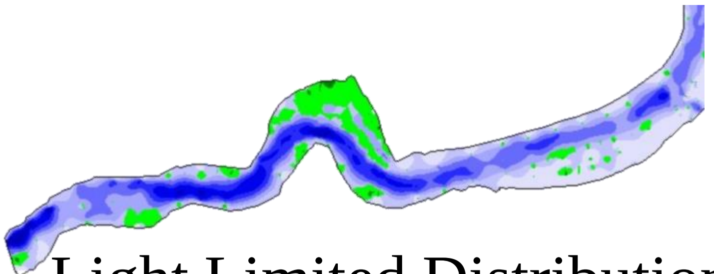
$$E_d(\lambda, z) = \exp[-K_d(\lambda)z]$$

$$K_d(\lambda) = f(a_{CDOM}, [Chl\ \bar{a}], TSM)$$





+ Bathymetry



Light Limited Distribution

Salinity & SAV in the Chester River System

- >22 spp. of SAV throughout Chesapeake Bay
- Species diversity greatest in the freshwater regions
- Distinct differences for which we may need to account:
  - Morphology
  - Optical properties
  - Physiology
- Current management practice set two water transparency thresholds
  - 13% $E(0-)$ for freshwater and mesohaline SAV
  - 22% $E(0-)$ for eelgrass and widgeon grass
  - No ability to predict density distribution
- With appropriate morphologic, optical and metabolic data, *GrassLight* can be formulated to test these practical thresholds and generate distribution maps for individual species and species assemblages

Native Freshwater SAV – upper reaches of Chester River System

Ceratophyllum demersum
Coontail

Callitriche sp.
Water starwort – 4 spp.

Elodea canadensis
Common waterweed

Heteranthera dubia
Water stargrass

Najas spp.
Naiads – 5 spp

Potamogeton pusilus
Slender pondweed

Potamogeton pectinatus
Sago pondweed

Vallisneria americana
Wild celery

Zanichellia palustrus
Horned pondweed

Invasive Freshwater SAV – upper reaches of Chester River System

Egeria densa
Brazilian waterweed

Hydrilla verticillata
Horned pondweed

Myriophyllum spicatum
Eurasian watermillfoil

Potamogeton cruspus
Curly pondweed

Mesohaline SAV – likely near the mouth of the Chester River

Ceratophyllum demersum
Coontail

Potamogeton pectinatus
Sago pondweed

Ruppia maritima
Widgeon grass

Zanichellia palustrus
Horned pondweed

Polyhaline SAV

Ruppia maritima
Widgeon grass

Zostera marina
eelgrass

not in the Chester River System

Applying *GrassLight* to the Chester River

- Mesohaline near the mouth
- Oligohaline to fresh in the upper reaches
- Highly turbid
  - TSM $\approx$ 30 mg L^{-1}
- Eutrophic
  - Chl *a* $\approx$ 20 mg m^{-3}

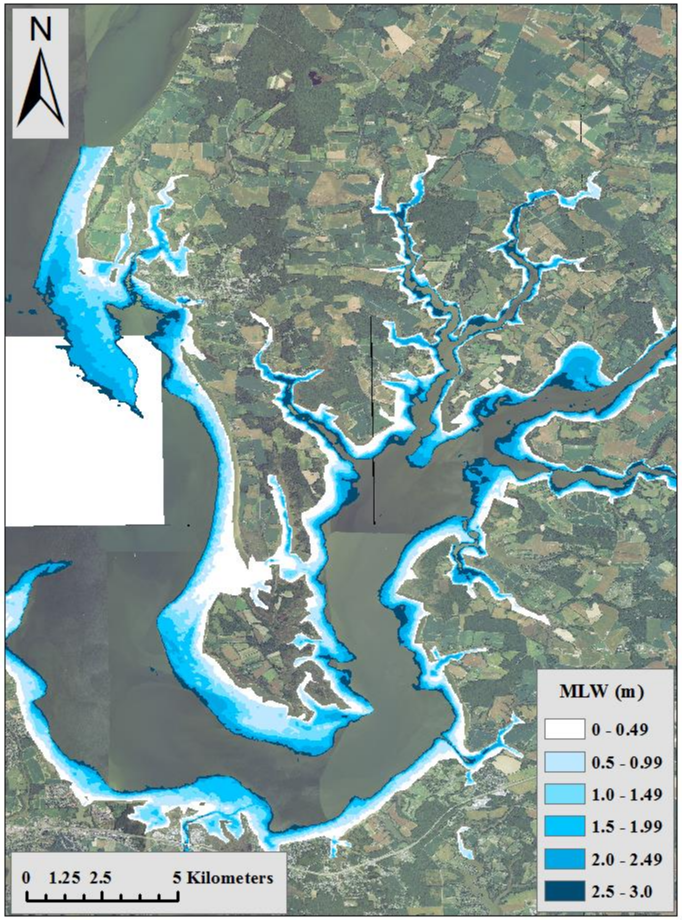
Chester River Potential SAV Habitat

Imagery from Geospatial Data Gateway; 2013 National Ag. Imagery Program Mosaic

Applying *GrassLight* to the Chester River

- Mesohaline tributary
- Highly turbid
  - TSM ≈ 30 mg L^{-1}
- Eutrophic
  - Chl *a* ≈ 20 mg m^{-3}
- Gridded 30 m bathymetry
- Potential SAV habitat (< 3 m depth) fringing the shore

Chester River DEM

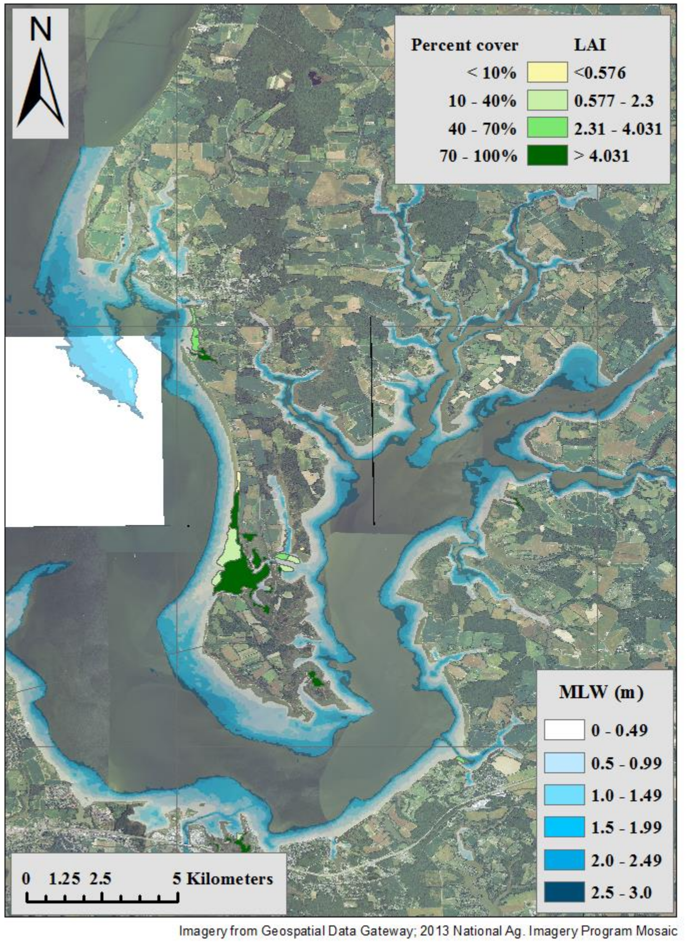


Imagery from Geospatial Data Gateway; 2013 National Ag. Imagery Program Mosaic

Applying *GrassLight* to the Chester River

- SAV distribution
  - Most persistent in shallows around Eastern Neck Island and Chester shoreline
  - Species composition depends on salinity
  - Abundance depends on water quality
  - Temporally variable

Chester River VIMS SAV distribution 2011



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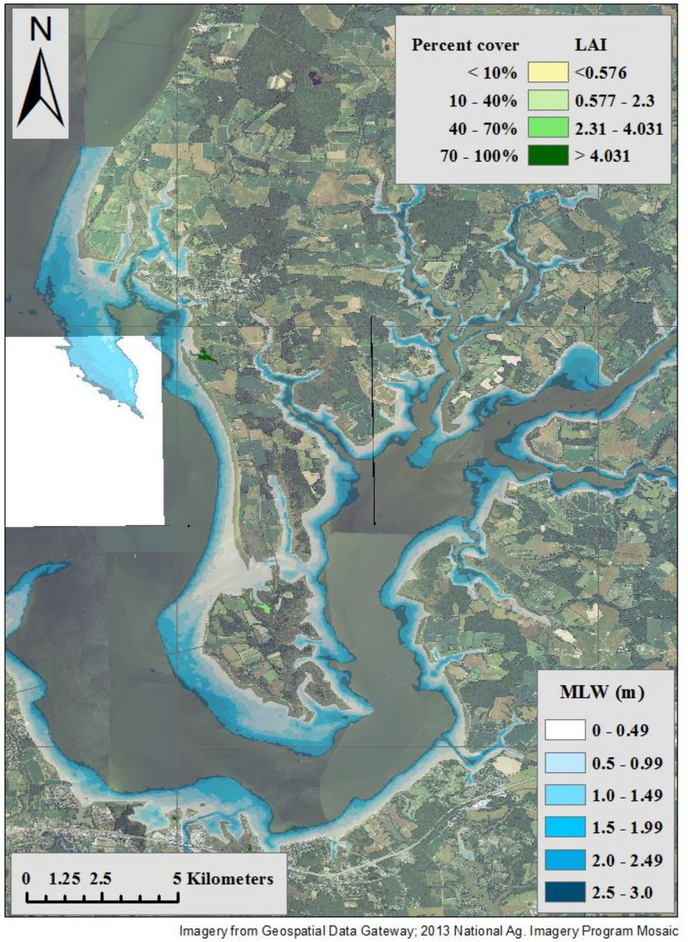
Chester River VIMS SAV distribution 2013

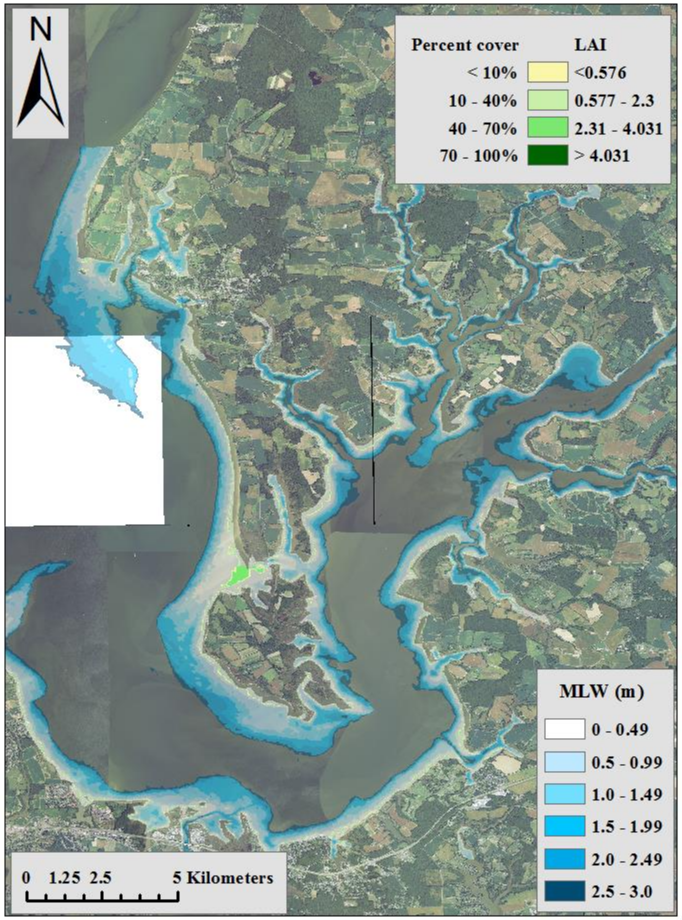


Imagery from Geospatial Data Gateway; 2013 National Ag. Imagery Program Mosaic

Applying *GrassLight* to the Chester River

- GrassLight prediction of SAV density based on average WQ data is consistent with VIMS field observations
- TSM = 30 mg L^{-1}
- Chl *a* = 20 mg m^{-3}
- $z_{E(13\%)}$ = 0.3 m
- $z_{E(22\%)}$ = 0.2 m
- $z_{E(1\%)}$ = 0.8 m

Chester River potential SAV distribution Corsica WQ

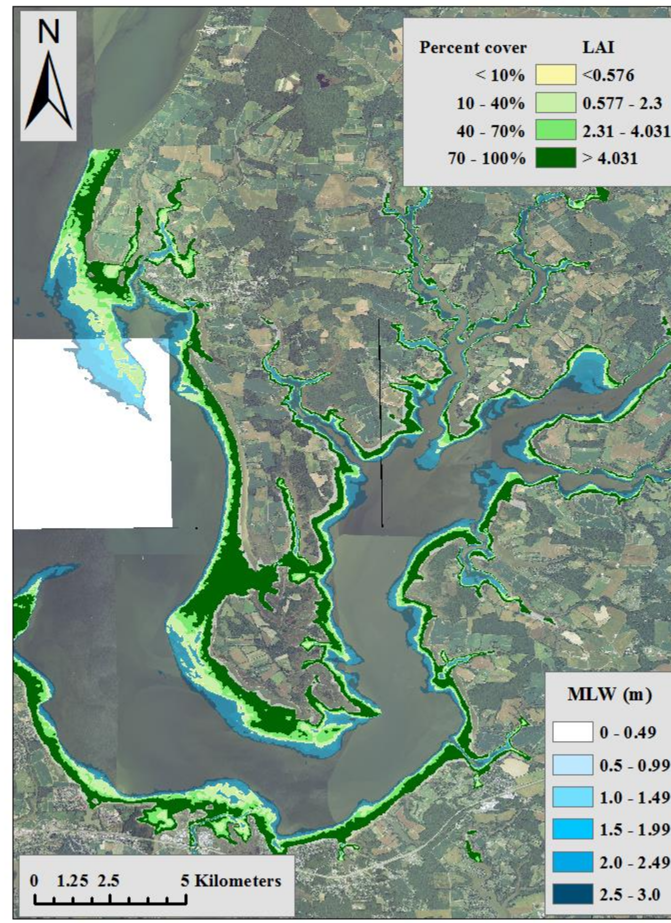


Imagery from Geospatial Data Gateway; 2013 National Ag. Imagery Program Mosaic

Applying *GrassLight* to the Chester River

- Improving water quality to average for Sandy Point
  - TSM = 10 mg L^{-1}
  - Chl *a* = 10 mg m^{-3}
  - $z_{E(13\%)}$ = 0.7 m
  - $z_{E(22\%)}$ = 0.9 m
  - $z_{E(1\%)}$ = 2 m
- Projects a significant expansion of SAV distribution in this system
- Still below 'historic" distribution limit of 3 m

Chester River potential SAV distribution Sandy Pt WQ



Imagery from Geospatial Data Gateway; 2013 National Ag. Imagery Program Mosaic

Modeling the plankton component

- Bio-optical components already built into *GrassLight* for given levels of Chl *a*
- Metabolic component required to calculate
  - Gas exchange
  - Nutrient removal & regeneration
  - Algae growth, grazing and sinking
  - Subsequent impact on water transparency

Modeling the plankton component

- $P^{B}{}_{g}(z)$ is controlled by light availability:

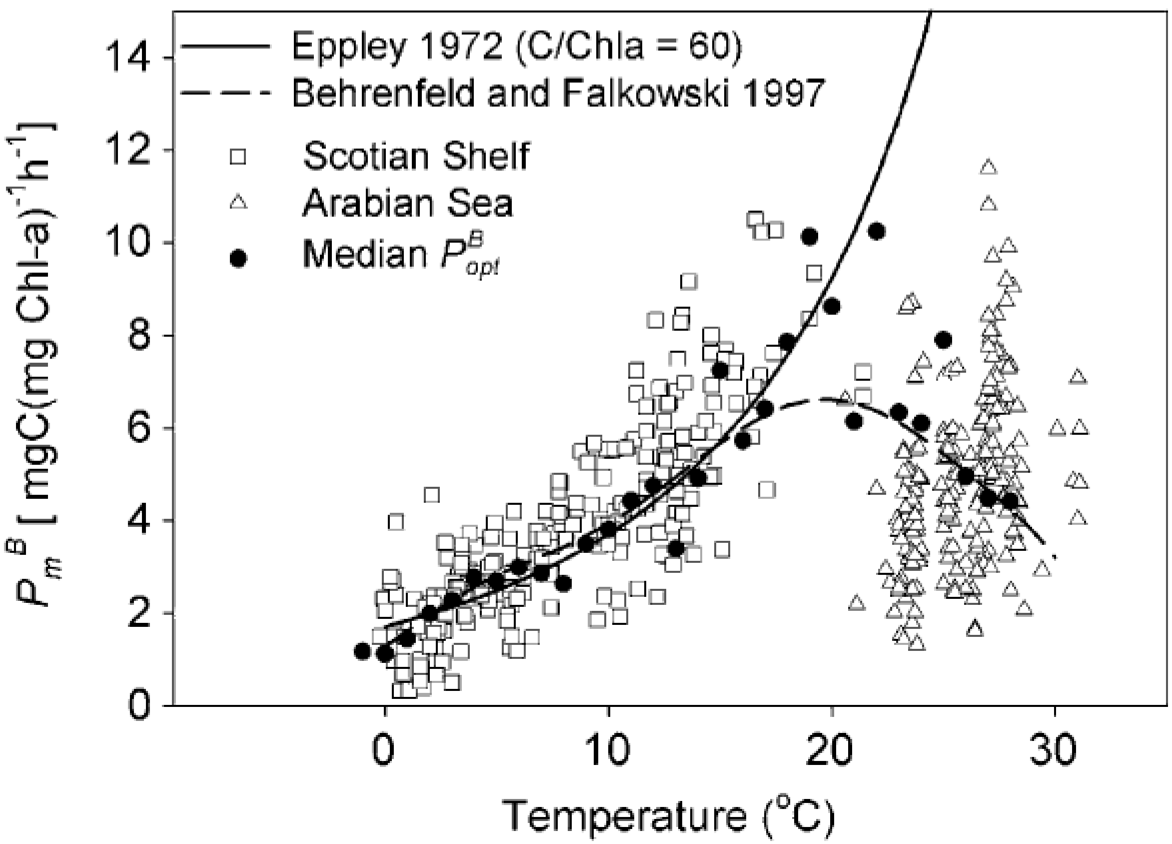
$$P_g^B = P_E^B \left(1 - \mathrm{e}^{\frac{\phi_{\mathrm{P}} \cdot A_{\phi}^{*}(\lambda) \cdot [\mathrm{Chl}\, a] \cdot E(\lambda, t, z)}{P_E^B}} \right)$$

- ϕ_{P} – quantum yield of photosynthesis (=1/8)
- $A^{*}{}_{\phi}(\lambda)$ – spectral phytoplankton absorptance
- [Chl *a*] – biomass, to scale absorptance
- $E(\lambda,t,z)$ – wavelength, time and depth-dependent irradiance

Modeling the plankton component

$$\log P_E^B \text{ or } \log R^B = T\left(\frac{\log Q_{10}}{10}\right) + C$$

- P^B_E and R are temperature dependent
- Q_{10} = 3 to 20° C
- P^B_E decreases linearly with T to 38° C



Bouman, H., T. Platt, S. Sathyendranath, and V. Stuart. 2005. Dependence of light-saturated photosynthesis on temperature and community structure. Deep Sea Research Part I: Oceanographic Research Papers **52: 1284-1299.**

Modeling the plankton component

- Net productivity is defined by the balance between photosynthesis and respiration

$$P_{net}^{V} = B\left[P_g^B - R^B \right]$$

- Redfield Ratios define the amounts of dissolved inorganic nitrogen (N) and phosphorus (P) required to convert net photosynthesis into new biomass:

$$\frac{\partial \mathrm{N}}{\partial t} = \frac{16}{106} P_{net}^{V}$$

$$\frac{\partial \mathrm{P}}{\partial t} = \frac{1}{106} P_{net}^{V}$$

Modeling the plankton component

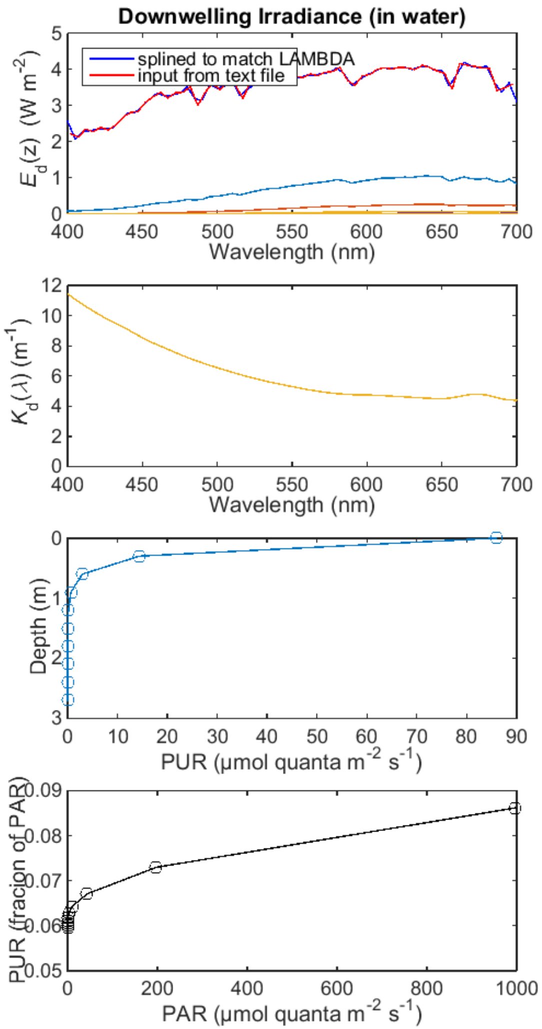
- if $\frac{\partial \mathrm{N}}{[\mathrm{N}]} \leq 1$ and $\frac{\partial \mathrm{P}}{[\mathrm{P}]} \leq 1$, phytoplankton growth is defined by $P^{V}{}_{net}$ and the concentrations of dissolved inorganic N and P are reduced accordingly
- NH_4^+ taken up before NO_3^-
- If $\frac{\partial \mathrm{N}}{[\mathrm{N}]} > 1$ or $\frac{\partial \mathrm{P}}{[\mathrm{P}]} > 1$, phytoplankton growth is limited by the nutrient in shortest supply, all of which is taken up:

$$\frac{\partial Phyto}{\partial t} = P_{net}^{V} \cdot lesser\,of\ \frac{[\mathrm{N}]}{\partial \mathrm{N}}, \frac{[\mathrm{P}]}{\partial \mathrm{P}}$$

Chester River WQ

Chl *a* = 20 mg m^{-3}

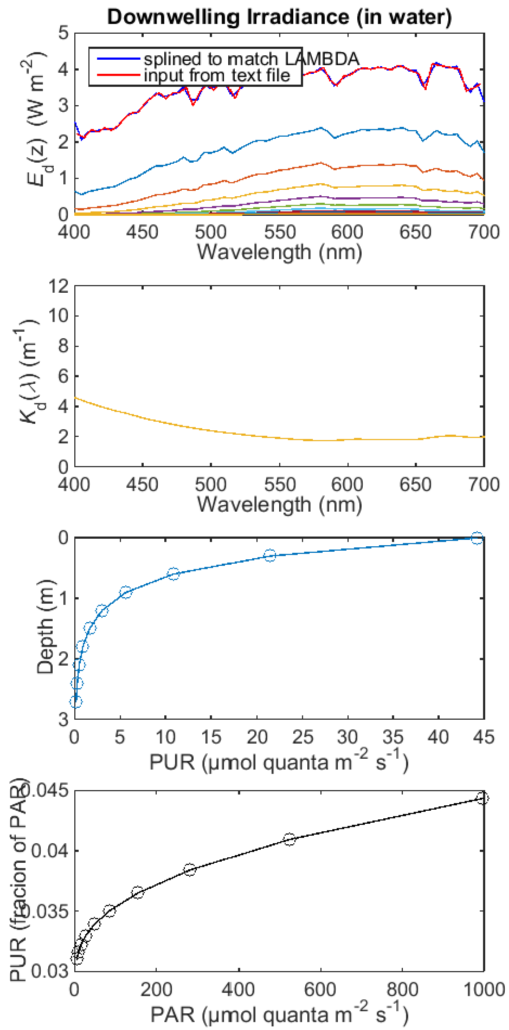
TSM = 30 mg L^{-1}



Sandy Pt WQ

Chl *a* = 10 mg m^{-3}

TSM = 10 mg L^{-1}



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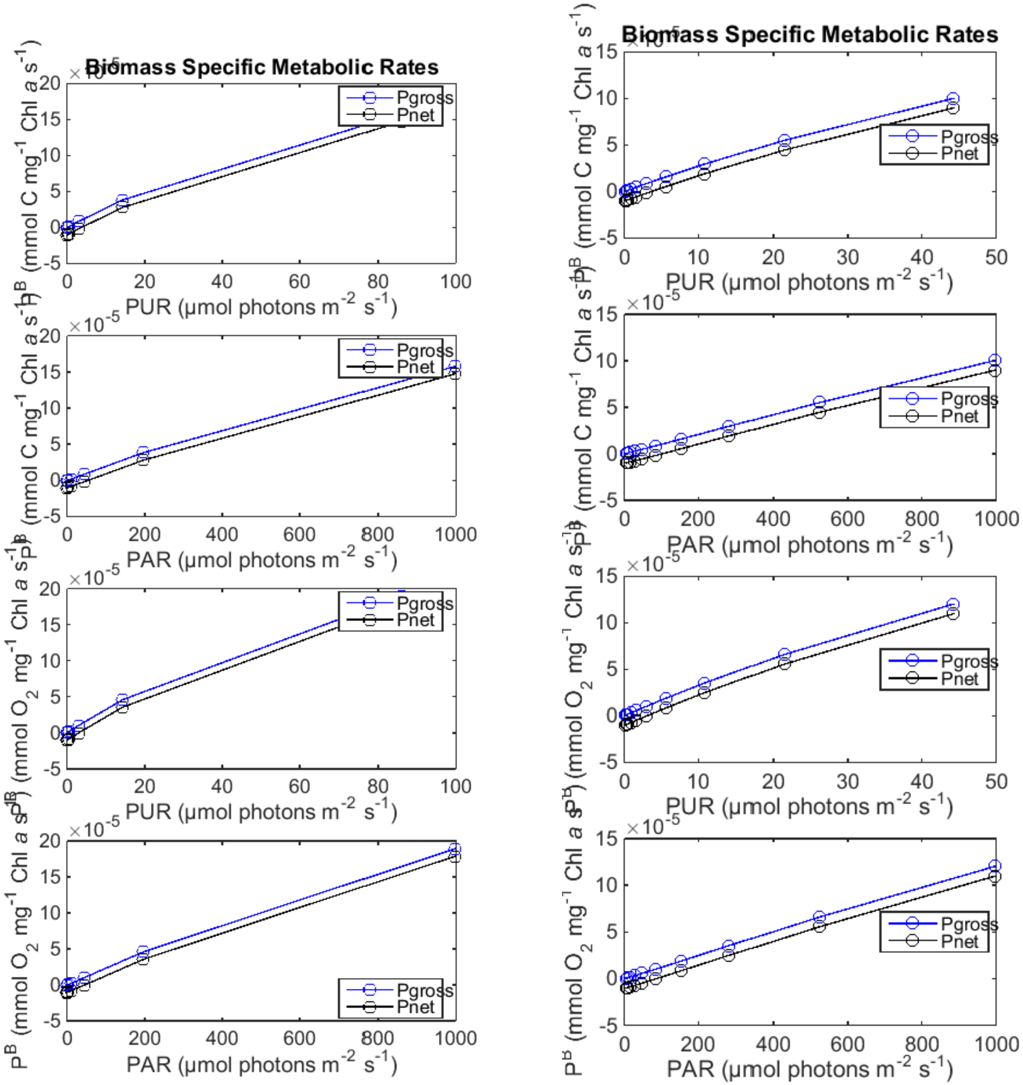

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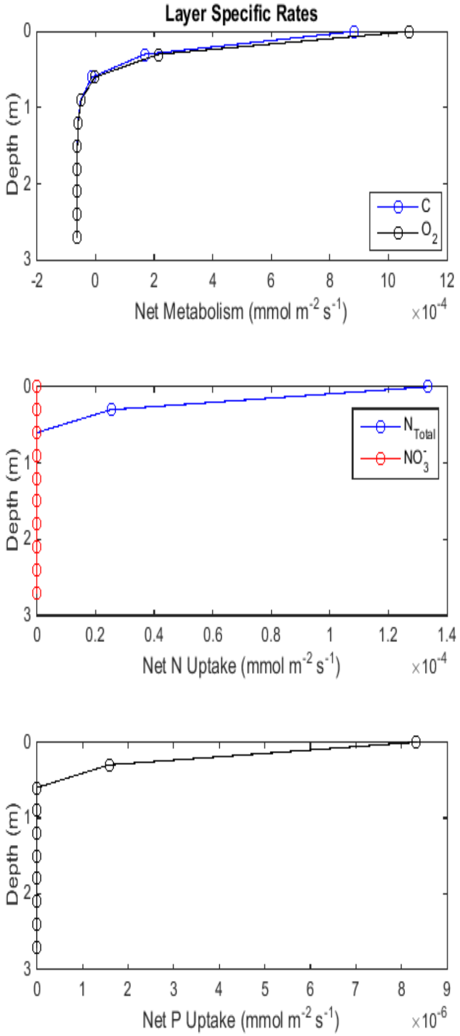

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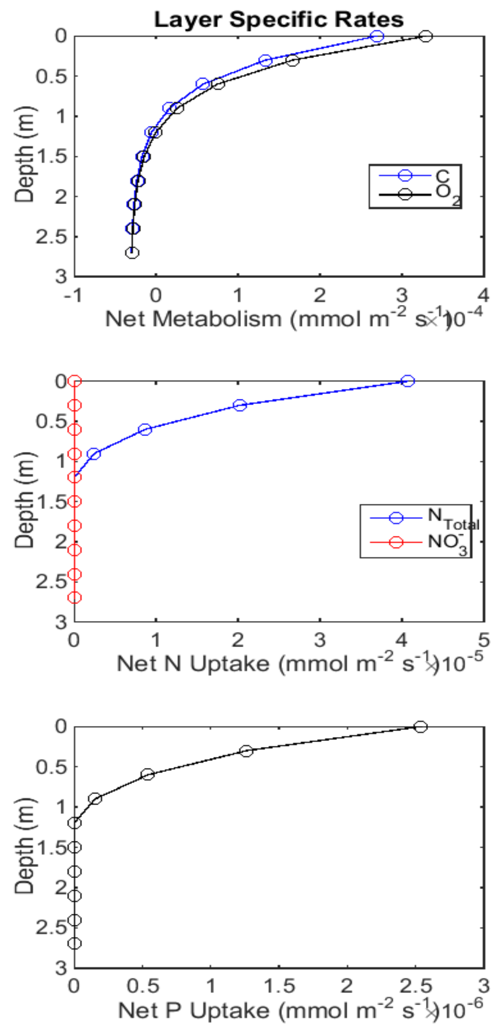

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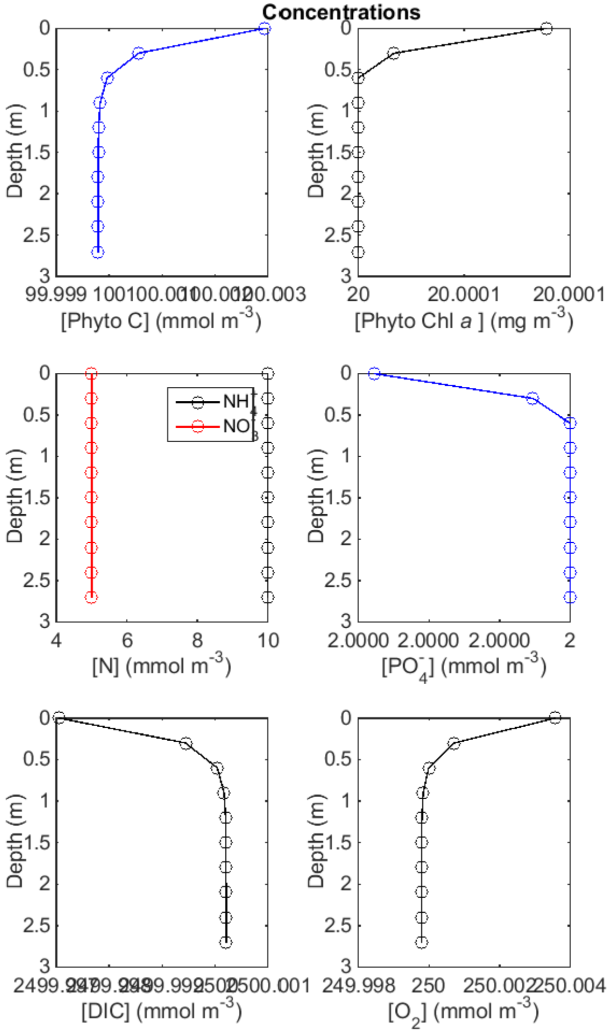

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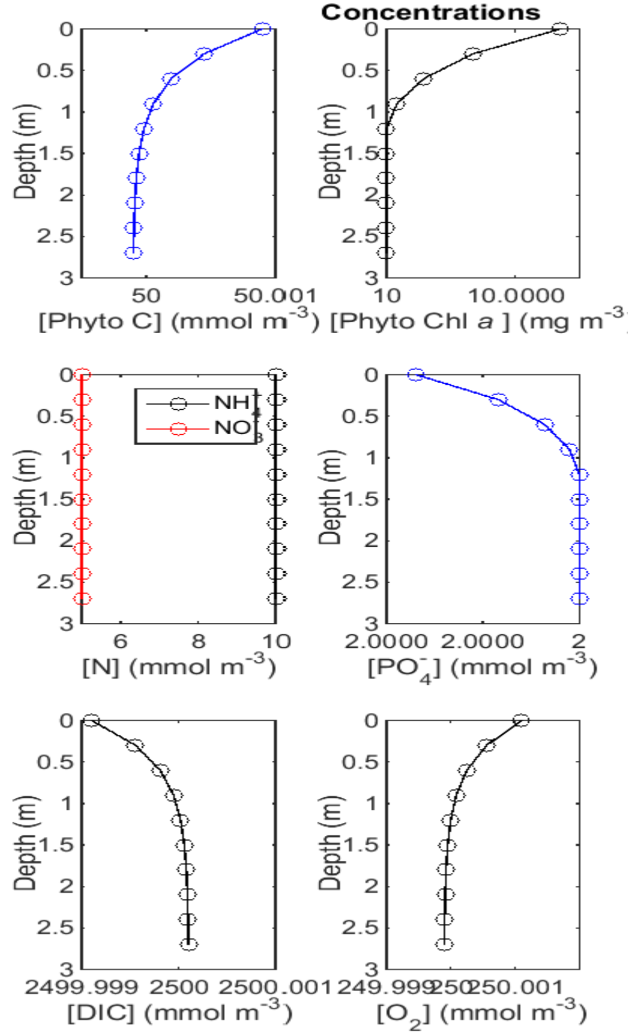
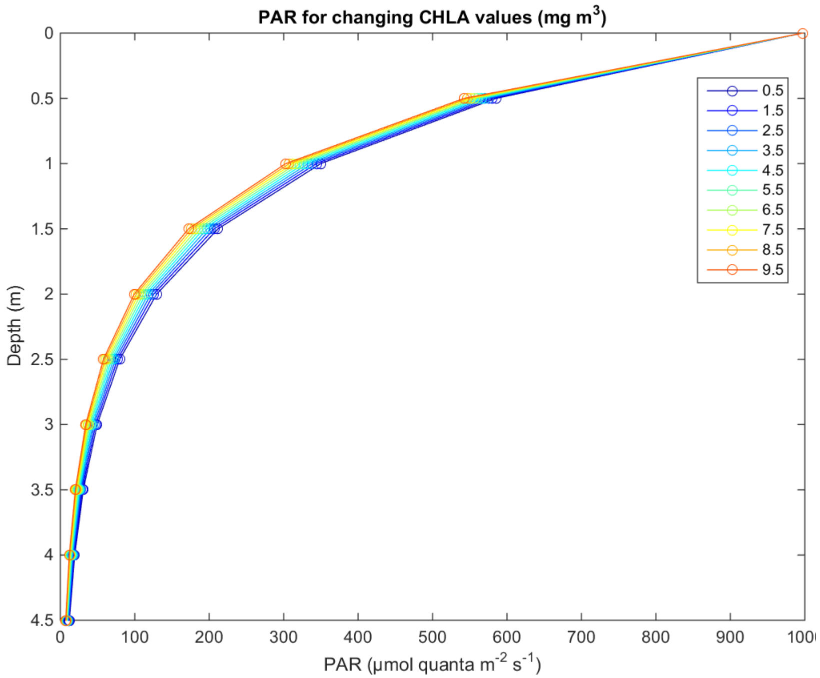
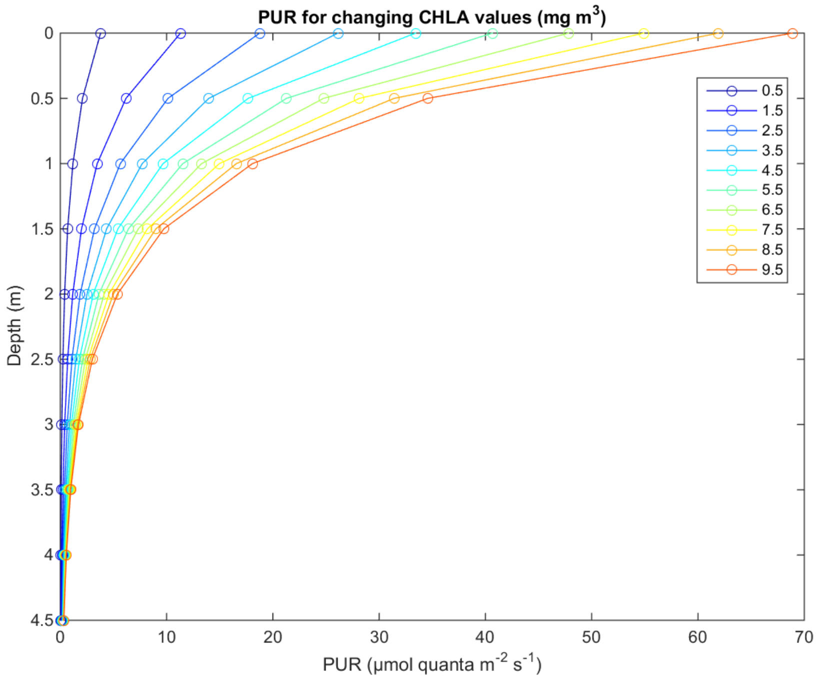
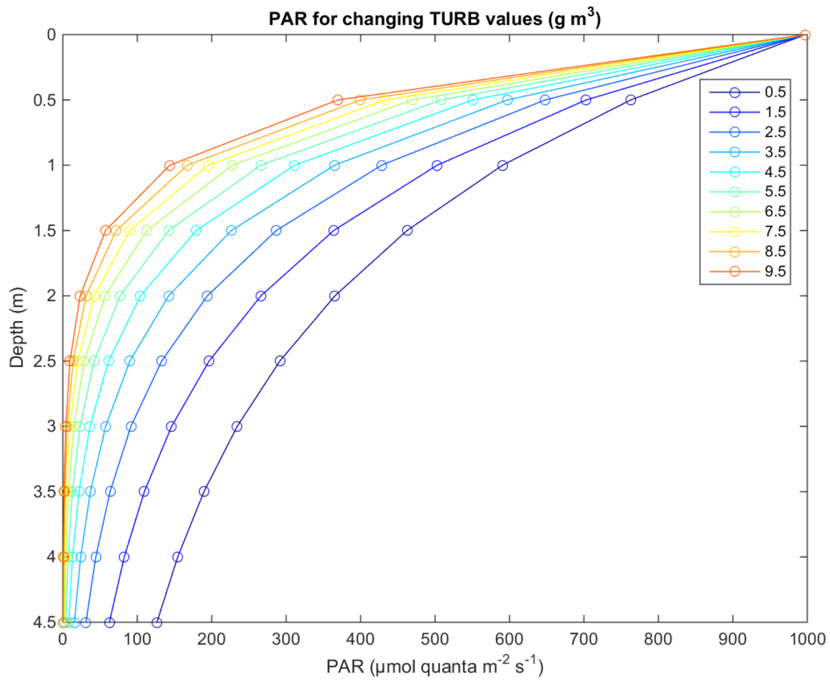


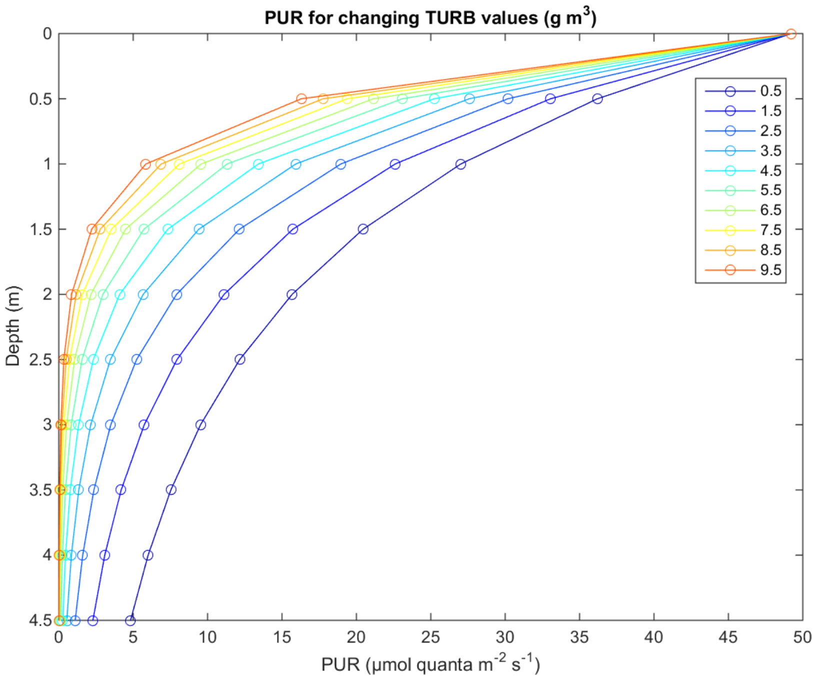
Model Sensitivity to [Chl *a*]





Model Sensitivity to Turbidity





Modeling the plankton component

- The 1-D model:
  - Easily integrated into *GrassLight* bio-optical structure
  - Calculates biologically mediated changes in
    - O2, DIC & therefore pH
    - Dissolved nutrients
  - Ultimately driven by light availability
    - Includes a self-shading component from algal biomass
  - Responsive to nutrient concentrations
    - But does not require explicit definition of Michaelis-Menten coefficients
  - Represents a single time-step
    - Sinking & mixing processes under hydrodynamic control external to this module

- It does NOT presently consider
  - Mixotrophic & motile algae (e.g. Dinoflagellates) that exhibit complex behaviors & trophic relations
  - Benthic & pelagic grazing