Development of Multiple Tributary Model (MTM)
-- Modules for the Shallow Water Ecosystem

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Modeling Quarterly Review, April 6, 2022

Outline

- Review of the shallow habitat modules in SCHISM
- Implementation in the York and James Rivers
- Preliminary results
- Discussions and plans

Outline

Review of the shallow habitat modules in SCHISM

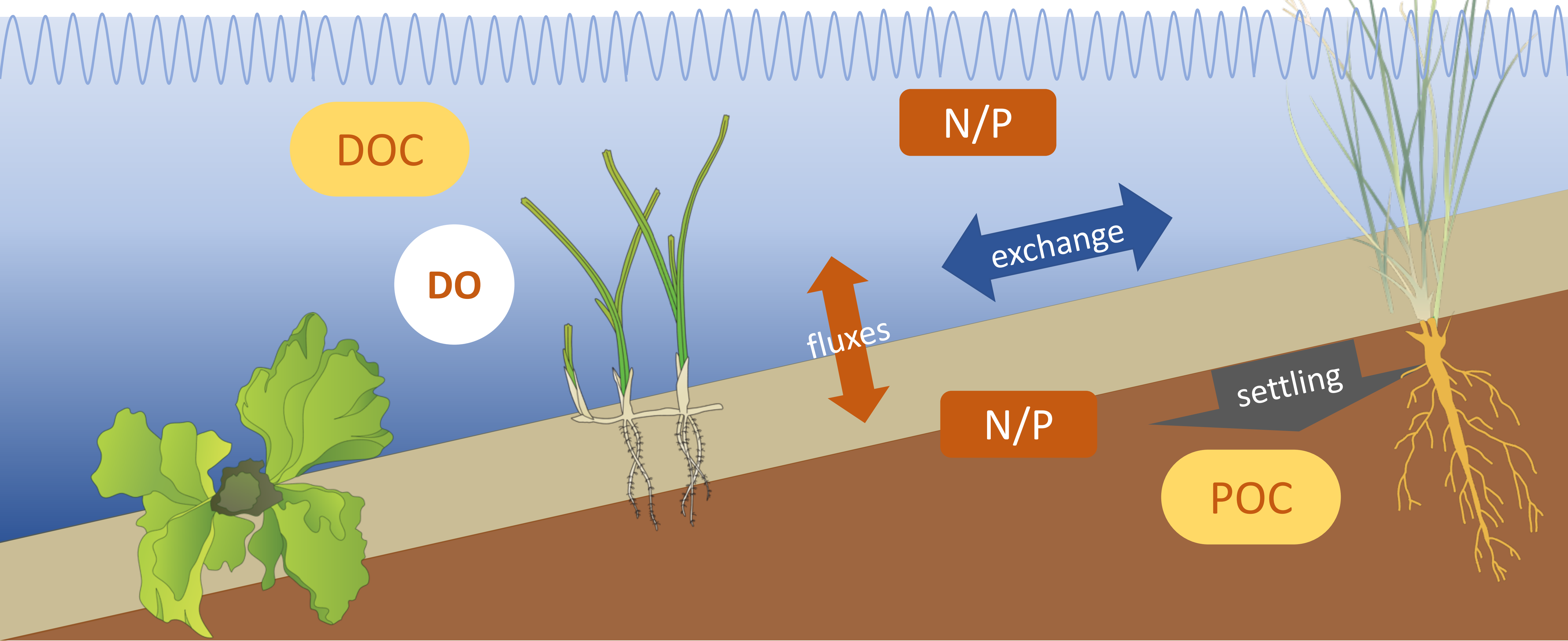
Implementation in the York and James Rivers

Preliminary results

Discussions and plans

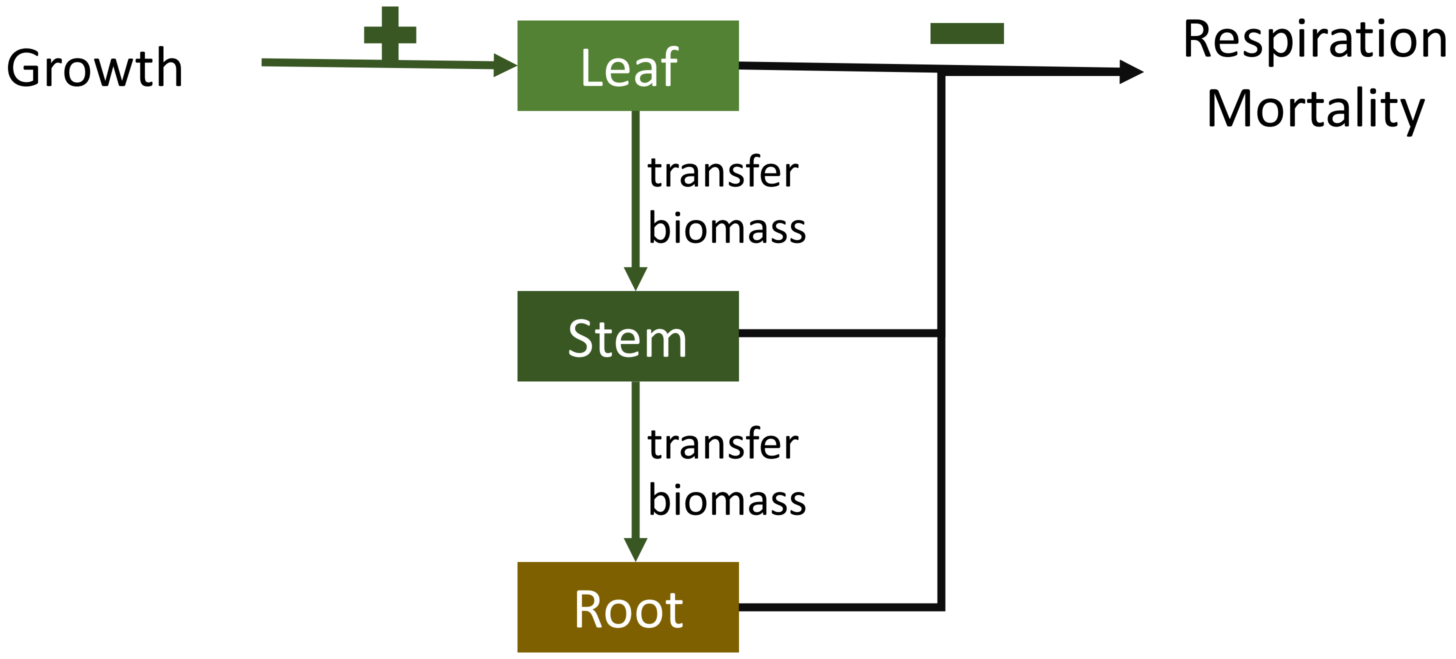
Motivations

- Significant producers in the shallow water habitats
- Diel DO and other biochemical processes
- Receiving significant impacts from SLR

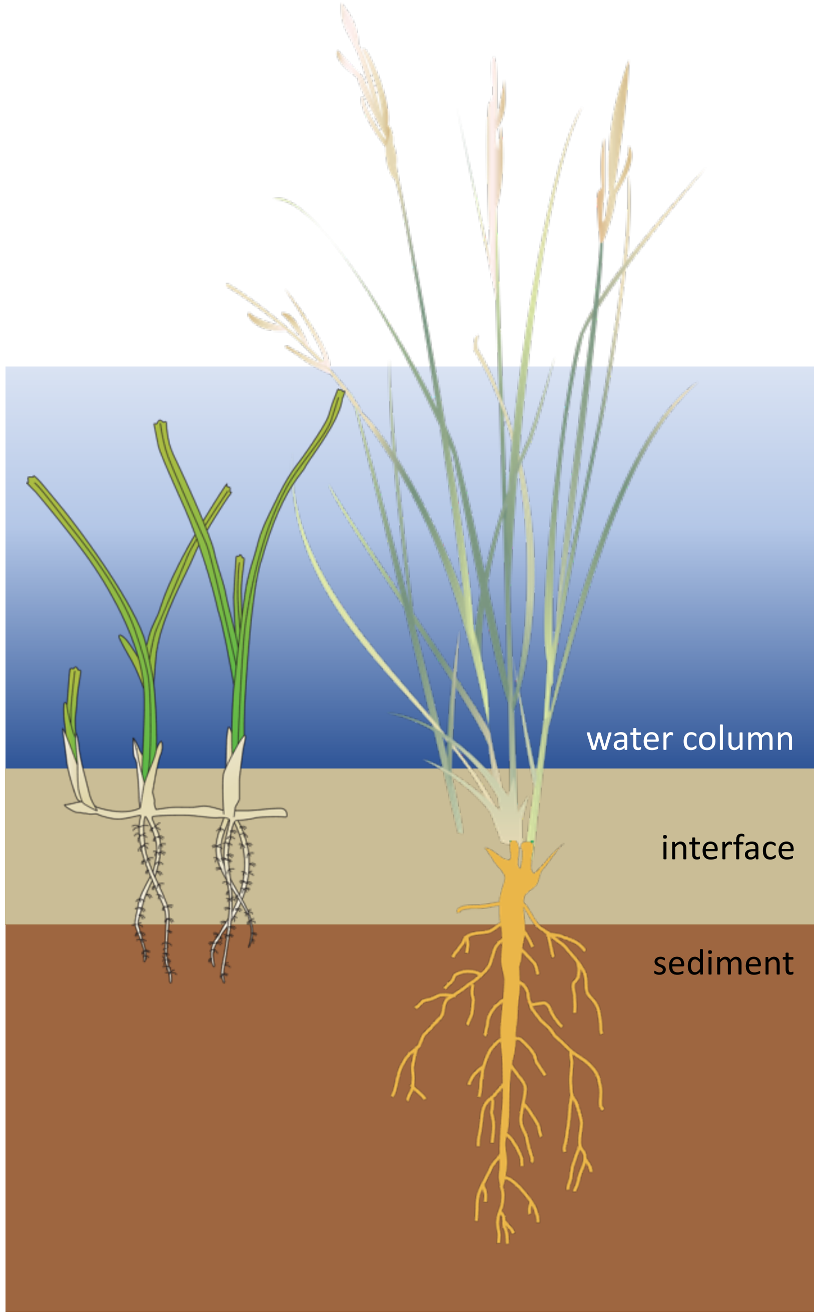


Model structure – biomass

Benthic algae



SAV and marsh



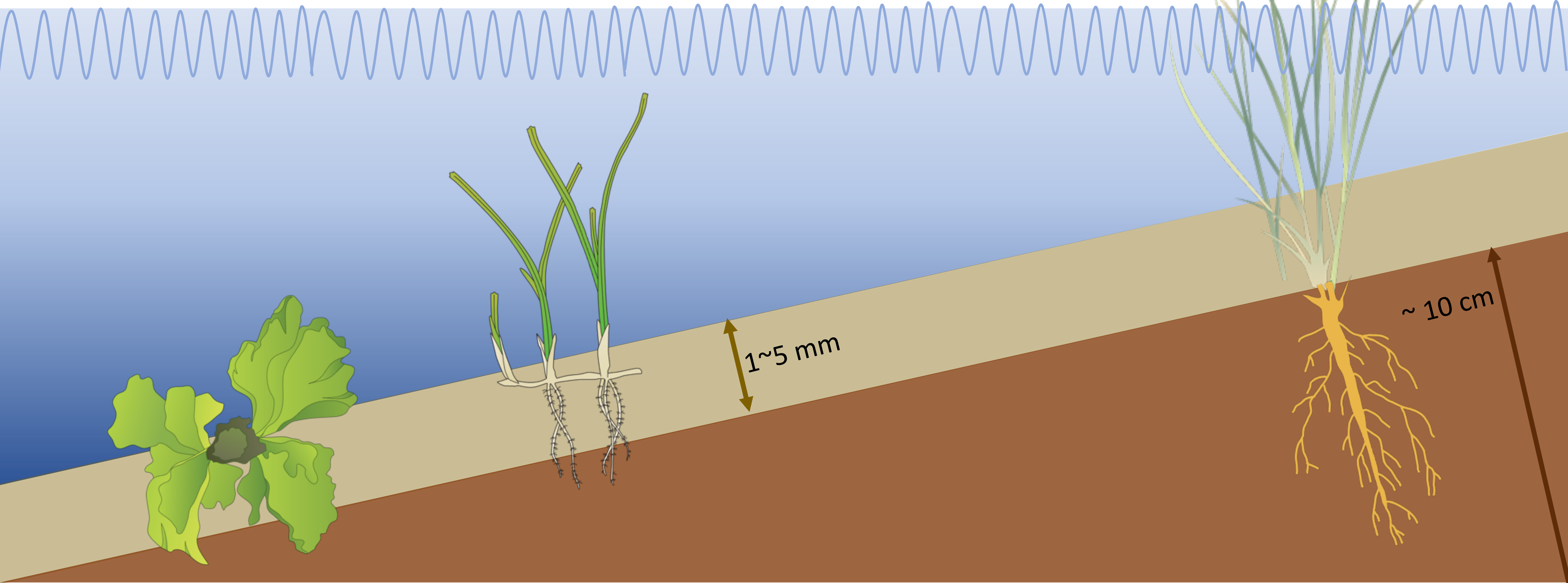
Model structure – biomass

Temperature
Light
Nutrients
Inundation
Salinity

growth — respiration/predation/mortality

$$\frac{d\,M}{dt} = G \cdot M - BM(T) \cdot M$$

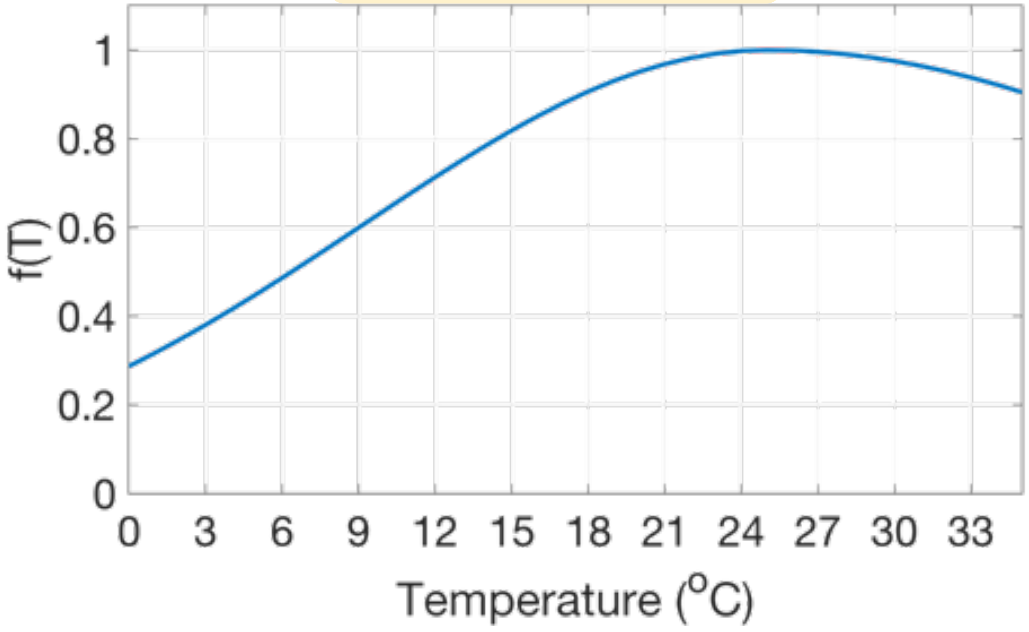
take up nutrients, produce oxygen — release nutrients, consume oxygen



Model structure – similarities

Limitation functions

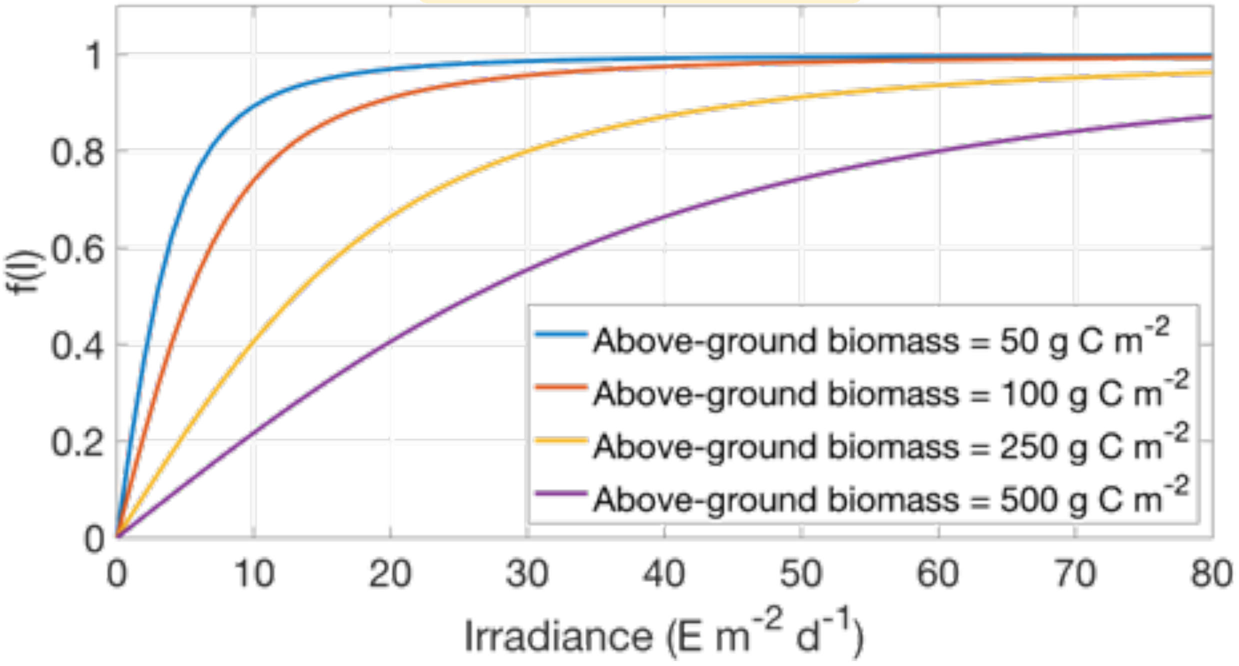
Temperature



$$e^{-KTg1\cdot(T-Topt)^2}, when\ T \le Topt$$

$$e^{-KTg2\cdot(T-Topt)^2}, when\ T > Topt$$

Light



$$f(I) = \frac{Iwc}{\sqrt{Iwc^2 + Ik^2}}$$

$$Ik = \frac{Pm(T)}{\alpha}$$

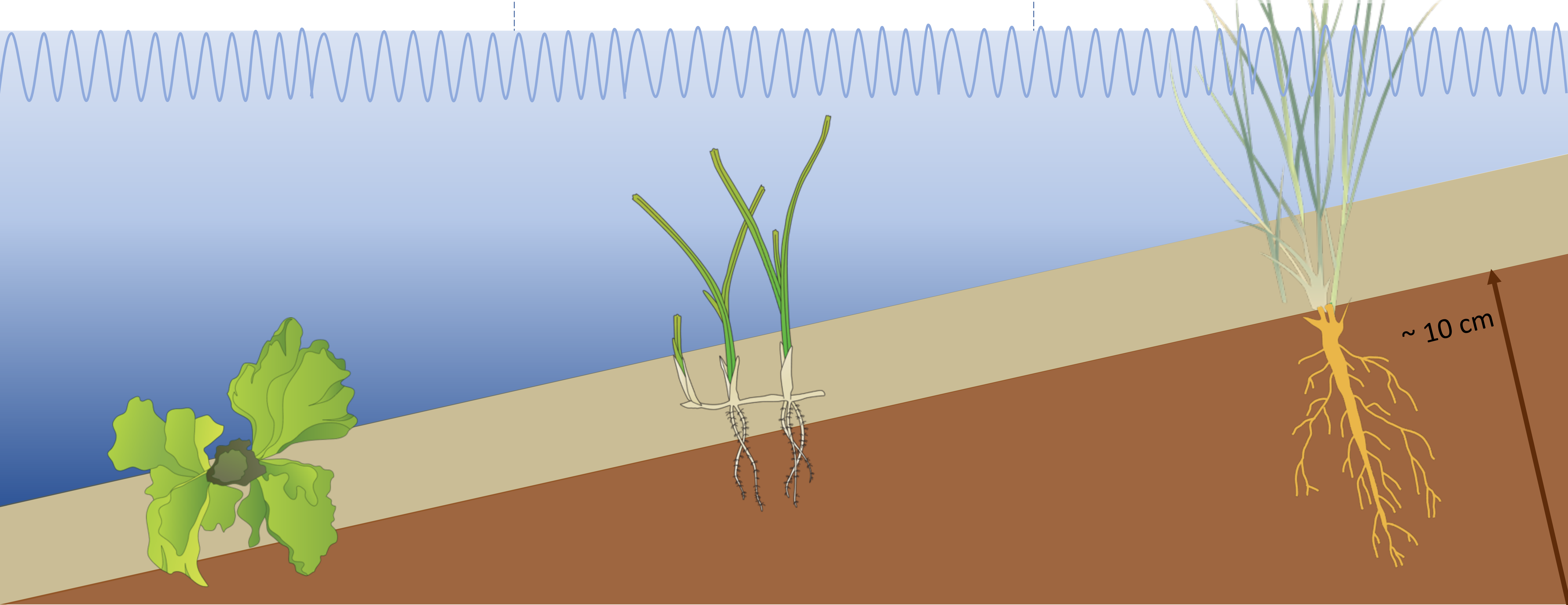
Iwc (E m^{-2}) is irradiance utilized by benthic algae/SAV/marsh

Model structure – key differences

- Stay in the bottom
- Separate terms of respiration and predation for nutrient recycling

- Submerged
- Active interaction with N/P in the water column

- Periodically emerged
- Not consider direct uptake/release of N/P in the water column



Growth and respiration – benthic algae

$$\frac{d\,\boldsymbol{BBM}}{dt} = (G(T,I,N/P)\cdot -BM(T) - PR(T))\cdot \boldsymbol{BBM}$$

Growth

$$G = Gmax \cdot f(T) \cdot f(I) \cdot \min\left(f(N), f(P)\right)$$

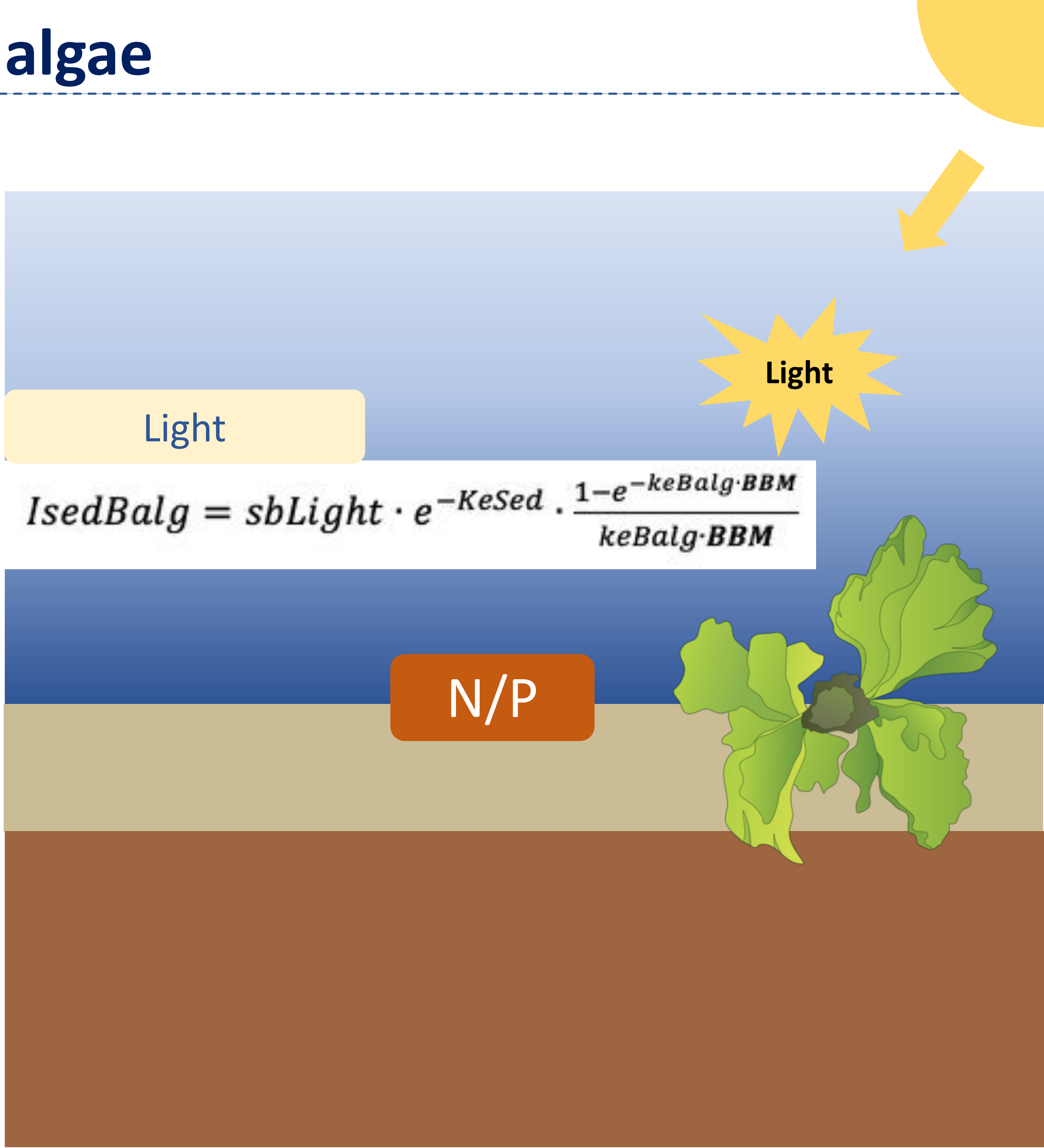
Nutrient

$$f(N) = \frac{NH4avl + NO3avl}{khn + NH4avl + NO3avl} \qquad f(P) = \frac{PO4avl}{khp + PO4avl}$$

Respiration/predation

$$BM = BMr \cdot e^{KTr\cdot(T-Tr)}$$

$$PR = PRr \cdot e^{KTr\cdot(T-Tr)}$$



$$IsedBalg = sbLight \cdot e^{-KeSed} \cdot \frac{1-e^{-keBalg\cdot \boldsymbol{BBM}}}{keBalg\cdot \boldsymbol{BBM}}$$

Growth and respiration – SAV

$$\frac{d\,LF}{dt} = Plf(T,I,N/P)\cdot(1-Fam)\cdot FPlf\cdot LF - BMlf(T)\cdot LF$$

$$\frac{d\,ST}{dt} = Plf(T,I,N/P)\cdot(1-Fam)\cdot FPst\cdot LF - BMst(T)\cdot ST$$

$$\frac{d\,RT}{dt} = Plf(T,I,N/P)\cdot(1-Fam)\cdot FPrt\cdot LF - BMrt(T)\cdot RT$$

Growth

$$Plf = Pm(T)\cdot \min\left(f(I), f(N), f(P)\right)/Acdw$$

Nutrient

$$f(N) = \frac{NH4w+NO3w+\frac{KHNw}{KHNs}\cdot NH4s}{KHNw+NH4w+NO3w+\frac{KHNw}{KHNs}\cdot NH4s}$$

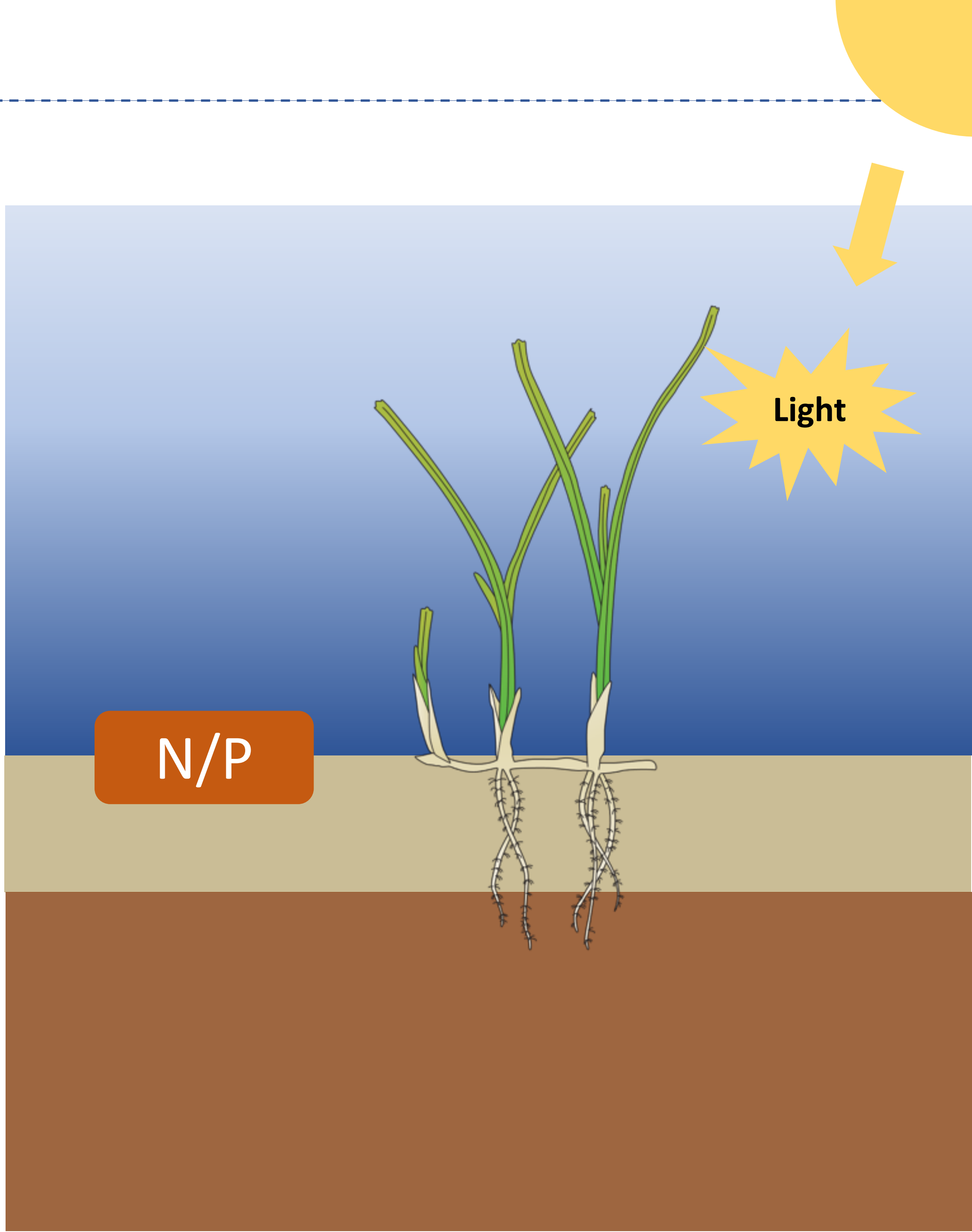
$$f(P) = \frac{PO4w+\frac{KHPw}{KHPs}\cdot PO4s}{KHPw+PO4w+\frac{KHPw}{KHPs}\cdot PO4s}$$

Respiration/predation

$$BMlf = BMrlf\cdot e^{KTblf\cdot(T-Trlf)}$$

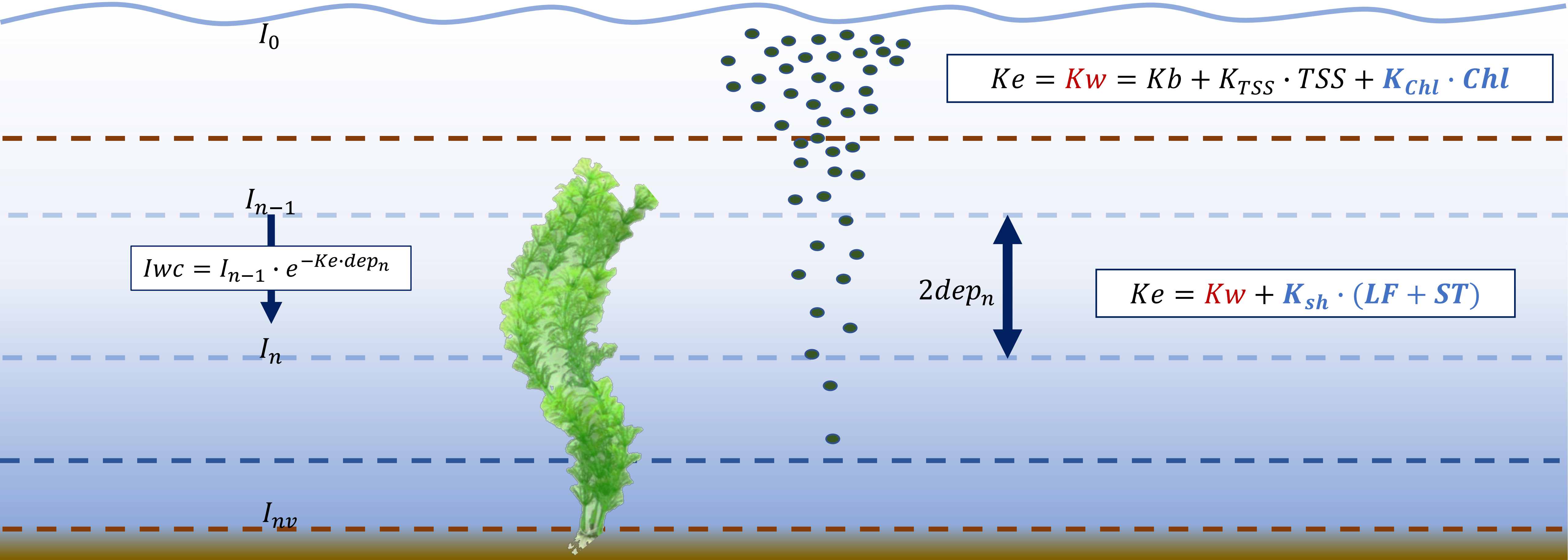
$$\mathrm{BMst} = \mathrm{BMrst}\cdot \mathrm{e}^{\mathrm{KTbst}\cdot(\mathrm{T}-\mathrm{Trst})}$$

$$\mathrm{BMrt} = \mathrm{BMrrt}\cdot \mathrm{e}^{\mathrm{KTbrt}\cdot(\mathrm{T}-\mathrm{Trrt})}$$



SAV Interactions with Light

- Iwc is the irradiance at certain layer ($\mathrm{E\ m^{-2}\ d^{-1}}$); I_0 is surface irradiance; I_n is irradiance at the bottom of vertical layer n.
- Ke is total diffuse light attenuation ($\mathrm{m^{-1}}$); Kw is diffuse light attenuation in layers without SAV ($\mathrm{m^{-1}}$); Ksh is light attenuation by SAV absorption ($\mathrm{m^2\ g^{-1}\ C}$).



Growth and respiration – marsh

$$\frac{d\,\mathbf{LF}}{dt} = Plf(T,I,S,F)\cdot(1-Fam)\cdot FPlf\cdot\mathbf{LF} - MTlf(T)\cdot BMlf(T)\cdot\mathbf{LF}$$

$$\frac{d\,\mathbf{ST}}{dt} = Plf(T,I,S,F)\cdot(1-Fam)\cdot FPst\cdot LF - MTst(T)\cdot BMst(T)\cdot\mathbf{ST}$$

$$\frac{d\,\mathbf{RT}}{dt} = Plf(T,I,S,F)\cdot(1-Fam)\cdot FPrt\cdot LF - BMrt(T)\cdot\mathbf{RT}$$

Growth

$$Plf = Pm(T)\cdot f(S)\cdot f(I)\cdot f(F)/acdw$$

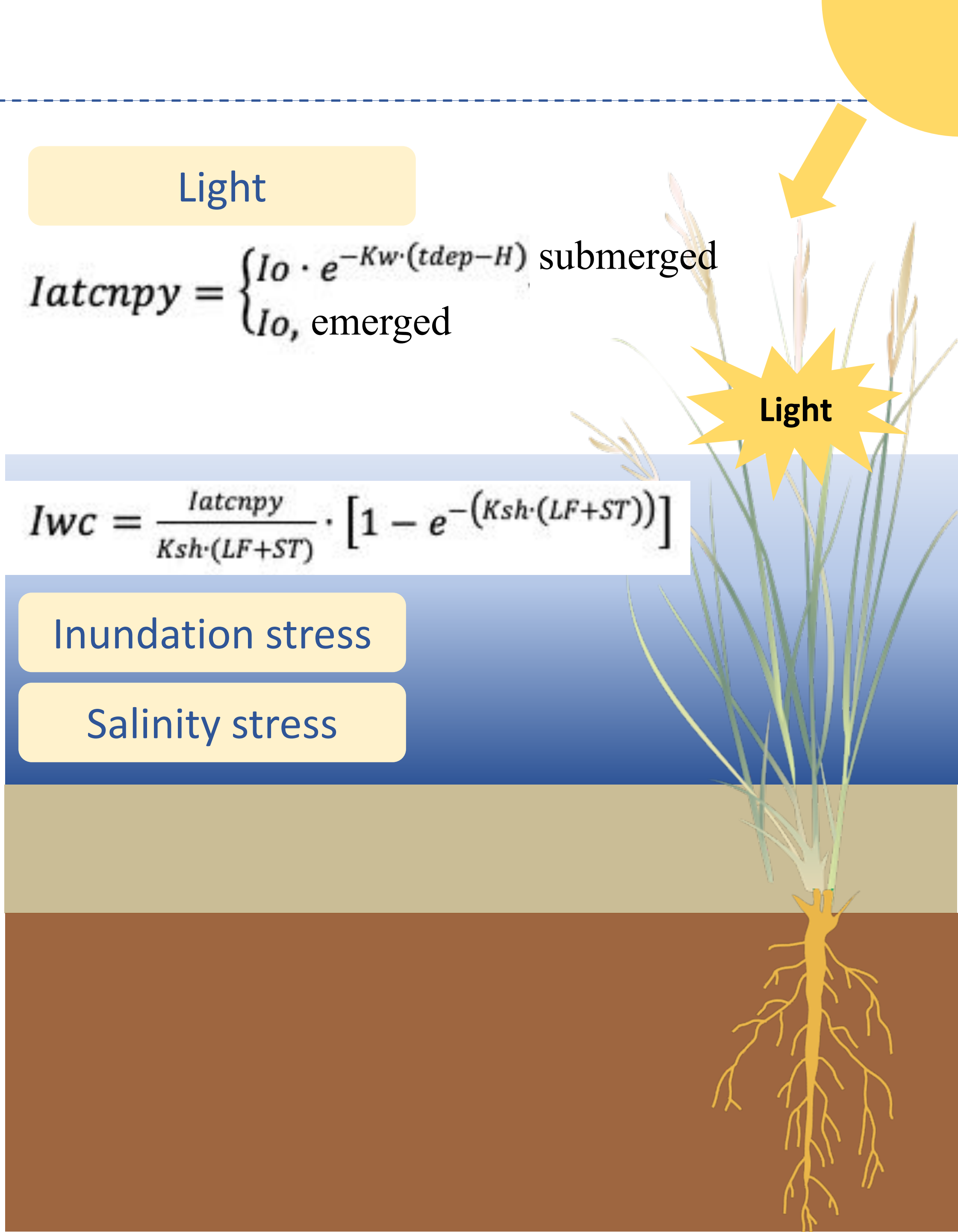
Light

$$Iatcnpy = \begin{cases} Io\cdot e^{-Kw\cdot(tdep-H)} & \text{submerged} \\ Io, & \text{emerged} \end{cases}$$

$$Iwc = \frac{Iatcnpy}{Ksh\cdot(LF+ST)}\cdot\left[1-e^{-(Ksh\cdot(LF+ST))}\right]$$

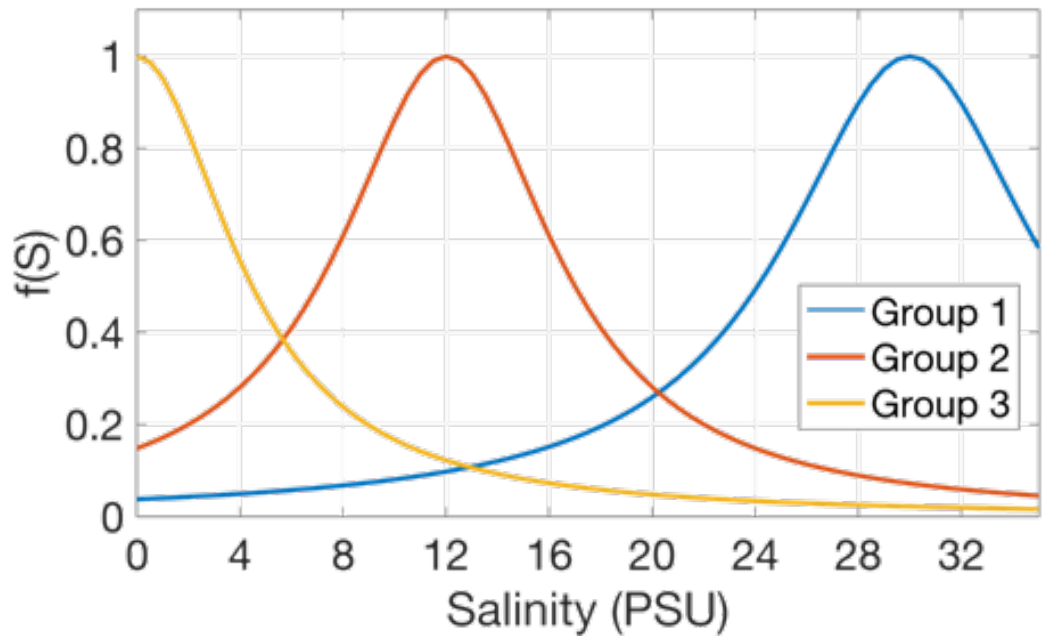
Inundation stress

Salinity stress



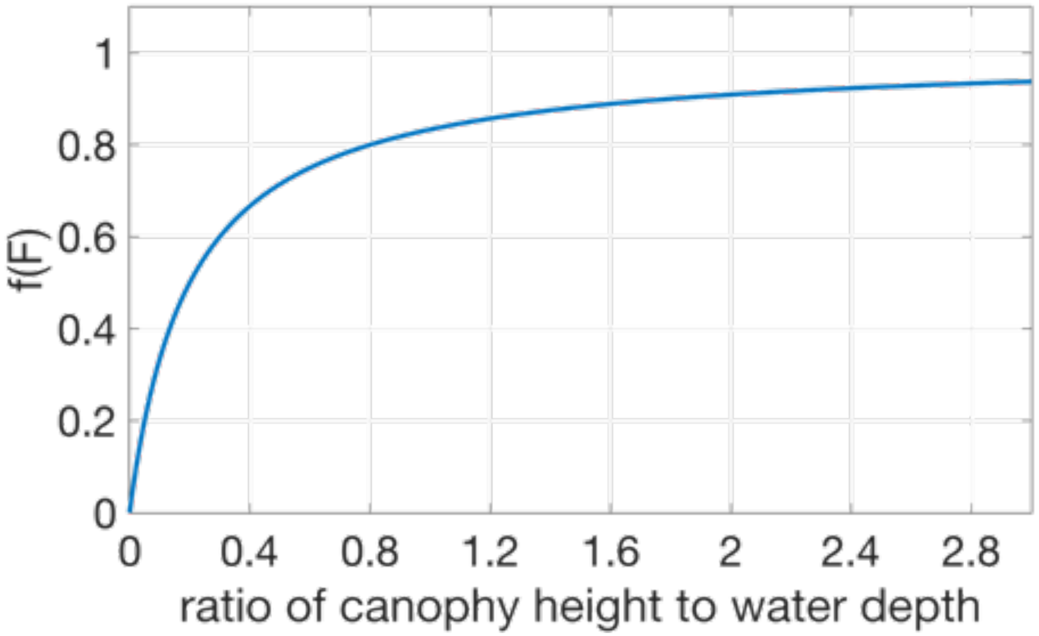
Limitation functions for marsh growth

Salinity stress



$$f(S) = \frac{ST}{ST + (Salt - Saltopt)^2}$$

Inundation stress



$$f(F) = \frac{rdephcan}{tinun + rdephcan}$$

$$rdephcan = \frac{H}{tdep}$$

Growth and respiration – marsh

$$\frac{d\,\mathbf{LF}}{dt} = Plf(T,I,S,F)\cdot(1-Fam)\cdot FPlf\cdot \mathbf{LF} - MTlf(T)\cdot BMlf(T)\cdot \mathbf{LF}$$

$$\frac{d\,\mathbf{ST}}{dt} = Plf(T,I,S,F)\cdot(1-Fam)\cdot FPst\cdot LF - MTst(T)\cdot BMst(T)\cdot \mathbf{ST}$$

$$\frac{d\,\mathbf{RT}}{dt} = Plf(T,I,S,F)\cdot(1-Fam)\cdot FPrt\cdot LF - BMrt(T)\cdot \mathbf{RT}$$

Growth

$$Plf = Pm(T)\cdot f(S)\cdot f(I)\cdot f(F)/acdw$$

Respiration/mortality

$$BMlf = BMlfr\cdot e^{KTblf\cdot(T-Trlf)}$$

$$BMst = BMstr\cdot e^{KTbst\cdot(T-Trst)}$$

$$BMrt = BMrtr\cdot e^{KTbrt\cdot(T-Trrt)}$$

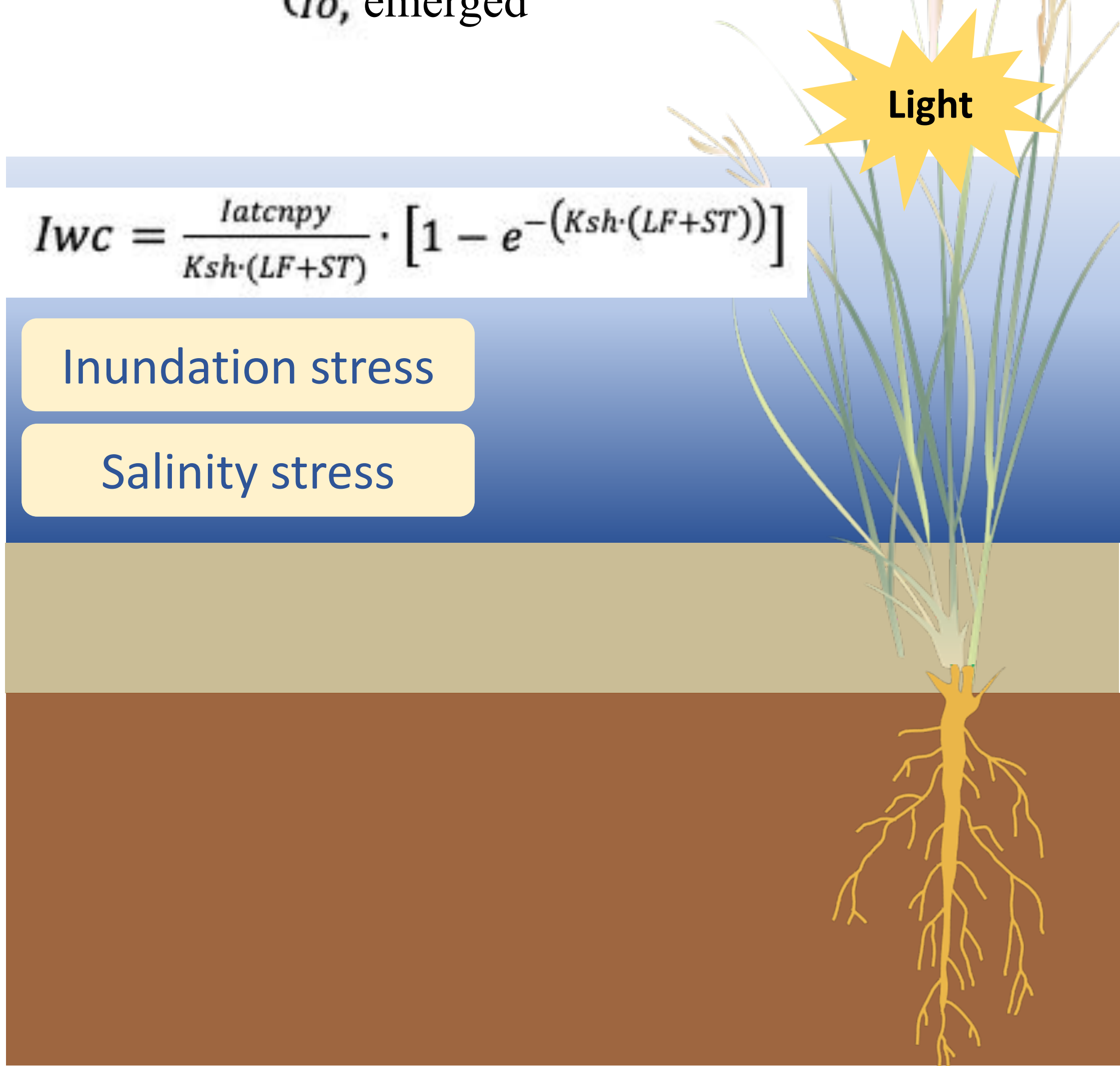
$$MTlf = \frac{adlf}{1+e^{-bdlf\cdot(T-cdlf)-ddlf}} + 1$$

$$MTst = \frac{adst}{1+e^{-bdst\cdot(T-cdst)-ddst}} + 1$$

Light

$$Iatcnpy = \begin{cases} Io\cdot e^{-Kw\cdot(tdep-H)} & \text{submerged} \\ Io, & \text{emerged} \end{cases}$$

$$Iwc = \frac{Iatcnpy}{Ksh\cdot(LF+ST)}\cdot\left[1-e^{-\left(Ksh\cdot(LF+ST)\right)}\right]$$



Interactions with the water column

Model structure – nutrient interactions: benthic algae

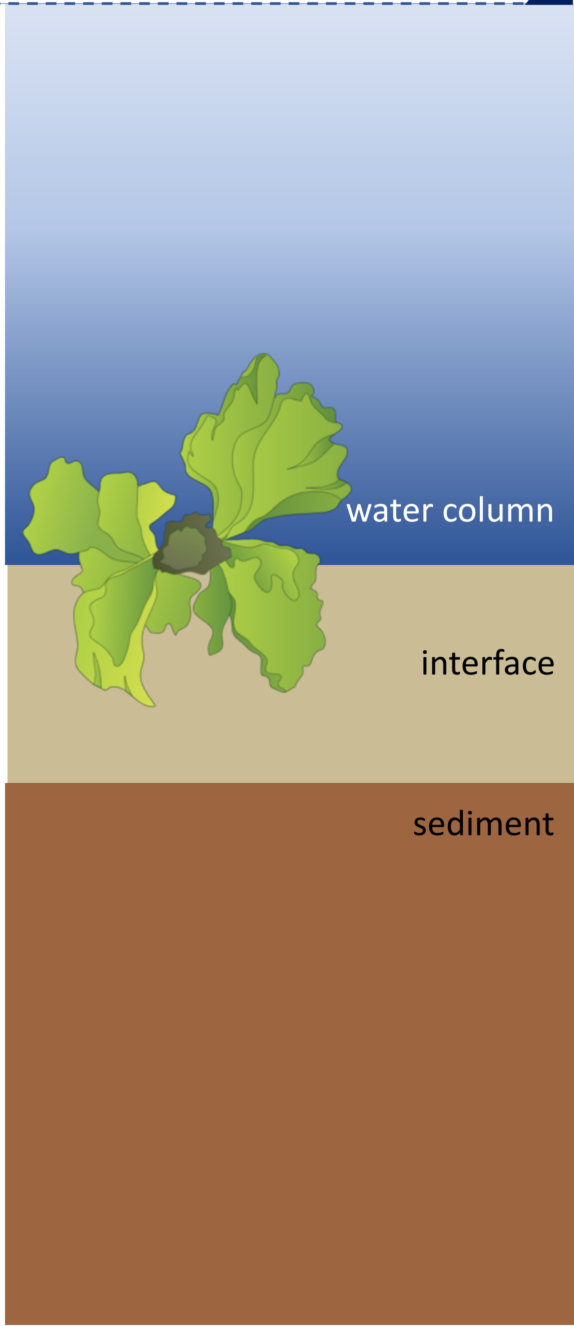
- take up inorganic nutrients
- produce oxygen

take up inorganic nutrients

Benthic algae

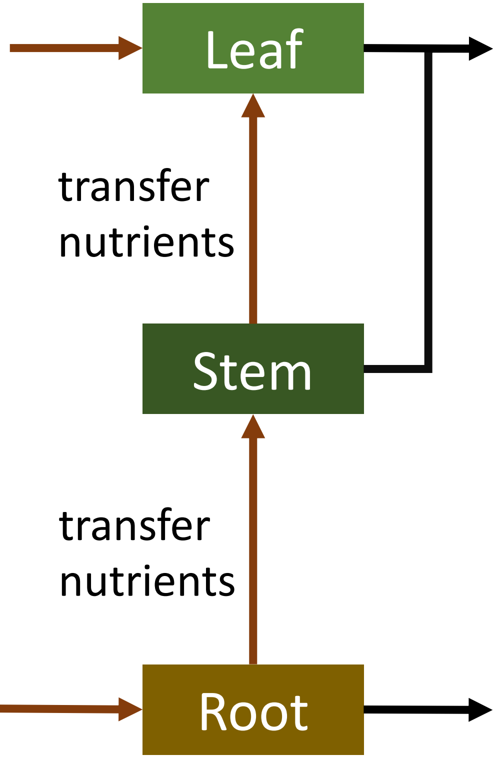
- consume oxygen
- release DOC
- release inorganic nitrogen/phosphorus

settle particulate organic carbon/nitrogen/phosphorus



Model structure – nutrient interactions: SAV

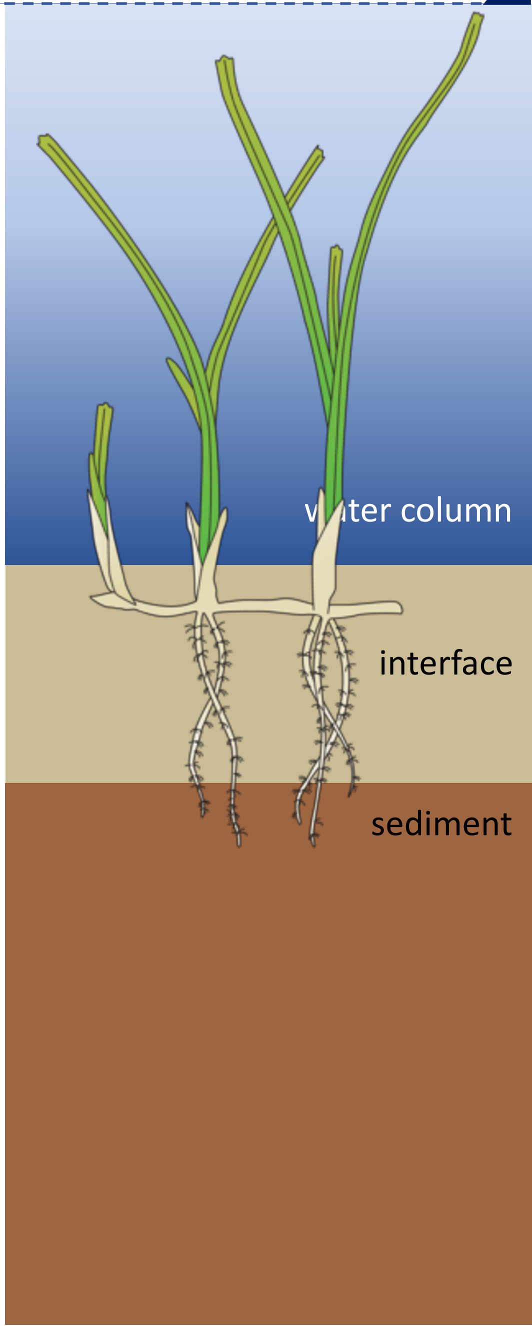
- take up inorganic nutrients
- produce oxygen



- release nutrients in both inorganic and organic forms
- consume oxygen

take up inorganic nutrients

- settle particulate organic carbon/nitrogen/phosphorus
- call for sediment oxygen demand



Model structure – nutrient interactions: marsh

produce oxygen ← **Leaf**

transfer nutrients (Stem → Leaf)

Stem

Leaf, Stem → Detritus

Detritus ↓

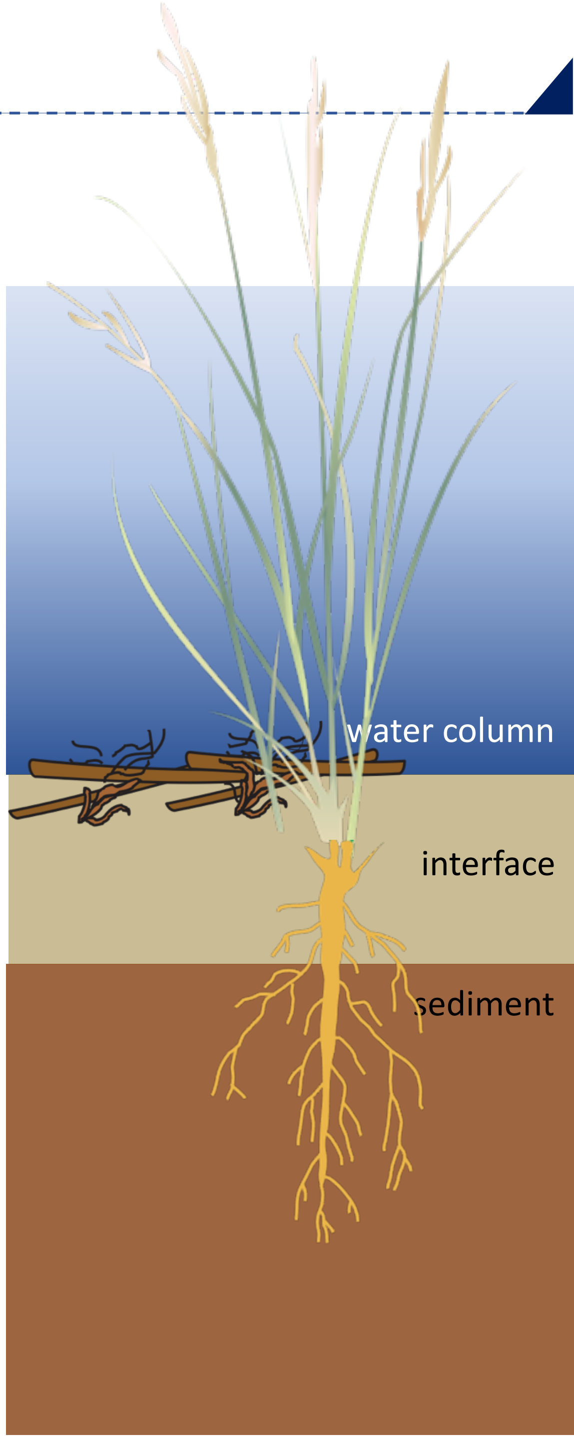
- consume oxygen
- release DOC

↓

transfer nutrients (Root → Stem)

take up inorganic nutrients → **Root** →

- settle particulate organic carbon/nitrogen/phosphorus
- consume oxygen



Water column oxygen and DOC

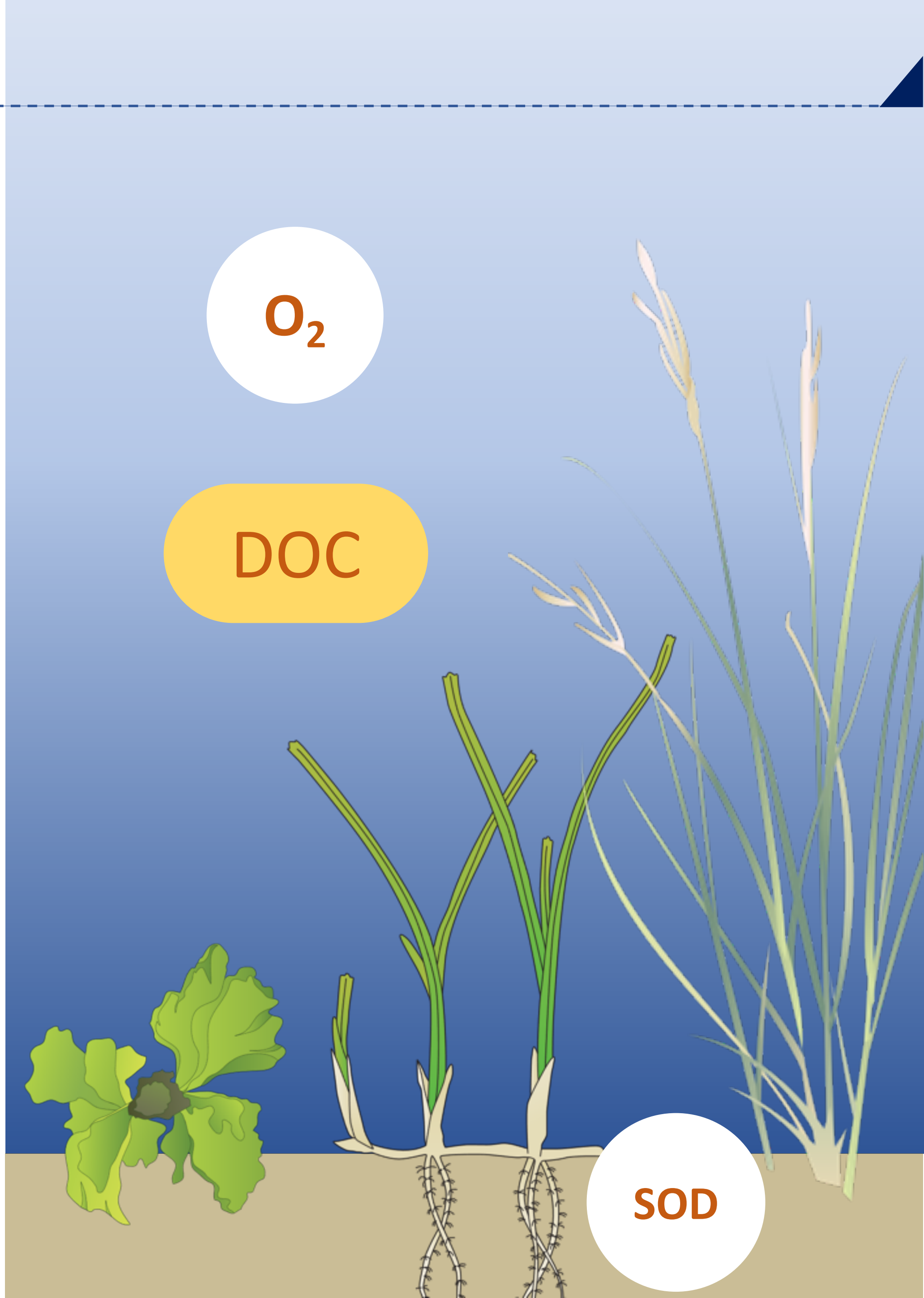
$$\frac{d\,DO}{dt} = Aocr \cdot Plf \cdot LF - Aocr \cdot FDO \cdot [(BMlf + Plf \cdot Fam) \cdot LF + BMst \cdot ST]$$

$$\frac{dDOC}{dt} = FCD \cdot [(BMlf + Plf \cdot Fam) \cdot LF + BMst \cdot ST]$$

$$\frac{dLPOC}{dt} = FCLP \cdot [(BMlf + Plf \cdot Fam) \cdot LF + BMst \cdot ST]$$

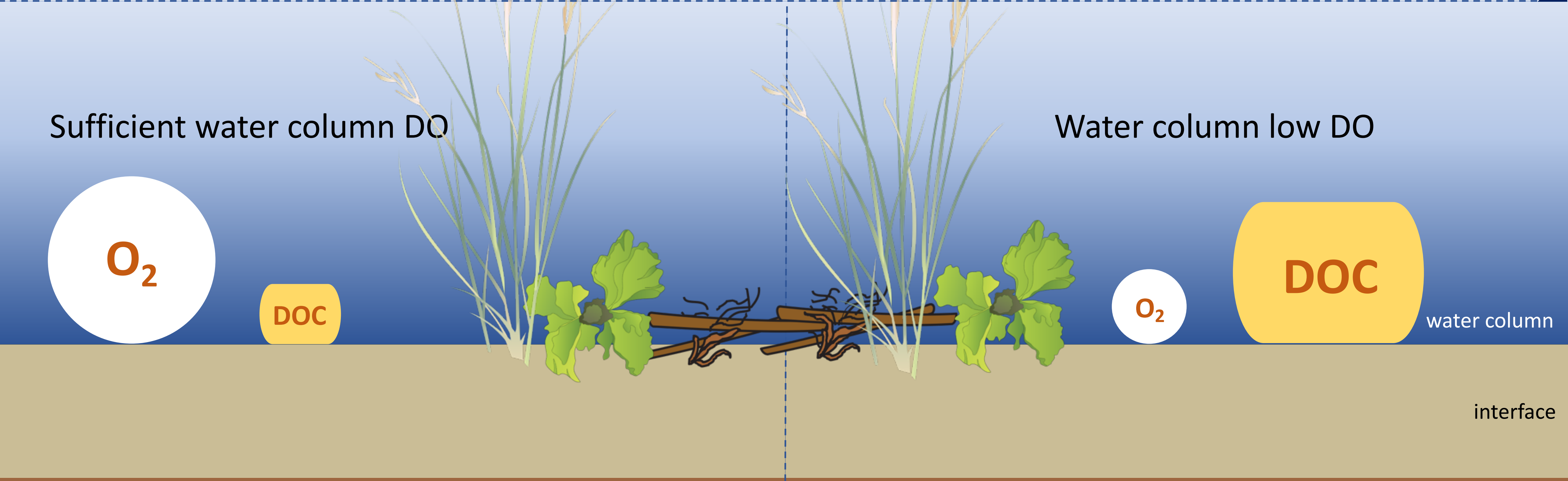
$$\frac{dRPOC}{dt} = FCRP \cdot [(BMlf + Plf \cdot Fam) \cdot LF + BMst \cdot ST]$$

$$rtdosav = \frac{dDO}{dt} = -Aocr \cdot FDO \cdot BMrt \cdot RT$$



SAV

Water column oxygen and DOC



$$DOfluxF = DOflux + Aoc \cdot [(1.3 - 0.3 \cdot prN) \cdot G - (1 - \frac{Khr}{DObot+Khr}) \cdot R] \cdot \boldsymbol{BBM}$$

$$DOCfluxF = \frac{Khr}{DObot+Khr} \cdot R \cdot \boldsymbol{BBM}$$

Benthic algae

$$sedDO = -Aocr \cdot \left\{FrtDO \cdot BMrt \cdot \boldsymbol{RT} + FDO \cdot \frac{DO_0}{khr+DO_0} \cdot [(Plf \cdot Fam + MTlf \cdot BMlf) \cdot \boldsymbol{LF} + MTst \cdot BMst \cdot \boldsymbol{ST}]\right\}$$

$$sedDOC = FDO \cdot \frac{khr}{khr+DO_0} \cdot [(Plf \cdot Fam + MTlf \cdot BMlf) \cdot \boldsymbol{LF} + MTst \cdot BMst \cdot \boldsymbol{ST}]$$

Marsh

Water column nitrogen

$$prN = \frac{NH4avl}{khn+NO3avl} \cdot \left(\frac{NO3avl}{(khn+NH4avl)} + \frac{khn}{(NH4avl+NO3avl)}\right)$$

$$NH4fluxF = NH4flux - Anc \cdot (ratNH4 \cdot prN \cdot G - R) \cdot BBM$$

$$NO3fluxF = NO3flux - Anc \cdot ratNO3 \cdot (1 - prN) \cdot G \cdot BBM$$

Benthic algae

$$\frac{dNH_4}{dt} = Anc \cdot FNI \cdot [(BMlf + Plf \cdot Fam) \cdot LF + BMst \cdot ST] - Anc \cdot (1 - FNsed) \cdot NPRsav \cdot Plf \cdot LF$$

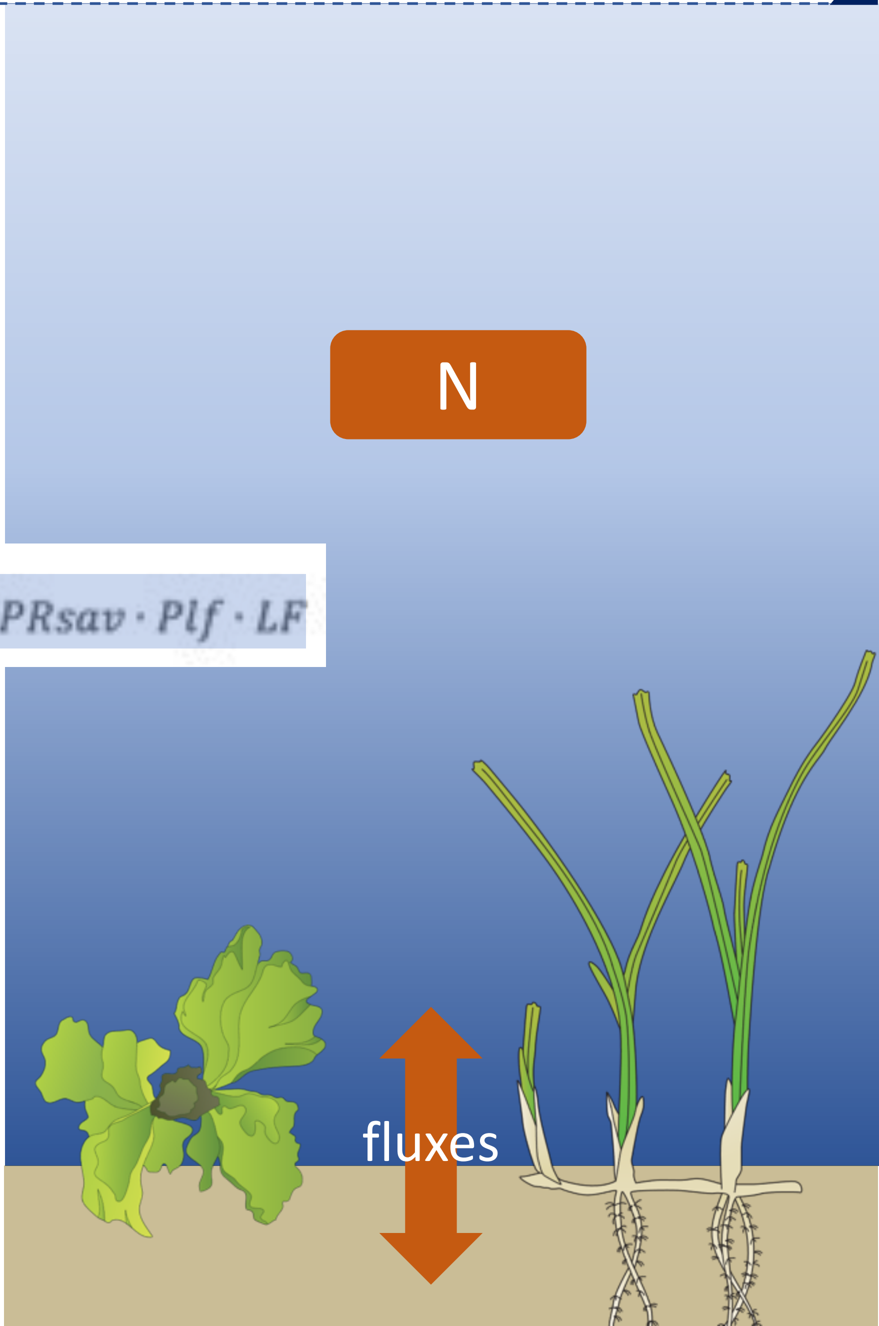
$$\frac{dNO_3}{dt} = -Anc \cdot (1 - FNsed) \cdot (1 - NPRsav) \cdot Plf \cdot LF$$

$$\frac{dDON}{dt} = Anc \cdot FND \cdot [(BMlf + Plf \cdot Fam) \cdot LF + BMst \cdot ST]$$

$$\frac{dLPON}{dt} = Anc \cdot FNLP \cdot [(BMlf + Plf \cdot Fam) \cdot LF + BMst \cdot ST]$$

$$\frac{dRPON}{dt} = Anc \cdot FNRP \cdot [(BMlf + Plf \cdot Fam) \cdot LF + BMst \cdot ST]$$

SAV



Water column phosphate

$$PO4fluxF = PO4flux - Apc \cdot (ratPO4 \cdot G - R) \cdot \boldsymbol{BBM}$$

Benthic algae

$$FPsed = \frac{Psed}{Psed + \frac{KHPs}{KHPw} PO4}$$

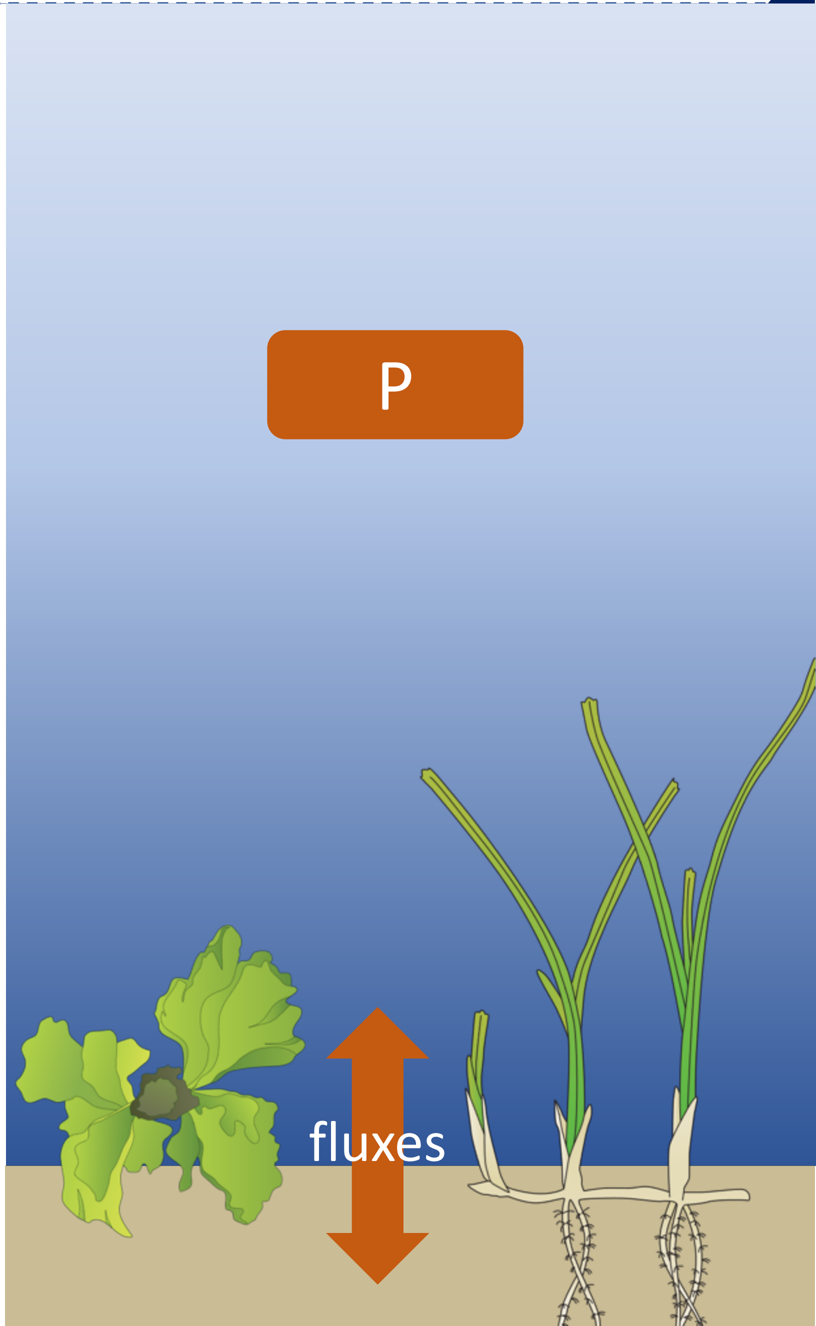
$$\frac{dPO_4}{dt} = Apc \cdot FPI \cdot [(BMlf + Plf \cdot Fam) \cdot LF + BMst \cdot ST] - Apc \cdot (1 - FPsed) \cdot Plf \cdot LF$$

$$\frac{dDOP}{dt} = Apc \cdot FPD \cdot [(BMlf + Plf \cdot Fam) \cdot LF + BMst \cdot ST]$$

$$\frac{dLPOP}{dt} = Apc \cdot FPLP \cdot [(BMlf + Plf \cdot Fam) \cdot LF + BMst \cdot ST]$$

$$\frac{dRPOP}{dt} = Apc \cdot FPRP \cdot [(BMlf + Plf \cdot Fam) \cdot LF + BMst \cdot ST]$$

SAV



Interactions with the sediment

Sediment inorganic nutrients

$$NH4fluxS = -Anc \cdot (1 - ratNH4) \cdot prN \cdot G \cdot \boldsymbol{BBM} \cdot \Delta t/HSED$$

$$NO3fluxS = -Anc \cdot (1 - ratNO3) \cdot (1 - prN) \cdot G \cdot \boldsymbol{BBM} \cdot \Delta t/HSED$$

$$PO4fluxS = -Apc \cdot (1 - ratPO4) \cdot G \cdot \boldsymbol{BBM} \cdot \Delta t/HSED$$

Benthic algae

$$lfNH4sav = -Anc \cdot FNsedsav \cdot Plf \cdot LF$$

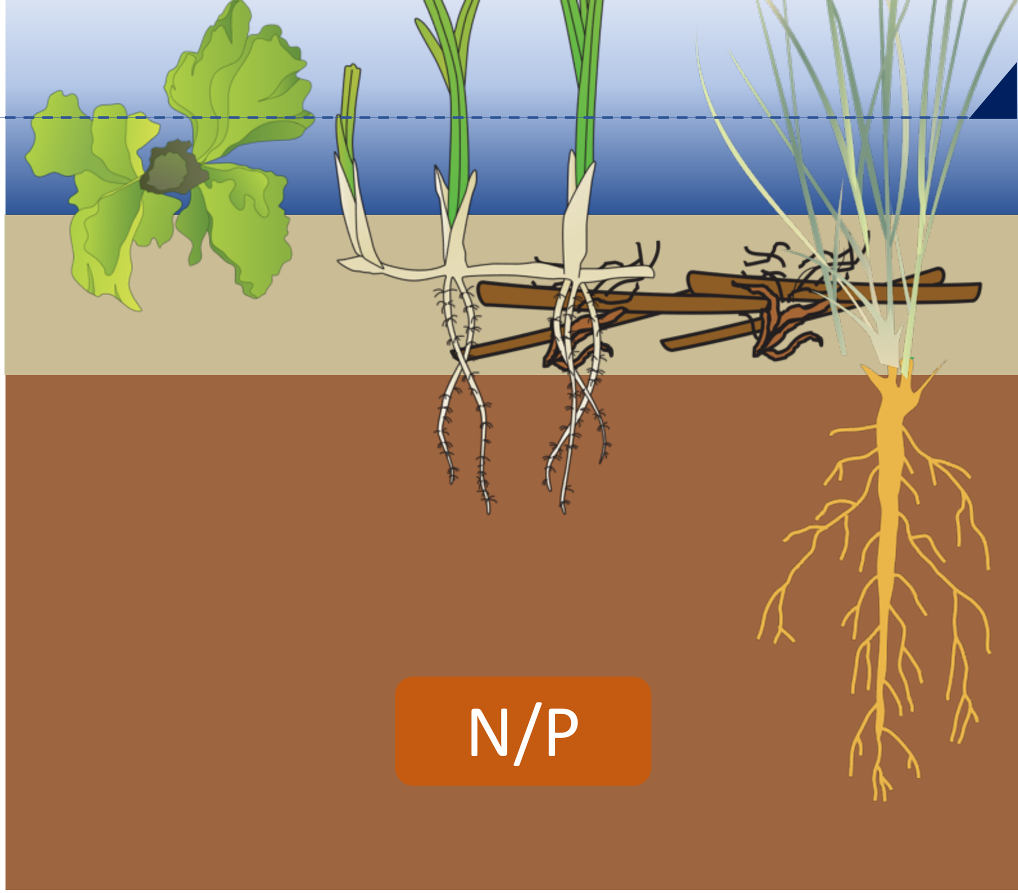
$$lfPO4sav = -Apc \cdot FPsedsav \cdot Plf \cdot LF$$

SAV

$$uptakeNH4 = -Anc \cdot Plf \cdot \boldsymbol{LF}$$

$$uptakePO4 = -Apc \cdot Plf \cdot \boldsymbol{LF}$$

marsh



Sediment POM

$$PONfluxF = Anc \cdot PR \cdot \boldsymbol{BBM}$$

$$POPfluxF = Apc \cdot PR \cdot \boldsymbol{BBM}$$

$$POCfluxF = PR \cdot \boldsymbol{BBM}$$

Benthic algae

$$rtponsav = Anc \cdot BMrt \cdot RT$$

$$rtpopsav = Apc \cdot BMrt \cdot RT$$

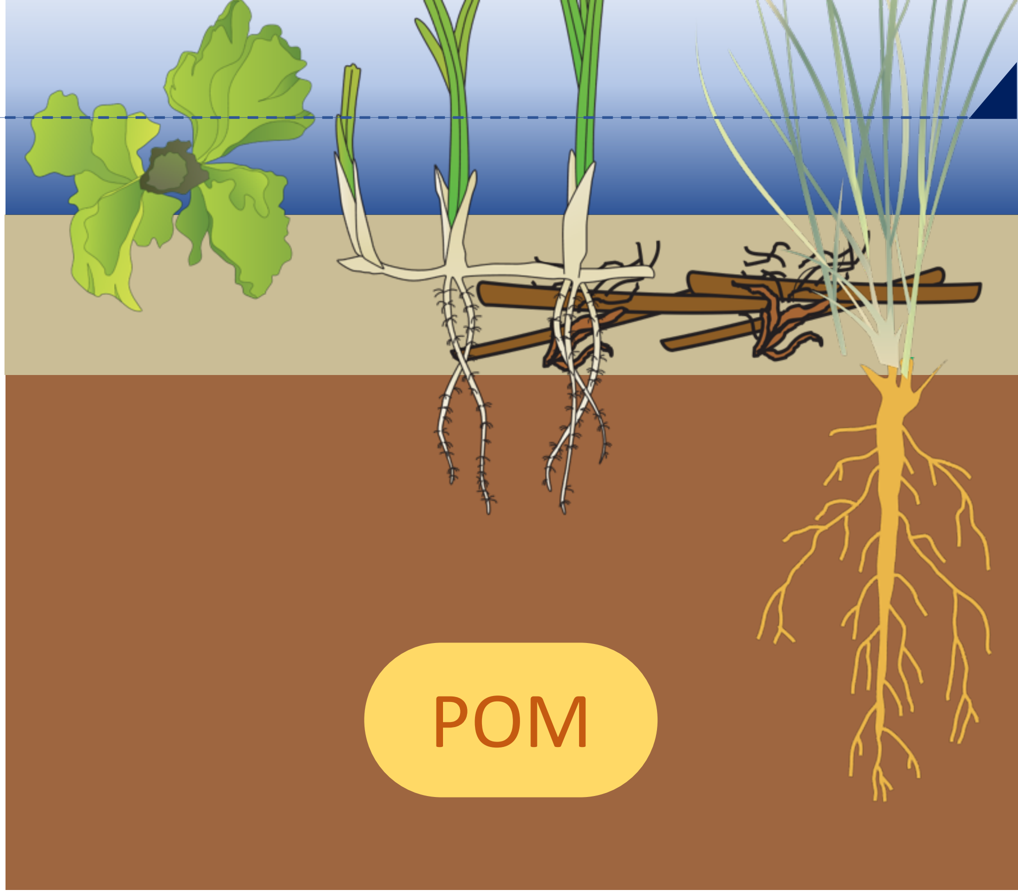
$$rtpocsav = (1 - FDO) \cdot BMrt \cdot RT$$

$$\frac{dPON(1{:}3)}{dt} = trtponsav \cdot frnsav(1{:}3)$$

$$\frac{dPOP(1{:}3)}{dt} = trtpopsav \cdot frpsav(1{:}3)$$

$$\frac{dPOC(1{:}3)}{dt} = trtpocsav \cdot frcsav(1{:}3)$$

SAV



$$setPOC = (1 - FDO) \cdot [(Plf \cdot Fam + MTlf \cdot BMlf) \cdot \boldsymbol{LF} + MTst \cdot BMst \cdot \boldsymbol{ST}] + (1 - FrtDO) \cdot BMrt \cdot \boldsymbol{RT}$$

$$setPON = Anc \cdot [(Plf \cdot Fam + MTlf \cdot BMlf) \cdot \boldsymbol{LF} + MTst \cdot BMst \cdot \boldsymbol{ST} + BMrt \cdot \boldsymbol{RT}]$$

$$setPOP = Apc \cdot [(Plf \cdot Fam + MTlf \cdot BMlf) \cdot \boldsymbol{LF} + MTst \cdot BMst \cdot \boldsymbol{ST} + BMrt \cdot \boldsymbol{RT}]$$

$$\frac{dPOC(1{:}3)}{dt} = setPOC \cdot frcveg(1{:}3)$$

$$\frac{dPON(1{:}3)}{dt} = setPON \cdot frnveg(1{:}3)$$

$$\frac{dPOP(1{:}3)}{dt} = setPOP \cdot frpveg(1{:}3)$$

Marsh

Outline

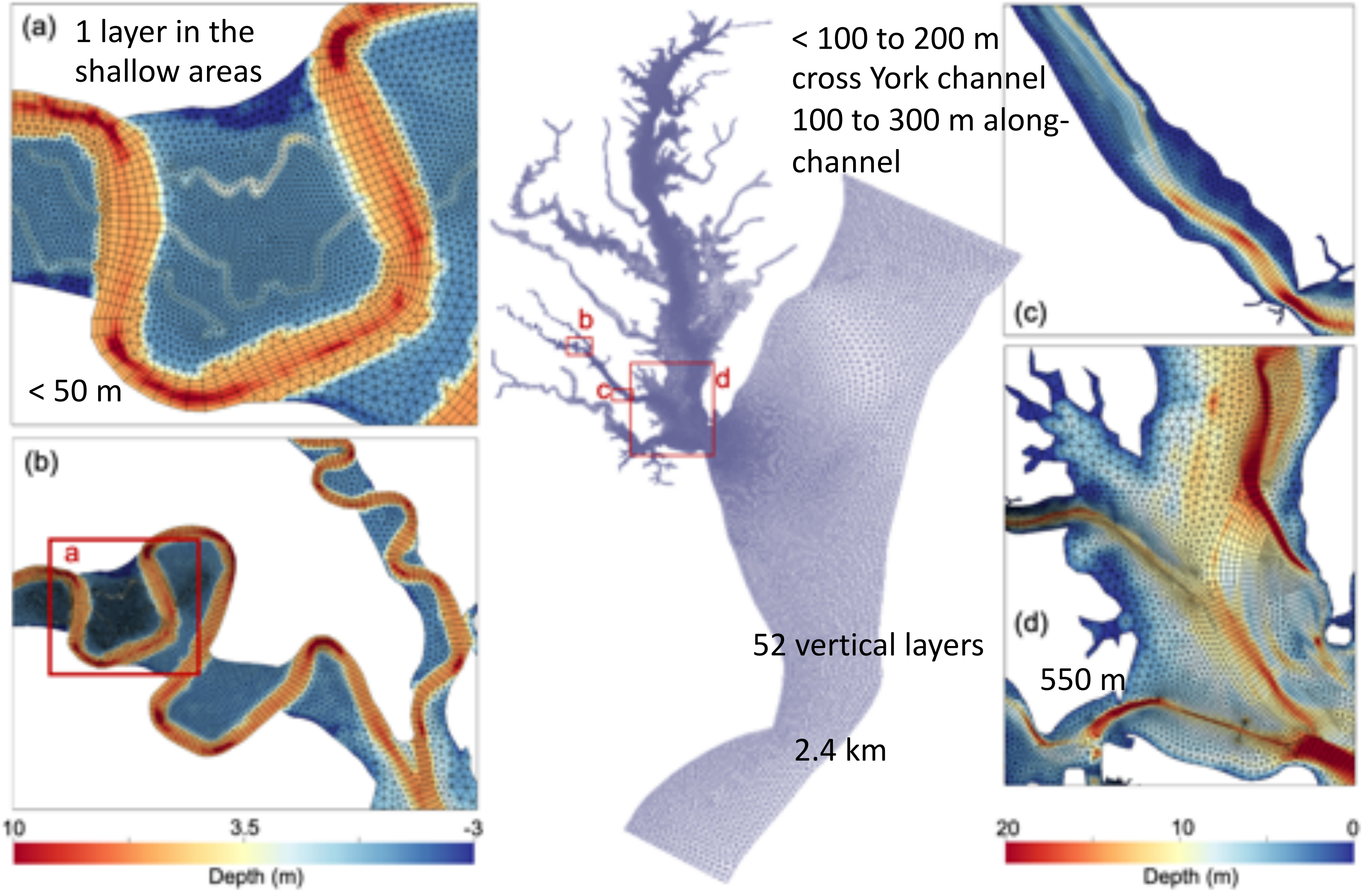
Review of the shallow habitat modules in SCHISM

Implementation in the York and James Rivers

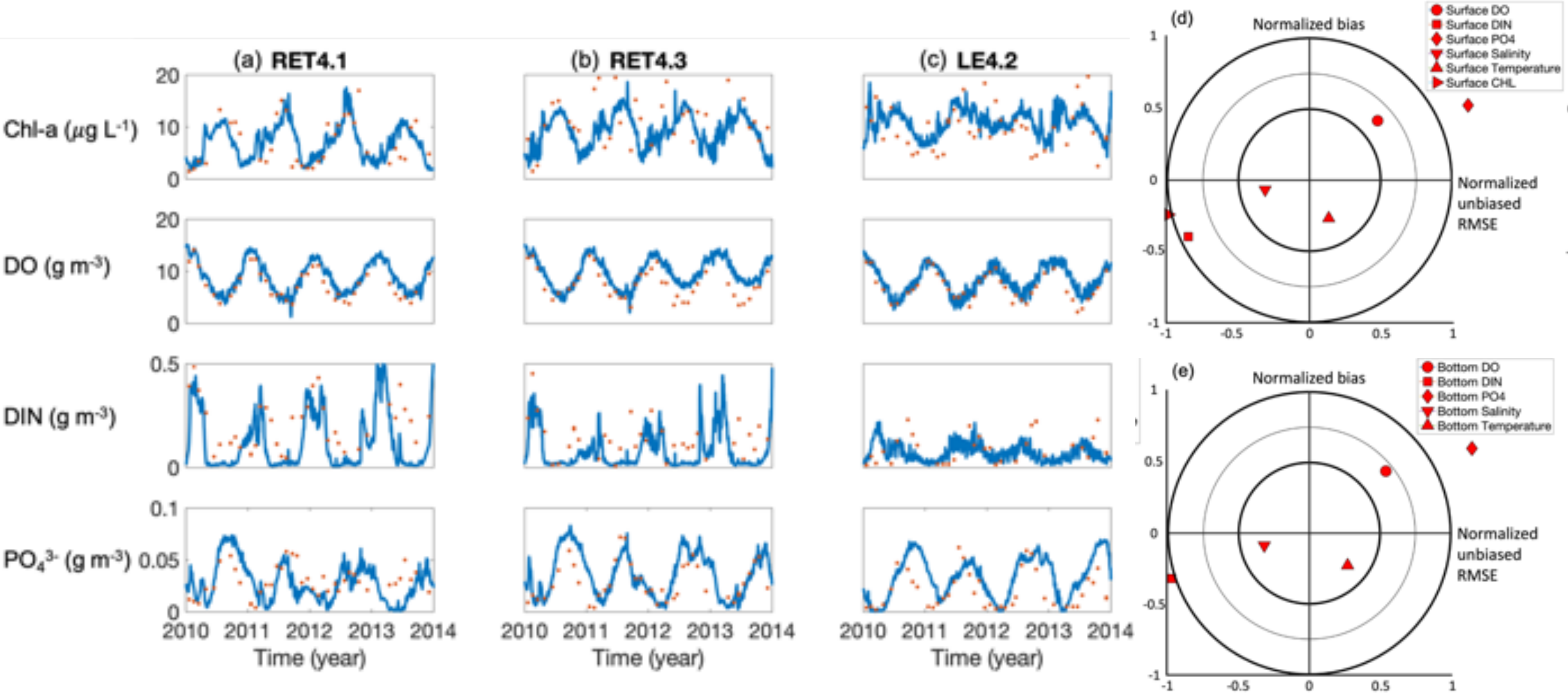
Preliminary results

Discussions and plans

Model implementation in the York River



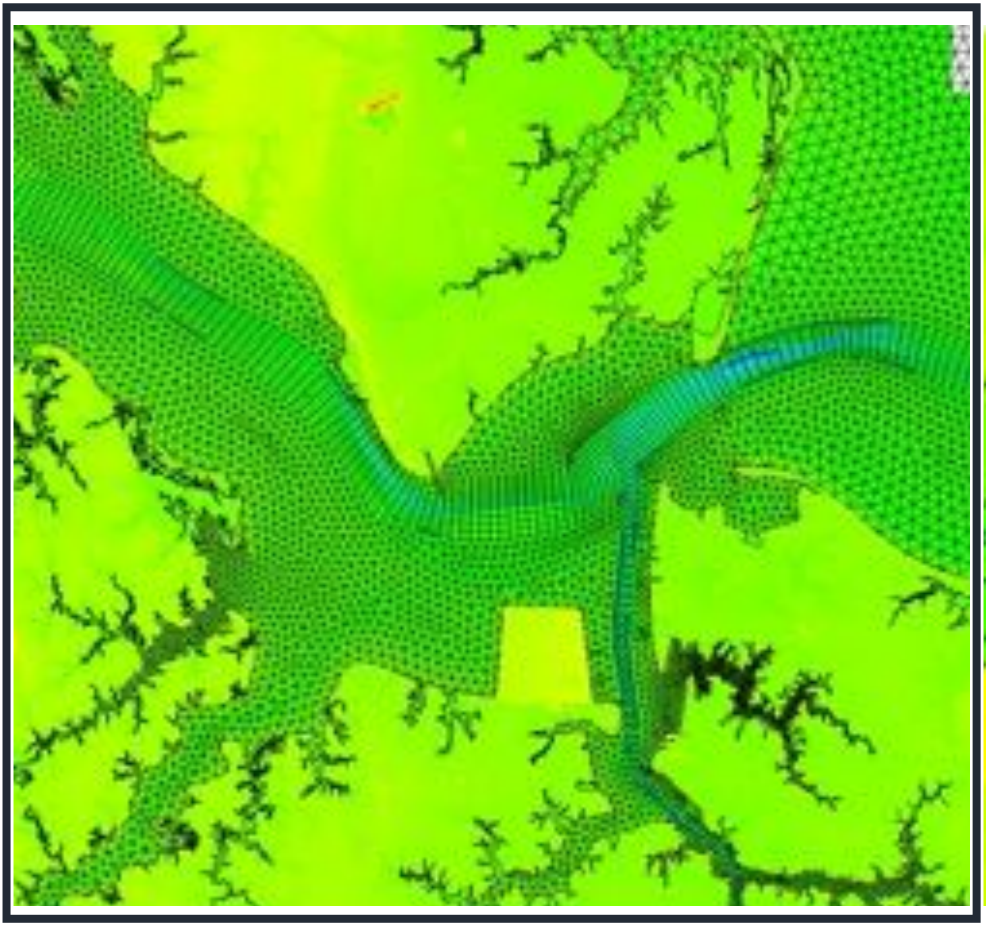
Model assessment in the York River

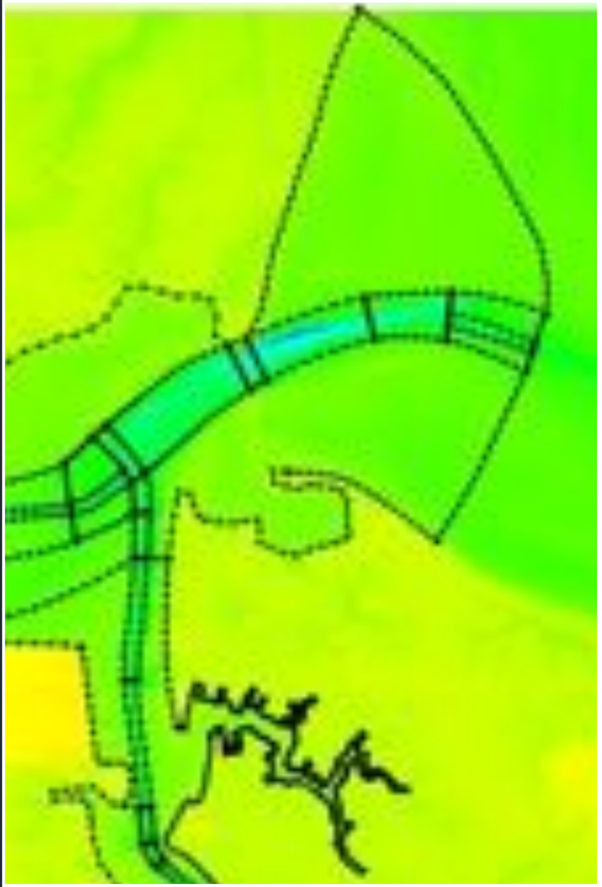


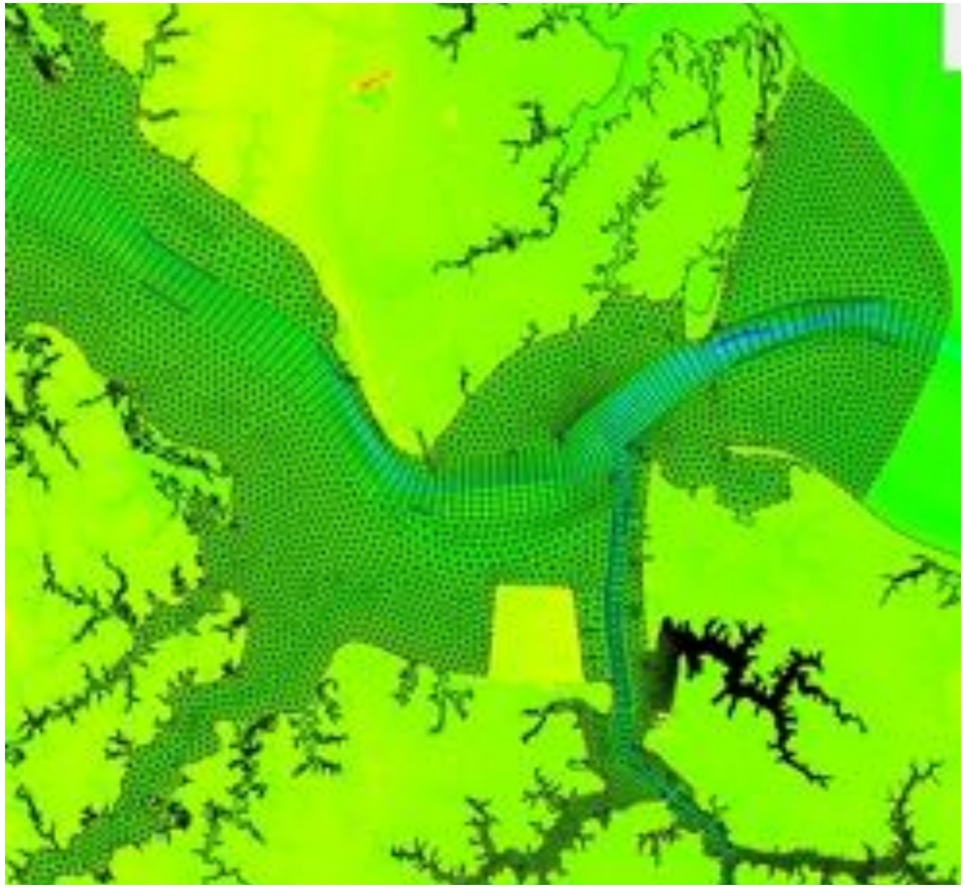
Model Implementation in the James River

Phase I: James River connected to the whole Bay grid

Phase II: single James River grid







- Unchanged channel arc's
- Refined shoals and sub-tributaries

- #63 boundary nodes

- #17,305 nodes, #25955 elements (32% of phase I)
- Maximum #32 vertical layers (62% of phase I)

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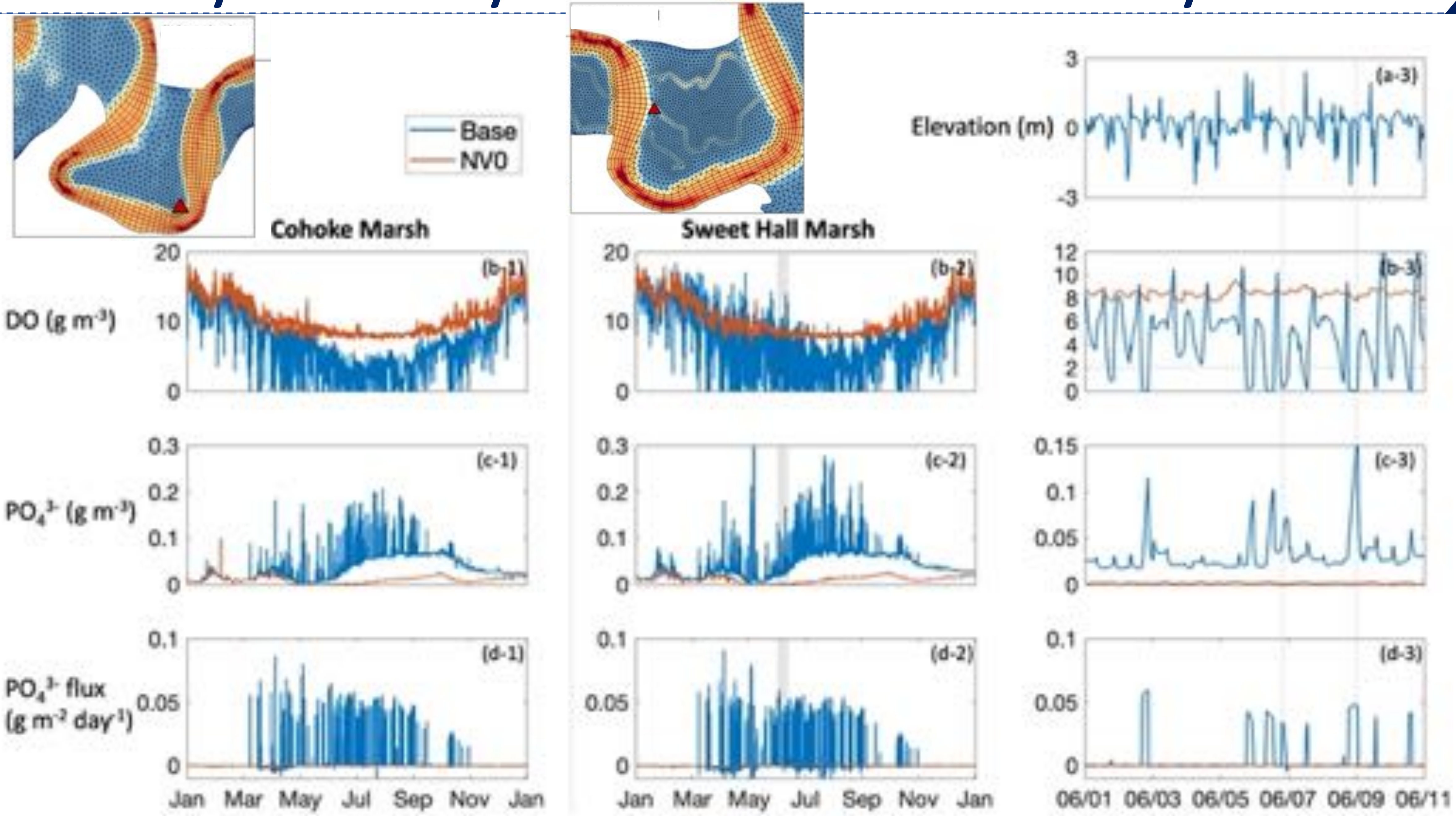
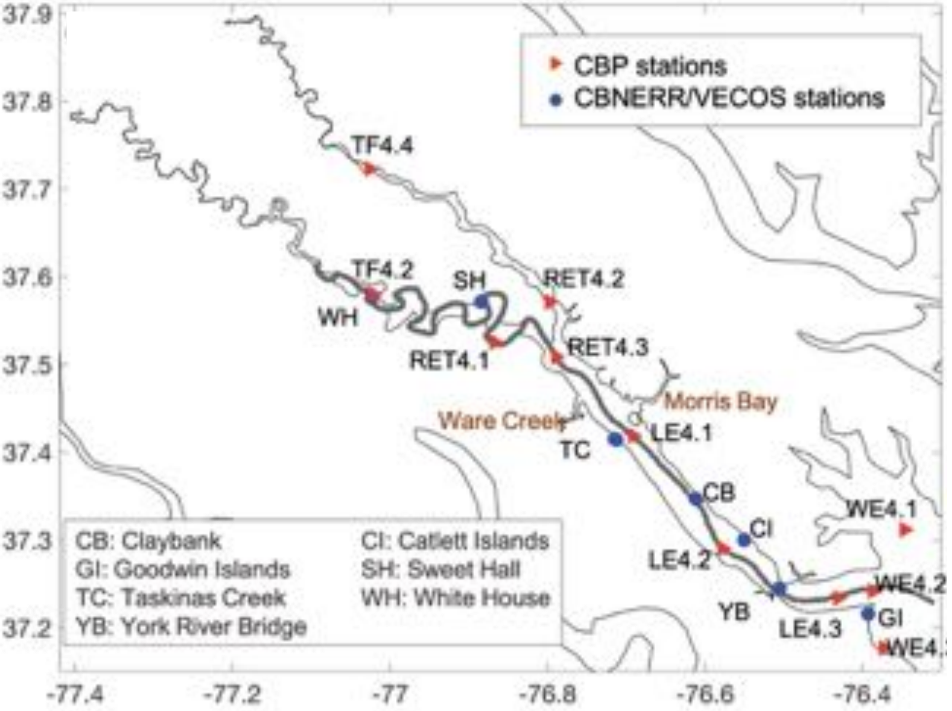
- Discussions and plans

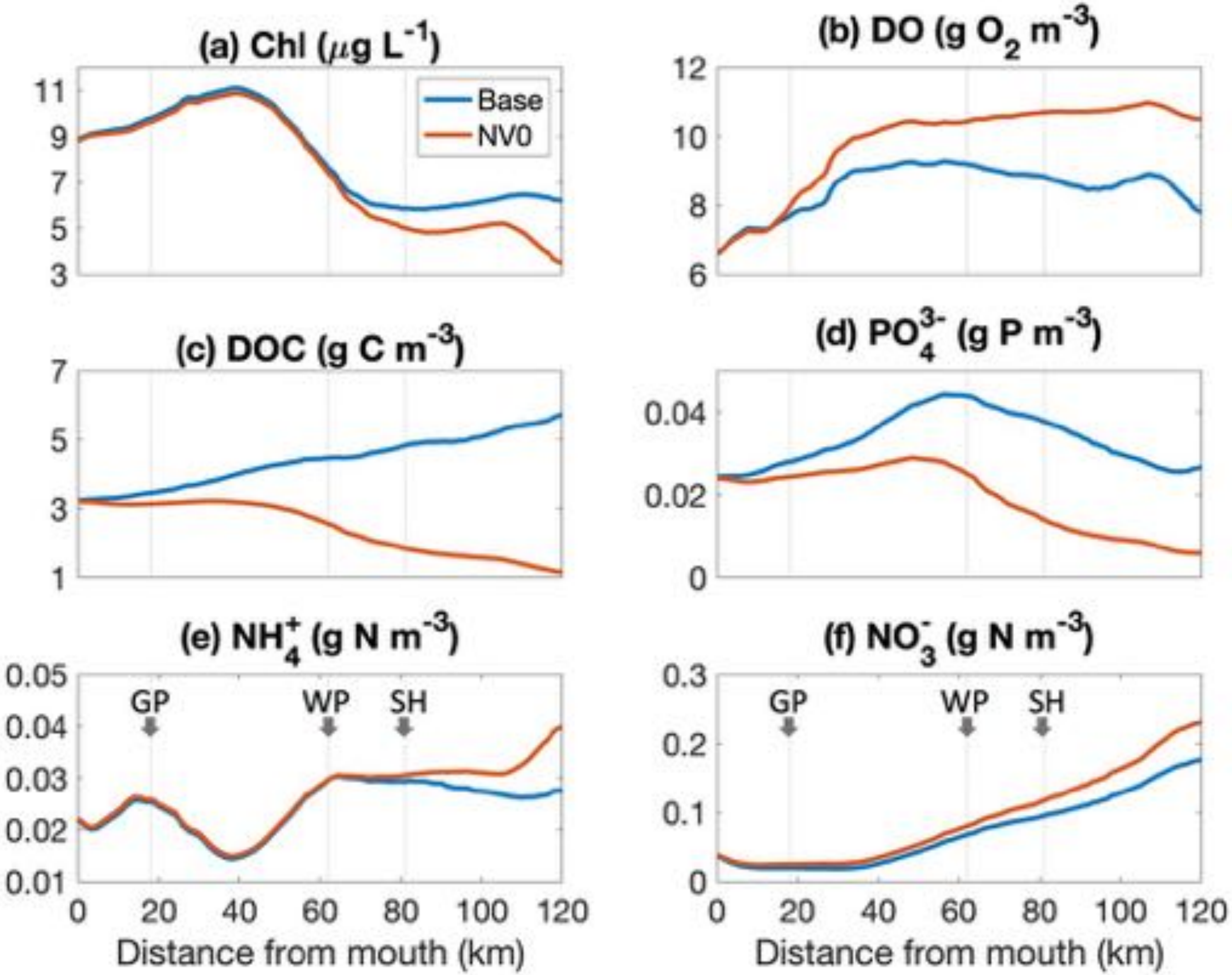
Tidal marshes

Diurnal DO cycle driven by marsh in the York River Estuary



Marsh biological affects in the York River Estuary



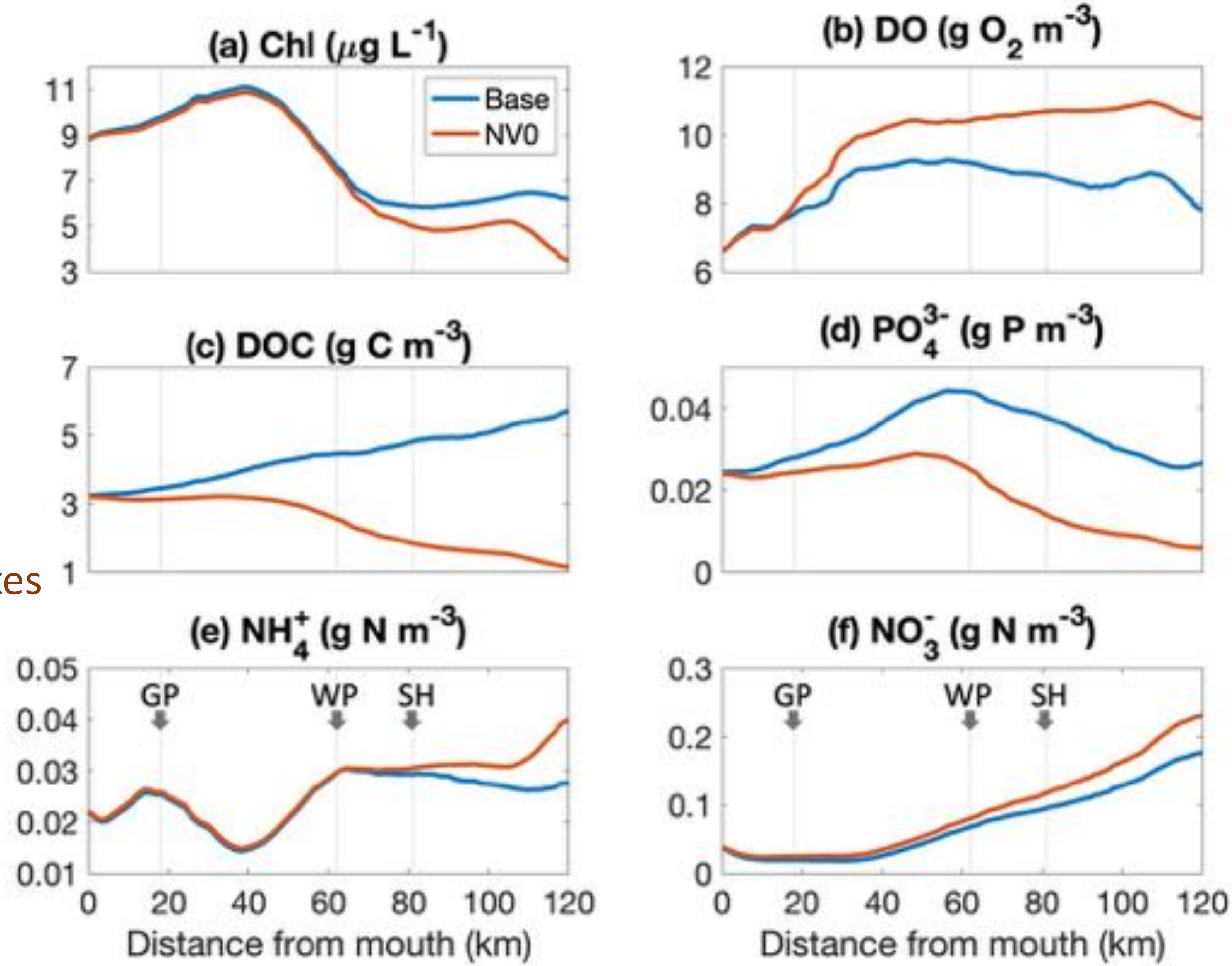


Marsh biological affects in the York River Estuary

- Slightly affect phytoplankton production, but phytoplankton is mainly controlled by flushing and light availability in the York River

- Diel DO, low-DO events
- More DOC
- More phosphate ⬅ sediment fluxes
- Less nitrogen

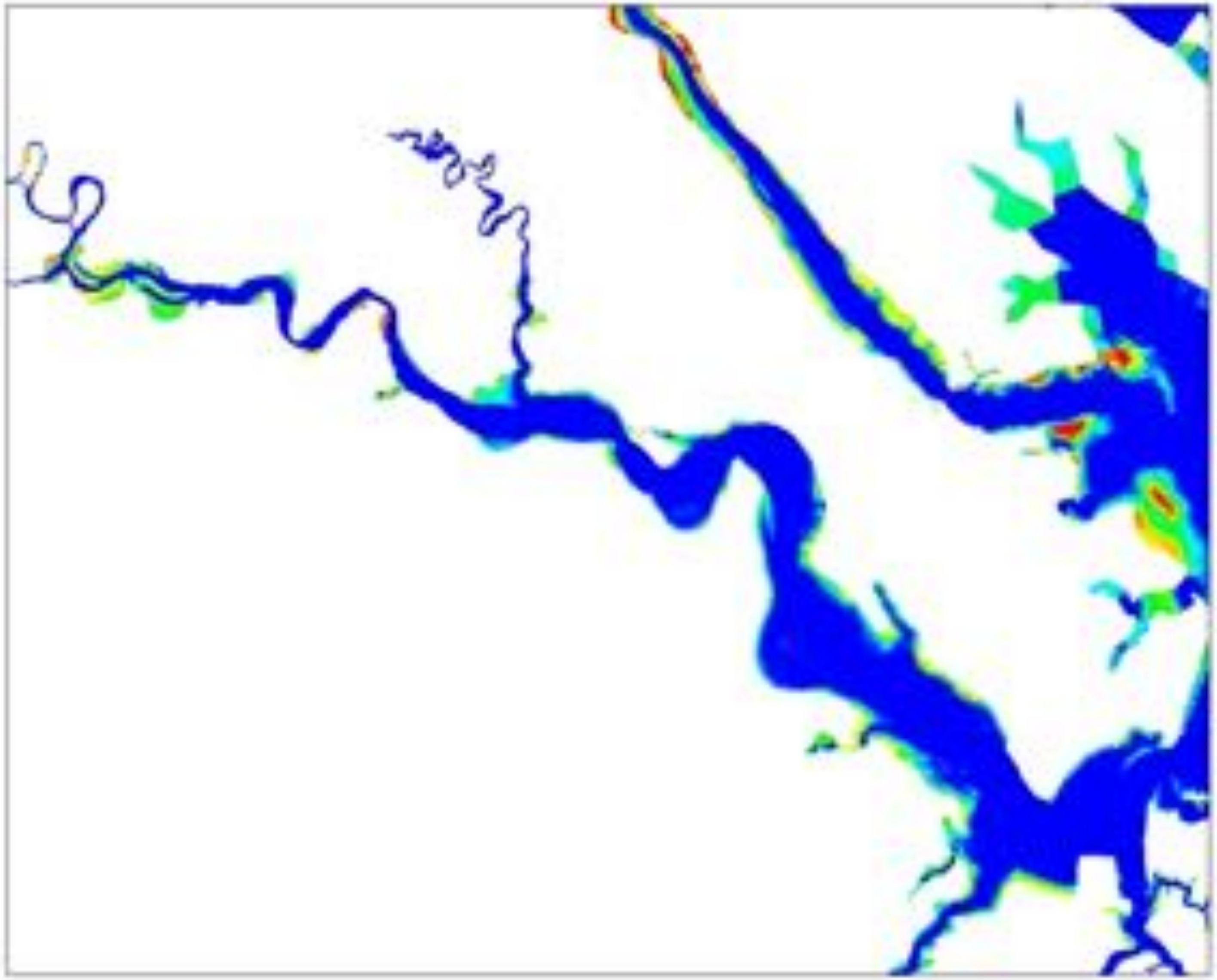
⬆ enhanced denitrification process



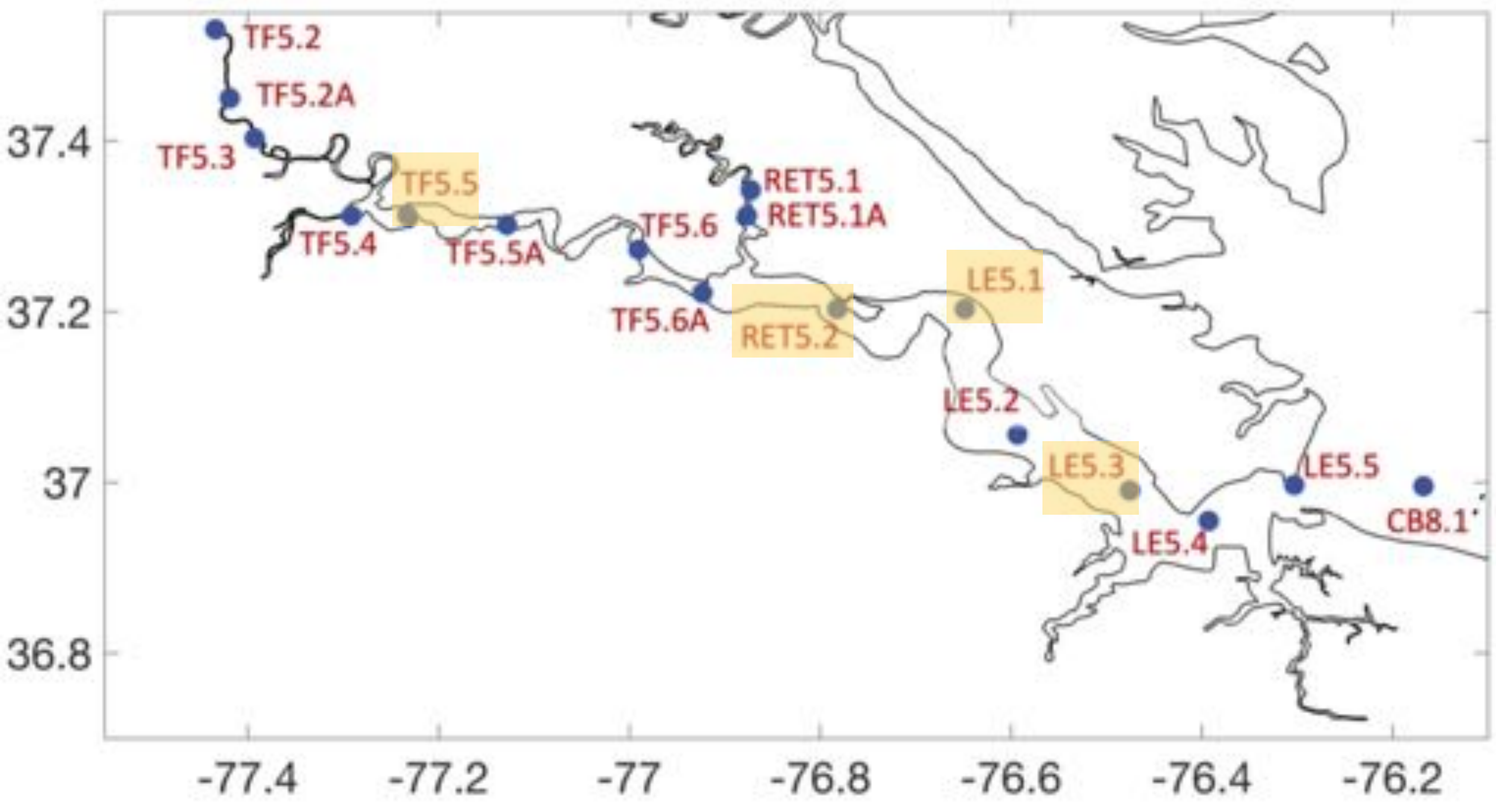
Benthic algae

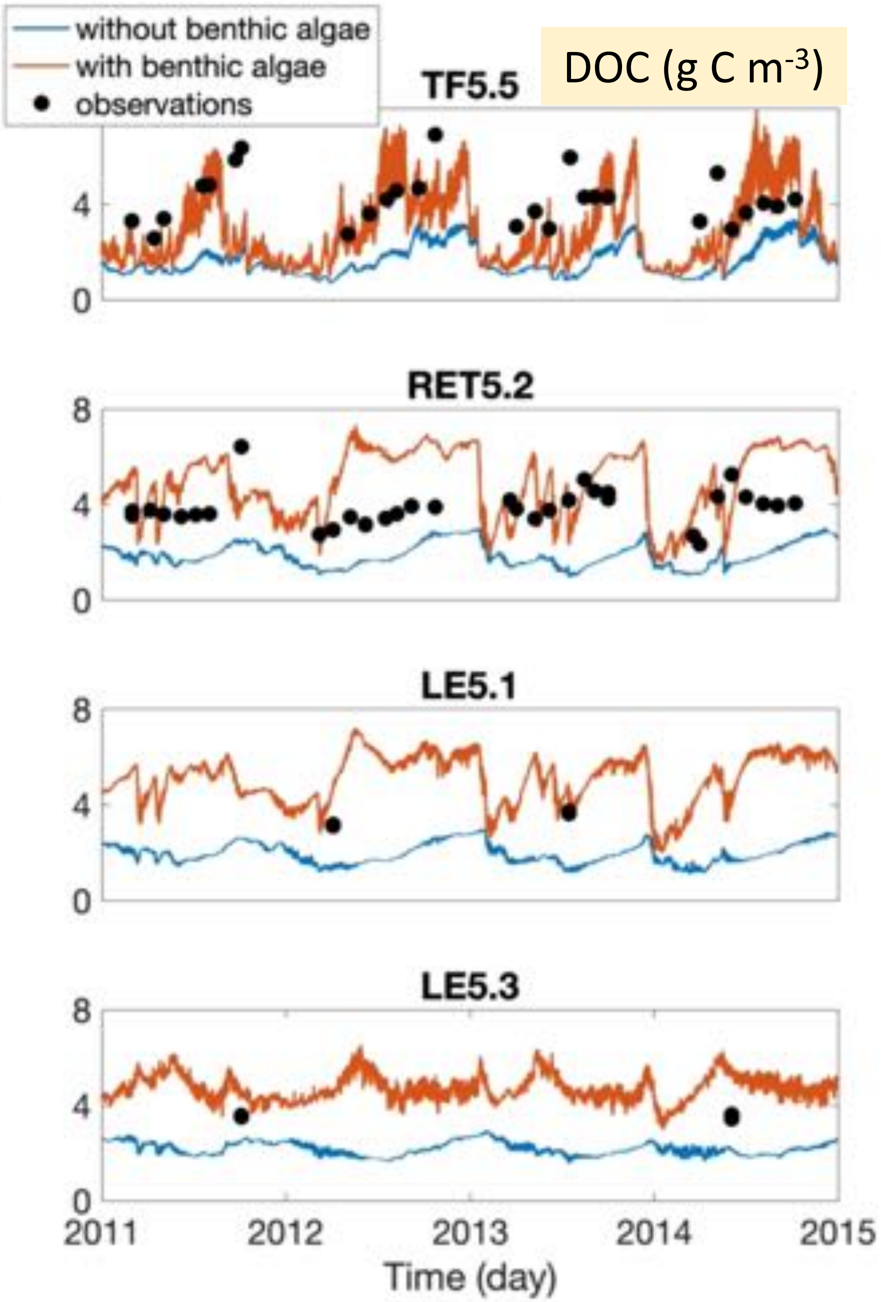
Simulated benthic algae in the James River

- Initialize everywhere
- Reasonable distributions



Impacts from the benthic algae in the James River

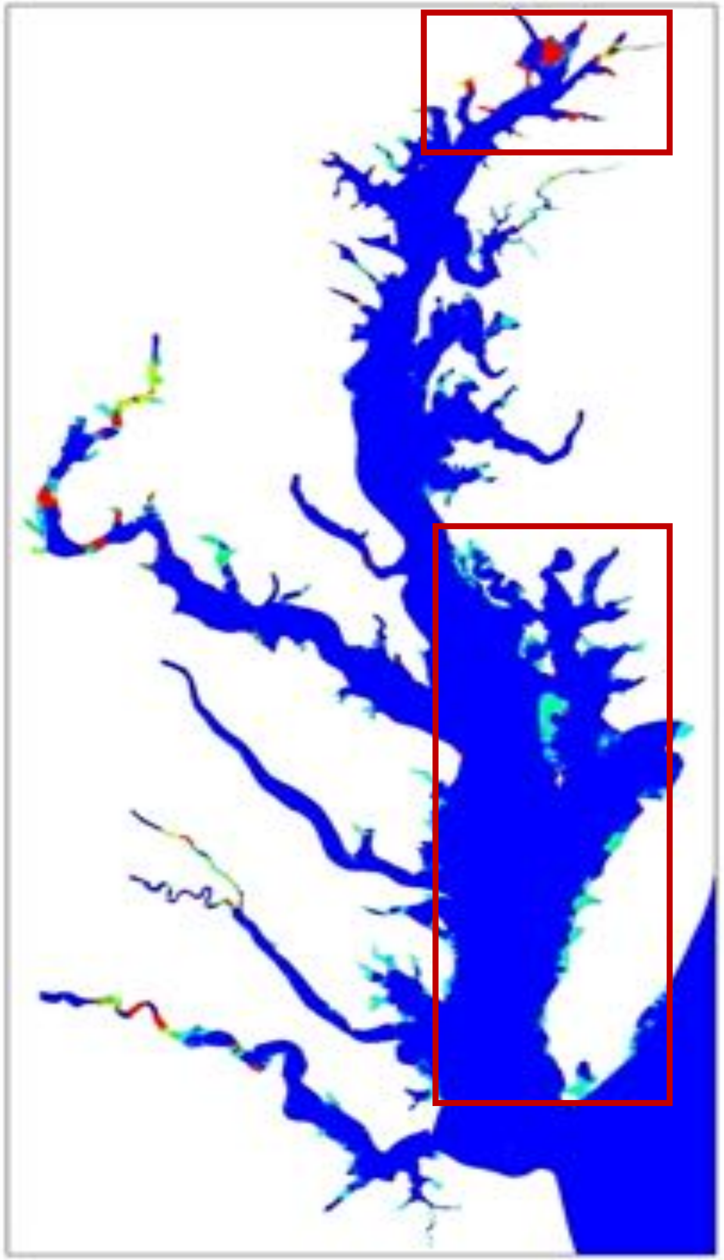


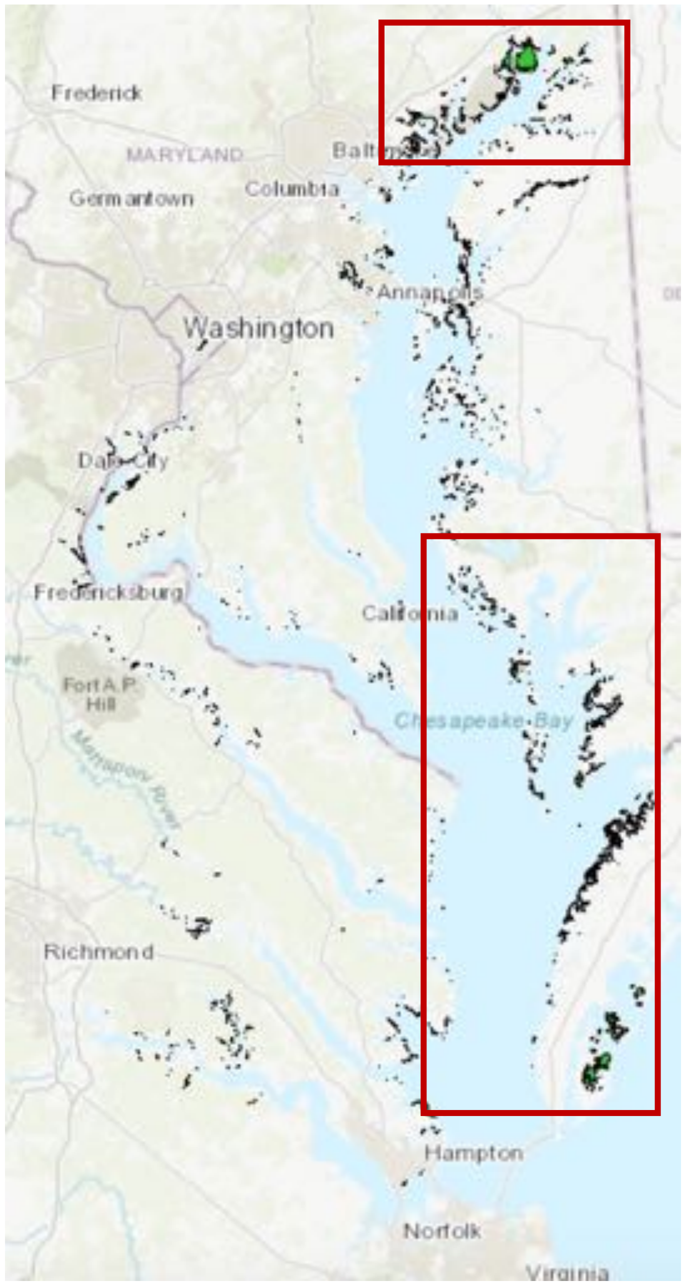


SAV

Simulated SAV in the Chesapeake Bay

- Initialize everywhere
- Reasonable distributions to the general observations
- Need to go to details with refined and upgraded MBM





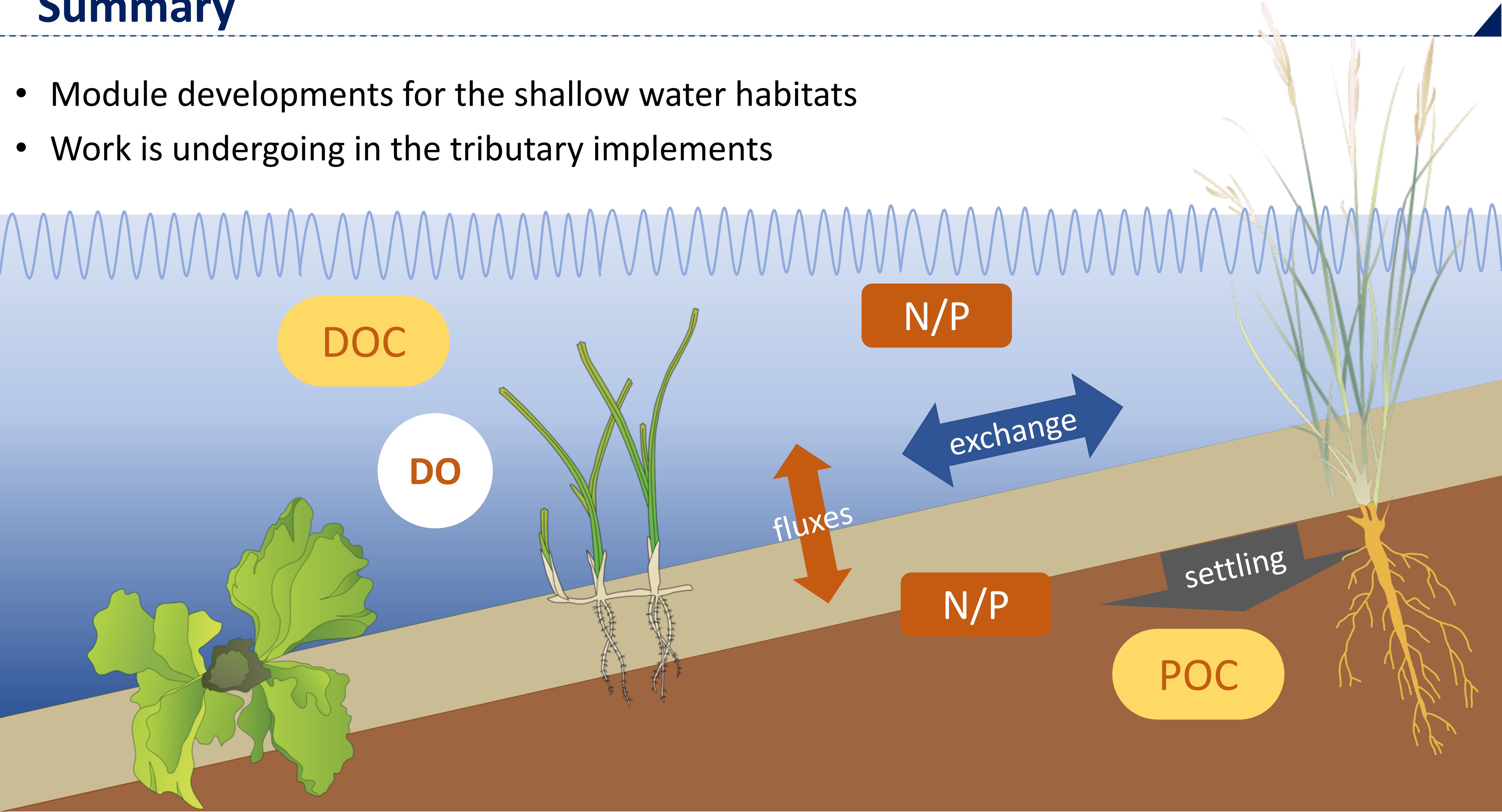
Current limitations and plans

- The habitats of benthic algae does not overlap the tidal marshes: for the convenience to conduct marsh-relevant scenarios
- Data availability to validate biomass and nutrient fluxes

- Further test and include options in the model development

Summary

- Module developments for the shallow water habitats
- Work is undergoing in the tributary implements



Questions?

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