Coastal biogeochemistry

OCN 623

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Coastal biogeochemistry

Learning objectives:

A. Apply the concepts of organic matter production, remineralization and early diagenesis to eutrophication and nutrient cycling in coastal areas
B. Understand how estuaries act as buffer zones between land and the open ocean
C. Relate the biogeochemistry of coastal areas to their physical properties
D. Learn about the stresses imposed to coastal areas by human activity

Coastal biogeochemistry

Outline

1. Importance of coastal environments

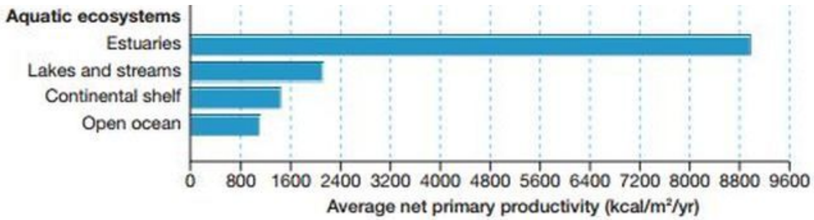
   Types of coastal environments:

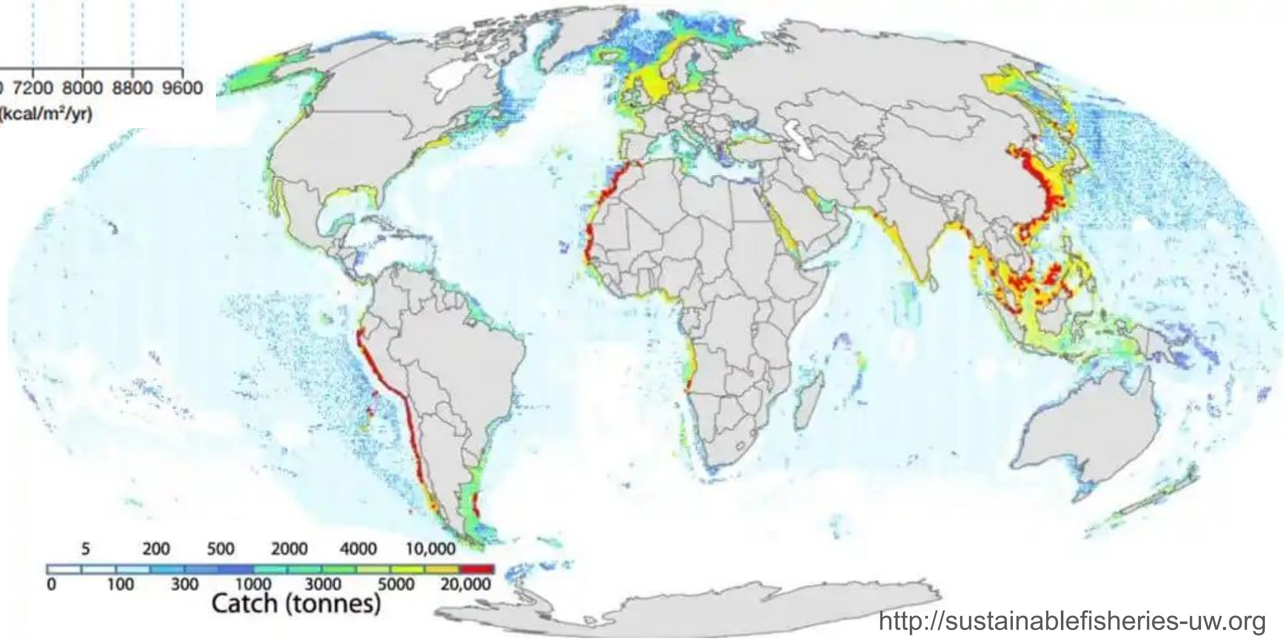
2. Coastal upwelling zones
3. Continental shelves
4. Estuaries

5. Current changes to coastal environments

1. Productive areas

Coastal environments are responsible for nearly 30% of the total net oceanic primary production and nearly 90% of the global fish catch

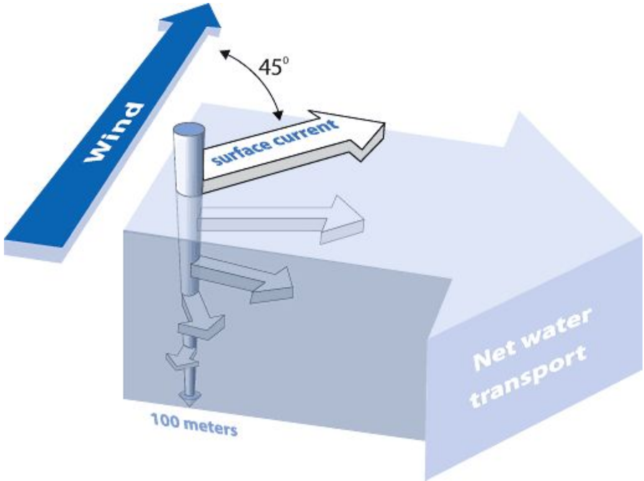




http://sustainablefisheries-uw.org

2. Upwelling along coasts

Ekman transport can drive upwelling



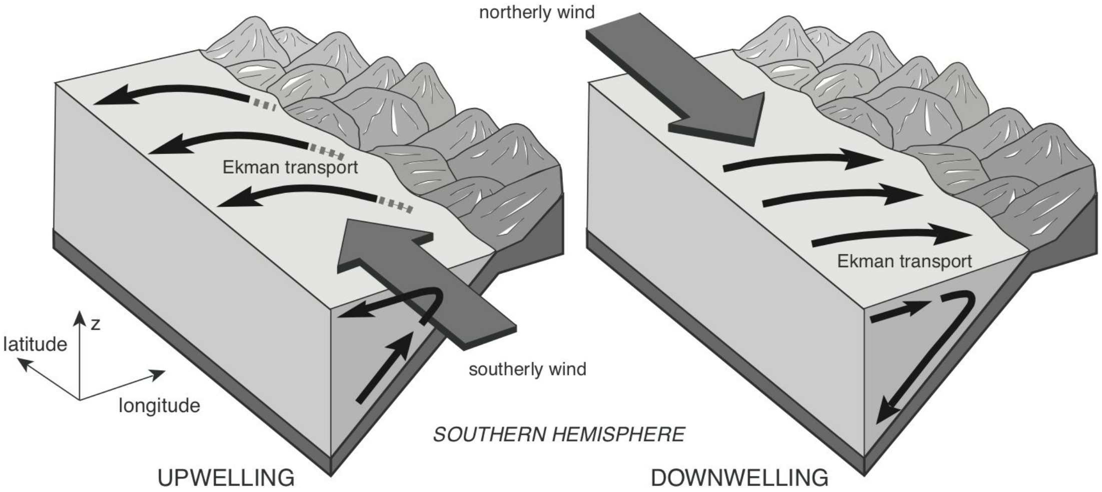
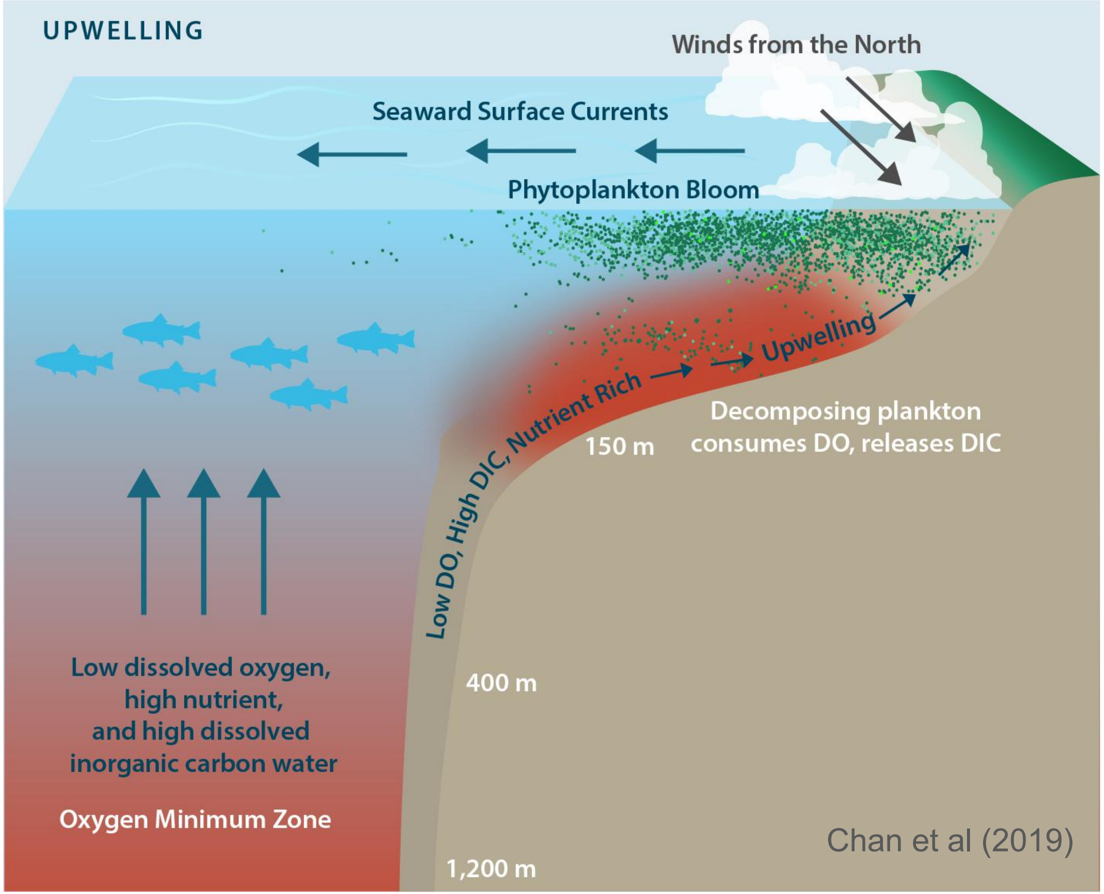


FIGURE 2.2.6: Ekman transport and associated upwelling and downwelling resulting from wind blowing parallel to shore [*Thurman*, 1990]

2. Upwelling along coasts

In coastal areas, nutrient cycling is *accelerated*

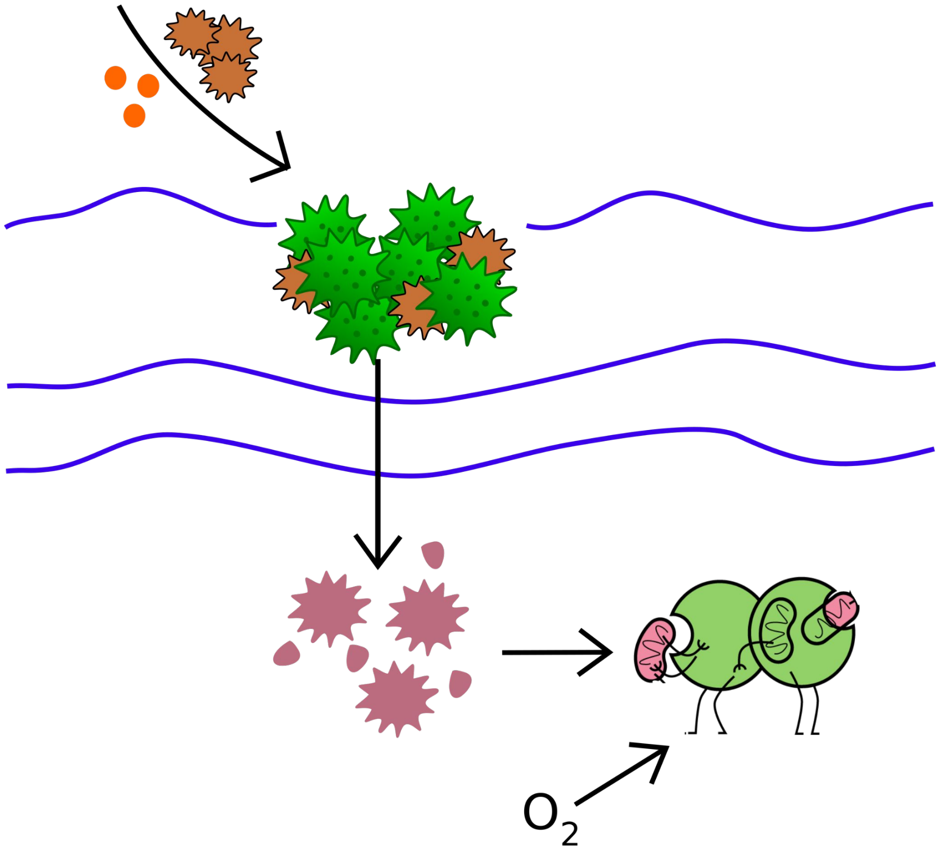
- Upwelling of low oxygen and nutrient rich waters
- High productivity and hence fisheries
- Further oxygen depletion through eutrophication



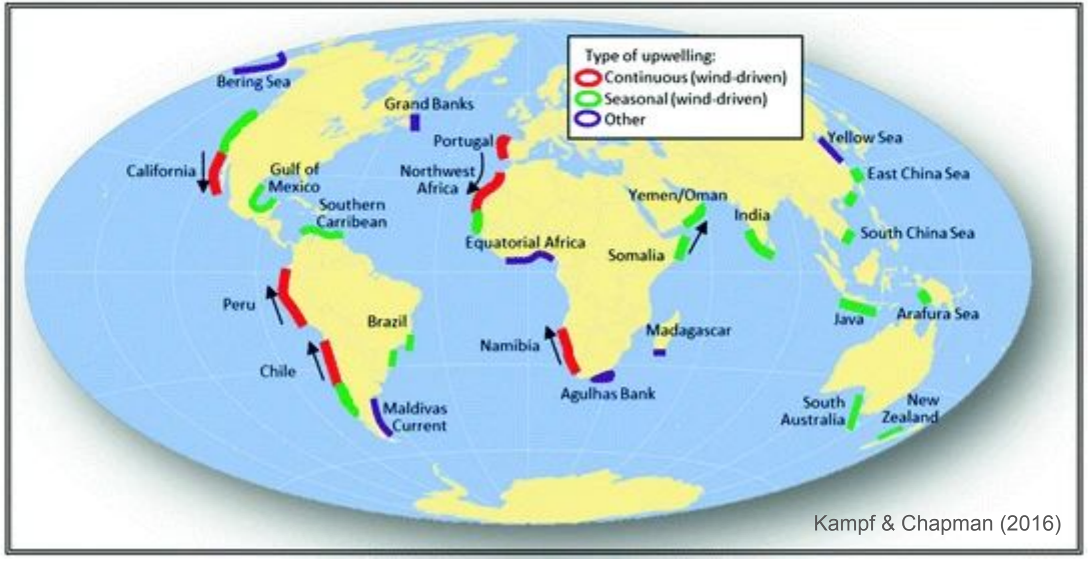
Chan et al (2019)

Eutrophication

1. Nutrient and organic matter input from land
2. Organic matter production
3. Settling of organic matter towards depth
4. Decomposition by aerobic bacteria (oxygen sink)



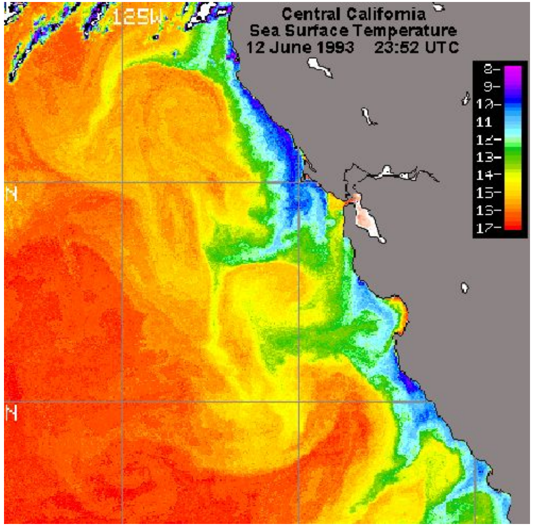
2. Upwelling along coasts



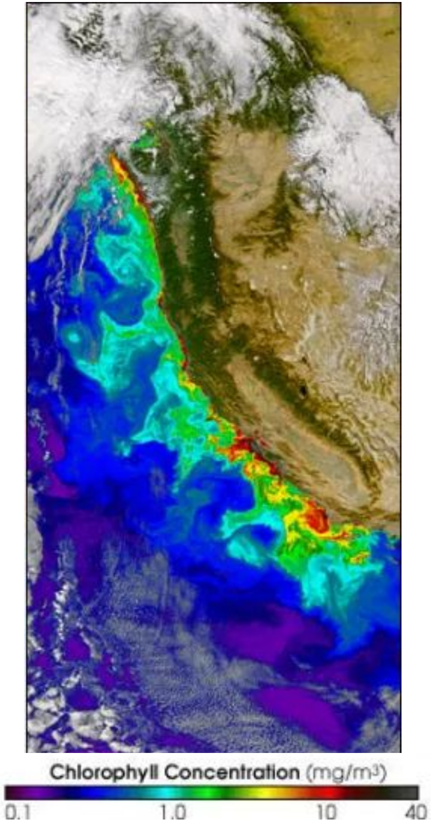
Kampf & Chapman (2016)

2. Upwelling along coasts

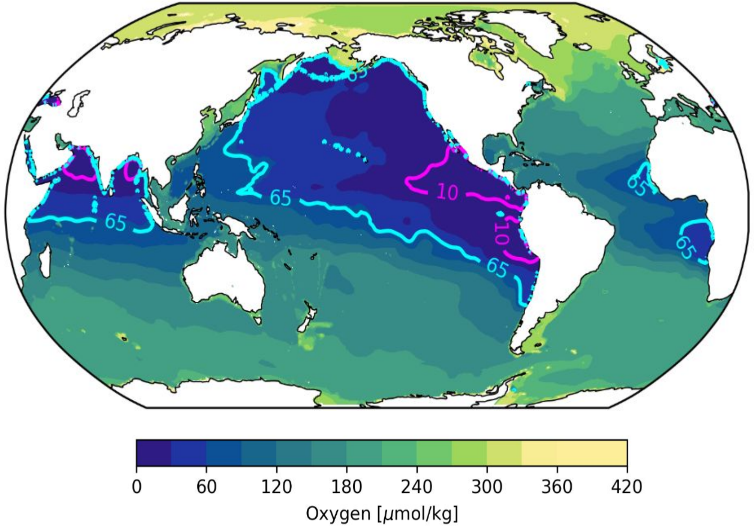
Surface temperature



Productivity

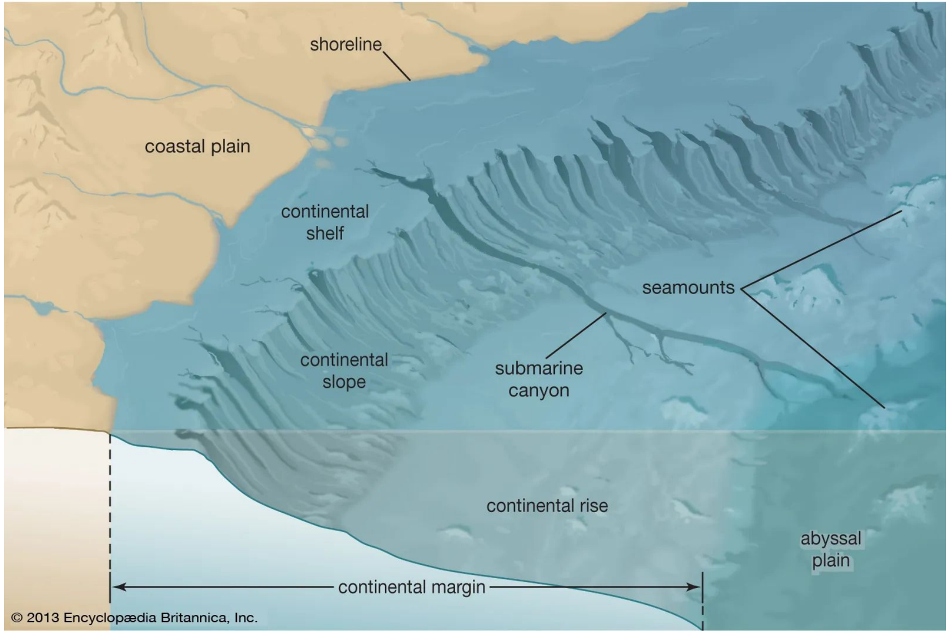


Oxygen minimum zones



Oxygen concentration at the minimum oxygen level. Data from the World Ocean Circulation Experiment. Cyan line: hypoxia. Pink line: anoxia.

3. Continental shelves



https://www.britannica.com/science/continental-shelf

Charaterized by large seasonal variations

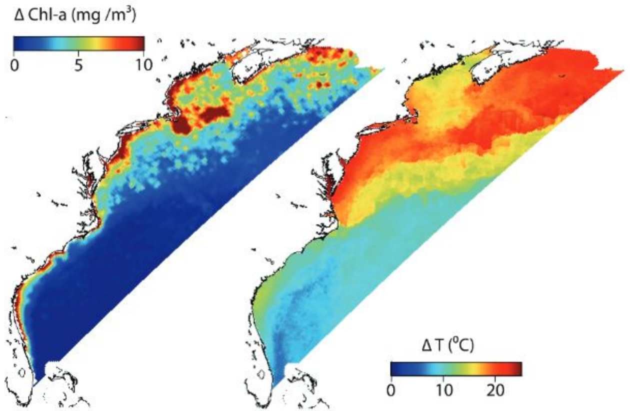


Fig. 1. Annual amplitude of surface chlorophyll concentration from the SeaWiFS satellite (left) and of sea surface temperature from AVHRR (right), calculated as maximum monthly mean minus minimum monthly mean, for the Northeastern North Atlantic shelves and adjacent deep ocean. The annual amplitude in chlorophyll is largest in coastal waters of the Middle Atlantic Bight (MAB), on Georges Bank, the Gulf of Maine and the Scotian Shelf. The annual amplitude in sea surface temperature is largest in coastal regions of the MAB and on the Scotian Shelf; tidal mixing in the Bay of Fundy (northern Gulf of Maine) and on Georges Bank lead to comparatively smaller seasonal temperature differences there.

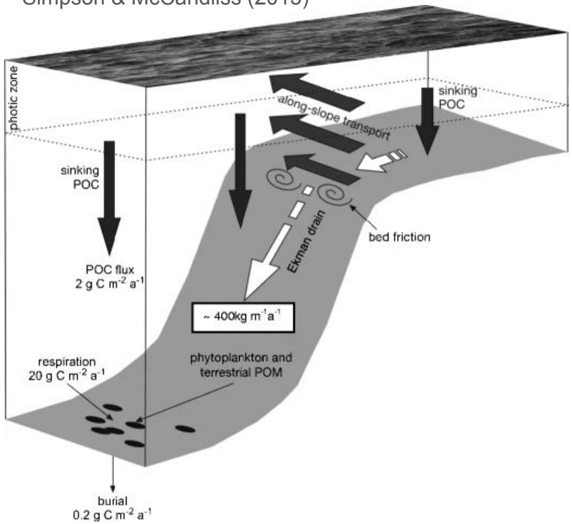
Fennel (2010)

3. Continental shelves

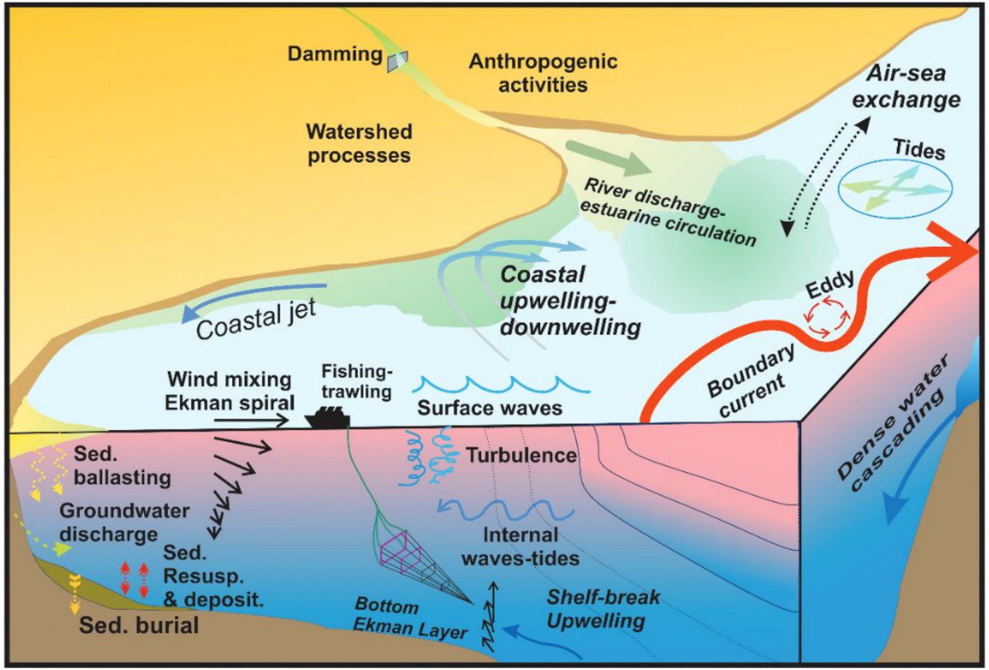
- Nutrient sources:
  - From land (river export)
  - Upwelling
  - Remineralization

High productivity

Simpson & McCandliss (2013)



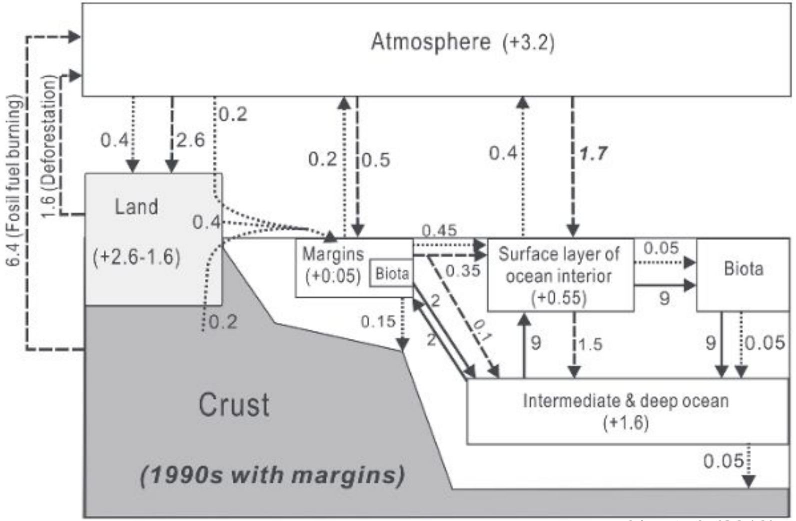
- Cross-shelf exchanges:
  - Interaction with boundary currents
  - Upwelling (> river input)
  - Eddy shedding and filaments
  - Ekman drain



Liu et al. (2010)

3. Continental shelves

- Most global burial occurs on shelves
- Shelves absorb more CO_2 than the open ocean (in most areas)



Liu et al. (2010)

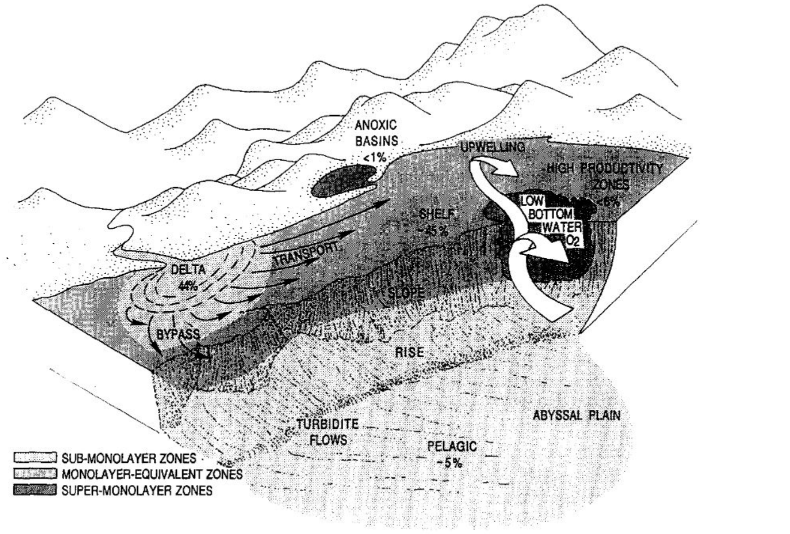


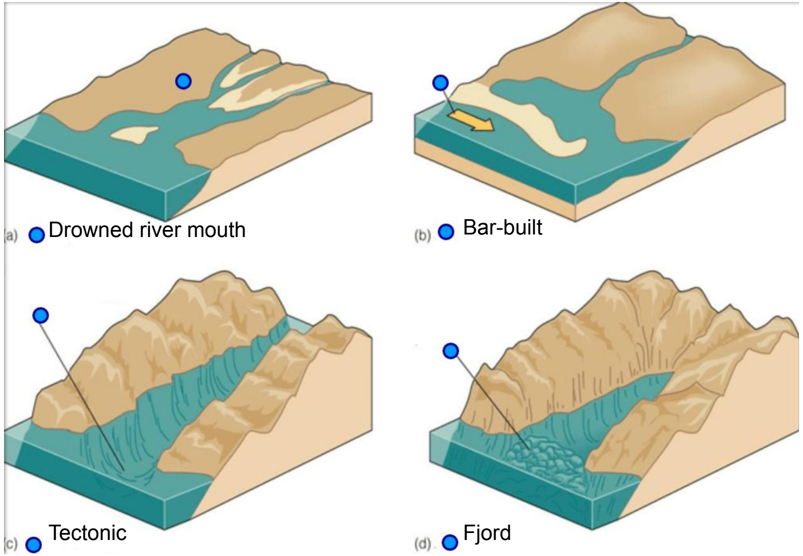
Fig. 1. Idealized diagram depicting current estimates of the percentage of total organic matter burial occurring within various marine sediment types (see Table 2). Light sections represent sediments which contain organic loadings lowe yr than a monolayer equivalent. Stippled sediments contain monolayer-equivalent loadings, and dark sediments contain loadings that are more than monolayer-equivalent.

Hedges & Keil (1995)

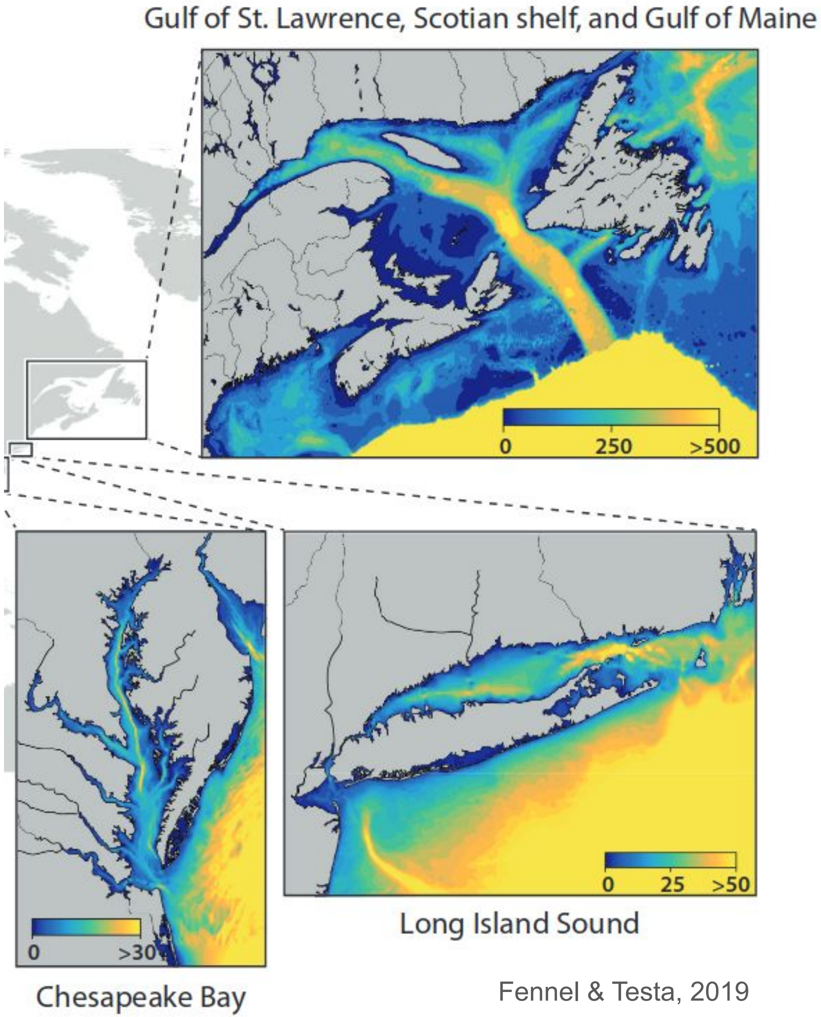
- **Continental shelf pump**
  - Process 1: stronger cooling on shelves results in more dissolution
  - Process 2: biological carbon pump from high production
  - Carbon sequestration then depends on the **transport off the shelf**

4. Estuaries

Where the river meets the sea



Graphonic 2016



Fennel & Testa, 2019

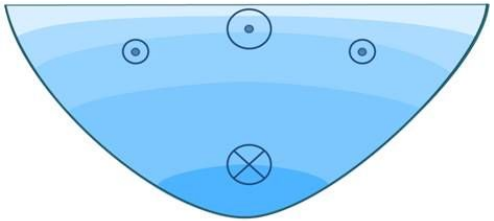
4. Estuaries

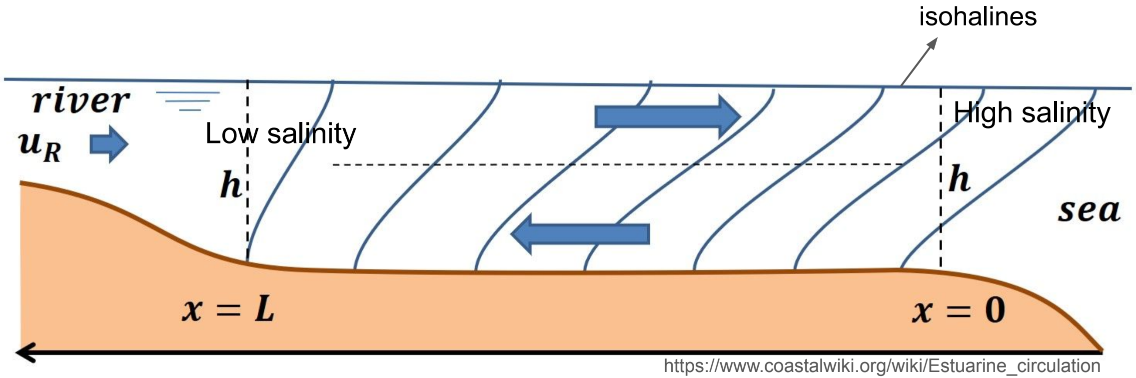
Gravitational (or estuarine) circulation

Denser waters sink, intruding inland

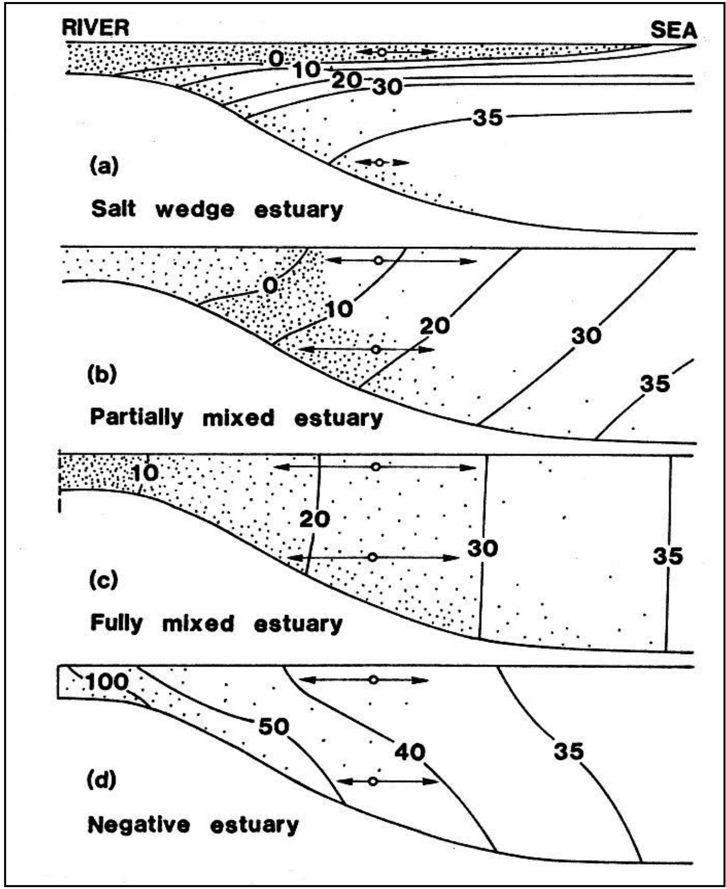
Seaward flow at the surface to balance out

Tides



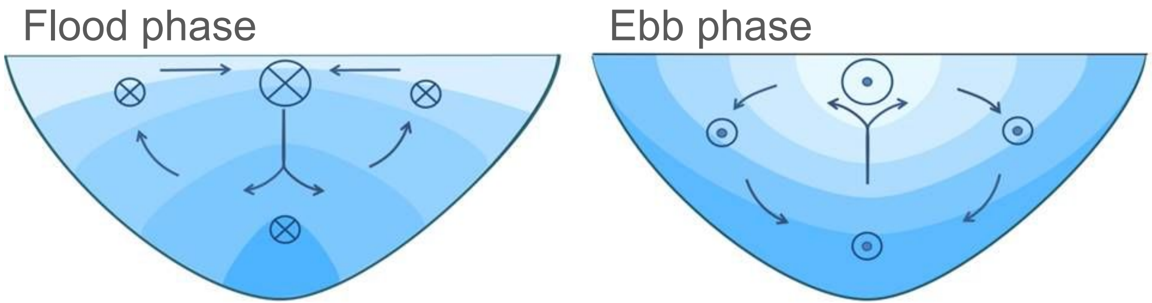


https://www.coastalwiki.org/wiki/Estuarine_circulation



4. Estuaries

Gravitational (or estuarine) circulation: tides



1. Tides + estuarine circulation = shear
2. Shear induces turbulent mixing
3. Mixing maintains the gravitational circulation

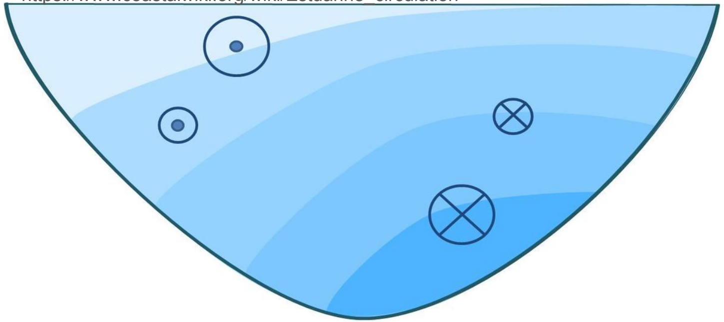
Fennel & Testa, 2019

4. Estuaries

Gravitational (or estuarine) circulation: jets

Coriolis effect:

https://www.coastalwiki.org/wiki/Estuarine_circulation



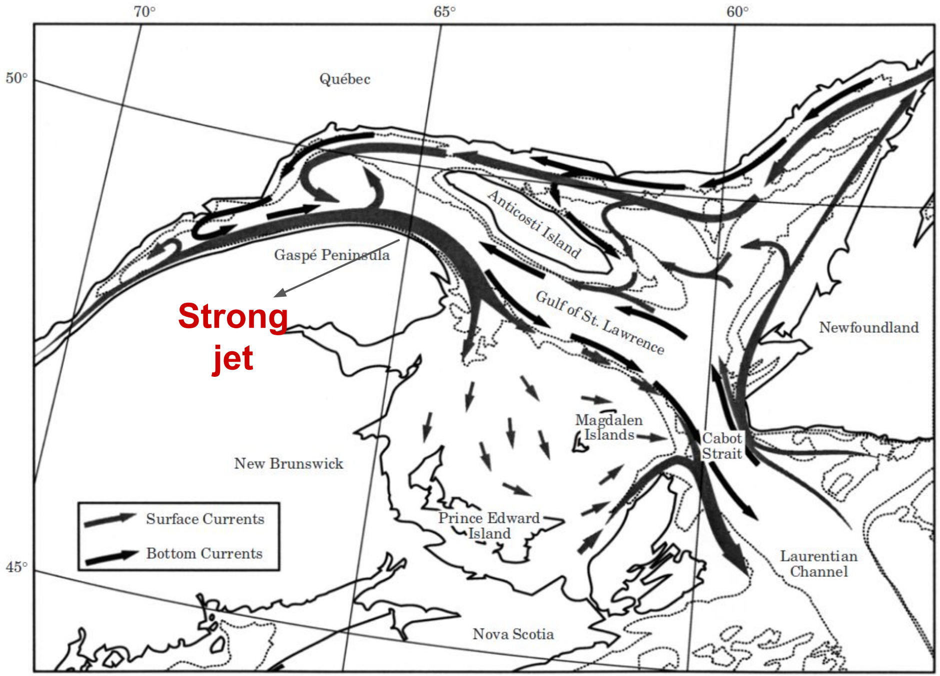


FIGURE 2. Mean summer near-surface and near-bottom currents in the Gulf of St. Lawrence, based on the model solution of Han *et al.* (1999).

Savenkoff et al. (2001)

4. Estuaries

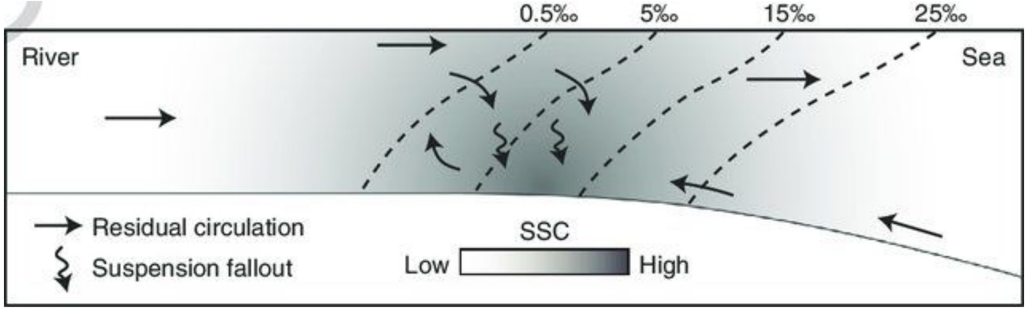
What is the effect of gravitational circulation on biogeochemical cycles?

4.1 Sediment in estuaries

Estuaries can act as sediment and pollution trap

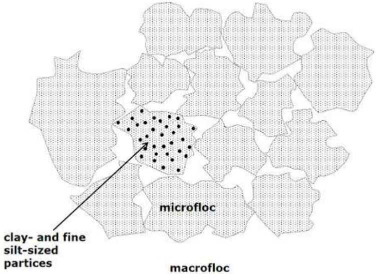
Turbidity maximum:

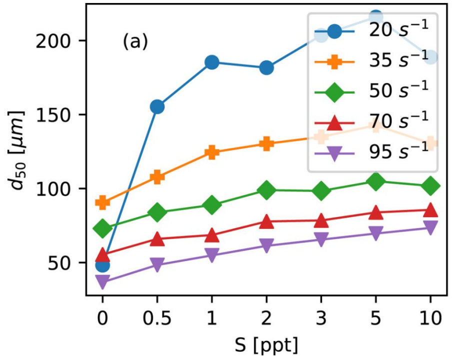
https://www.smiddest.fr/le-fonctionnement-du-bouchon-vaseux.html



Fitzgerald et al (2015), Estuaries and Tidal Inlets, in book Coastal Environments and Global Change

1. Sediment resuspension
2. Chemical flocculation
    - Increases with salinity
    - Adsorption of pollutants on flocs

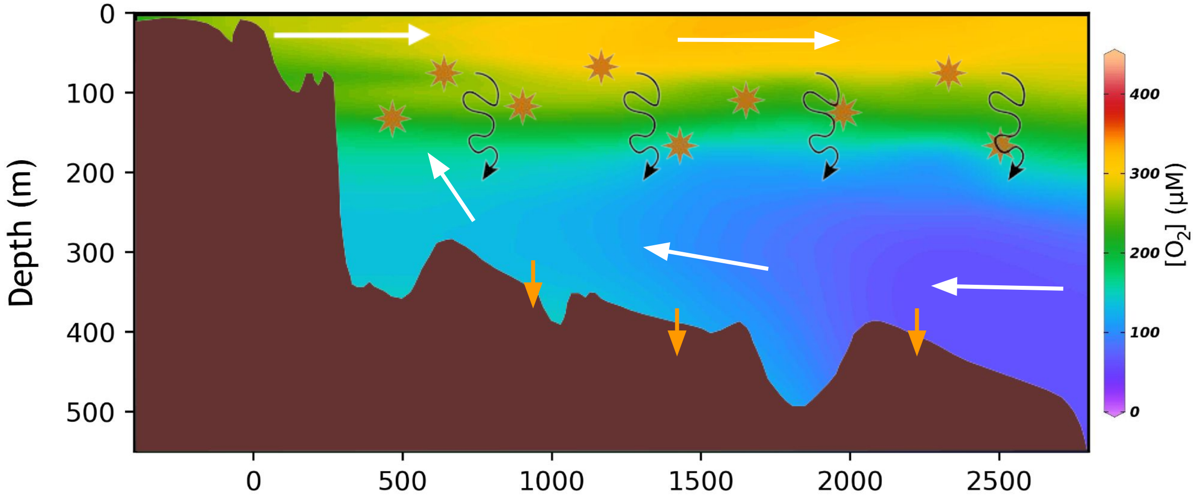




Size of the flocs versus salinity. Abolfazli & Strom, 2023

4.2 Nutrient cycling in estuaries

- Large river nutrient and OM export
- Nutrient upwelling
- **High production** in the surface
- Some export downstream
- Settling of OM and decomposition
- Burial in sediments

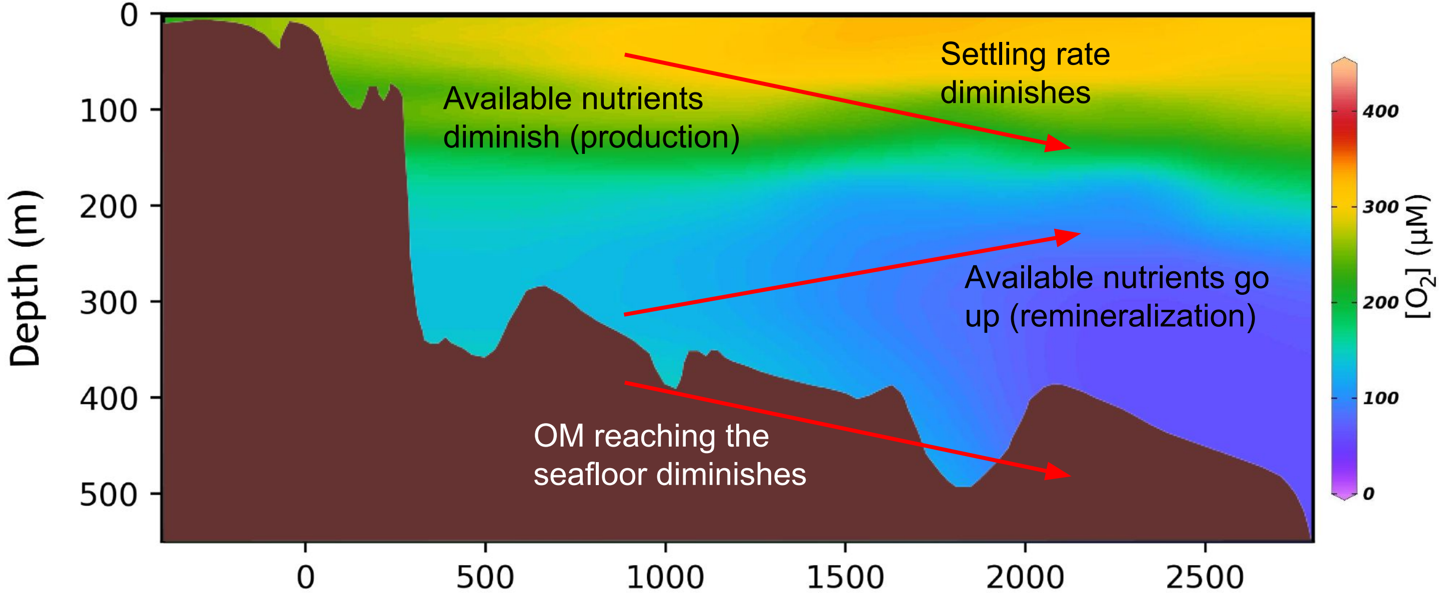


Estuaries act as **nutrient traps**

(Hence remove excess nutrients and do carbon sequestration before the waters reach the sea)

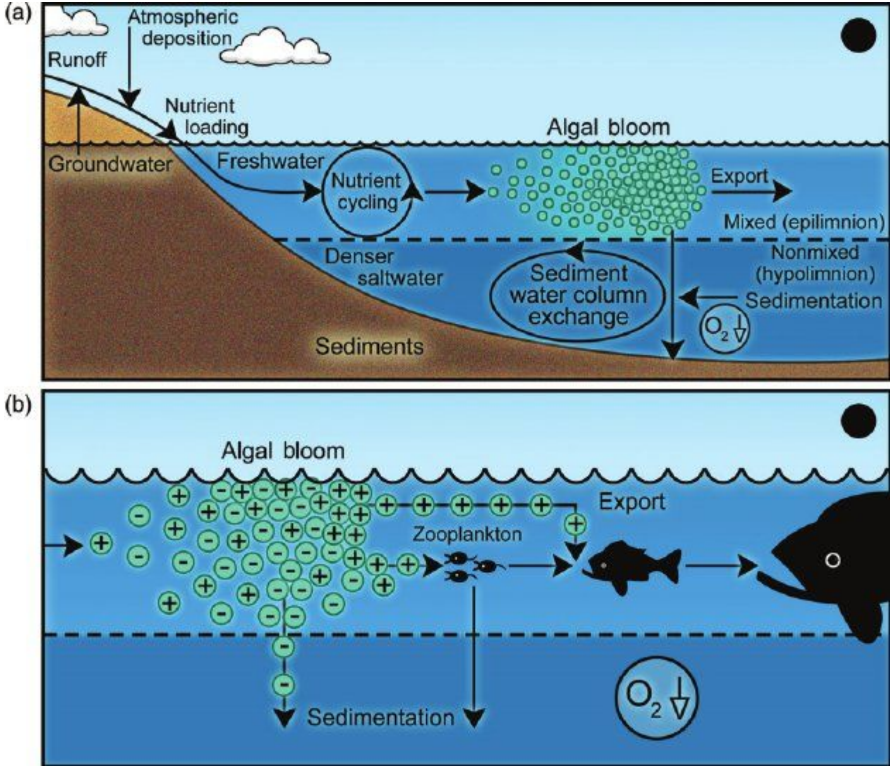
4.2 Nutrient cycling in estuaries

Along estuary gradients



4.2 Nutrient cycling in estuaries

OM decomposition can lead to hypoxia (eutrophication)

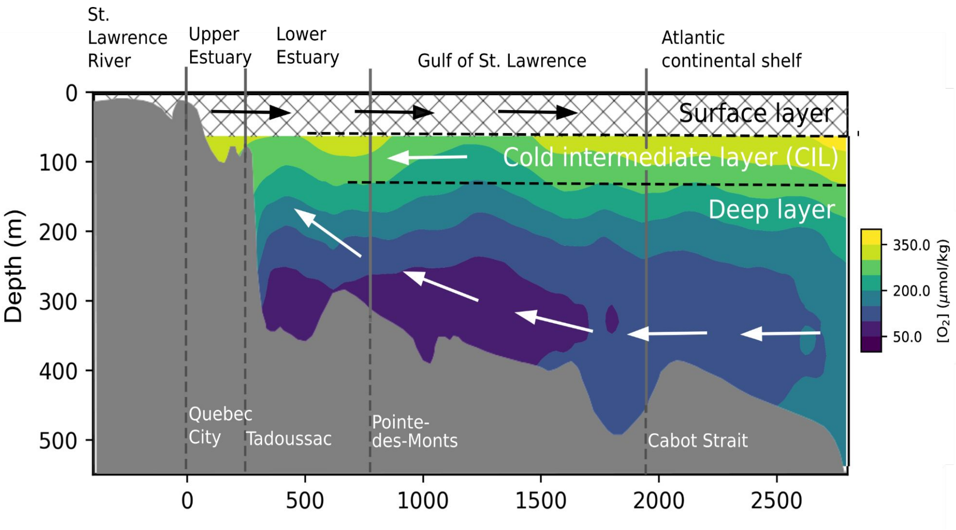


Pearl (2011), Phytoplankton Ecology and Trophic Dynamics in Coastal Waters

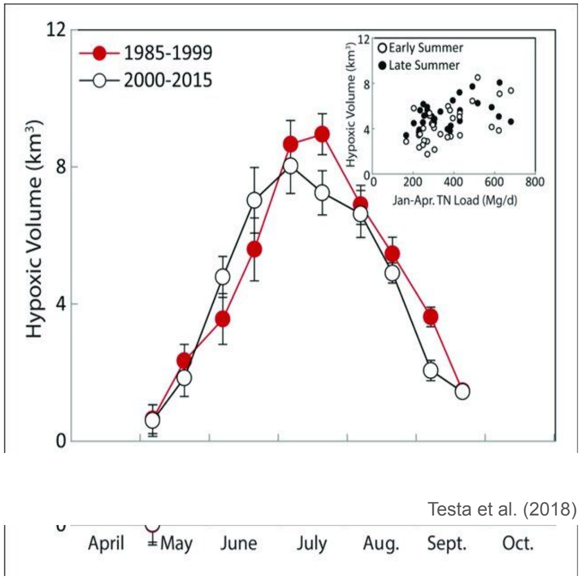
4.2 Nutrient cycling in estuaries

Hypoxia duration

Permanent stratification/hypoxia



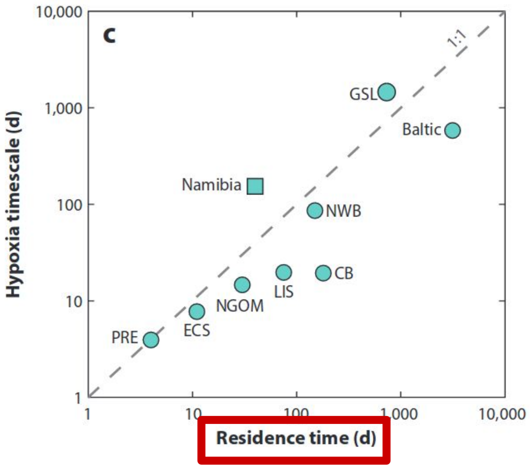
Seasonal stratification/hypoxia

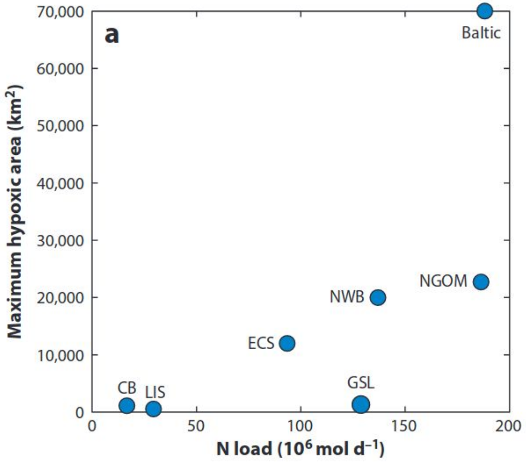


Testa et al. (2018)

4.2 Nutrient cycling in estuaries

Stratification = long residence time



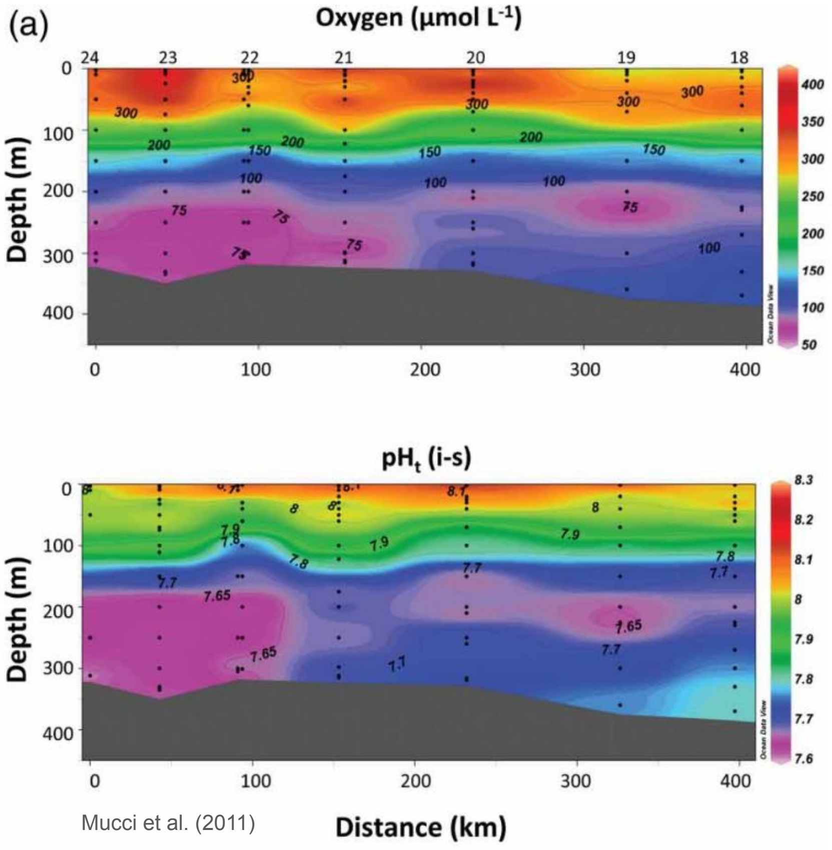


Fennel & Testa 2019

4.2 Nutrient cycling in estuaries

In the deep waters,
respiration = acidification

Example: St. Lawrence Estuary



Mucci et al. (2011)

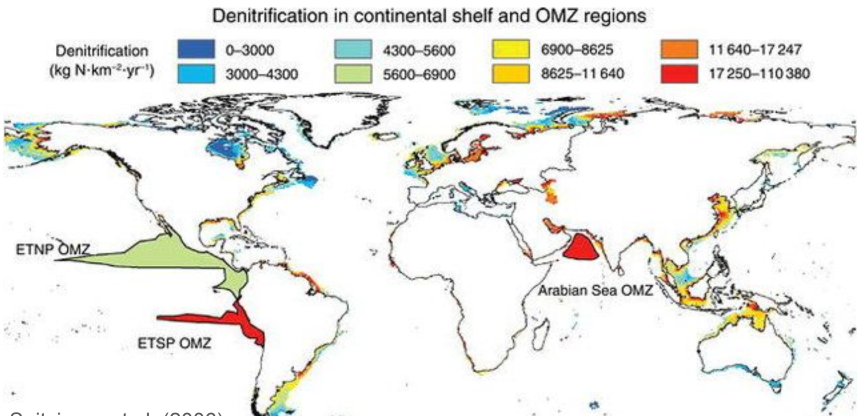
4.2 Nutrient cycling in estuaries

Denitrification

Table 1: Remineralization reactions (*Mucci et al.*, 2000)

Reaction	**ΔG (kJ/mol)**
Aerobic respiration $(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + \mathbf{138\ O_2} \longrightarrow H_3PO_4 + 16\ HNO_3 + 106\ CO_2 + 122\ H_2O$	-475
Denitrification $(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + \mathbf{94.4\ NO_3^-} \longrightarrow HPO_4^{2-} + 55.2\ N_2 + 106\ HCO_3^- + 71.2\ H_2O + 13.6\ H^+$	-448
Manganese reduction $(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + \mathbf{236\ MnO_2} + 364\ H^+ \longrightarrow HPO_4^{2-} + 236\ Mn^{2+} + 8\ N_2 + 106\ HCO_3^- + 636\ H_2O$	-349
Iron reduction $(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + \mathbf{424\ Fe_2O_3} + 756\ H^+ \longrightarrow HPO_4^{2-} + 424\ Fe^{2+} + 16\ NH_4^+ + 106\ HCO_3^- + 1060\ H_2O$	-114
Sulfate reduction $(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + \mathbf{53\ SO_4^{2-}} \longrightarrow HPO_4^{2-} + 53\ HS^- + 16\ NH_4^+ + 106\ HCO_3^- + 39\ H^+$	-77
Fermentation $(CH_2O)_{106}(NH_3)_{16}H_3PO_4 \longrightarrow H_3PO_4 + 16\ NH_3 + 53\ CO_2 + \mathbf{53\ CH_4}$	-58

44% of global denitrification occurs in continental shelf sediments.



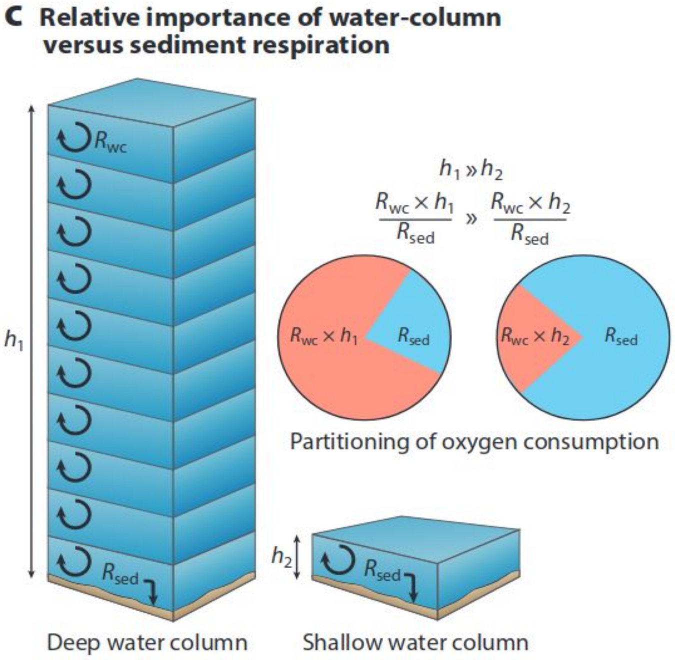
Seitzinger et al. (2006)

4.2 Nutrient cycling in estuaries

Cycling in sediments

High production → High deposition rates

Shallow waters



Fennel & Testa (2019)

4.2 Nutrient cycling in estuaries

Cycling in sediments

High production → High deposition rates

Shallow waters → More OM decomposition in sediments

→ Larger impact of nutrient release to the water column

Table 1: Remineralization reactions (*Mucci et al.*, 2000)

Reaction	**ΔG (kJ/mol)**
Aerobic respiration $(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + \mathbf{138\ O_2} \longrightarrow H_3PO_4 + 16\ HNO_3 + 106\ CO_2 + 122\ H_2O$	-475
Denitrification $(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + \mathbf{94.4\ NO_3^-} \longrightarrow HPO_4^{2-} + 55.2\ N_2 + 106\ HCO_3^- + 71.2\ H_2O + 13.6\ H^+$	-448
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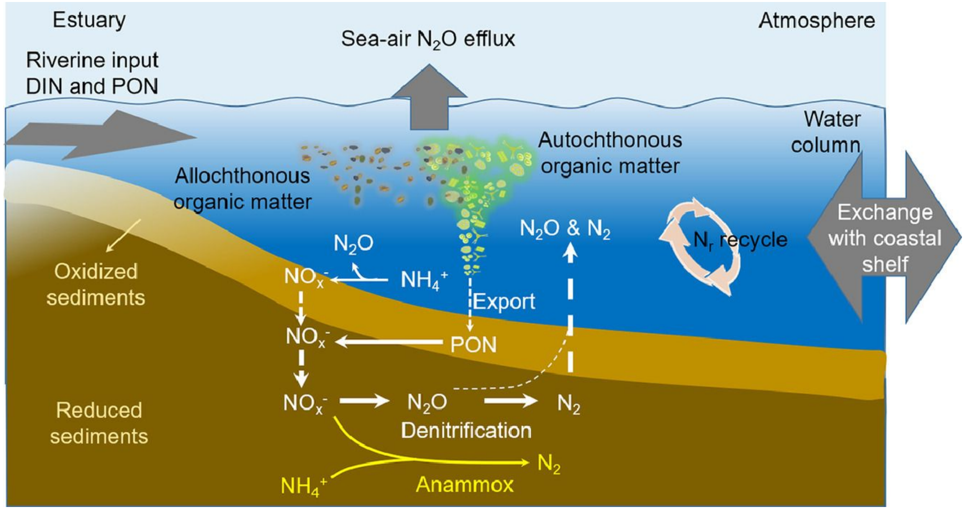
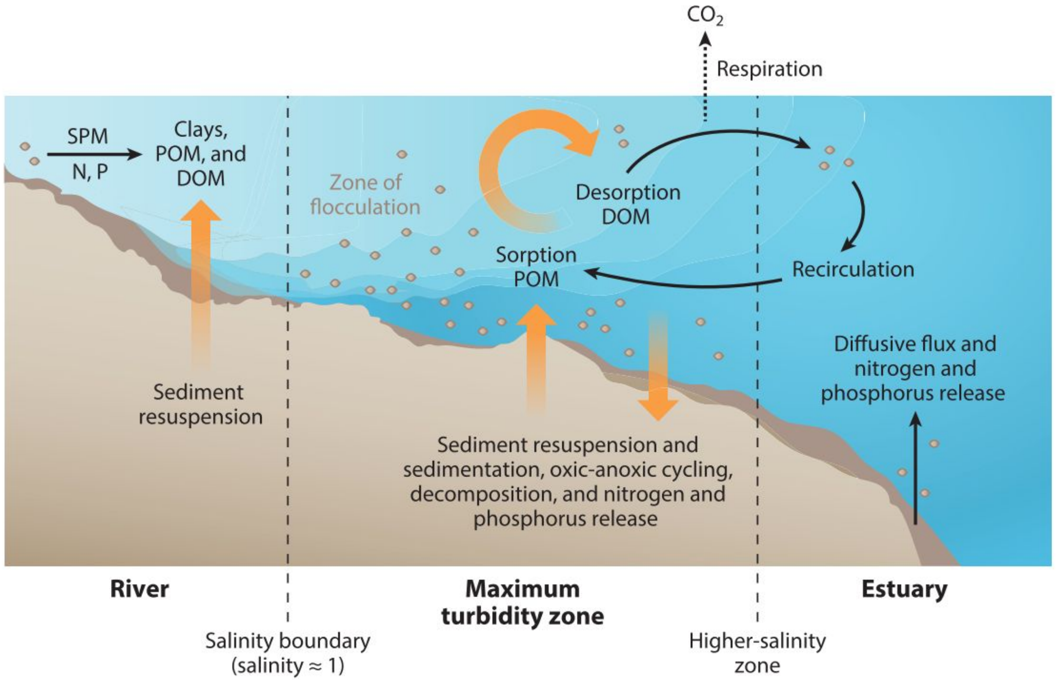


Tan et al. (2022)

4.2 Nutrient cycling in estuaries



Canuel and Hardison, 2016

4.2 Nutrient cycling in estuaries

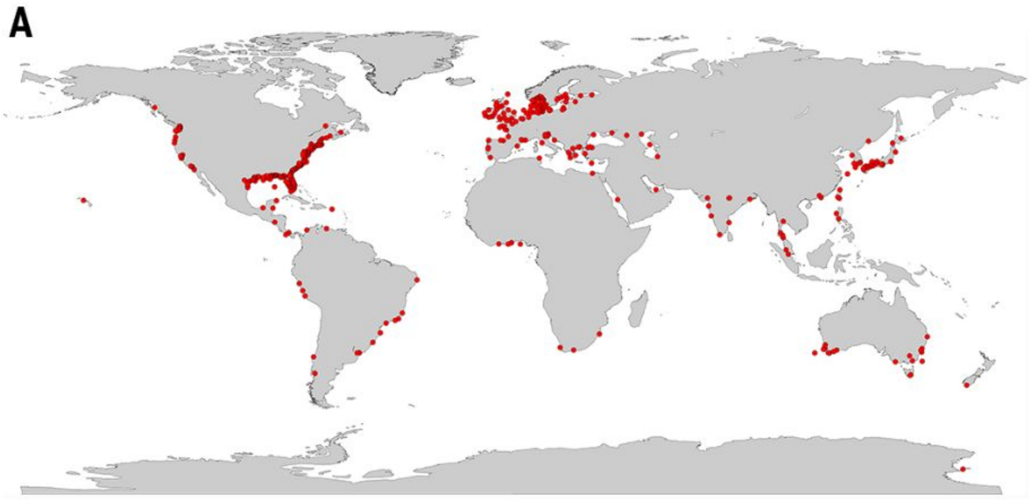
How is the influence of land affecting biogeochemical cycles in estuaries? How is the geography affecting these cycles?

5. Current changes in coastal BGC

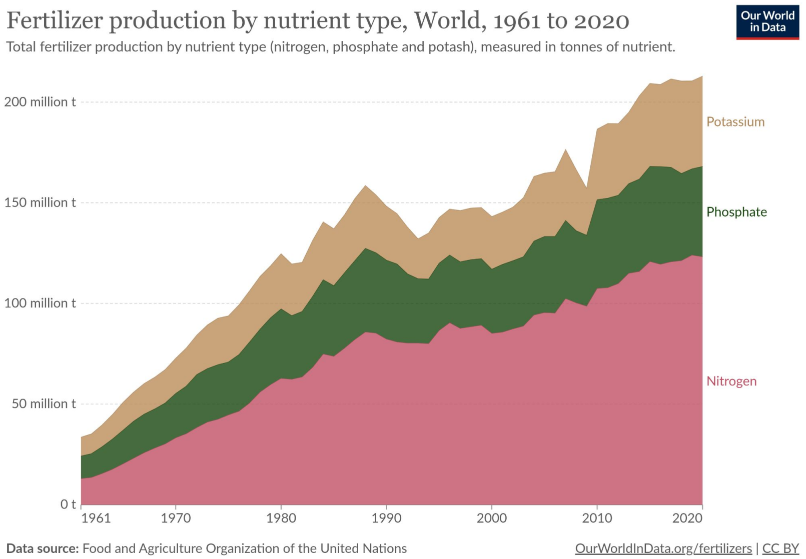
A. Enhanced anthropogenic export:

a. Fertilizers (¾ of the discharge)
b. Sewage water (¼ of the discharge)

- Nitrogen discharge from rivers increased by 70% from 1860 to 1990 and continues to increase

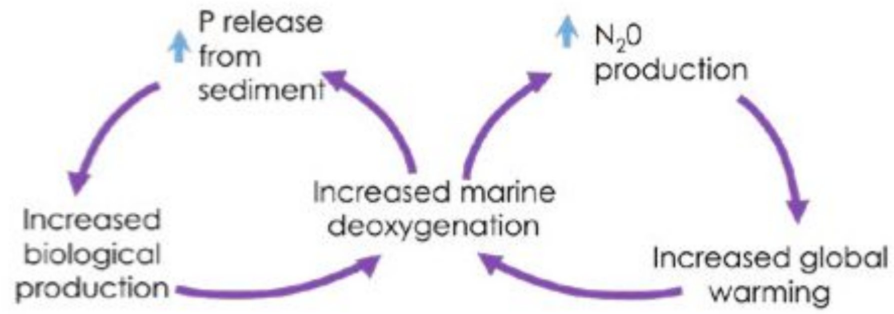


Coastal waters where oxygen concentrations ≤ 61 mmol/kg have been reported (red). Breitburg 2018.



5. Current changes in coastal BGC

B. Nutrient feedbacks

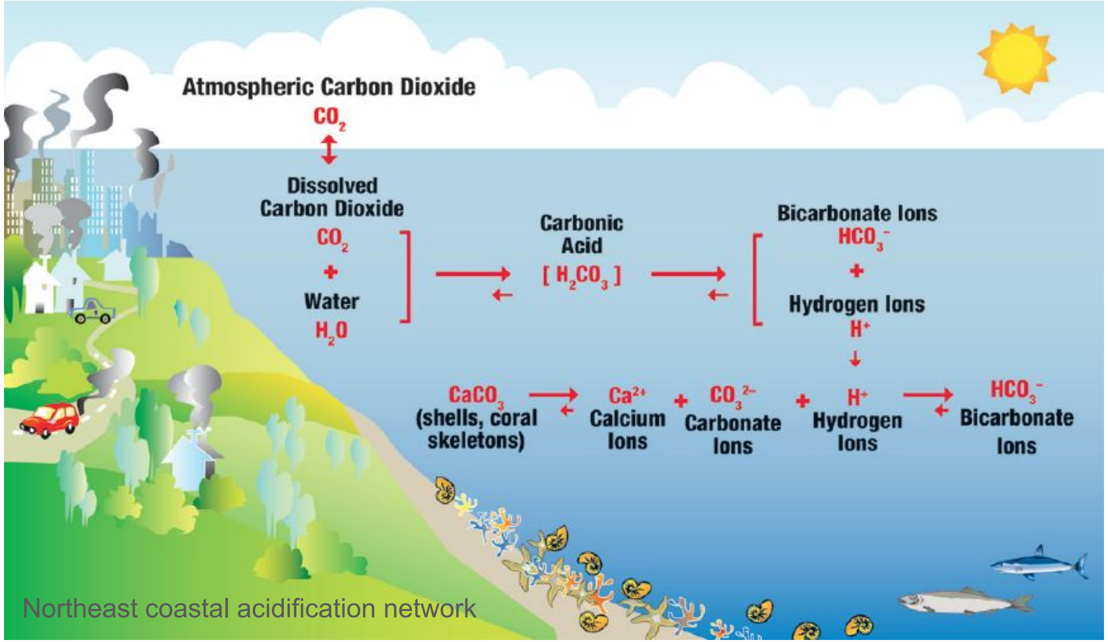


Positive feedbacks on deoxygenation with climate change. Breitburg 2018

5. Current changes in coastal BGC

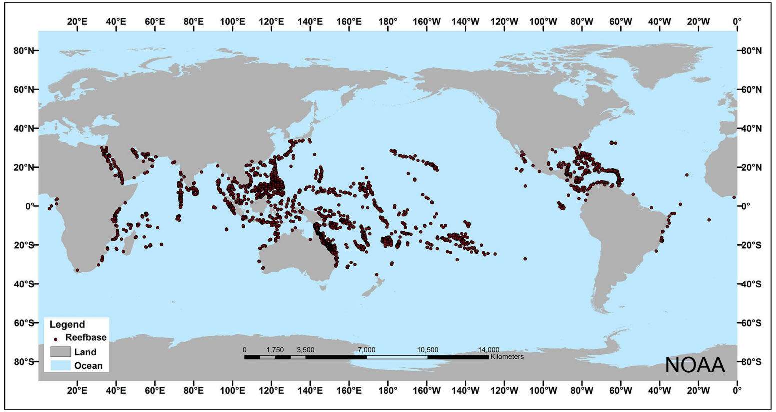
C. Acidification and bleaching

The Chemistry of Ocean Acidification



Northeast coastal acidification network

Corals in Kāneʻohe Bay demonstrated a range of bleaching responses during the 2019 heat stress event. Credit: Chuck Babbit Photography. NOAA.



NOAA

5. Current changes in coastal BGC

D. Physical changes

a) Warming and enhanced stratification

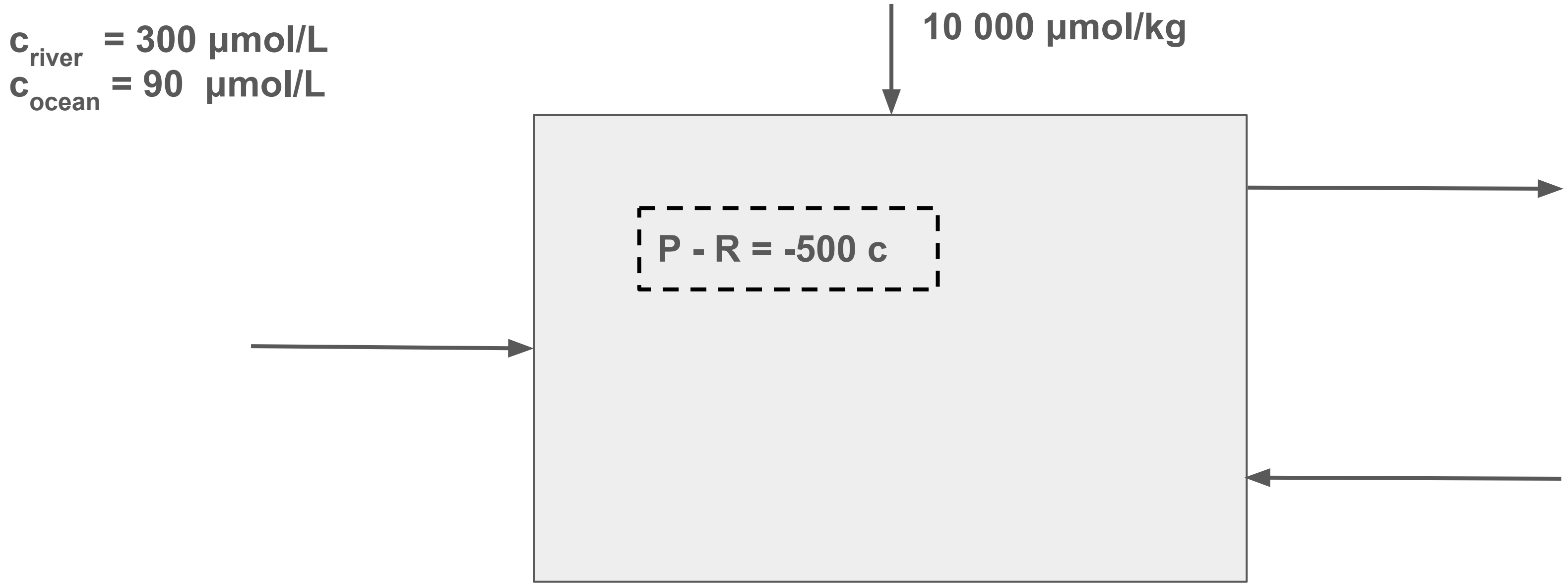
b) Sea level rise increases estuarine circulation

c) Sea ice melt and enhanced mixing

d) Changes in winds and Ekman pumping

In class exercise

Box model of biogeochemical cycling in a fish pond



In what flushing conditions will hypoxia develop?

Next class: **Paper discussion**

Biogeosciences, 15, 2649–2668, 2018
https://doi.org/10.5194/bg-15-2649-2018

Biogeosciences
Open Access
EGU

The competing impacts of climate change and nutrient reductions on dissolved oxygen in Chesapeake Bay

Isaac D. Irby, Marjorie A. M. Friedrichs, Fei Da, and Kyle E. Hinson
Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA 23062, USA

Think of

- What are the future changes that will affect the estuary’s biogeochemistry
- What are the main and surprising results
- The impact of these changes on hypoxia, but also on seasonality and interannual variability