Net Ecosystem Production in Estuarine and Coastal Systems

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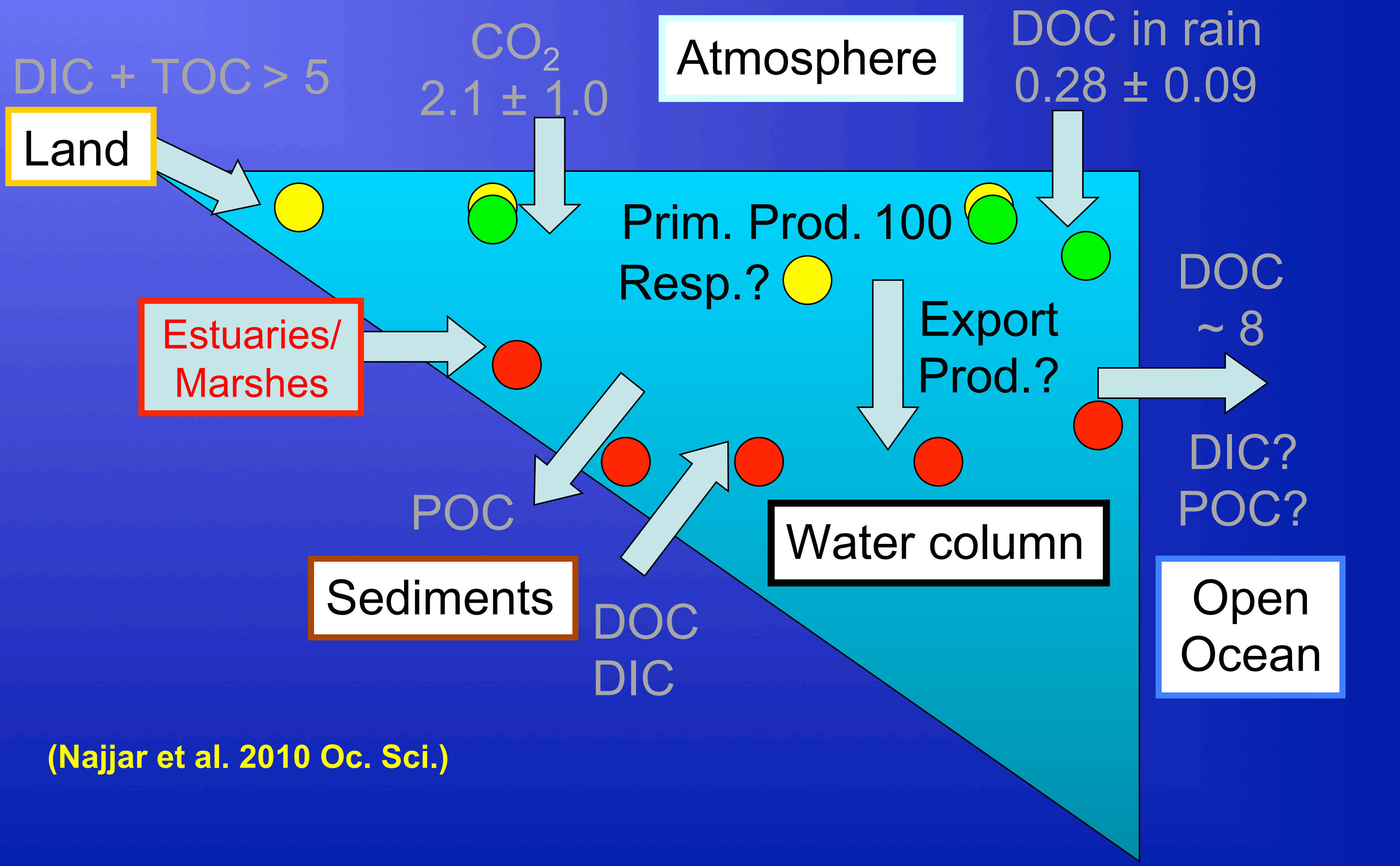
& MDSG, US EPA, NASA

Outline of Points Covered

- Background
- NEP Methods & Approaches: Examples
- Factors Controlling P, R and NEP
- Estuarine C-Budget East Coast US (GBC)
- Epilogue: Other Considerations
- Concluding Comments

Role of Estuaries in Shelf-Wide C Budget



(Najjar et al. 2010 Oc. Sci.)

Net Ecosystem Production Definitions & Concepts

(1) Positive net ecosystem production (NEP, P_n) contributes to TOC export from to shelf; negative P_n reduces TOC export to shelf.

(2) Net ecosystem production = gross production – total respiration.

$$P_n = \Sigma (P_g) - \Sigma (R)$$

(3) P_g & R from incubated rates or changes in environmental pools.

(4) *NEP* = physical TOC export - physical TOC import.

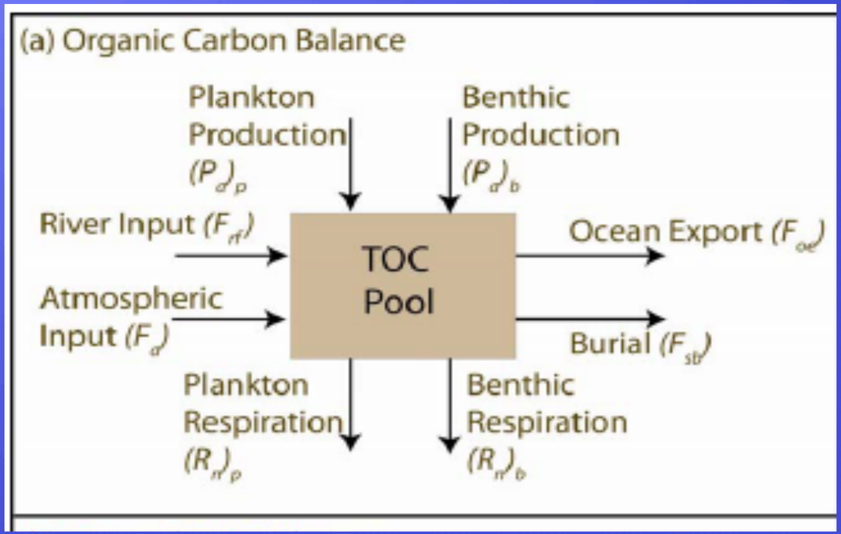
$$P_n = \Sigma (F_{CO}) - \Sigma (F_{CI}) \quad \text{[@ steady-state]}$$

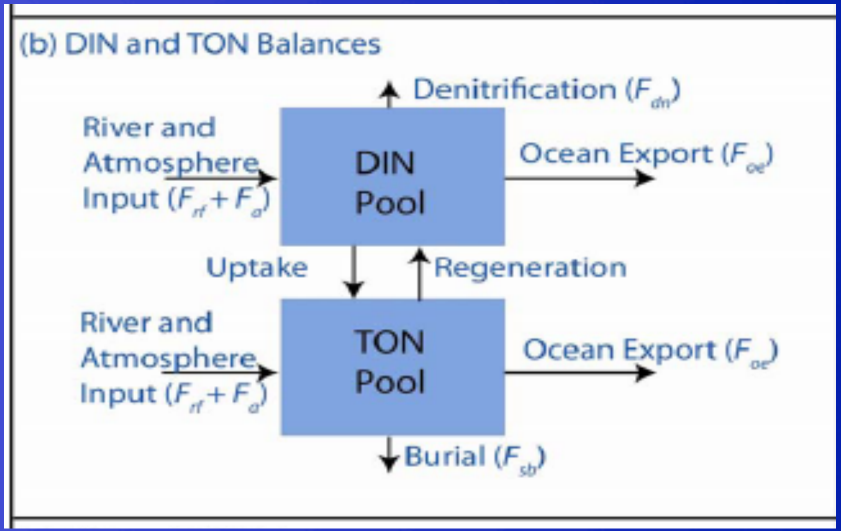
(5) *NEP* related to ratio of inorganic-to-organic nutrient inputs.

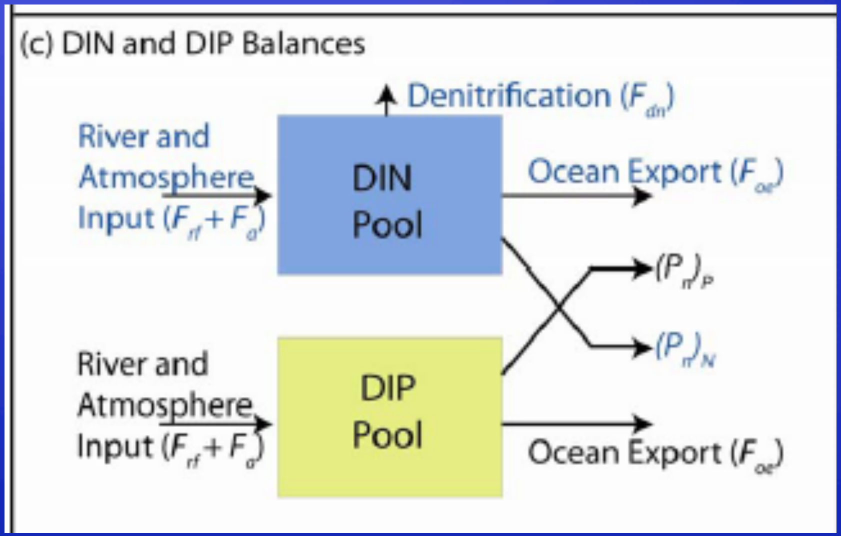
$$P_g = f \text{ (inorganic nutrient inputs)}$$

$$R = f \text{ (organic matter inputs)}$$

Estuarine NEP from C, N, P Mass-Balances

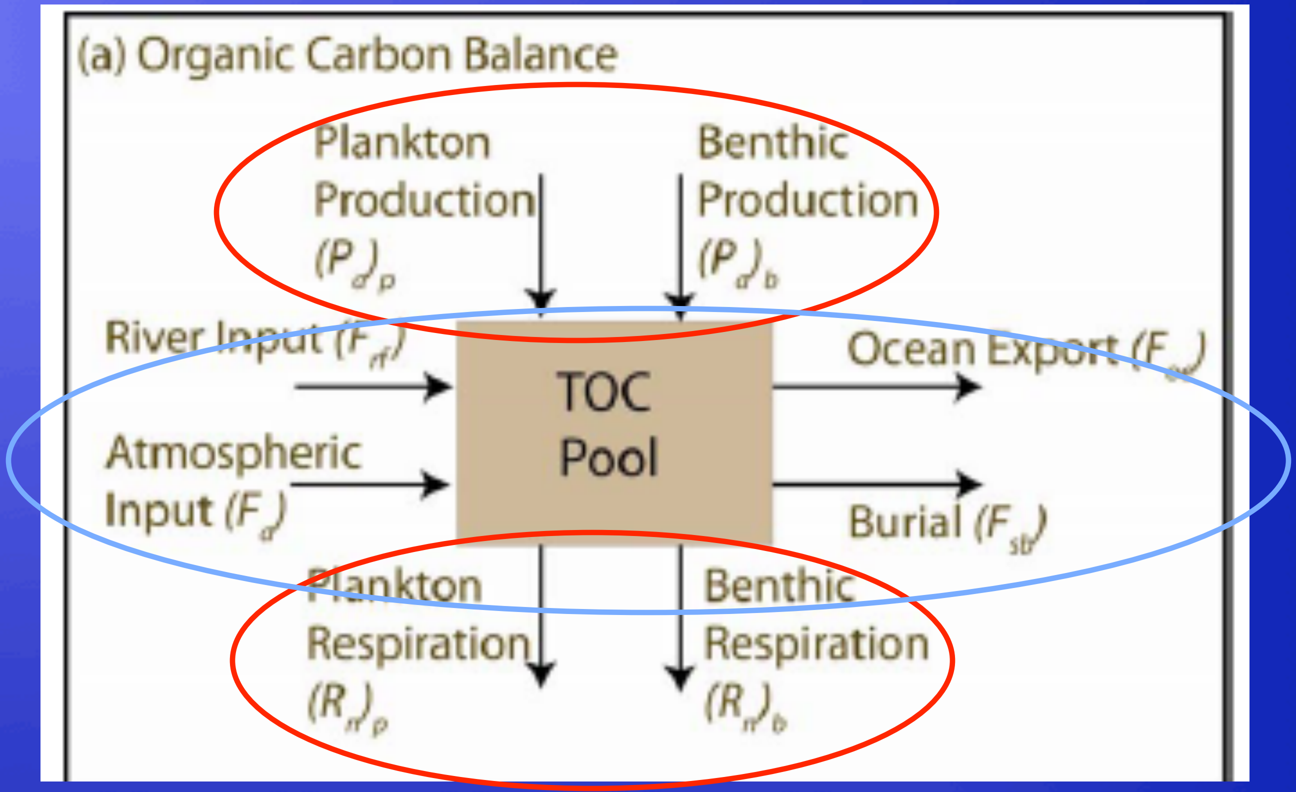






(Kemp et al. '97 MEPS)

Estuarine Net Ecosystem Production



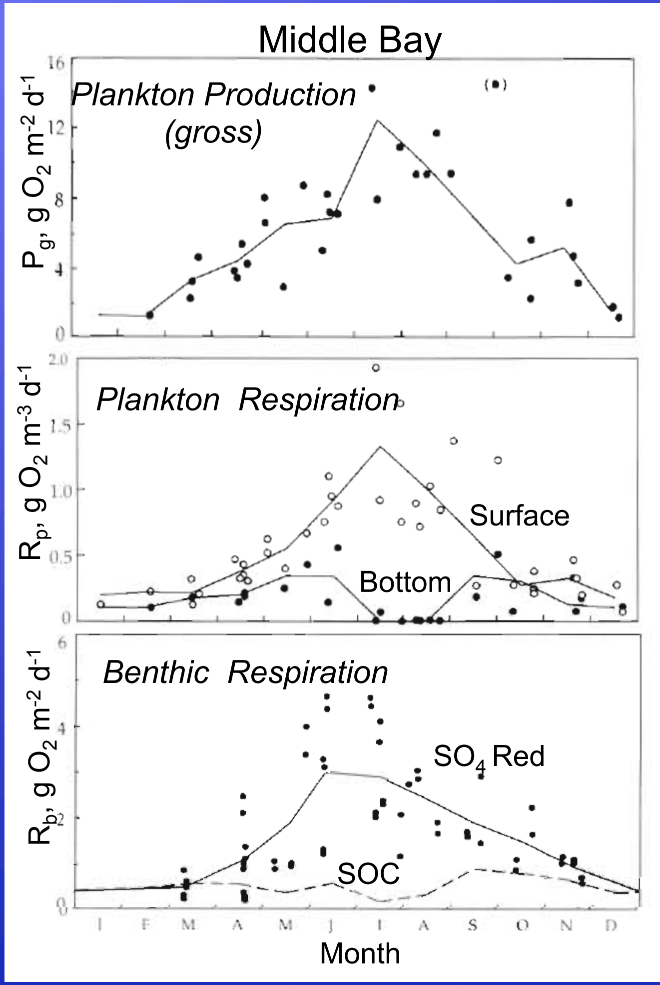
Sum Metabolic Rates

$$P_n = \Sigma (P_g) - \Sigma (R)$$

Physical Fluxes Balance

$$P_n = \Sigma (F_{CO}) - \Sigma (F_{CI})$$

P & R Rates From Container Incubations

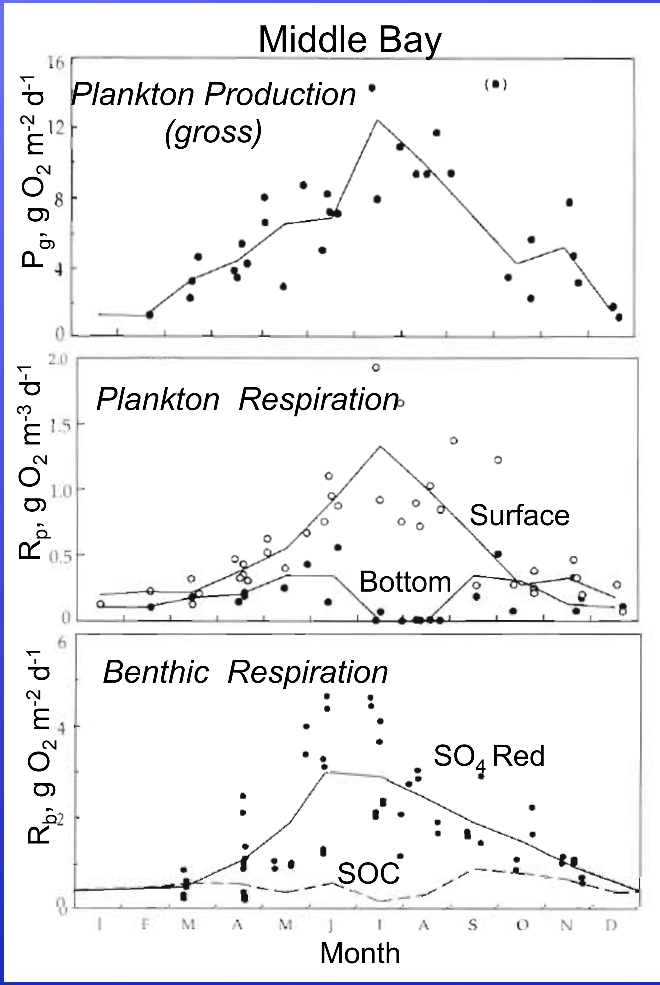


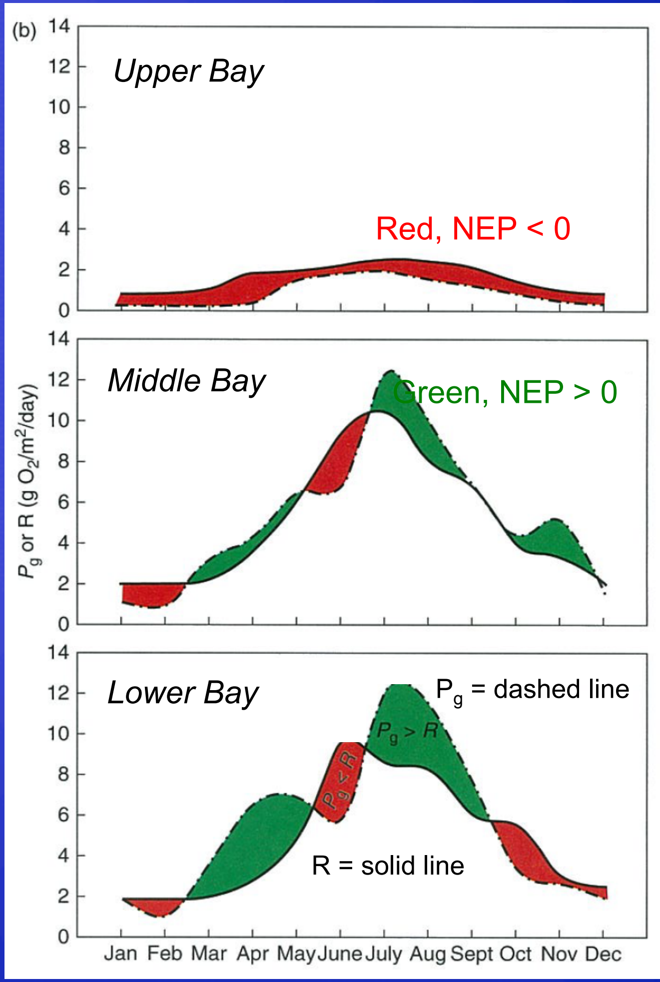
Red, NEP < 0

Green, NEP > 0

(after Kemp et al. 1997)

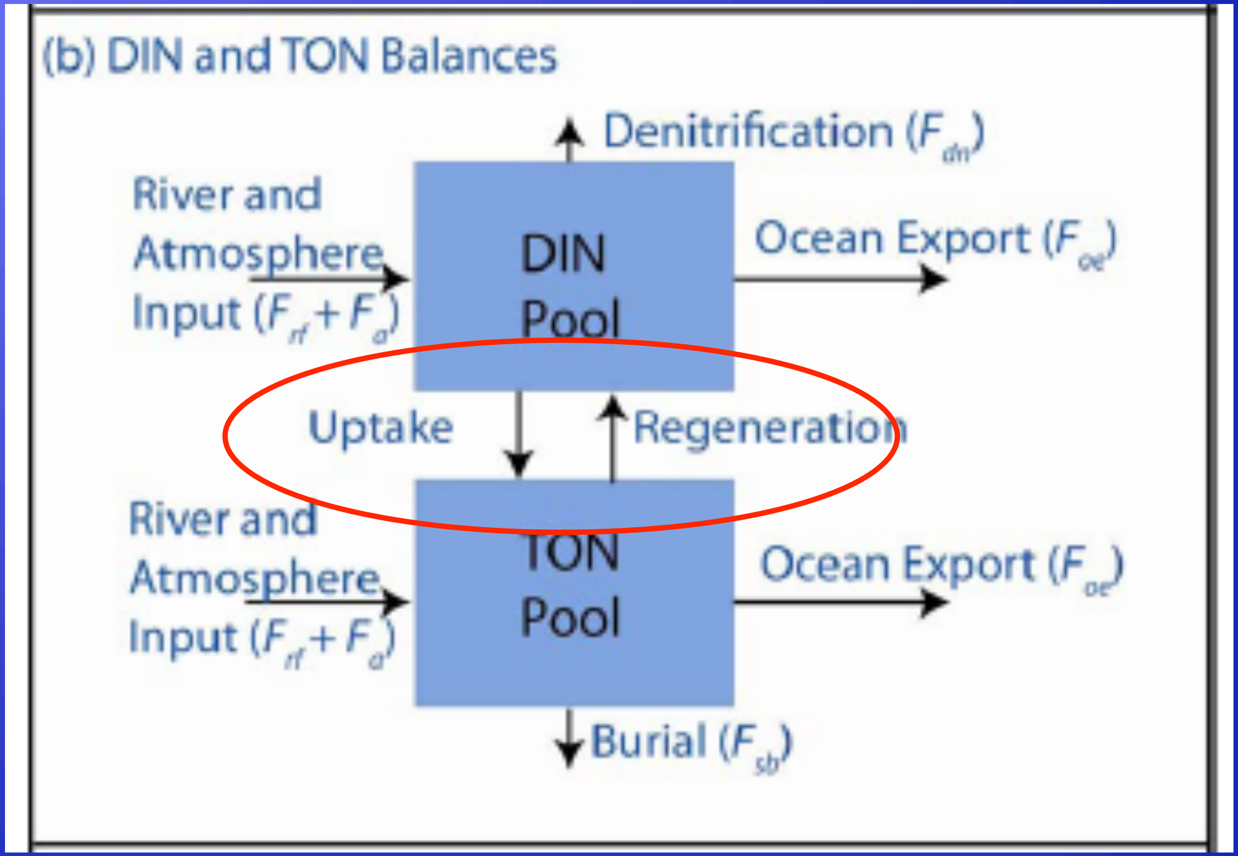
P & R Rates From Container Incubations





(after Kemp et al. 1997)

Estuarine Net Ecosystem Production

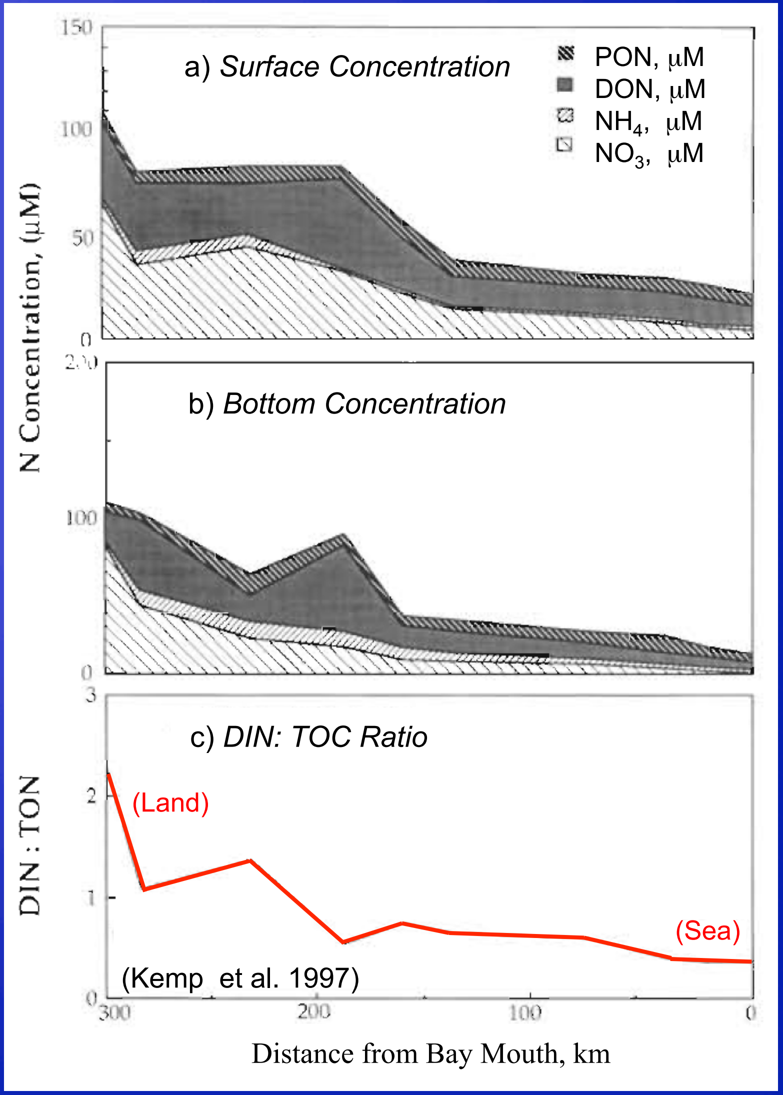


- *Net shift between inorganic and organic forms of N*
- *Compare DIN/TON in river vs. ocean end-members*

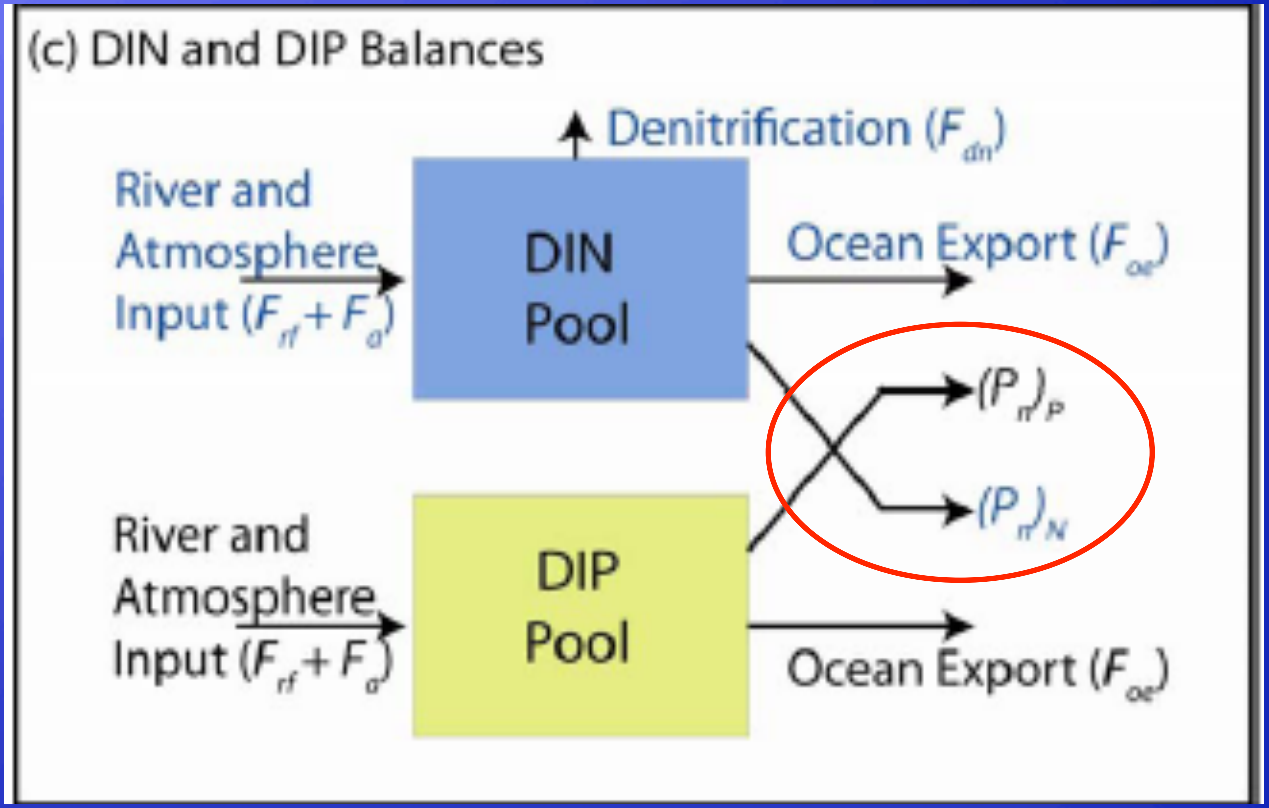
DIN:TOC Ratio Shifts Along Estuarine Axis

Changes in Ratio Reflect NEP

- **Increase → Heterotrophy**
- **Decrease → Autotrophy**



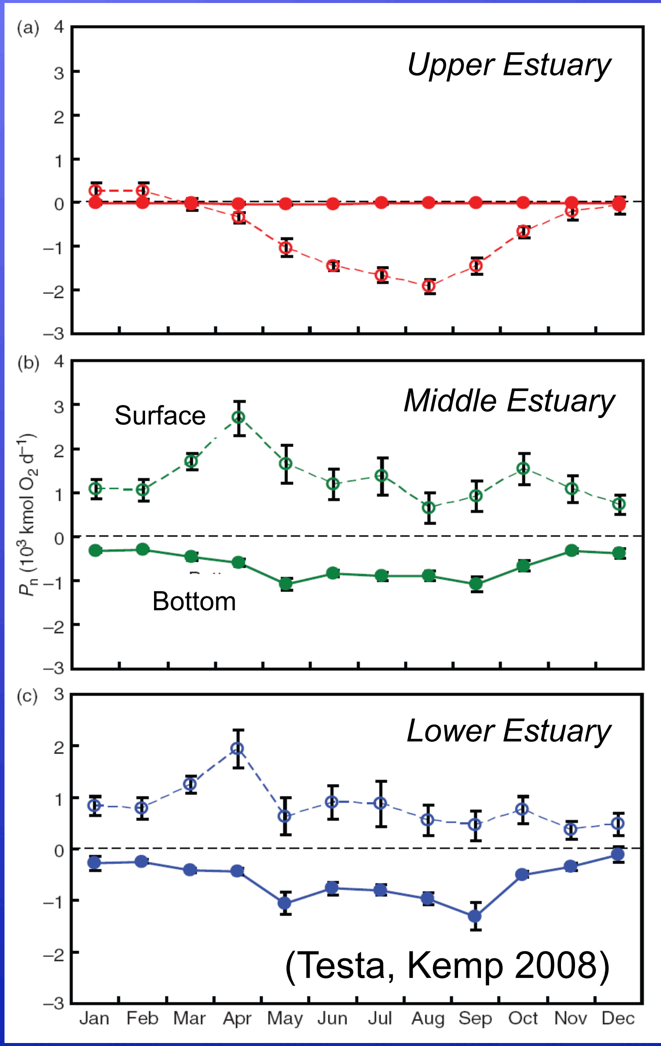
Estuarine Ecosystem Metabolism



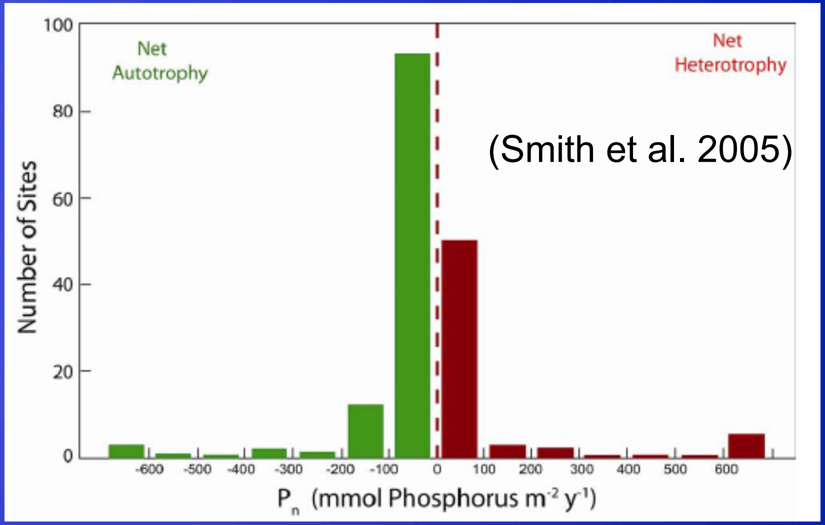
"LOICZ-Approach"

- *Estimate advective & dispersive transport salt- & water-balance eqns.*
- *Use transport & DIN data to estimate net production of DIN*
- *Use transport & DIP data to estimate net production of DIP*
- *Estimate net denitrification by stoichiometric difference*

LOICZ Computes NEP with WQ Monitoring Data

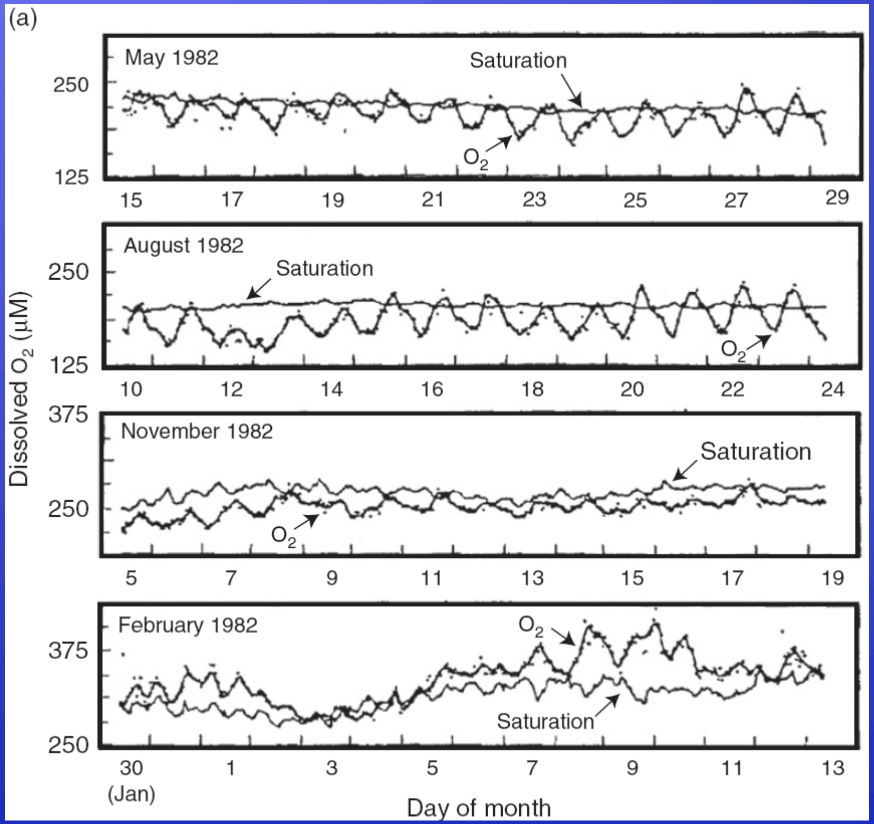


Frequency Distribution for NEP

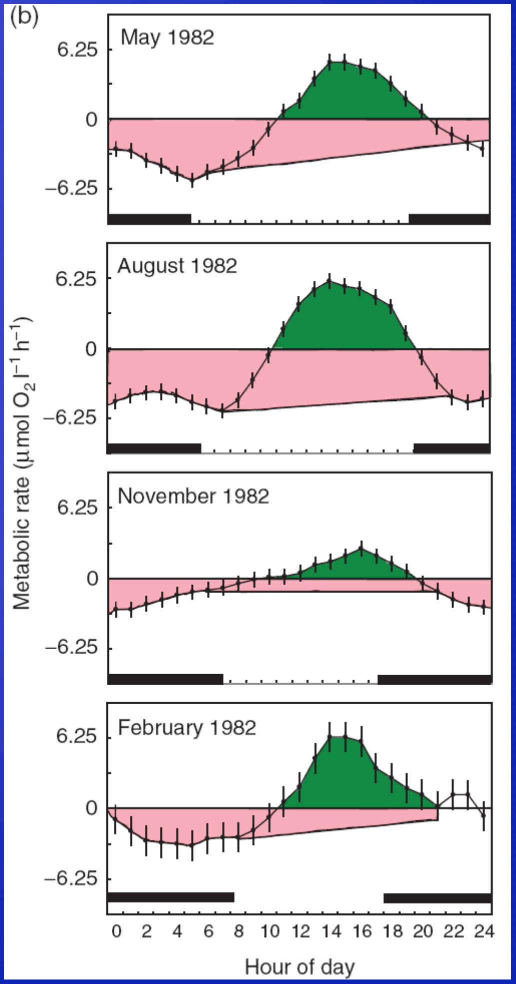


NEP Rates at Scales of Month
Region, Layers & Annual System

Other NEP Methods: Open-Water, High-Frequency Diel Variations in O_2 (or DIC)



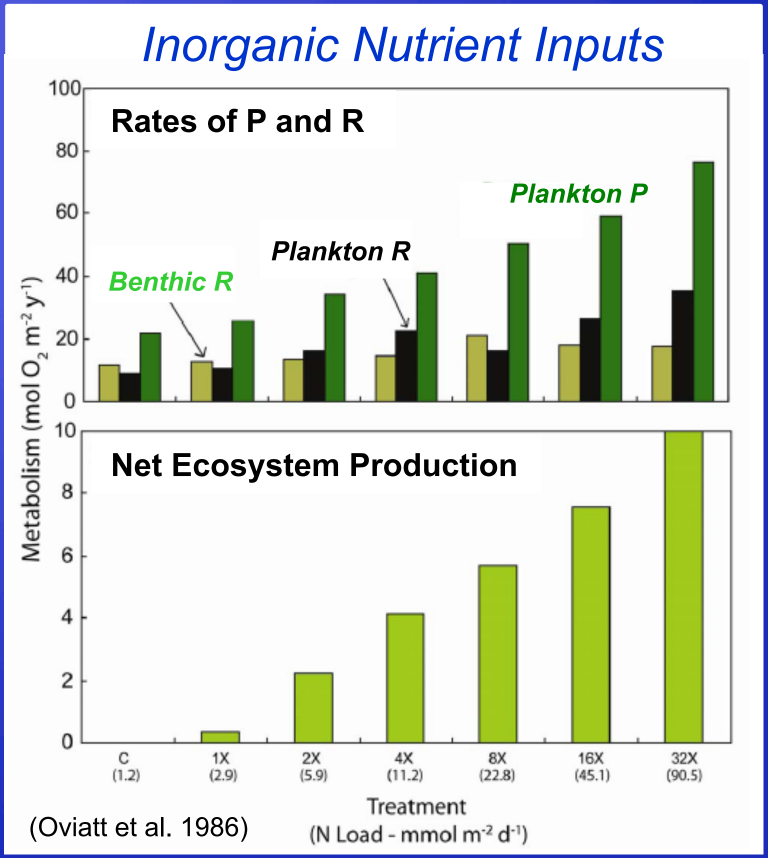
(after Kenney et al. 1988)



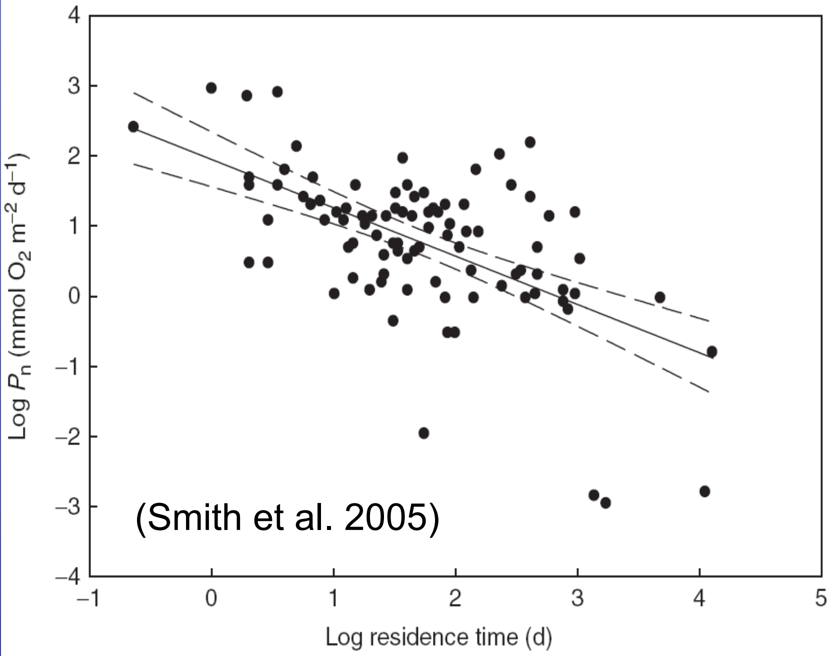
Factors Controlling Estuarine & Coastal NEP

Factors Controlling Estuarine & Coastal NEP: Inorganic Nutrient Loading

MERL Experiments
Nutrient Enrichment



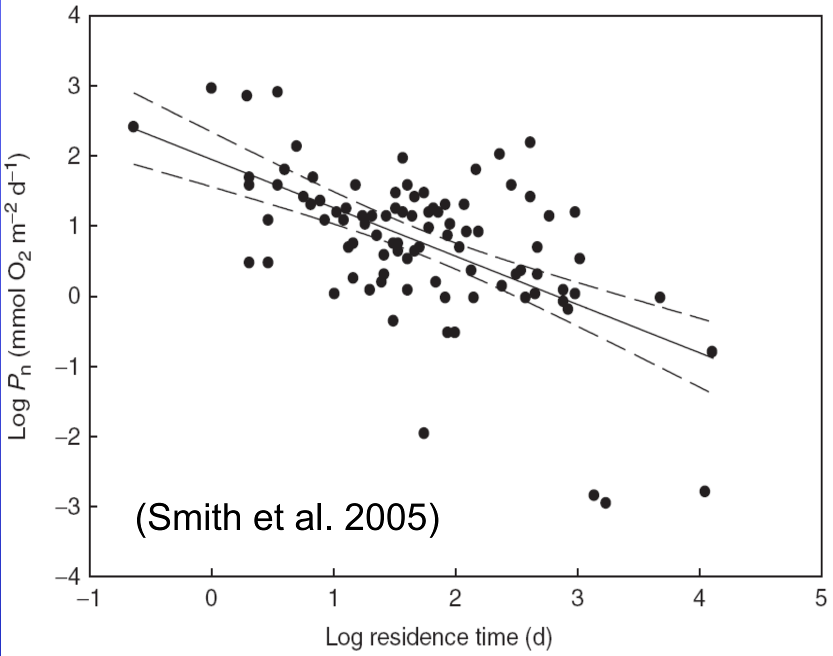
Factors Controlling Estuarine & Coastal NEP: Water Residence Time

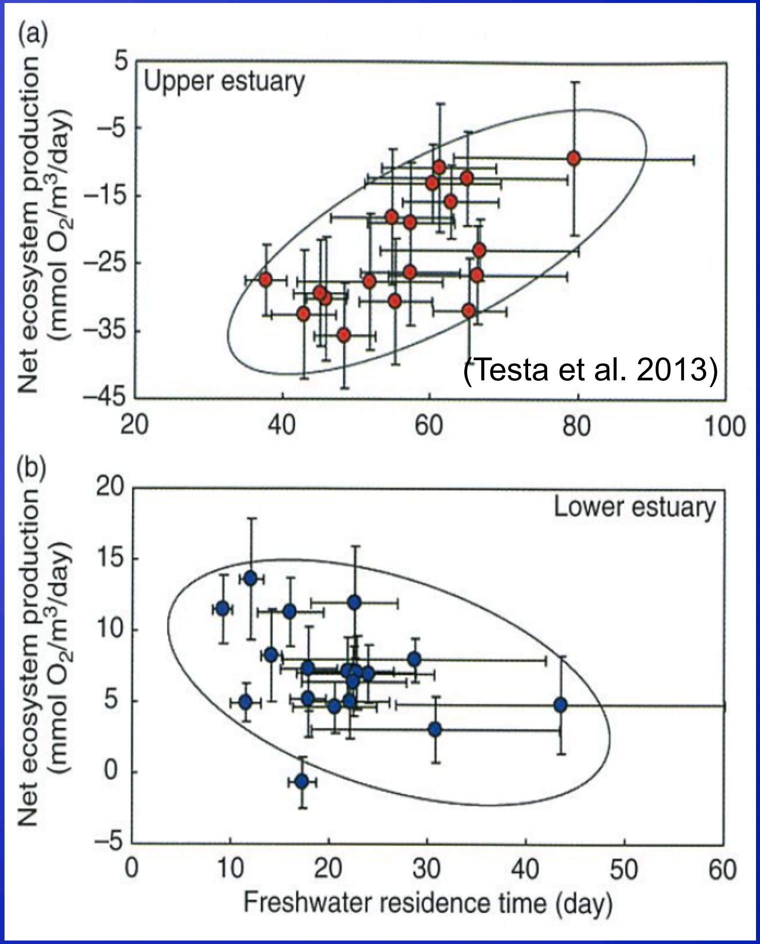


NEP-*Tau* Relationship Driven by Several Factors:

- Organic & inorganic nutrient pools in water are used at long *Tau* and exported more at short *Tau*.
- Thus, at long *Tau*, NEP → zero
- Benthic dominated systems are less affected.

Factors Controlling Estuarine & Coastal NEP: Water Residence Time





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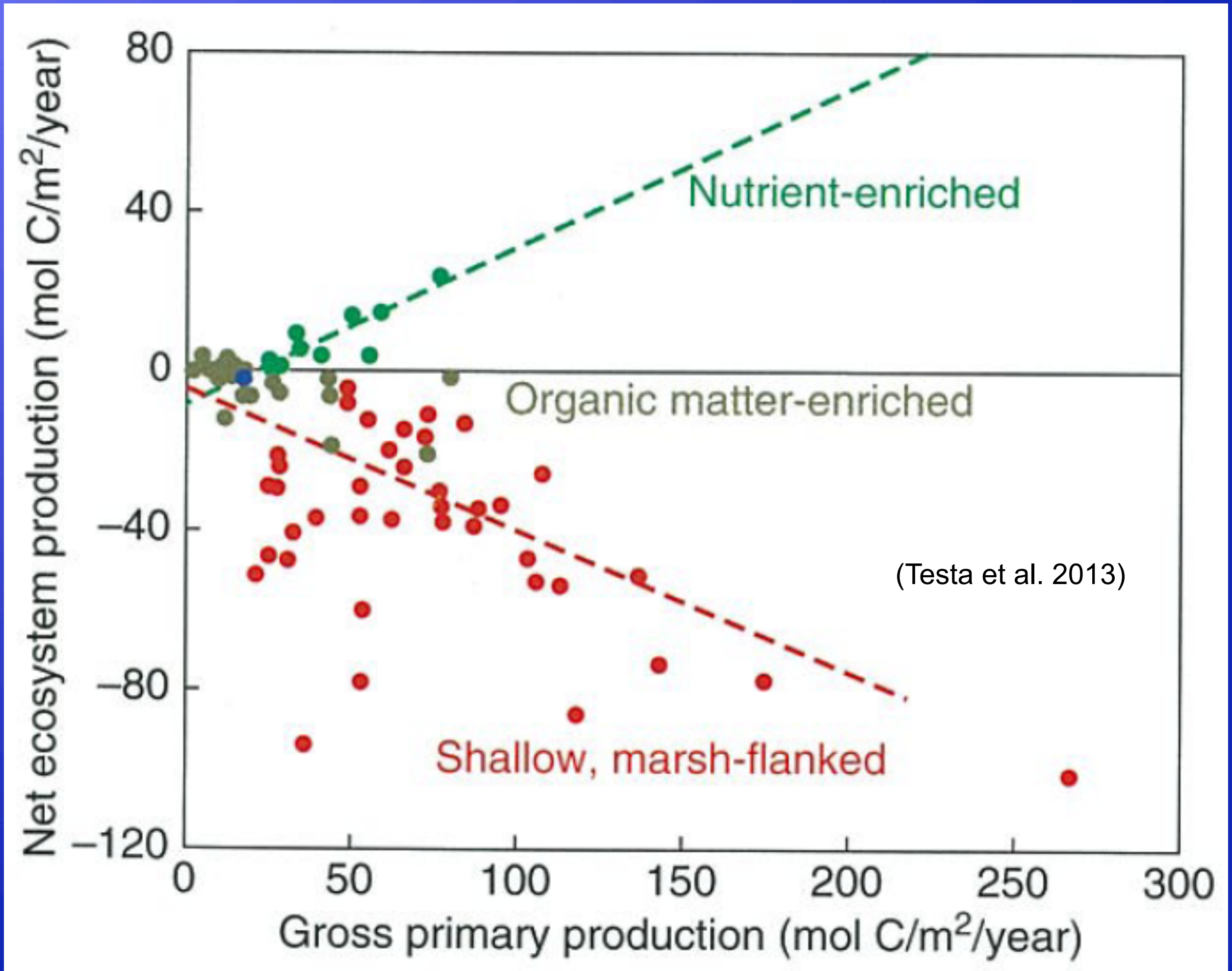
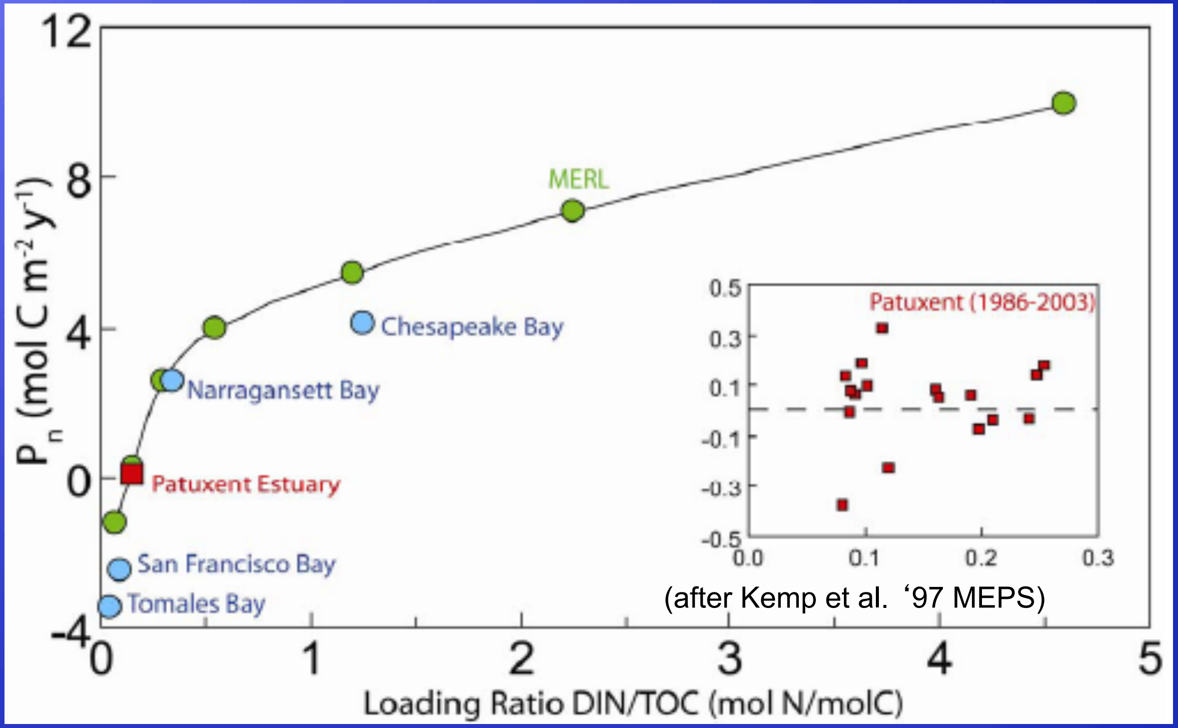
Factors Controlling Estuarine & Coastal NEP: Exchanges with Adjacent Wetlands

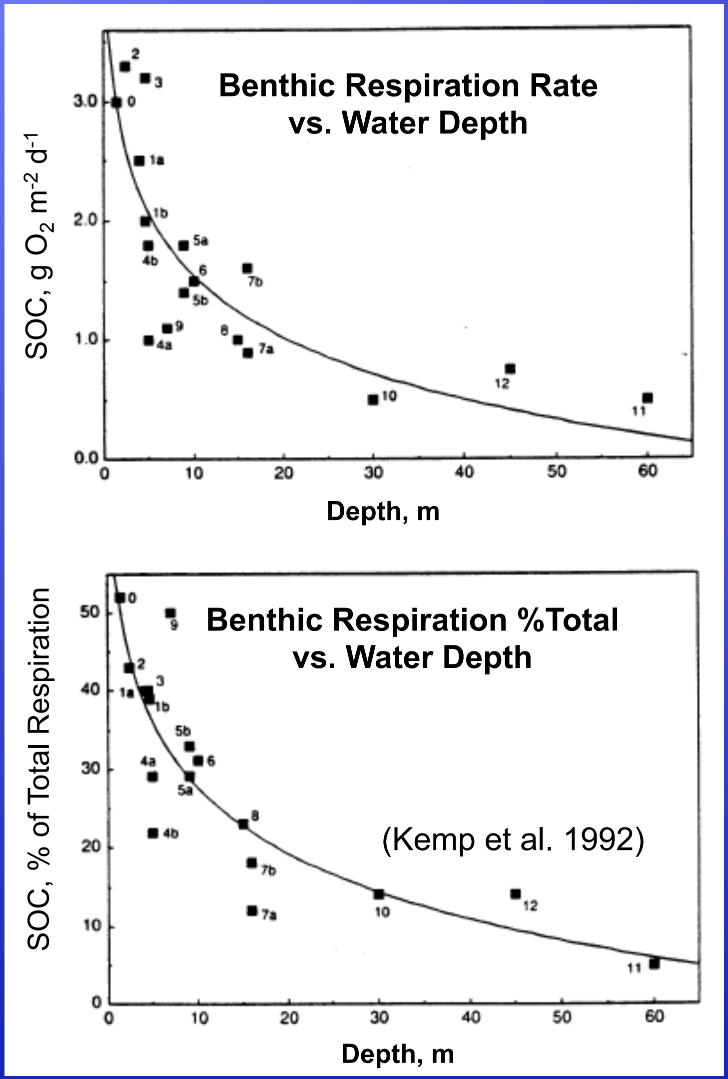


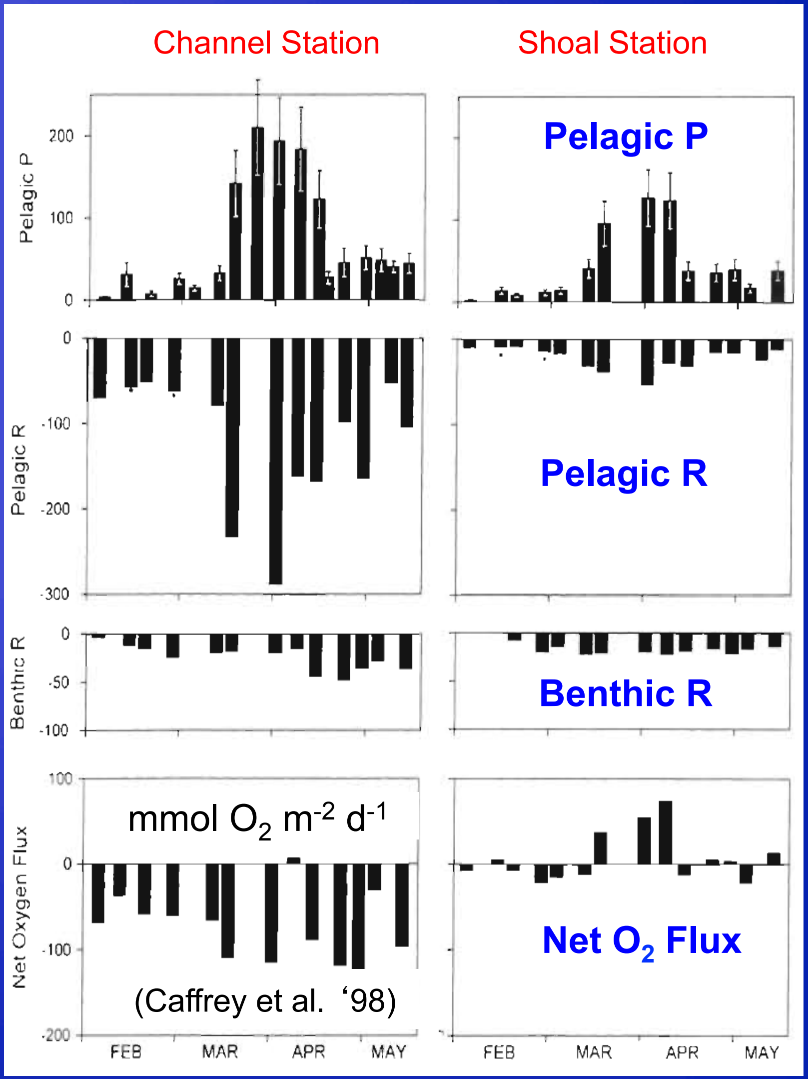
Factors Controlling Estuarine & Coastal NEP: DIN:TOC Ratio of Riverine Inputs



- DIN stimulates Autotrophy
- TOC stimulates Heterotrophy

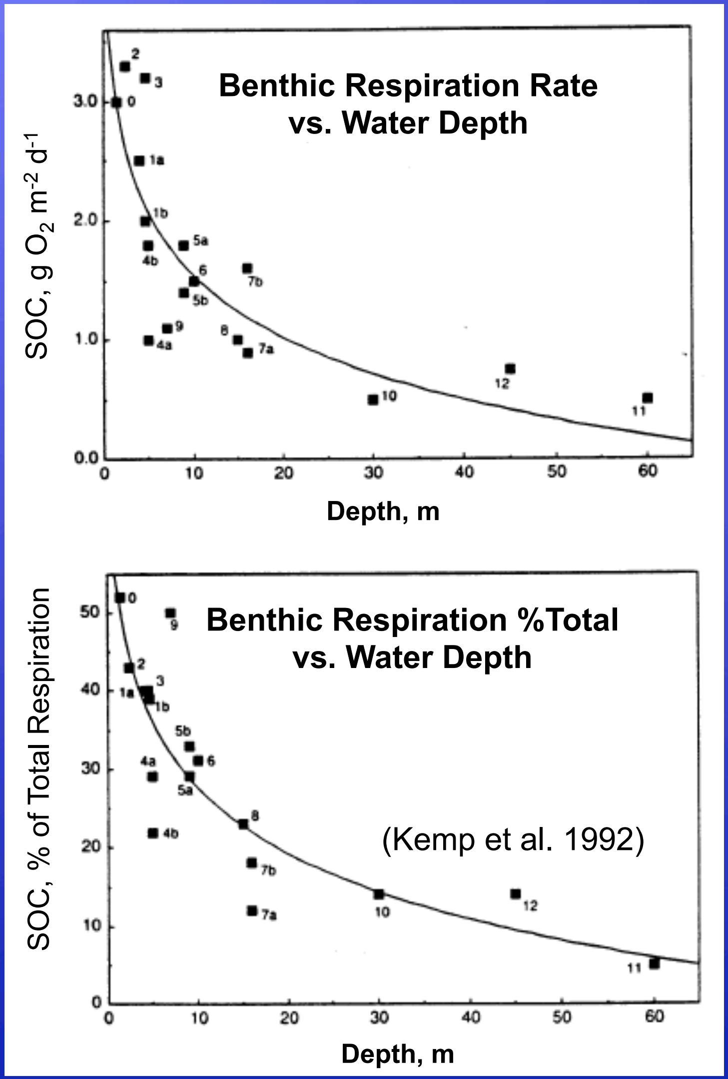
Factors Controlling NEP: Water Column Depth

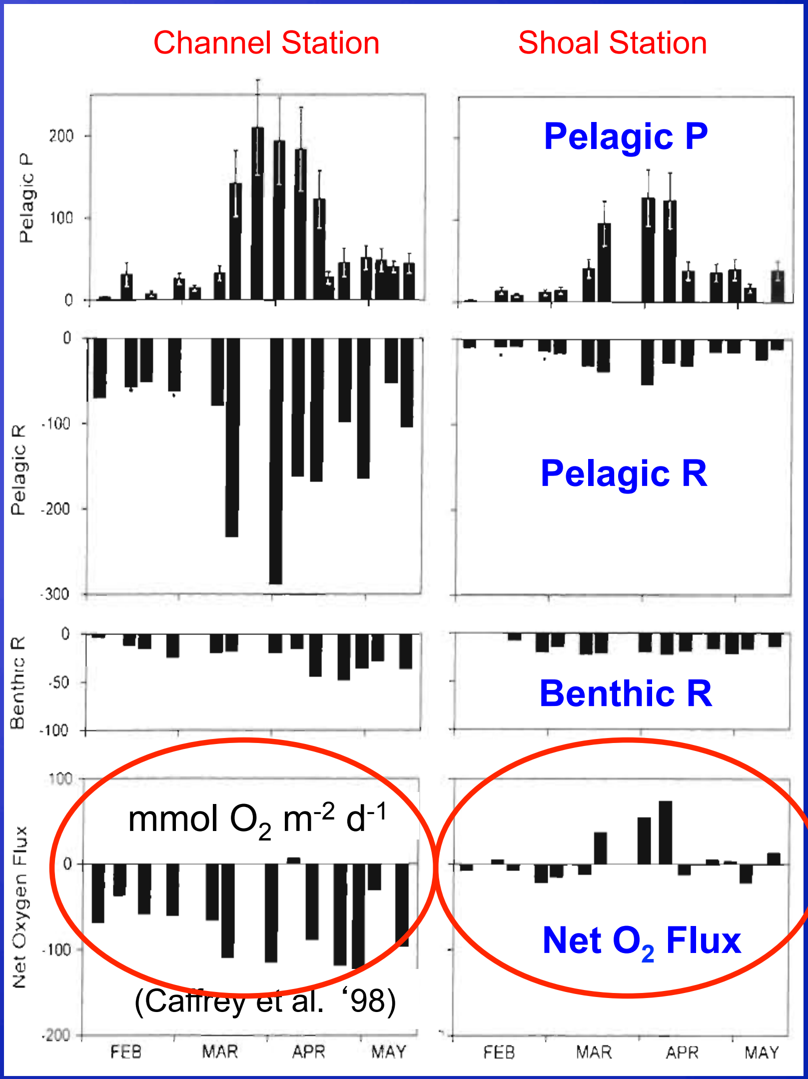




- Significant relationship across diverse systems
- However, lots of scatter among data

Factors Controlling NEP: Water Column Depth





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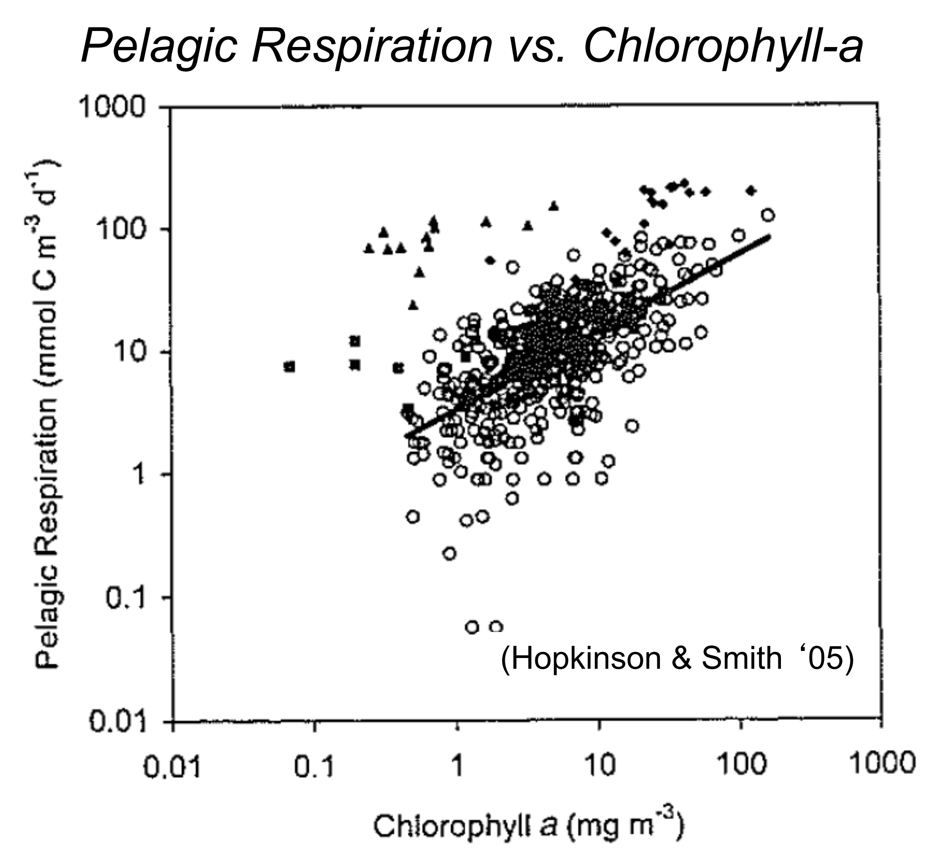
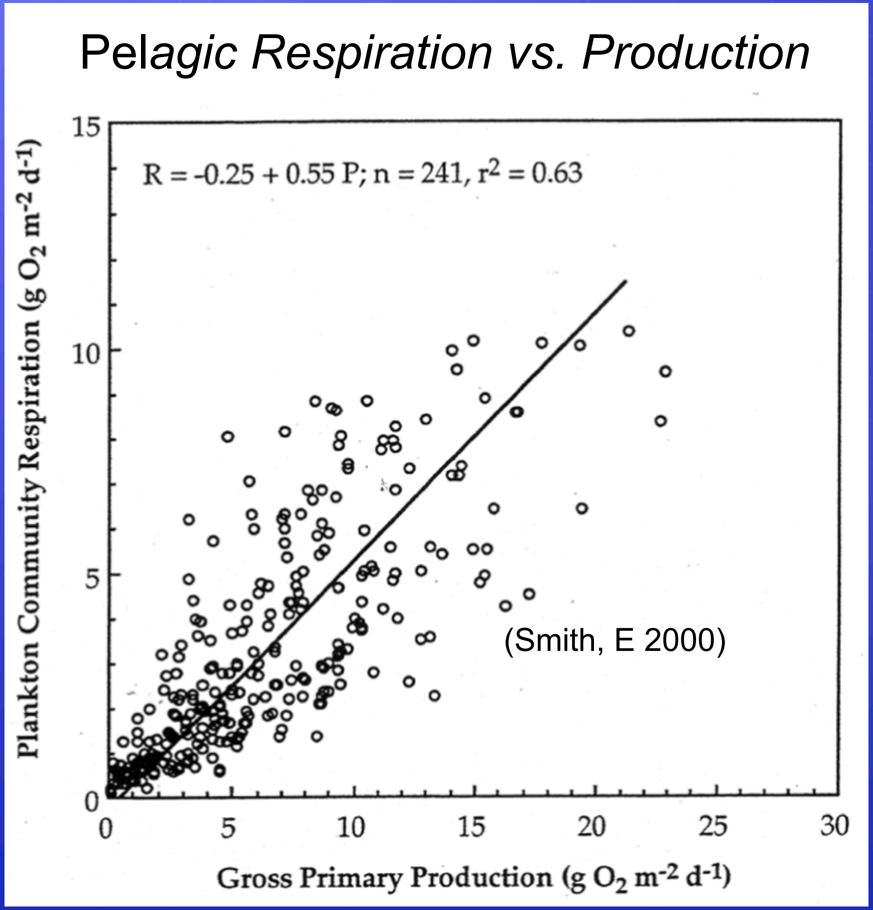
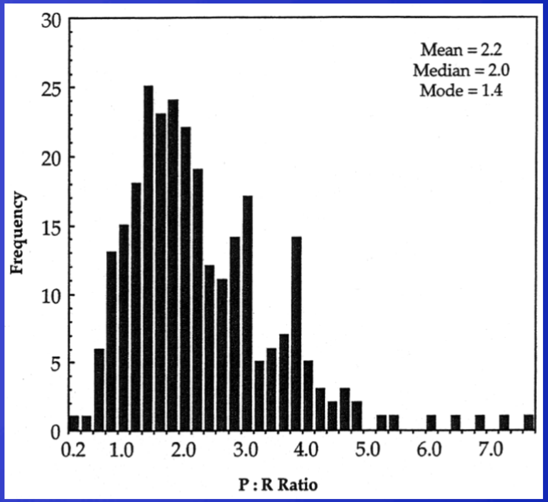
Factors Controlling Estuarine & Coastal NEP: Pelagic Respiration & Labile TOC



- **Significant relationship across diverse systems**
- **However, lots of scatter among data**

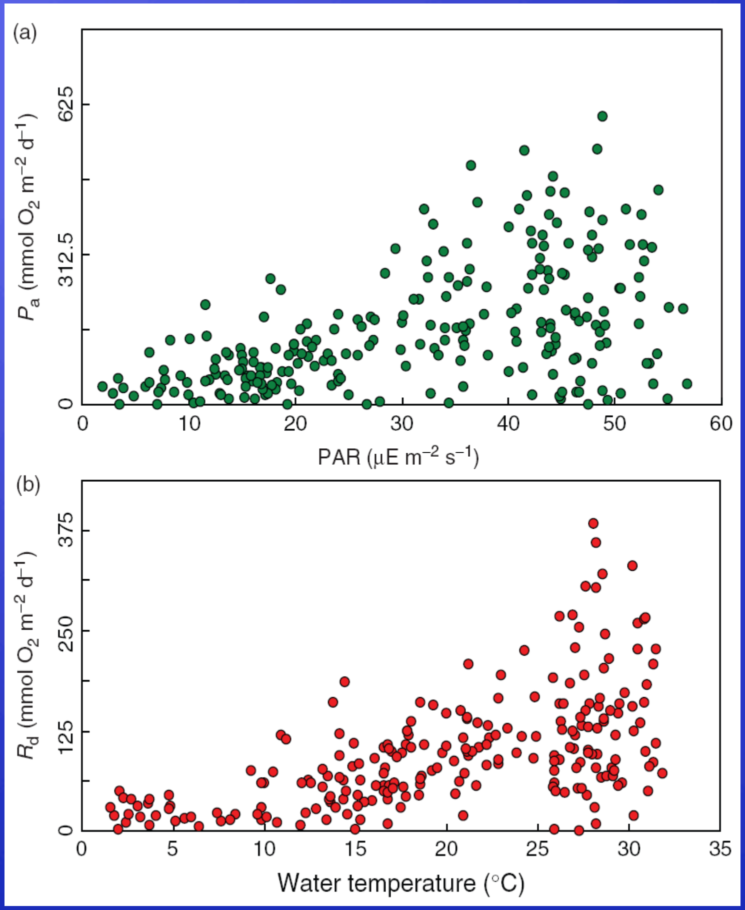
Factors Controlling Estuarine & Coastal NEP: Pelagic Respiration and Labile TOC





- Significant relationship across time & space
- However, lots of variance in P/R ratio (from 1 - 5)

Factors Controlling Estuarine & Coastal NEP: Light and Temperature Effects on P and R



(Kemp & Testa 2011)

- **Daytime NEP and Night NEP are proportional to Light & Temperature.**
- **But relationships are highly variable.**

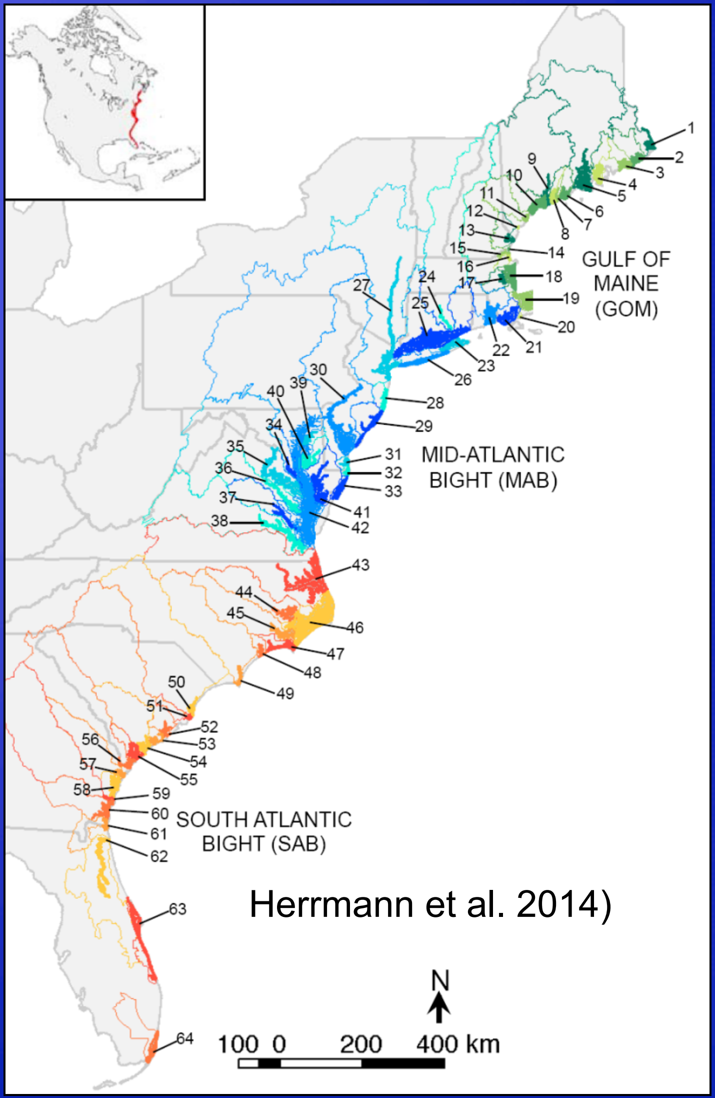
Estuarine C-Budget for East Coast USA: Preliminary Analysis

Estuarine C-Budget for East Coast USA

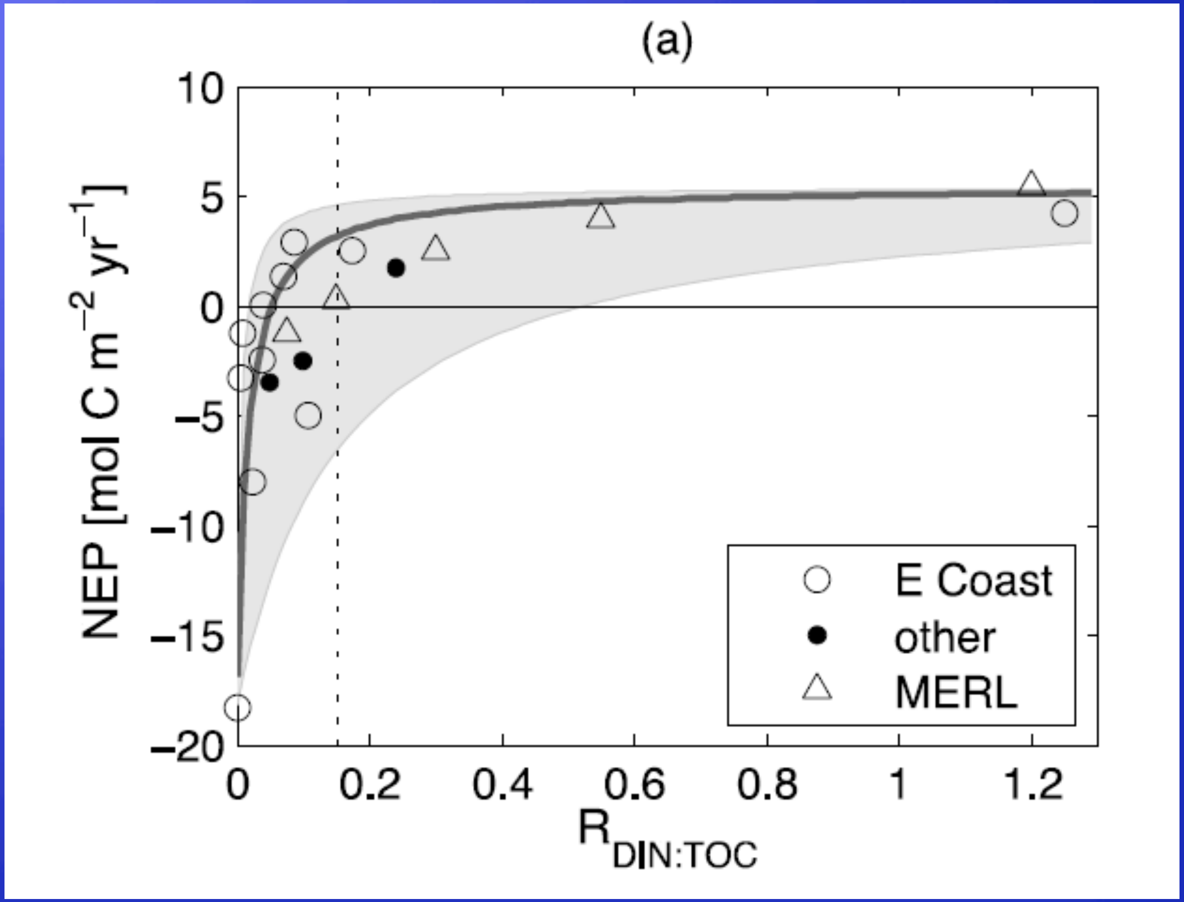
Follow-up from VIMS Workshop in Feb 2012 led to manuscript in review for *GBC* (Herrmann et al 2014)

Study area: East coast of USA divided into 3 regions:

- Gulf of Maine (GOM)
- Mid-Atlantic Bight (MAB)
- South Atlantic Bight (SAB)

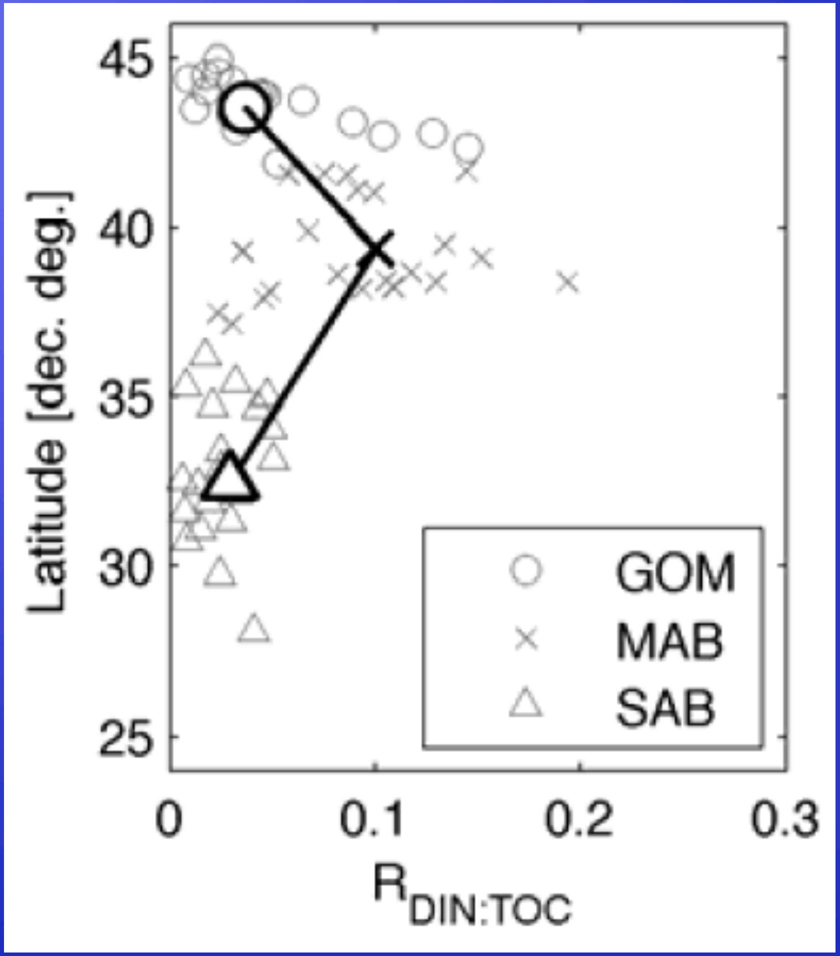


Estuarine C-Budget for East Coast USA



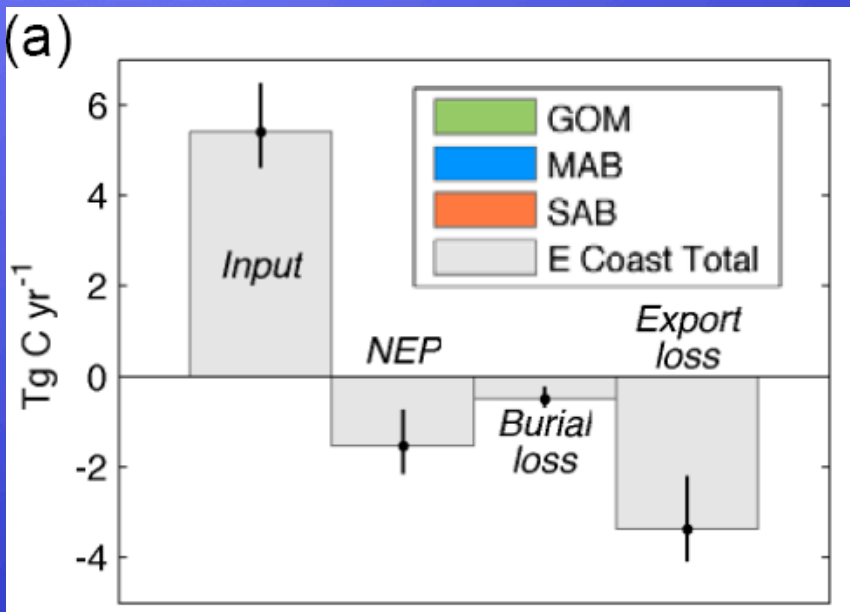
- Data added for other estuaries relating NEP vs. DIN:TOC
- Good fit, but sharp hyperbolic tangent relationship

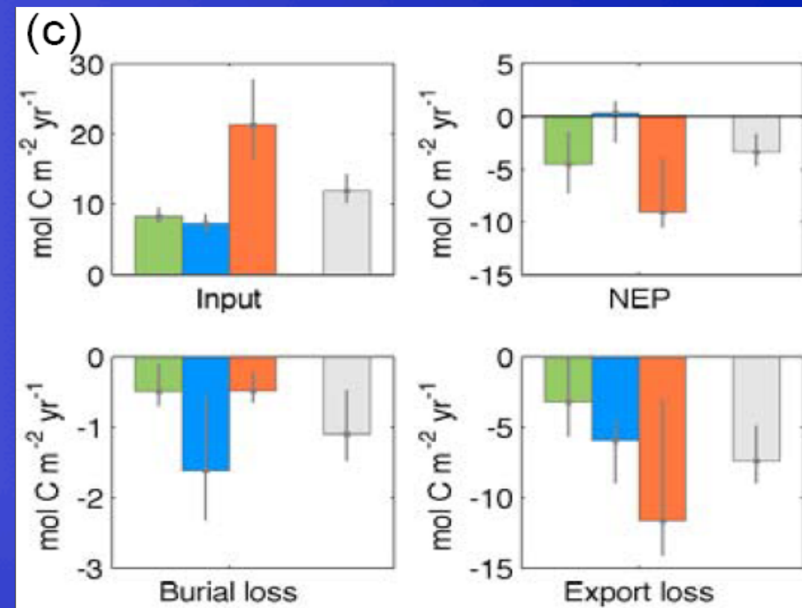
Estuarine C-Budget for East Coast USA



- **Distinct pattern of higher DIN:TOC in Mid Atlantic region**

Estuarine C-Budget for East Coast USA

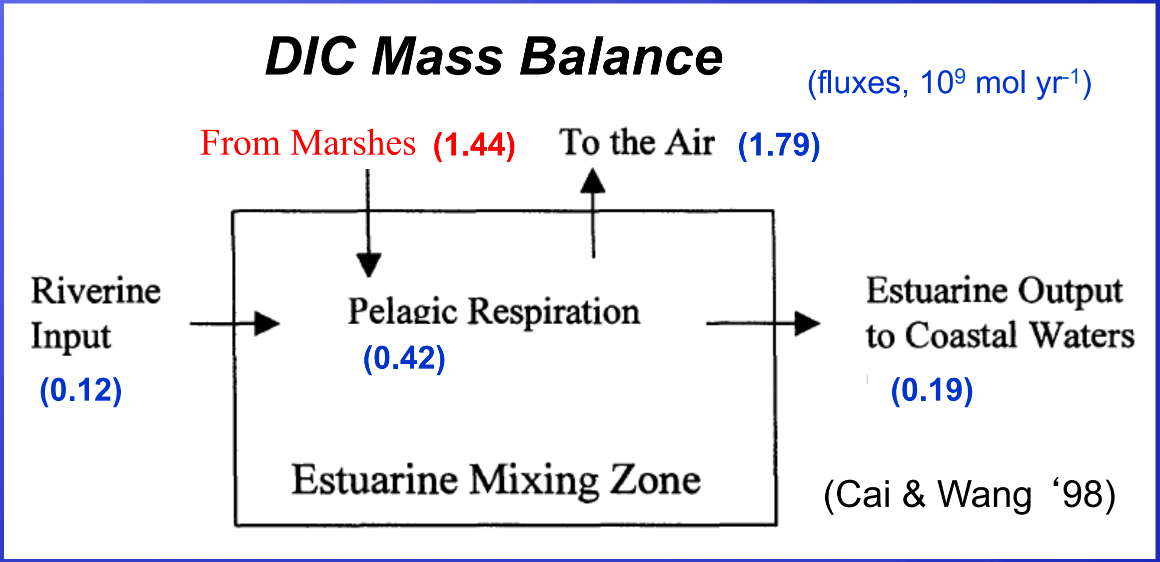




- Simple mass-balance model for 4 fluxes, Input, NEP, Burial, Export
- Only 2 fluxes within the estuary, with NEP 3.5 x Burial
- MAB NEP is slightly autotrophic, GOM & SAB are heterotrophic
- Both NEP and Burial contribute to estuary sink for Riverine Carbon

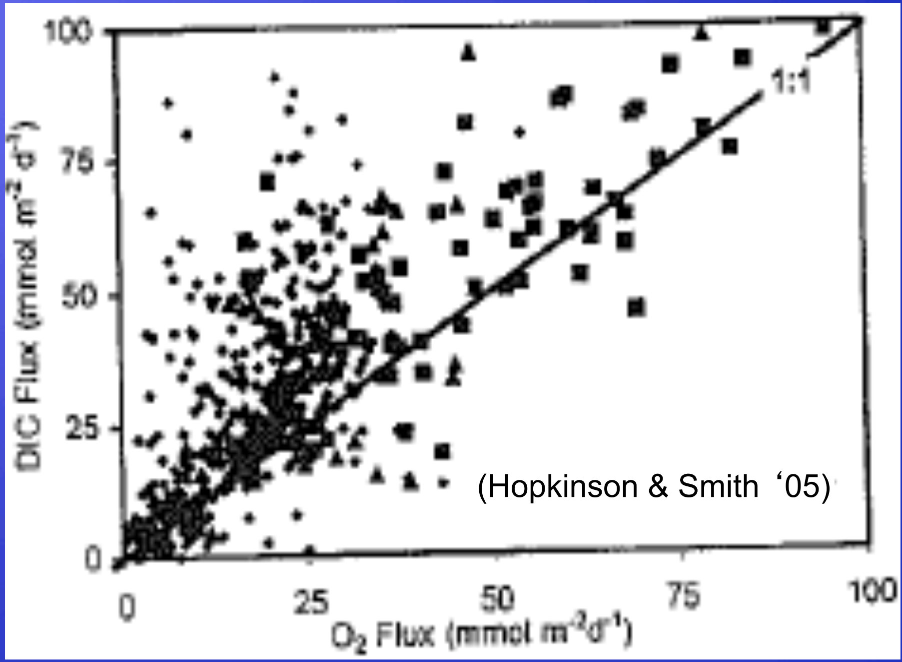
Epilogue: Other Considerations

Other Considerations: How to Measure Exchanges with Adjacent Wetlands



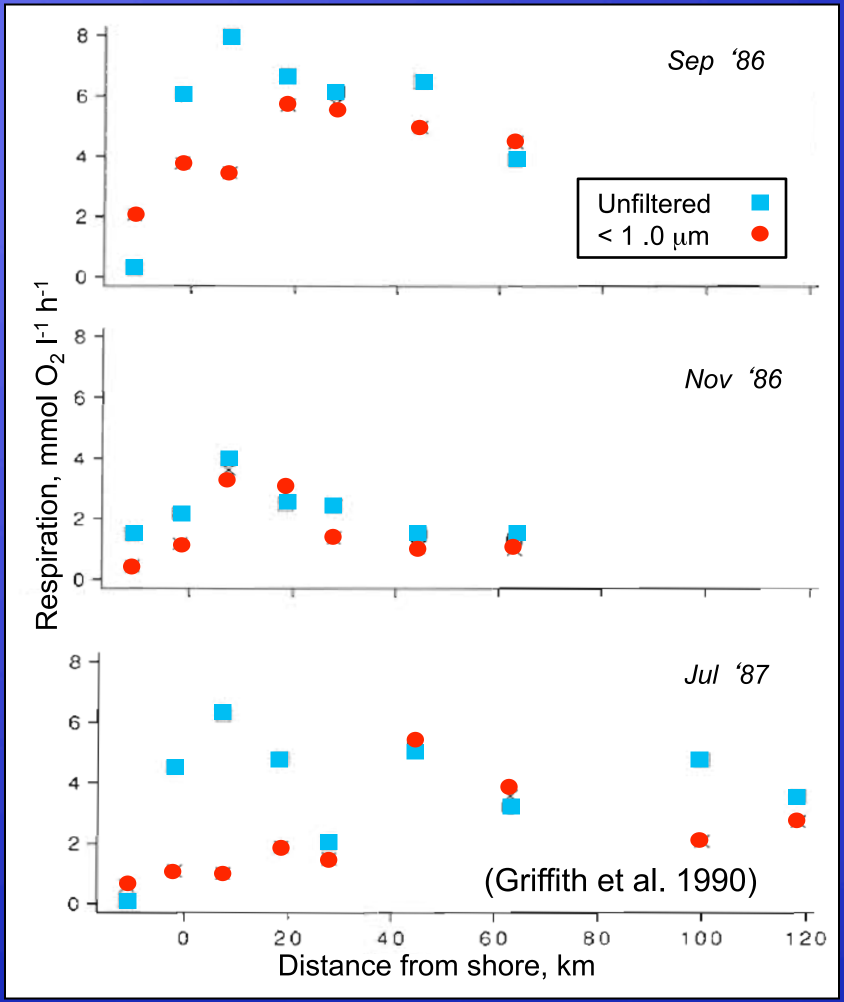
- **Wetland sources dominate the input side of Estuary DIC budget.**
- **What about Wetland sources of TOC and low-O_2 water?**
- **How can these fluxes be broadly quantified?**
- **How do the affect the Total carbon budget?**

Other Considerations: Benthic Respiration and Sulfide Burial



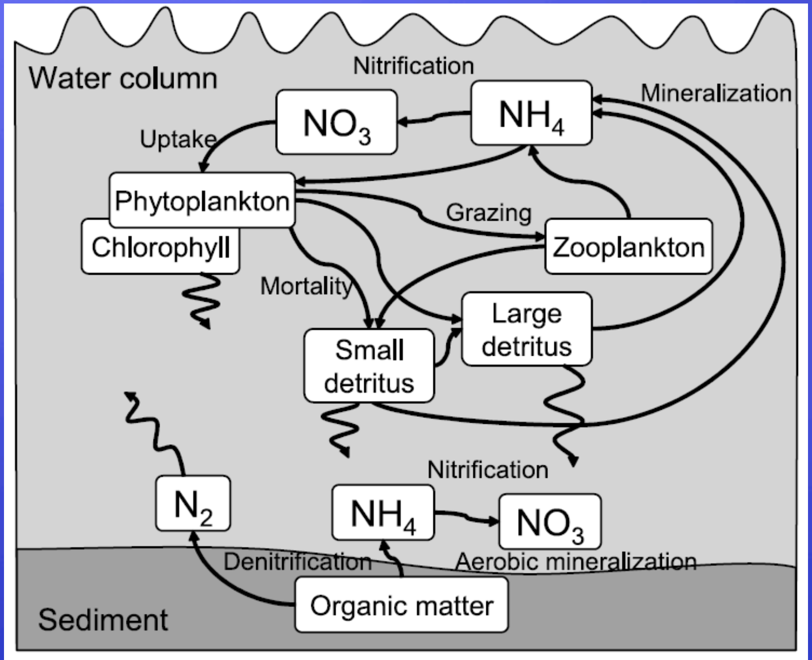
- **Anaerobic sulfate reduction causes O_2 flux to underestimate respiration**
- **Need ~ 10% correction for O_2 annual rates; more for seasonal rates**

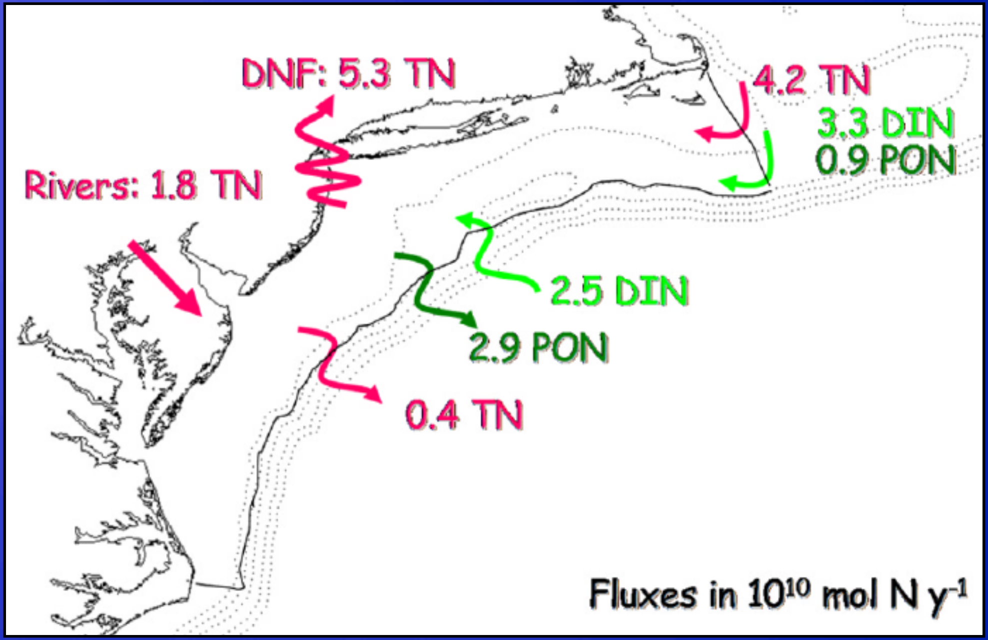
Other Considerations: Pelagic Respiration Trends



- **Peak pelagic respiration at 10 km from shore with gradual decline seaward.**
- **Bacterioplankton account for most pelagic respiration.**

Other Considerations: Can Numerical Models Compute Dependable C-Fluxes & Budgets





- Generating C, N budgets are undervalued outputs from numerical models.
- Many well-calibrated models represent state of bio-geo-physical knowledge.
- Empirical mass-balance for shelf control-volumes are difficult to constrain.

Concluding Comments

Current Status:

- Many methods available for estimating estuarine & shelf NEP.
- Possible general NEP gradient in estuaries from net heterotrophy in brackish waters to net autotrophic at high salinity zone.
- Need to expand effort for estimating NEP on shelf systems.
- Significant relations between NEP and physical or chemical factors, but variance complicates statistical scaling-up.

Challenges for Future:

- Effects of wetland C & O,exchange need to be quantified scaled-up.
- Need more NEP and C burial data and analyses for shelf systems.
- Need to find way to apply numerical bio-geo-physical models to quantify C-budgets for select estuary and shelf systems, and use to extrapolate across a broader sample of systems.

Epilogue: Other Considerations

- **Fluxes of DIC, TOC, and low-O_2 between estuary and Wetland?**
- **Sediment-water O2 fluxes underestimate benthic respiration?**
- **What are general NEP trends from river to shelf break?**
- **Can Bio-geo-physical models be useful for calculating integrated C fluxes and budgets?**

NEP Concepts & Approaches in Aquatic Science

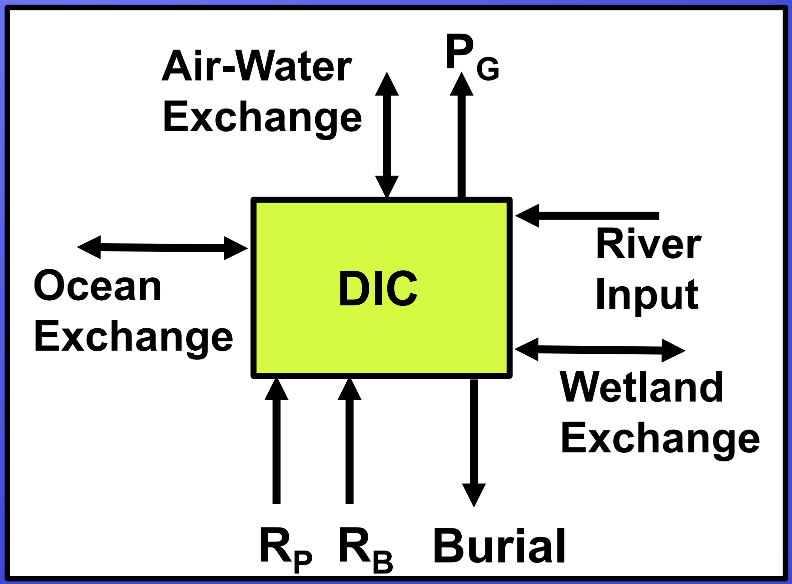
Key Early Researchers:

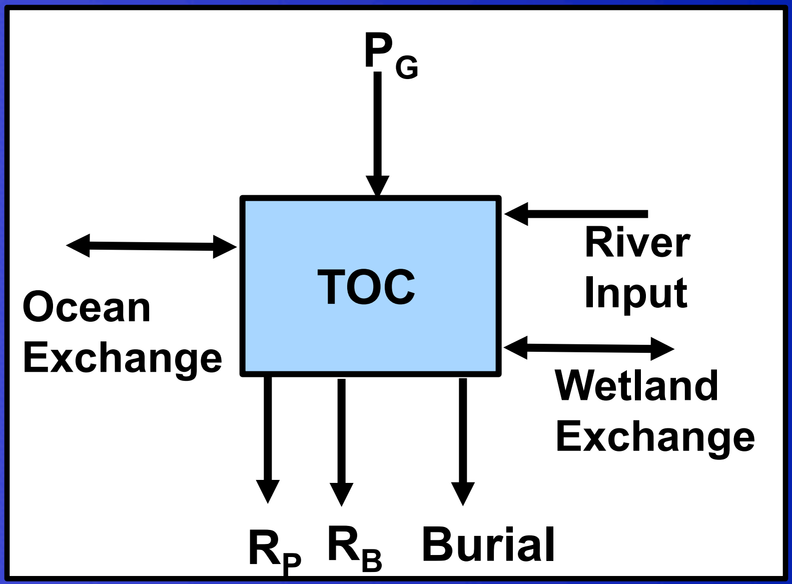
- Tomas Gaarder & H.H. Gran
- Chancy Juday
- Gordon Riley
- G.E. Hutchinson
- H.T. Odum

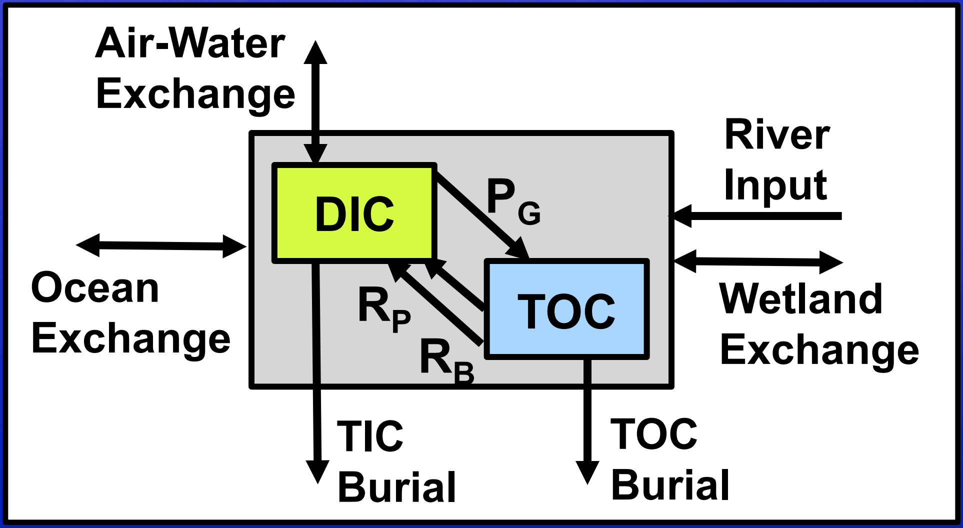
Approaches:

- Clear & Dark Bottles & Chambers
- AOU: Apparent Oxygen Utilization
- AHOD: Areal Hypolimnion O_2 Deficit
- Open-Water Diel O_2 (DIC) Variations
- Chemical Mass-Balance Models

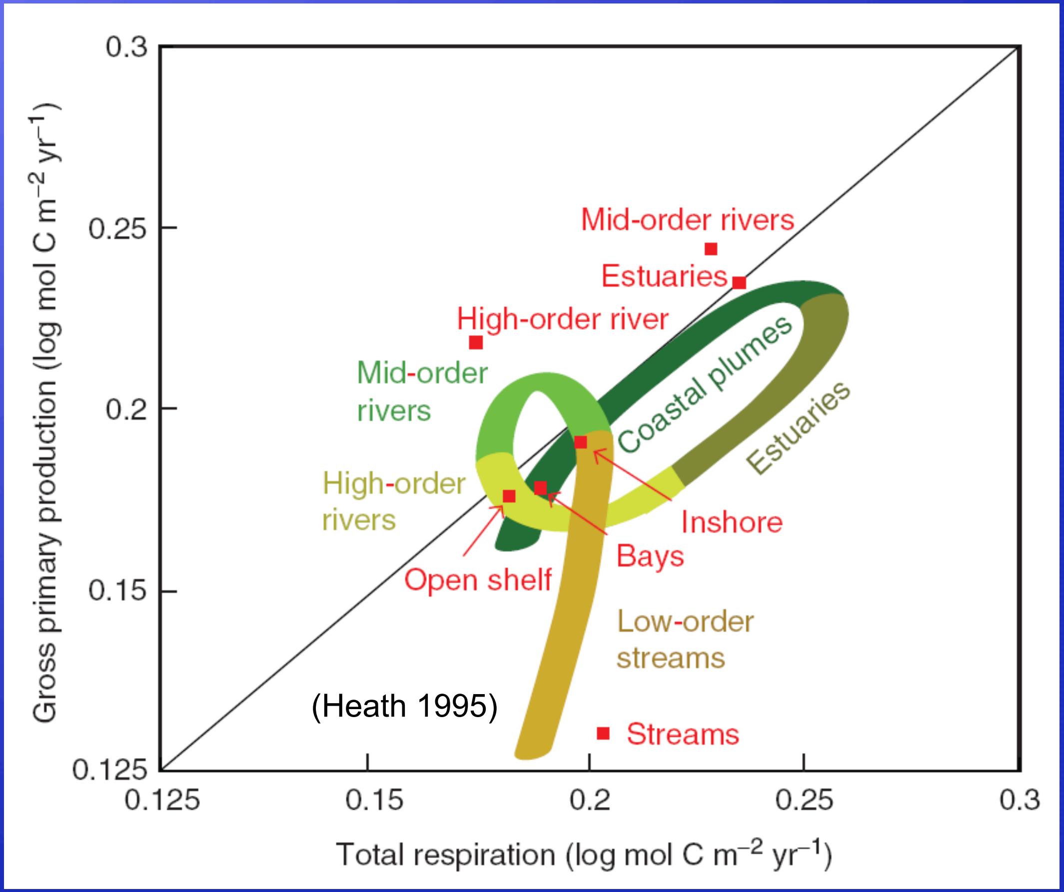
Estuarine Carbon Budget Conceptual Diagrams



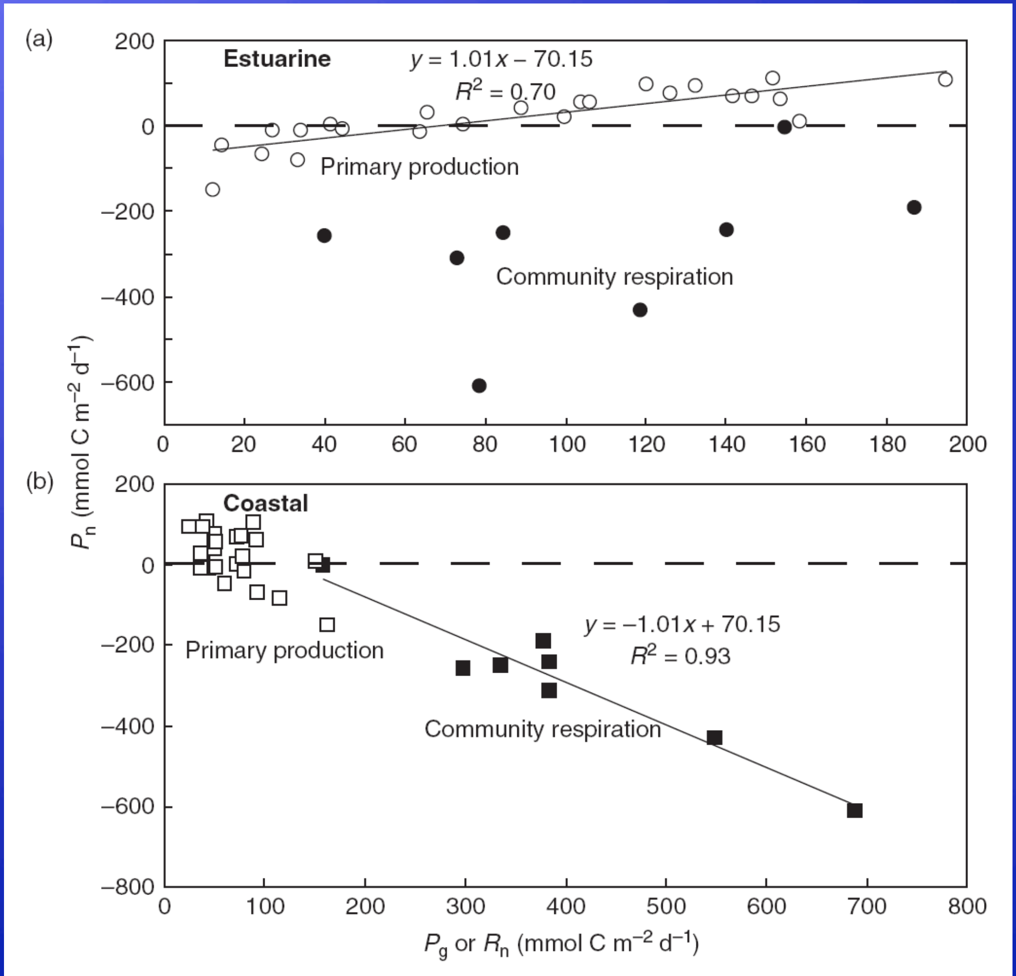




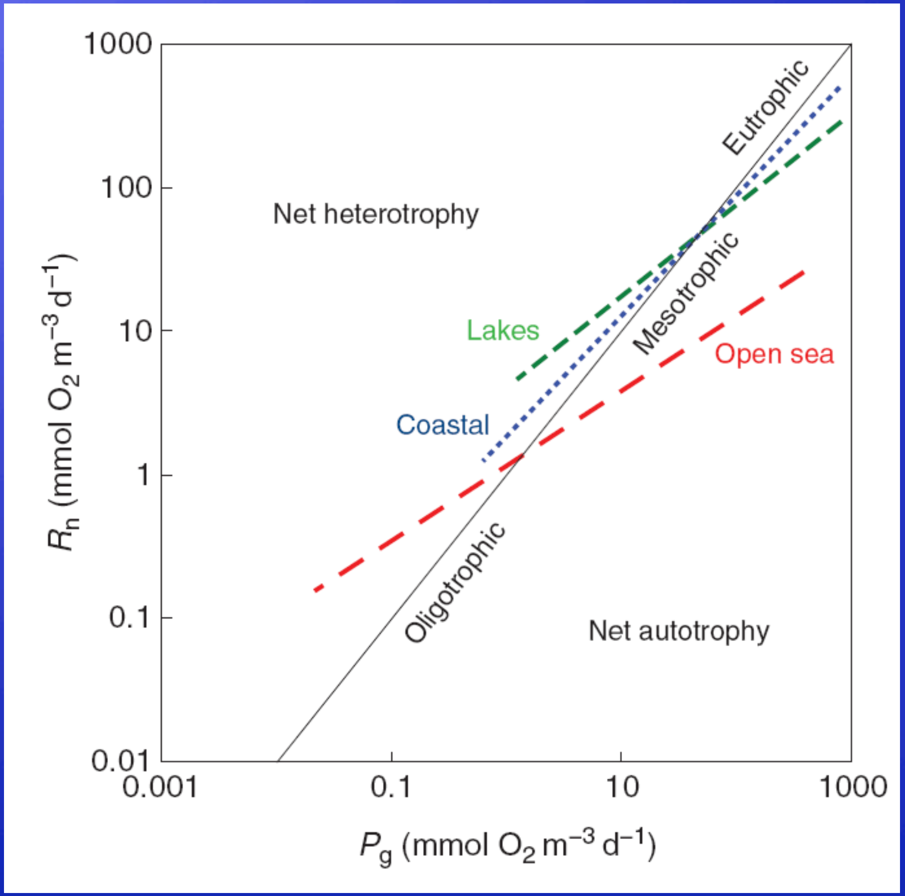
Other Considerations: NEP (P:R) Trends Across the Watershed-Ocean Transect



- **Significant relationship across diverse systems from streams to open shelf.**
- **However, trends are highly non-linear.**
- **Are there simpler monotonic trends from head of estuary to shelf break?**



(Kemp & Testa 2011)



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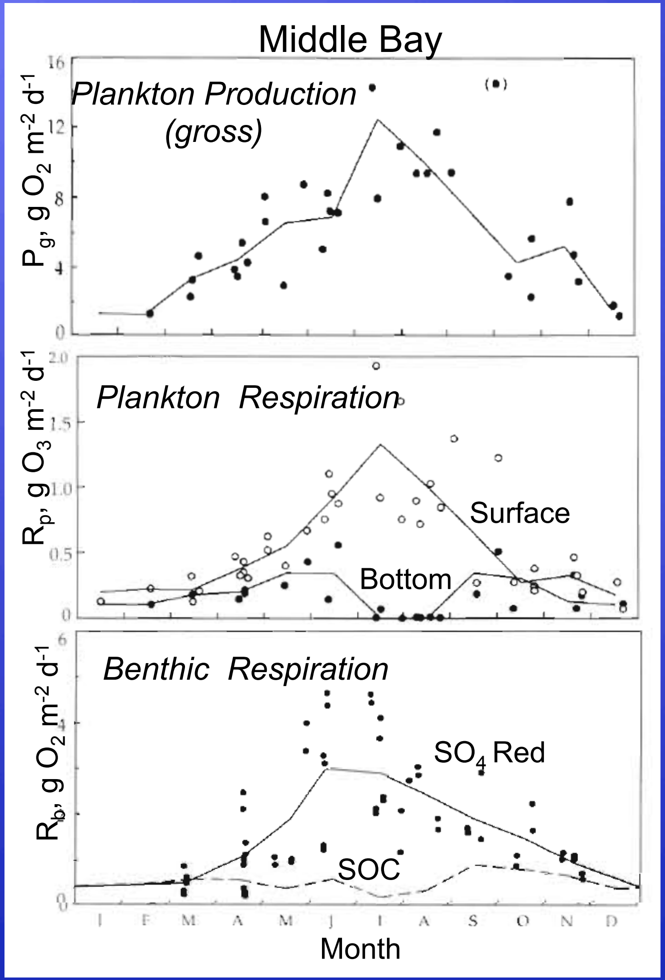
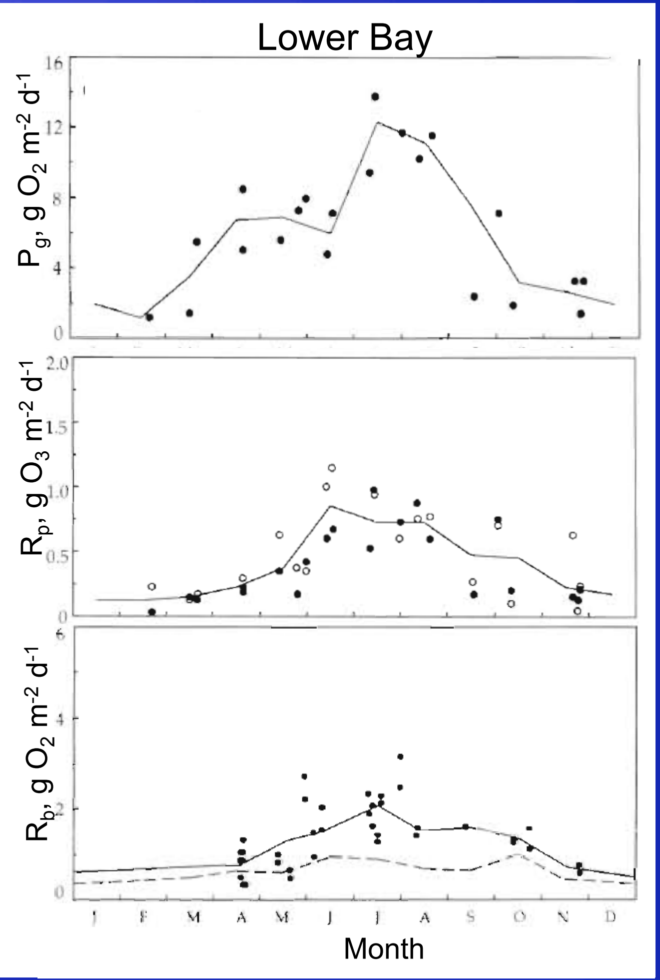
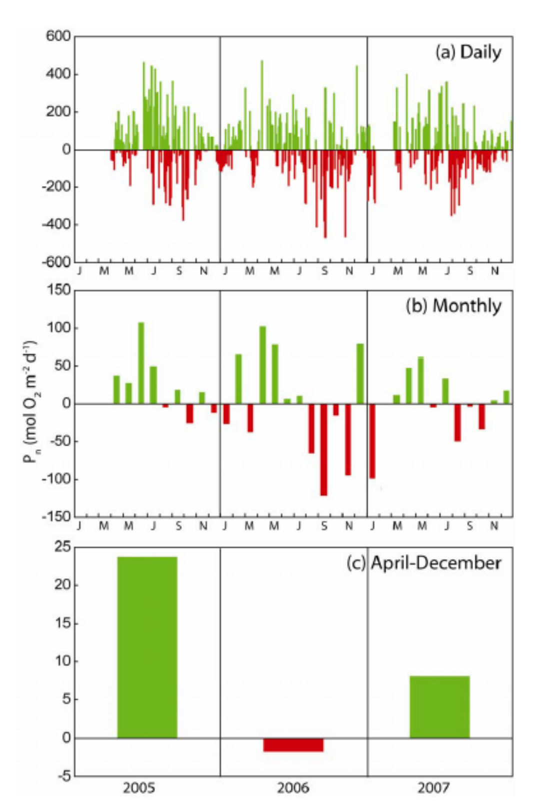
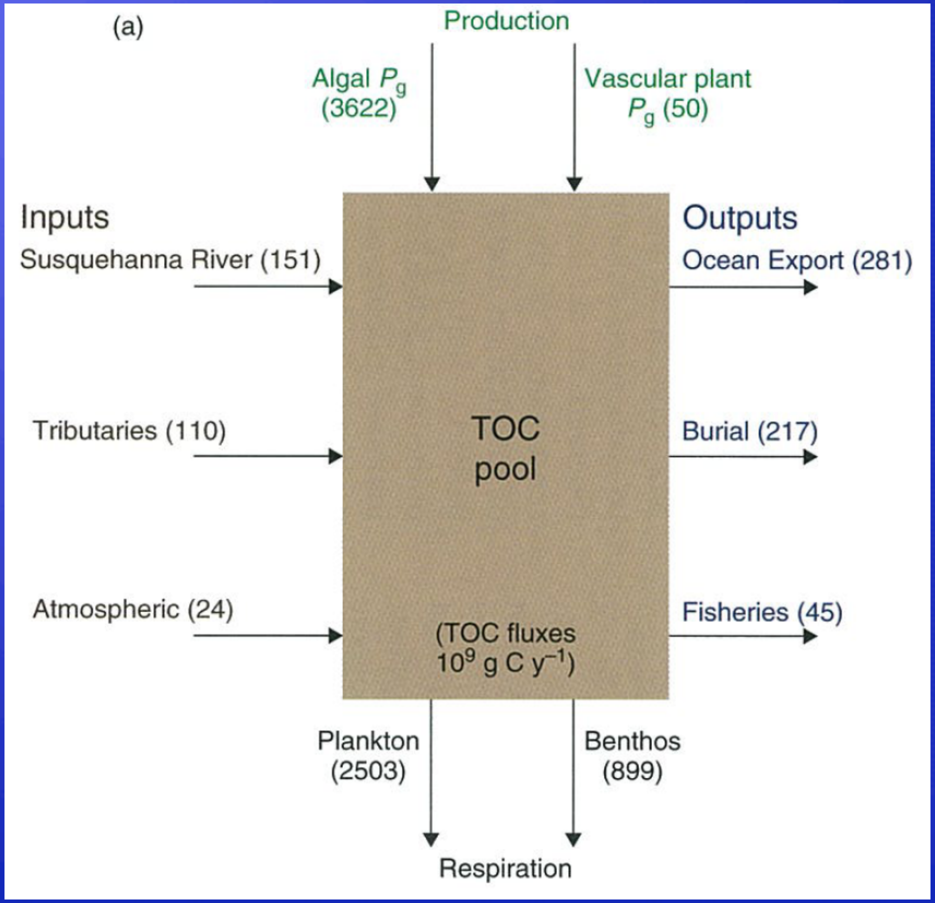

Middle Bay
Plankton Production (gross)
P_g, g O_2 m^{-2} d^{-1}
Plankton Respiration
Surface
Bottom
R_p, g O_3 m^{-2} d^{-1}
Benthic Respiration
SO_4 Red
SOC
R_b, g O_2 m^{-2} d^{-1}
J F M A M J J A S O N D
Month


Lower Bay
P_g, g O_2 m^{-2} d^{-1}
R_p, g O_3 m^{-2} d^{-1}
R_b, g O_2 m^{-2} d^{-1}
J F M A M J J A S O N D
Month

Open-Water Diel Variations in O_2 (or DIC)



(Testa et al. 2013)



(after Kemp et al. 1997)

Factors Controlling Estuarine & Coastal NEP:

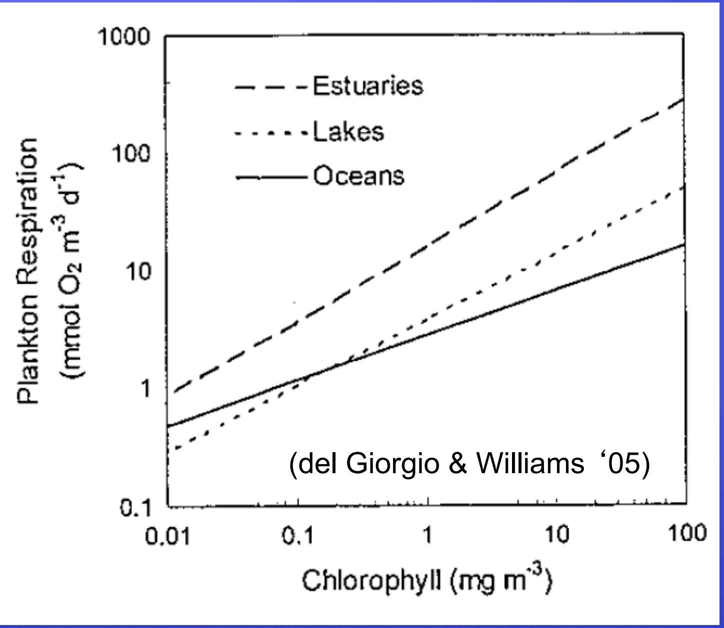


Table 14.2 Comparison of the rates of benthic and pelagic respiration in the major aquatic ecosystems. Rates as mmol Cm^{-2} d^{-1}

(del Giorgio & Williams '05)	Pelagic respiration	Benthic respiration	Benthic as % pelagic respiration
Lakes	71	11	15
Estuaries	114	34	30
Coastal ocean	109	19	17
Open ocean	105	1.6	1.5