The Impact of Bivalves on Carbon Cycling in the Chesapeake Bay

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Integrated Analysis Team (ITAT) Workgroup Meeting

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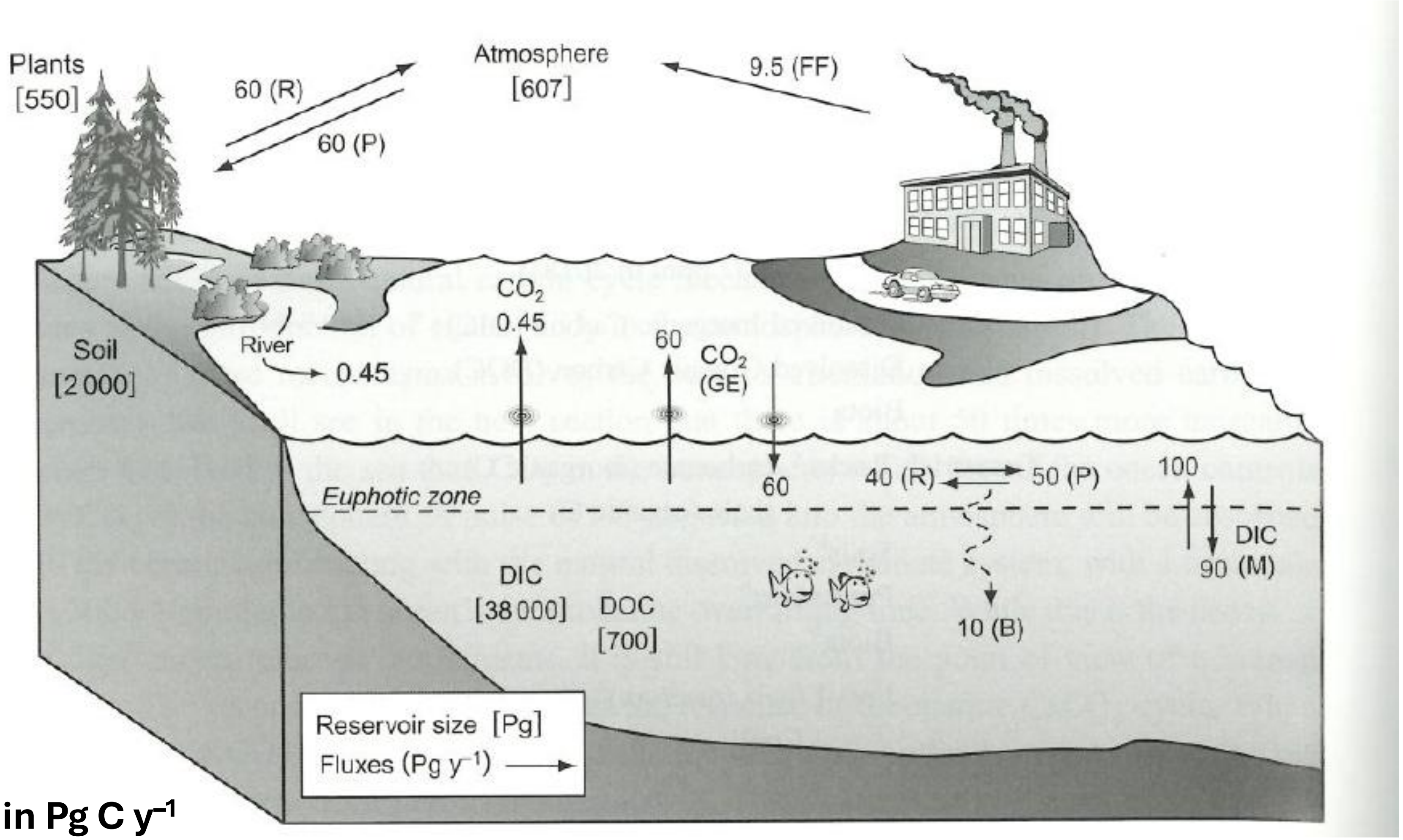
Science. Restoration. Partnership.

Our conceptualization of global carbon cycling often ignores the impact of estuaries and coastal waters

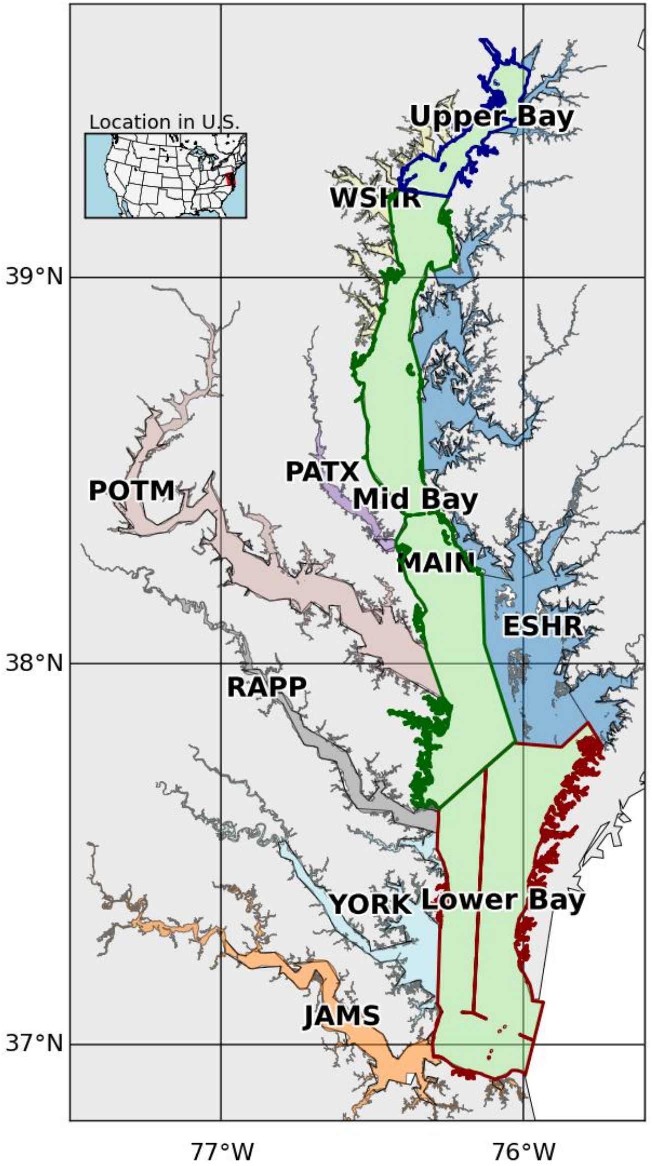


Fluxes in Pg C y^{-1}

[ ] = pre-anthropogenic, R = respiration, P = photosynthesis, FF = fossil fuel and cement production, GE = gas exchange, B=biological pump (export) flux, M=mixing between surface and deep ocean

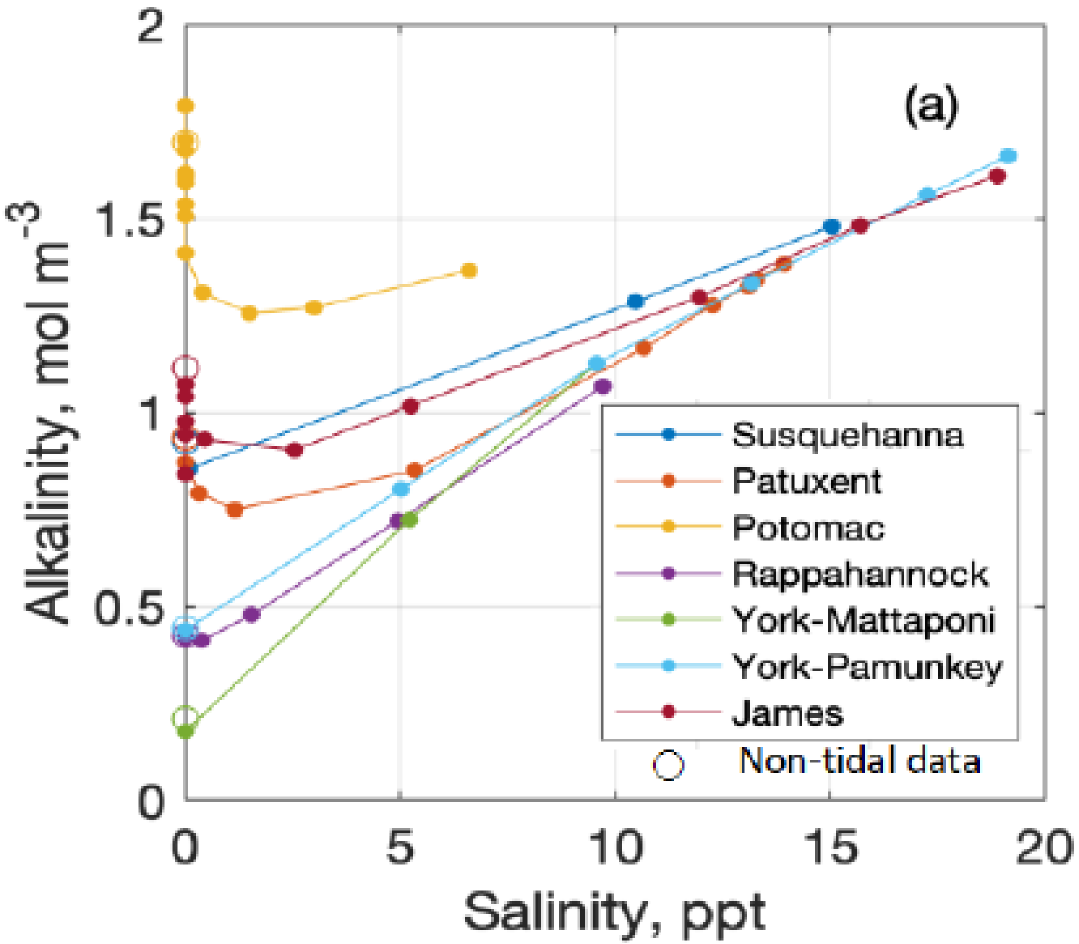
Figure 8.1 in Emerson and Hamme (2022)

The Chesapeake Bay spans the range of carbon and alkalinity dynamics seen in estuaries worldwide



$$\text{Dissolved Inorganic Carbon} = [HCO_3^-] + [CO_3^{2-}] + [CO_2]$$

$$\text{Carbonate Alkalinity} \approx [HCO_3^-] + 2[CO_3^{2-}]$$



Najjar et al. (2020)

Research questions:

1) To what extent do benthic macrofauna contribute to estuarine carbon cycling via respiration and calcification, and how might these contributions vary across space?

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Research article

Benthic macrofaunal carbon fluxes and environmental drivers of spatial variability in a large coastal-plain estuary

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Abstract. While the importance of carbon cycling in estuaries is increasingly recognized, the role of benthic macrofauna remains poorly quantified due to limited spatial and temporal resolution in biomass measurements. Here, we ask: (1) To what extent do benthic macrofauna contribute to estuarine carbon cycling via respiration and calcification? and (2) How well can routinely collected environmental variables predict their biomass? We analyzed data from 8128 benthic samples collected from the Chesapeake Bay between 1995 and 2022 and estimated associated carbon fluxes using empirical relationships. We then used generalized additive models to relate observed and modeled environmental variables to the biomass. Biomass was highest in the upper mainstem of the Bay (Upper Bay) and upper Potomac River Estuary, the largest tidal tributary of the Bay. In the Upper Bay, benthic macrofauna respired 18 %–45 % of the

findings demonstrate that benthic macrofauna play a substantial and spatially structured role in estuarine carbon cycling. Incorporating their contributions into estuarine biogeochemical models will improve predictions of ecosystem responses to environmental and anthropogenic change.

1 Introduction

Benthic macrofauna are vitally important to estuarine ecosystems by improving water quality, producing and consuming organic matter, recycling nutrients, cycling pollutants, stabilizing and transporting sediment, and providing food for both human populations and estuarine organisms

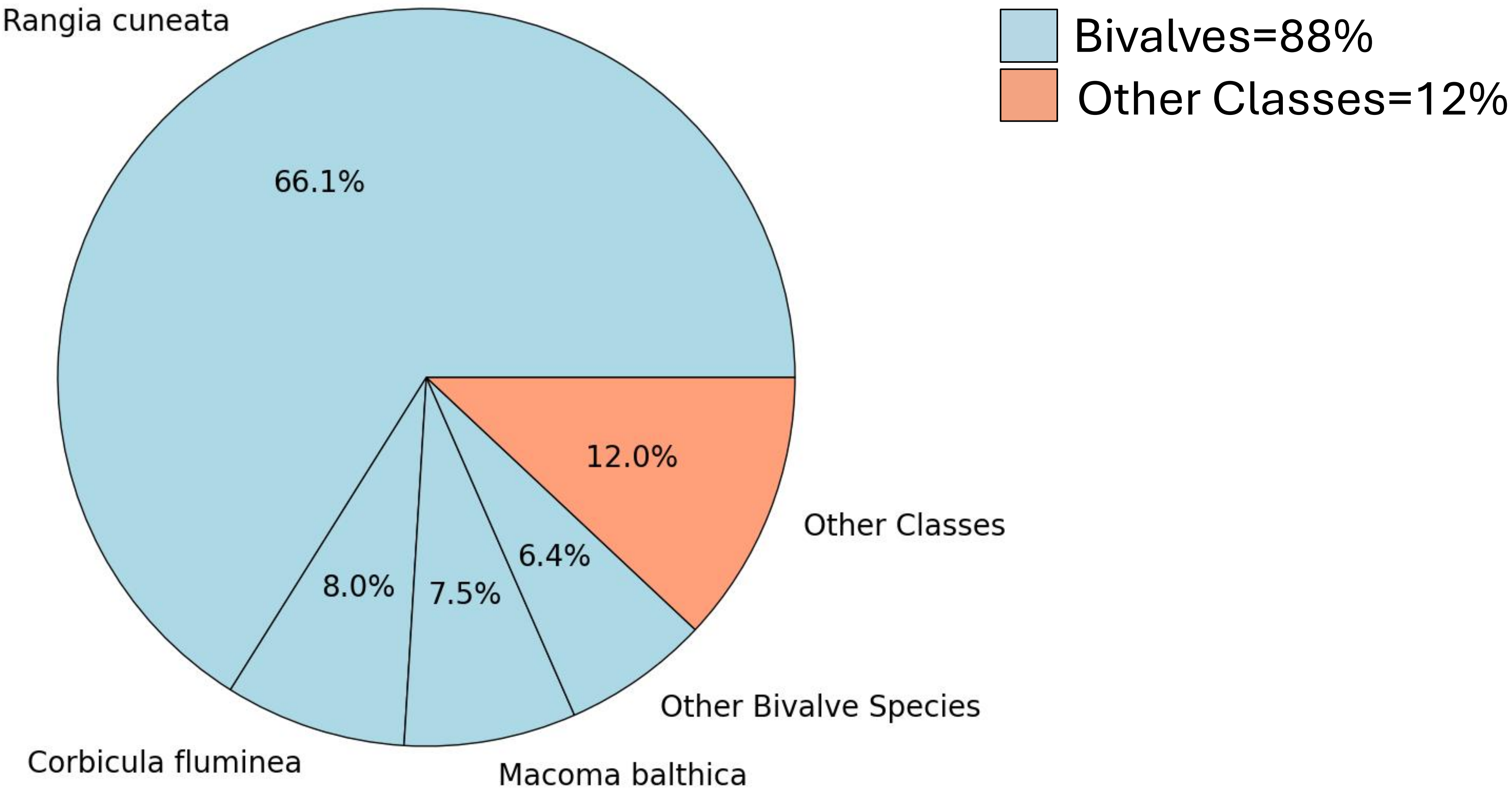
Calcifying bivalves dominate the benthic macrofauna in the Bay

Rangia cuneata

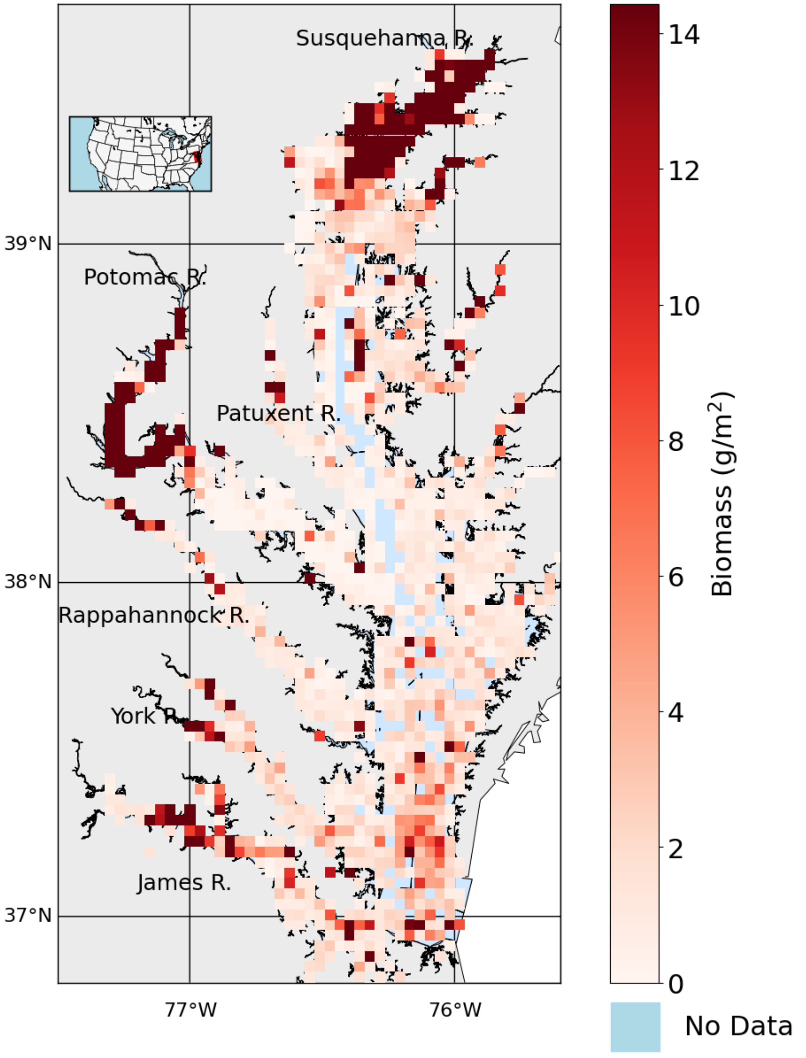
Photo by Robert Aguilar, SERC, (MBP list).

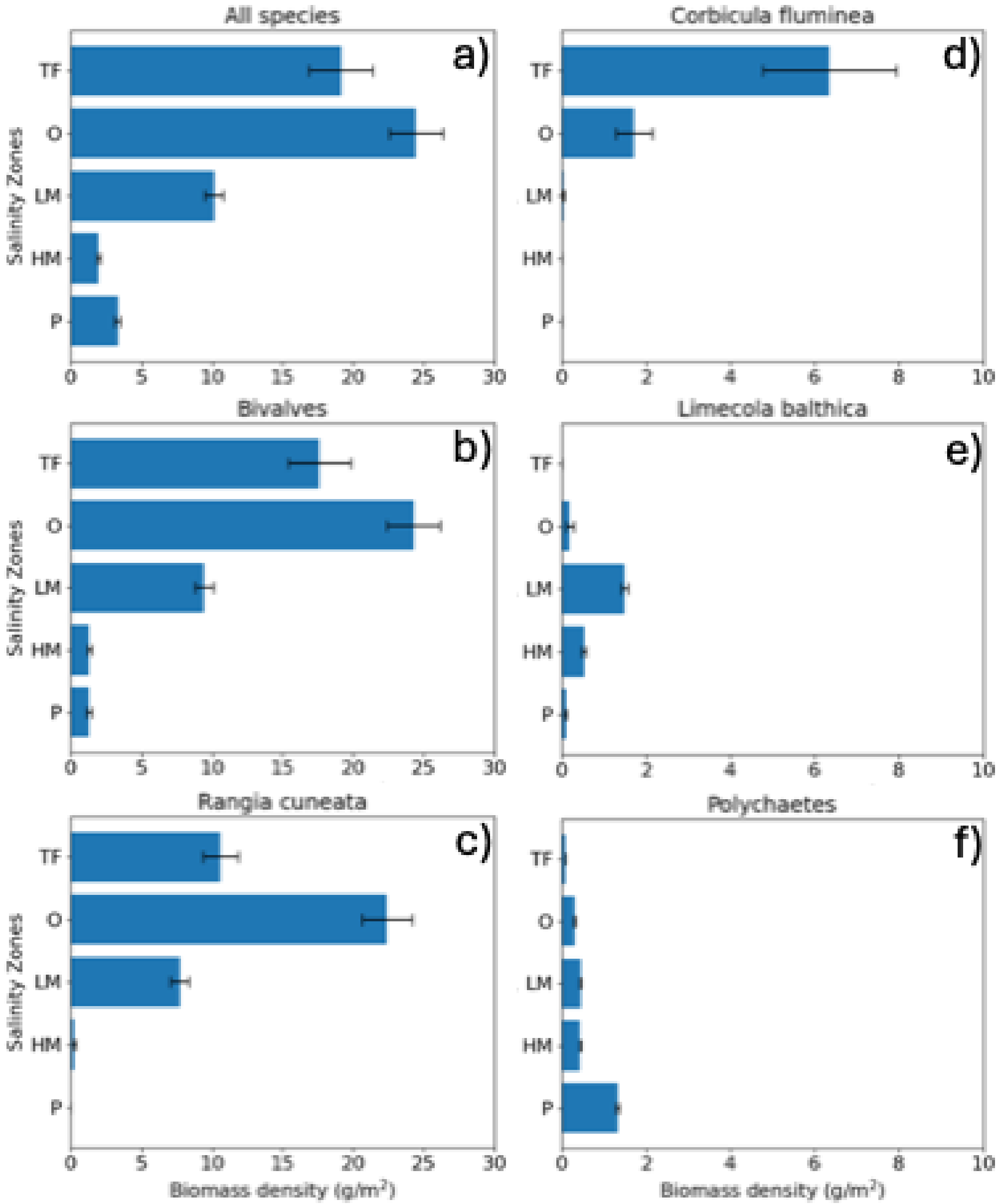
Corbicula fluminea

USGS - http://cars.er.usgs.gov/pics/nonindig_misc_mollusks/bivalves/bivalves_1.html retrieved 2024-08-28



These bivalves are concentrated in the tidal fresh and oligohaline zones of the Upper Bay and Potomac River





TF (Tidal Freshwater) 0-0.5 ppt
OH (Oligohaline) ≥0.5-5 ppt
LM (Low Mesohaline) ≥ 5-12 ppt
HM (High Mesohaline) ≥ 12-18 ppt
P (Polyhaline) ≥ 18 ppt

Benthic biomass can be quantitively linked to carbon fluxes

- Secondary Production

  $C_6H_{12}O_6 \rightarrow$ biomass

- Calcification

  $Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$

- Respiration

  $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + H_2O$

Alkalinity –
DIC –

Alkalinity ↓
DIC ↓

Alkalinity –
DIC ↑

Benthic biomass can be quantitively linked to carbon fluxes

- Secondary Production

  $C_6H_{12}O_6 \rightarrow$ biomass

$$\boldsymbol{S_1} = \alpha B_c$$

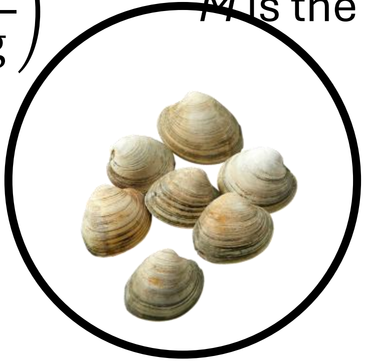
where α is the specific growth rate and B_c is carbon-based biomass (units of g C m^{-2})

$$\boldsymbol{S_2} = S_0 \left(\frac{B}{1\ \mathrm{g\ m^{-2}}}\right)^{0.87} \left(\frac{T}{1\ ^{\mathrm{o}}\mathrm{C}}\right)^{0.46}$$

where B is biomass(units of g m^{-2}), S_0 = 0.40 g C m^{-2} yr^{-1}

$$\log_{10}\left(\frac{\boldsymbol{S_3}}{1\ \mathrm{g\ C\ m^{-2}\ yr^{-1}}}\right) = \beta_0 + b\ \log_{10}\left(\frac{B}{1\ \mathrm{g\ m^{-2}}}\right) - m\ \log_{10}\left(\frac{M}{1\ \mathrm{mg}}\right) + t\ \left(\frac{T}{1\ ^{\mathrm{o}}\mathrm{C}}\right) - z\ \log_{10}\left(\frac{Z}{1\ \mathrm{m}} + 1\right)$$

where $\beta_0 = 0.24, b = 0.96, m = 0.21, t = 0.03, z = 0.16$, and M is the maximum individual body mass



Benthic biomass can be quantitively linked to carbon fluxes

- Calcification

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$$

$$\boldsymbol{C} = r_s S$$

where r_s is the ratio of shell $CaCO_3$ mass production to tissue organic C mass production, which has units of g $CaCO_3$ (g C)$^{-1}$

Benthic biomass can be quantitively linked to carbon fluxes

- Respiration

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + H_2O$$

$$\log_{10}\left(\frac{\boldsymbol{R}}{1\ \mathrm{kcal\ m^{-2}\ yr^{-1}}}\right) = \alpha_0 + s\log_{10}\left(\frac{S}{1\ \mathrm{kcal\ m^{-2}\ yr^{-1}}}\right)$$

where $s = 0.993$ and $\alpha_0 = 0.367$

Benthic biomass can be quantitively linked to carbon fluxes

- Respiration

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + H_2O$$

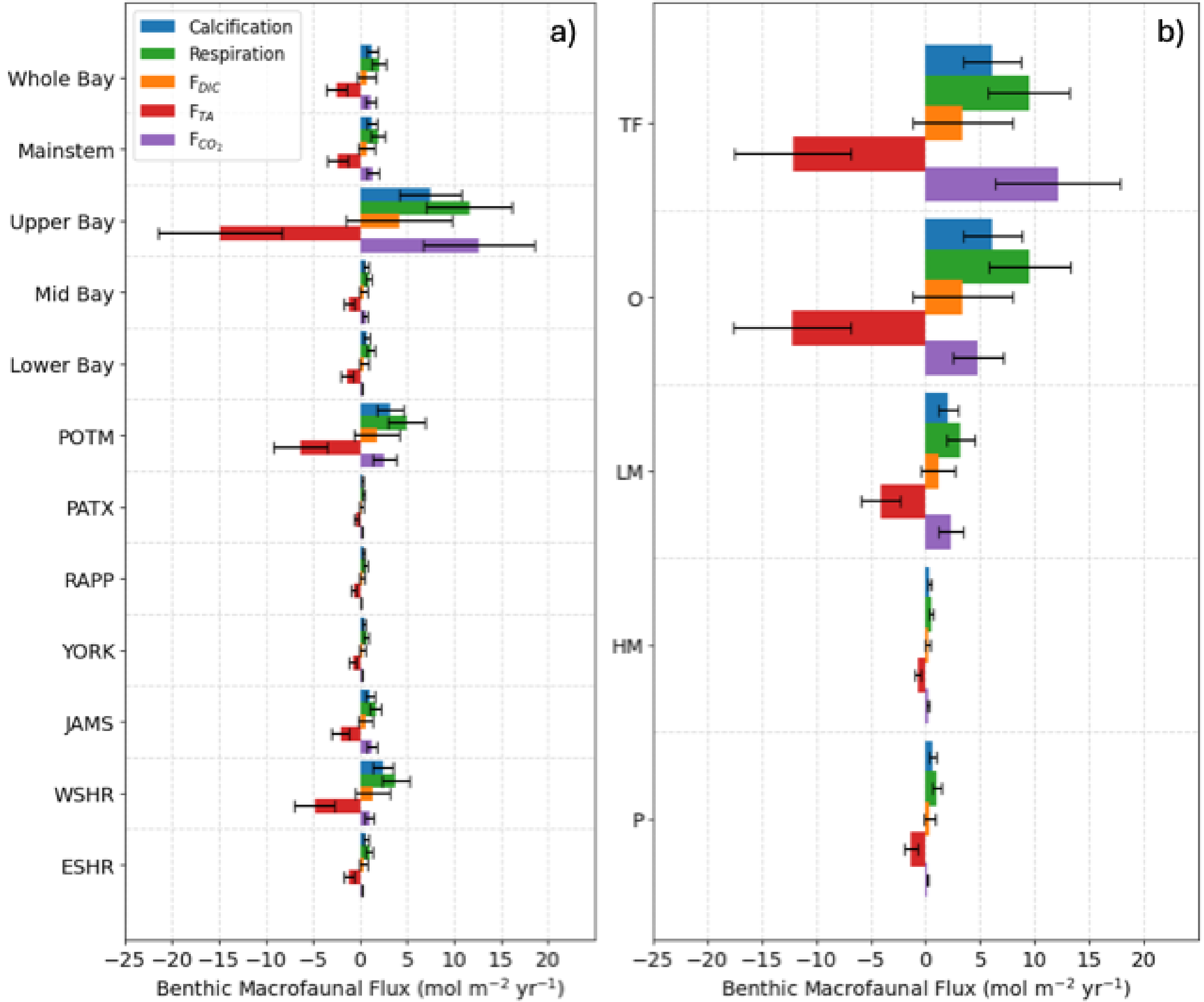
- Calcification

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$$

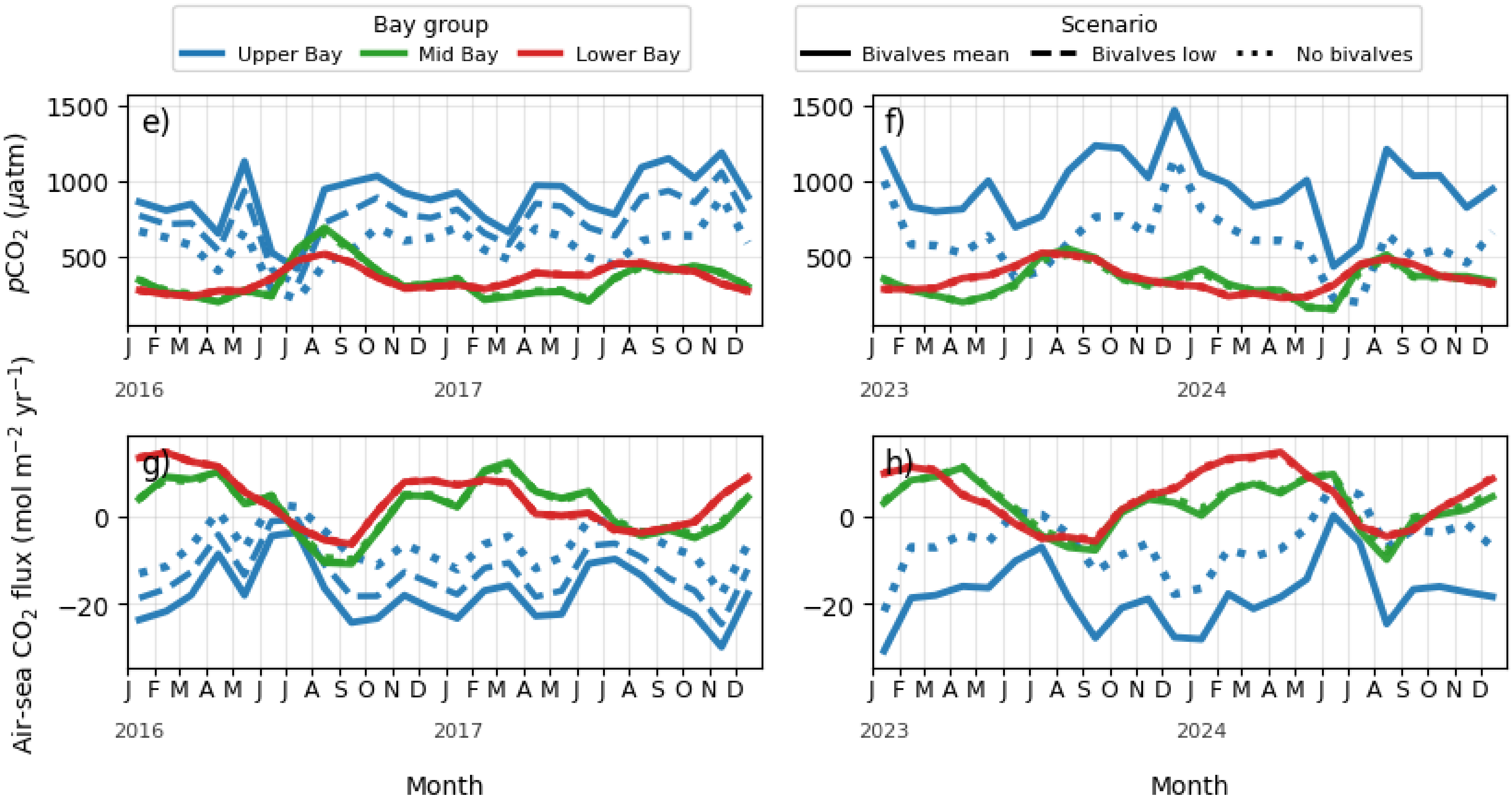
$$F_{\mathrm{TA}} = \frac{-2C}{M_{\mathrm{CaCO_3}}}$$

$$F_{\mathrm{DIC}} = \frac{R}{M_{\mathrm{C}}} - \frac{C}{M_{\mathrm{CaCO_3}}}$$

Areas of highest benthic biomass correspond to the strongest carbon fluxes



Including bivalve-driven TA and DIC fluxes in the ROMS-ECB hydrodynamic-biogeochemical model significantly affects pCO_2 and air-sea CO_2 fluxes in the Upper Bay



+=ingassing
– = outgassing

Research questions:

1) To what extent do benthic macrofauna contribute to estuarine carbon cycling via respiration and calcification?

Conclusions:

1) Benthic macrofauna play a substantial and spatially structured role in estuarine carbon cycling, particularly in upper estuarine zones where biomass is highest

Thank You!

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