Science, Service, Stewardship

A dynamic pathway to transition from vulnerable to resilient fisheries social ecological systems: A transdisciplinary case study of the U.S. Atlantic sea scallop fishery

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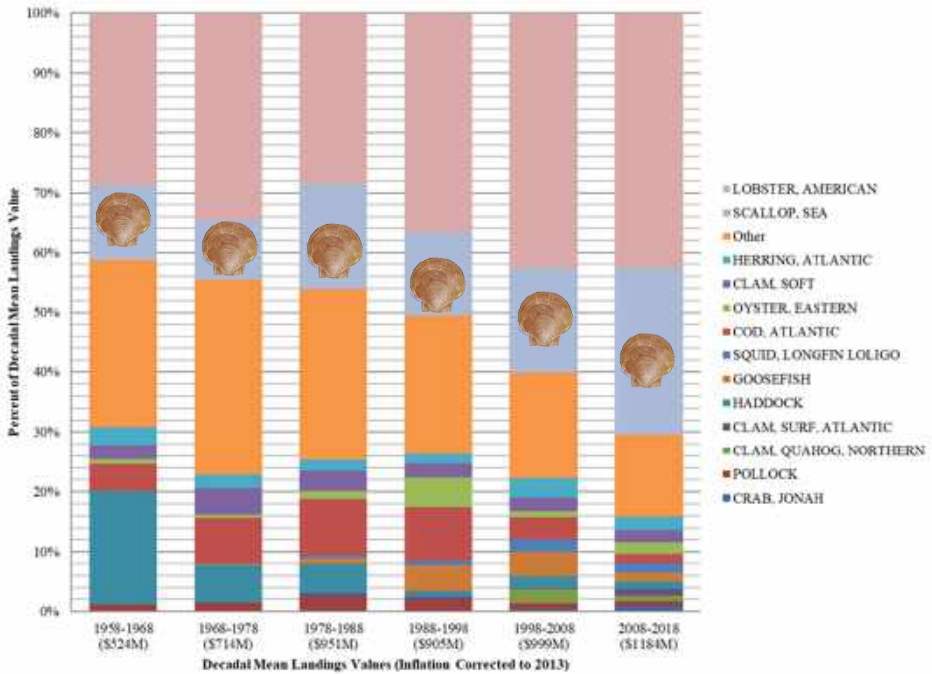
NOAA FISHERIES SERVICE

Climate Change Threatens Coastal Fisheries in the Northeast U.S.



(From Siedlecki et al. *2021*, updated from Gledhill et al. *2015*)

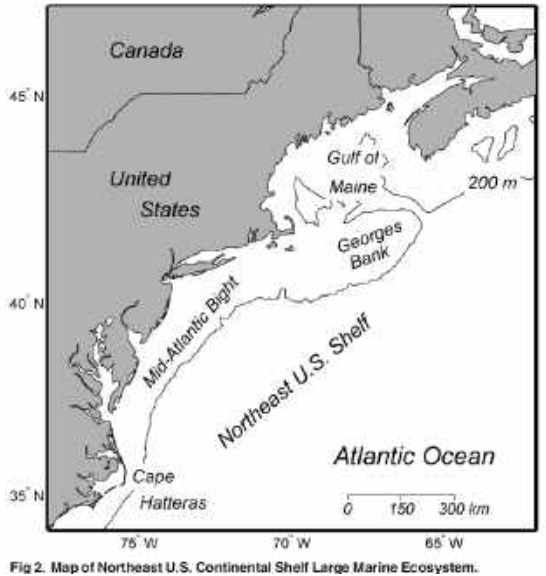
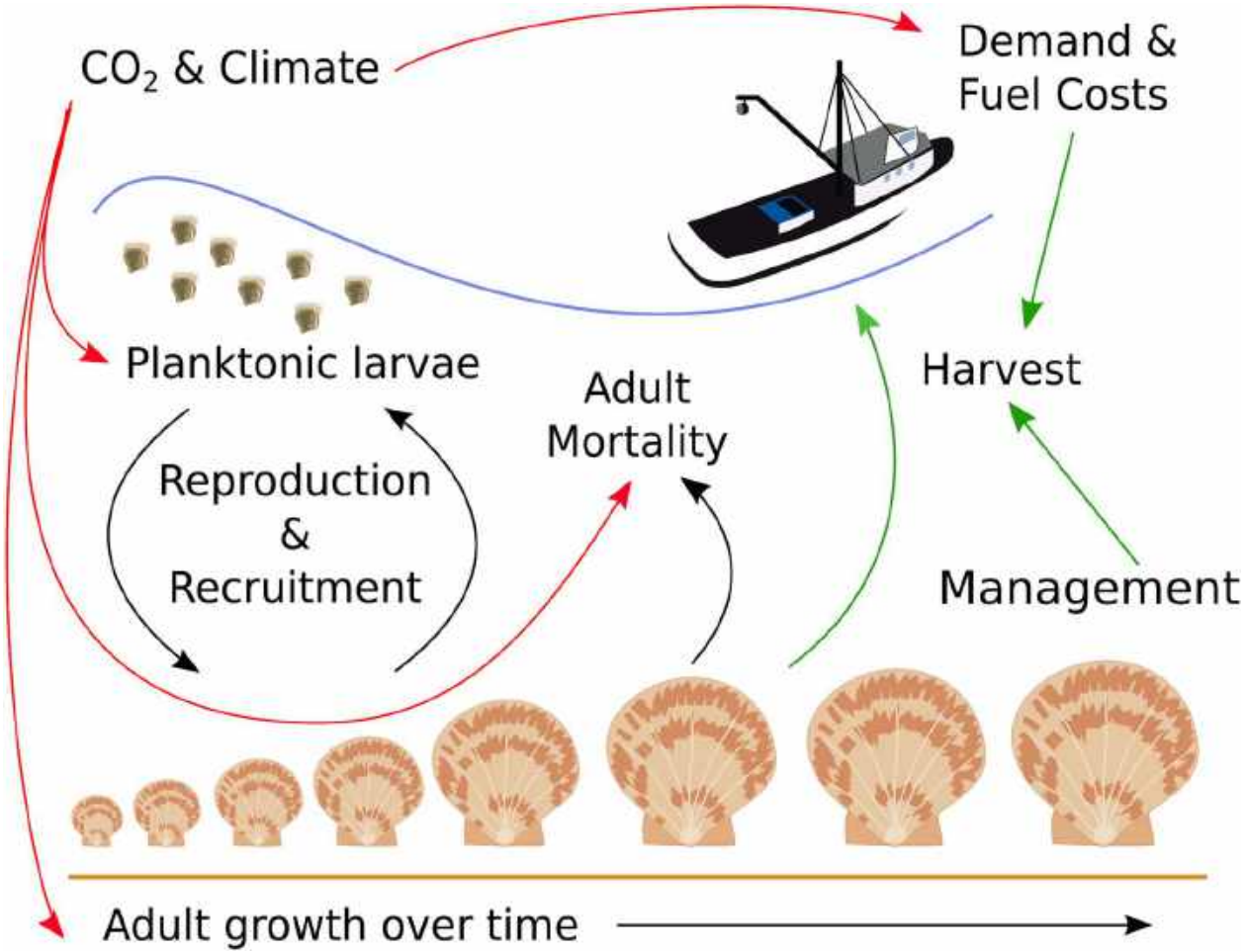


Fig 2. Map of Northeast U.S. Continental Shelf Large Marine Ecosystem.

(From Hare et al. *2016*)



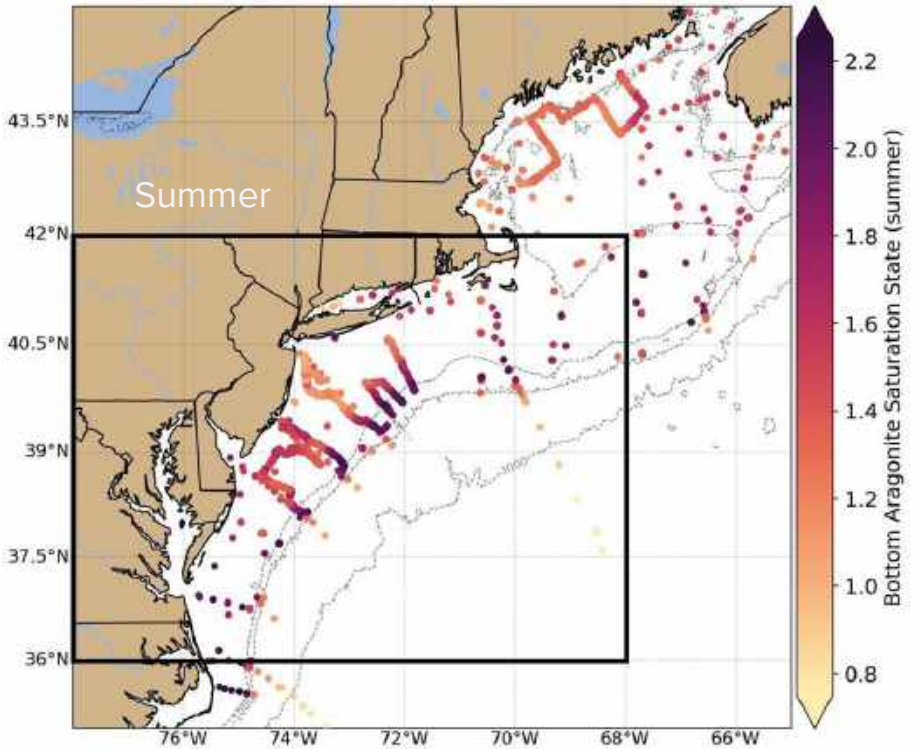
Scallops live for a **long time** – projections out to 2100 traverse

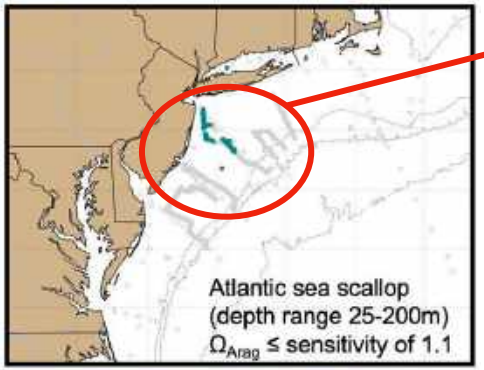
Adults grow for a **long time** – 4 to 5 years until harvest size currently

Larvae & adults occupy **different** regions of the water column

(Rheuban et al. *2018*)

Subsurface habitats already experience seasonally low Ω values





Hotspot region highlighted in the NOAA state of the ecosystem report as a repeat offender

G.K. Saba figure in 2023 NOAA State of the Ecosystem Mid Atlantic report

Fishery already seeing changes

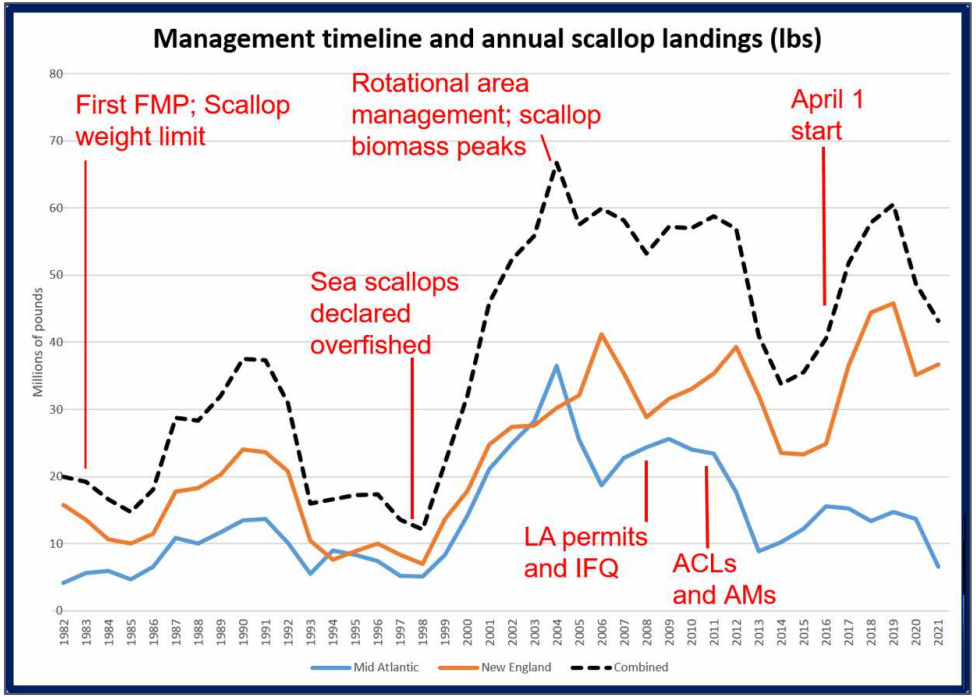
Ocean warming, ocean acidification, or both?

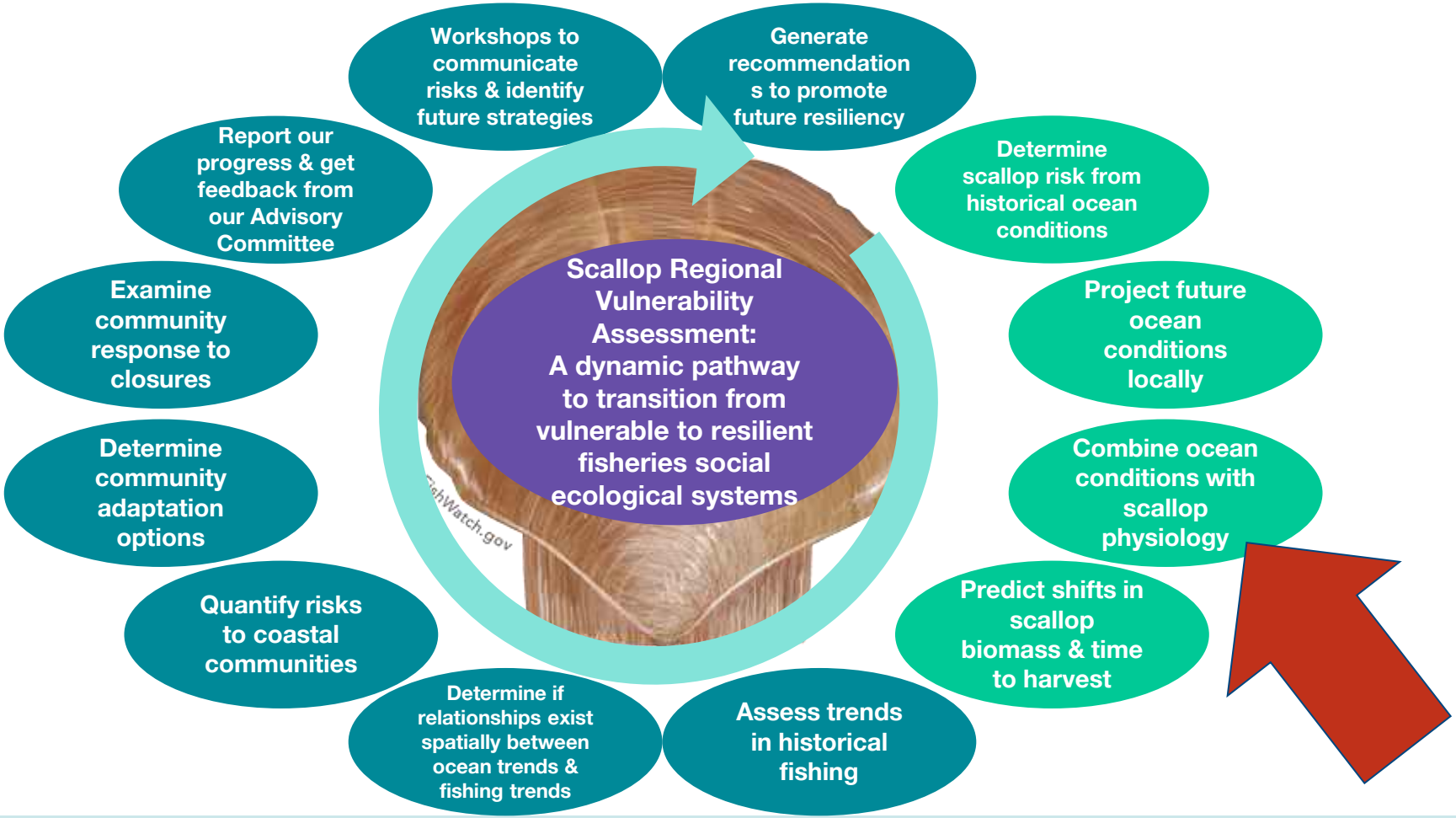
Shift in biomass north into the Gulf of Maine observed over many decades (1990-2015)

Formal managed rotational closure program began in 2004

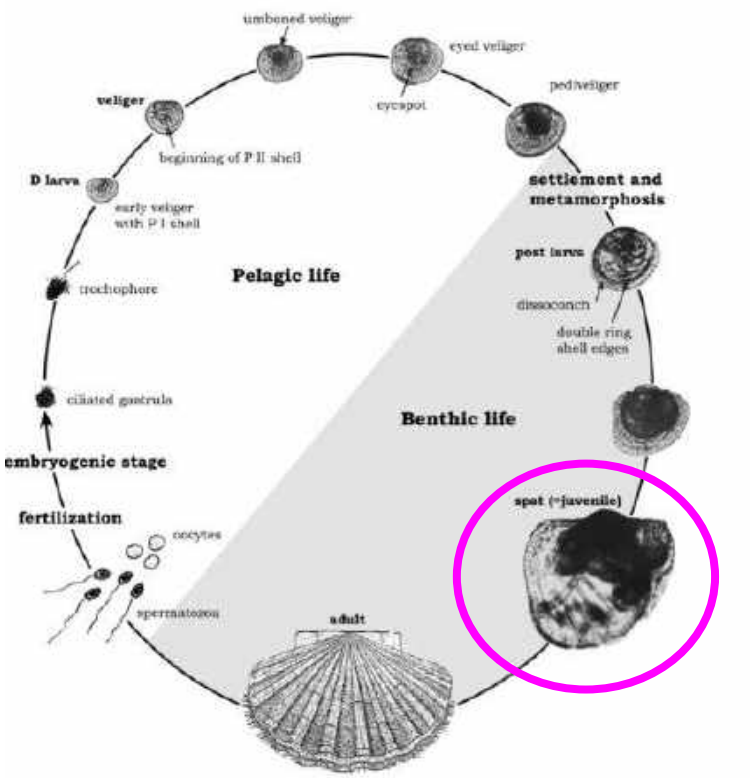
NEFMC closes areas with a lot of small, fast-growing sea scallops to protect them

This boosts sea scallop meat yield & yield per recruit (Hart *2003*)




Workshops to communicate risks & identify future strategies
Generate recommendations to promote future resiliency
Report our progress & get feedback from our Advisory Committee
Determine scallop risk from historical ocean conditions
Examine community response to closures
Project future ocean conditions locally
Scallop Regional Vulnerability Assessment: A dynamic pathway to transition from vulnerable to resilient fisheries social ecological systems
Determine community adaptation options
Combine ocean conditions with scallop physiology
Quantify risks to coastal communities
Predict shifts in scallop biomass & time to harvest
Determine if relationships exist spatially between ocean trends & fishing trends
Assess trends in historical fishing

A sea scallop's lifecycle



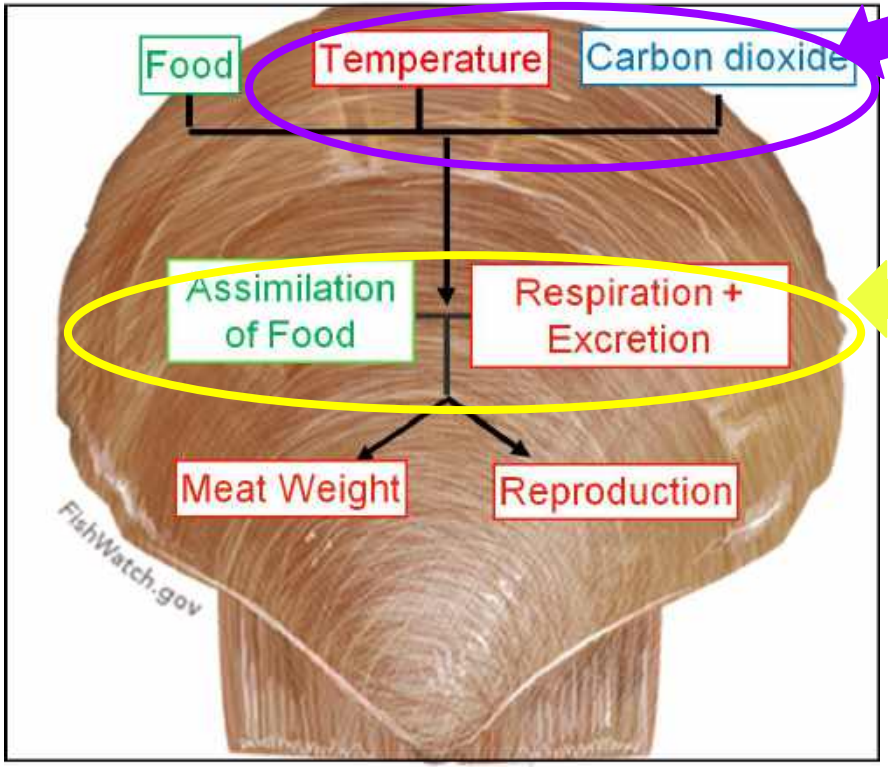
- Prodissoconch I
  - 24-48 hours D-stage
    - Amorphous calcium carbonate (ACC)
- Prodissoconch II
  - Veliger to pediveliger
    - Aragonite phase

- Teleoconch
  - Post-Larva- Adult
    - Oyster (calcite/aragonite)
    - Scallops (calcite)
    - Surfclams (aragonite)
    - Ocean quohogs (aragonite)

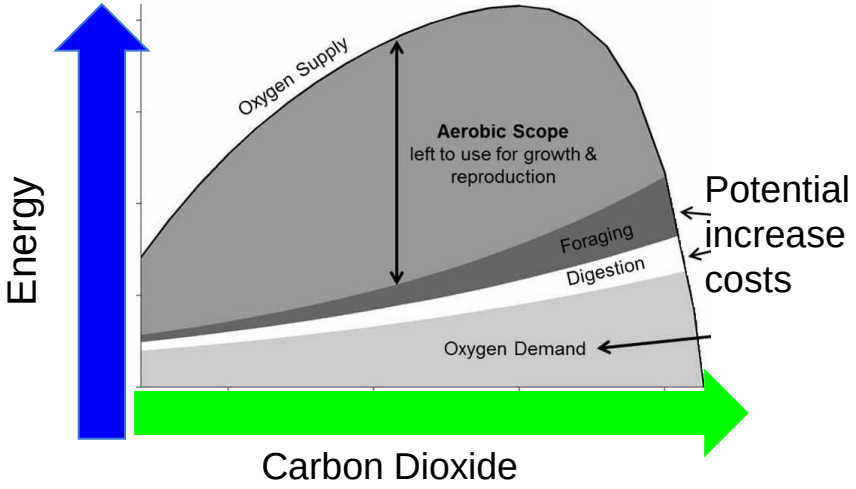
Image credit: https://www.open.edu/openlearncreate/mod/page/view.php?id=176460

Scallop Biology Response

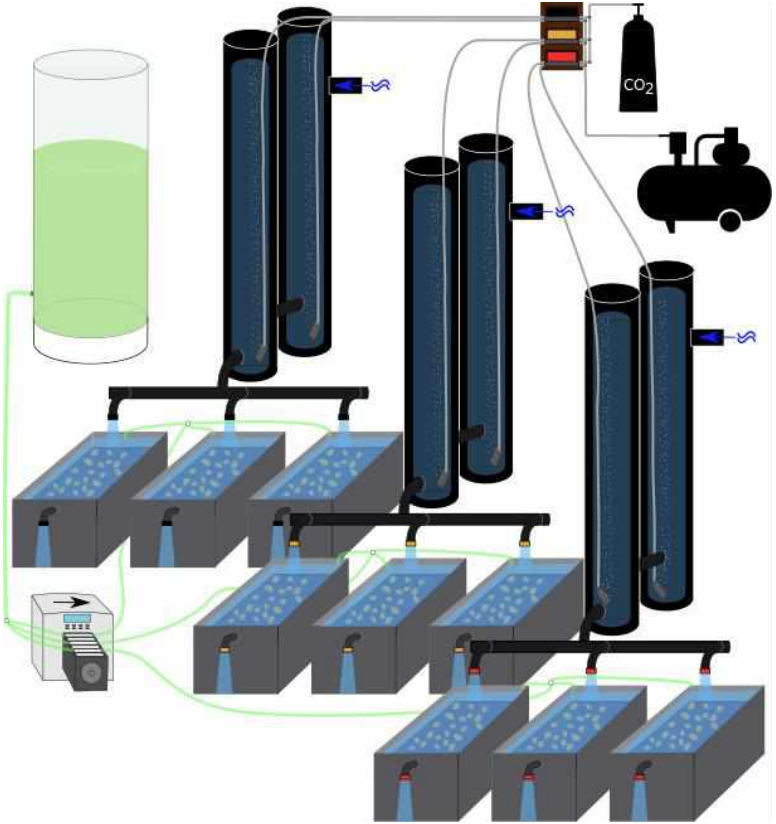
Varied in our experiment

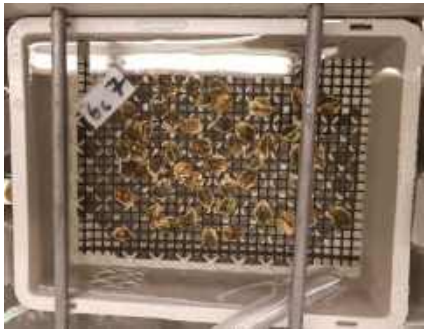


Excess energy from these processes is available for Growth & Reproduction



Methods-Juvenile Sea scallop experiment





Measurements:

→ **Daily:**

- Algal food available
- Temperature, salinity

→ **Each 3 days:**

- Water carbonate chemistry

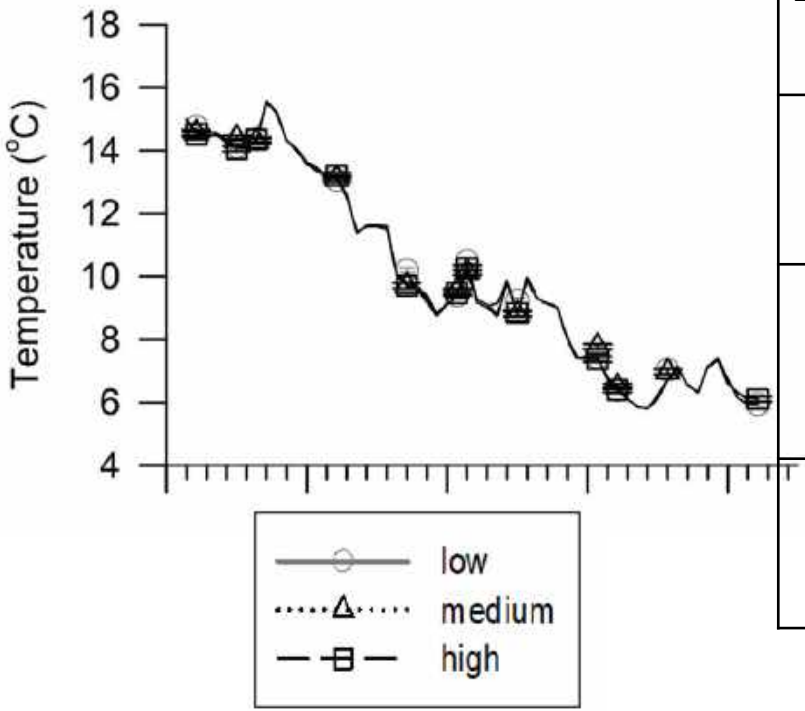
→ **Each two weeks (8 week experiment):**

- Respiration rates (7 ind./cond)
- Feeding rates (7 ind./cond)
- Excretion rates (7 ind./cond)

Measured at 4 temperatures: 13.1, 9.4, 7.4, and 6.1 °C

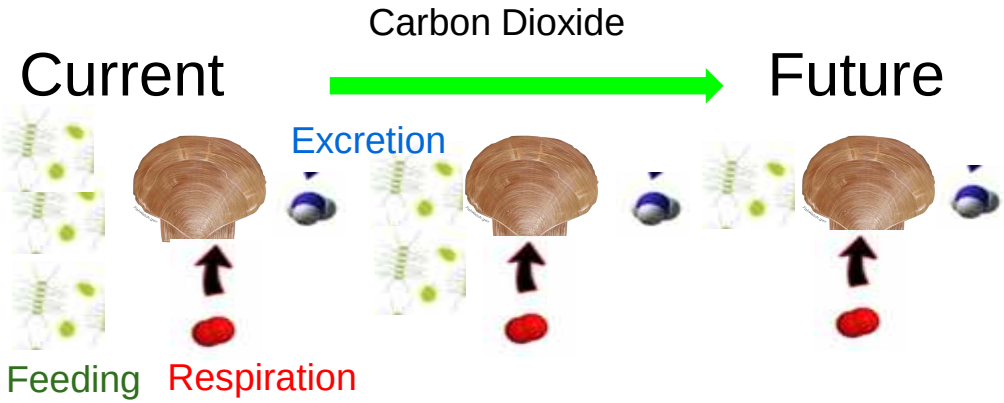
Pousse E, Poach ME, Redman DH, Sennefelder G, Hubbard W, Osborne K, Munroe D, Hart D, Hennen D, Dixon MS, Li Y, Wikfors, GH, Meseck, SL. Juvenile Atlantic sea scallop, Placopecten magellanicus, energetic response to increased carbon dioxide and temperature changes. PLOS Climate. 2023 Feb 22;2(2):e0000142.

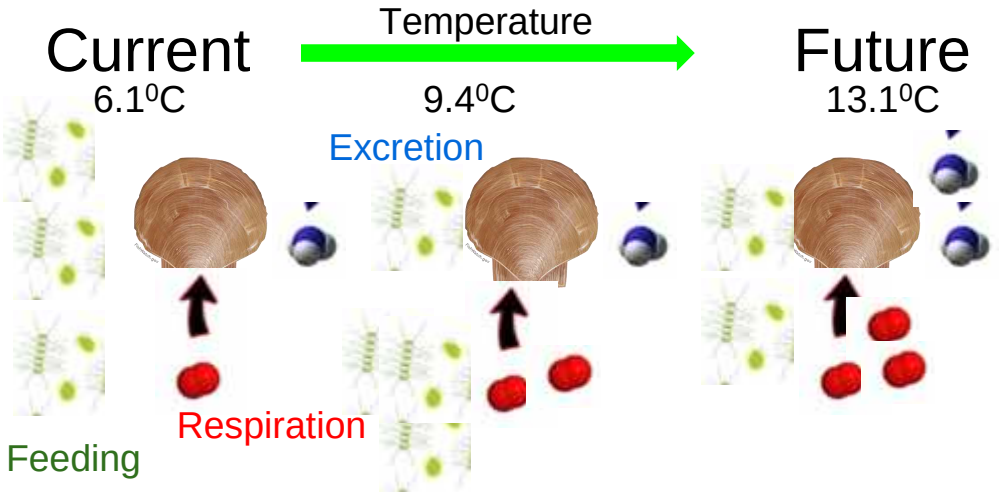
Incoming Seawater Chemistry- Enriched



Treatment	pH	DIC (µmol kg^{-1})	pH*	ρCO_2 (µatm)	Calcite
Low	7.7939 ± 0.0036[1]	1996.25 ± 6.69[1]	7.9262± 0.0055[1]	501± 7[1]	2.21± 0.02[1]
Medium	7.6229 ± 0.0109[2]	2061.47 ± 9.30[2]	7.7491± 0.0147[2]	802± 29[2]	1.54± 0.03[2]
high	7.4842 ± 0.0212[3]	2104.95± 9.80[3]	7.6125± 0.0236[3]	1164± 72[3]	1.18± 0.05[3]

Physiology



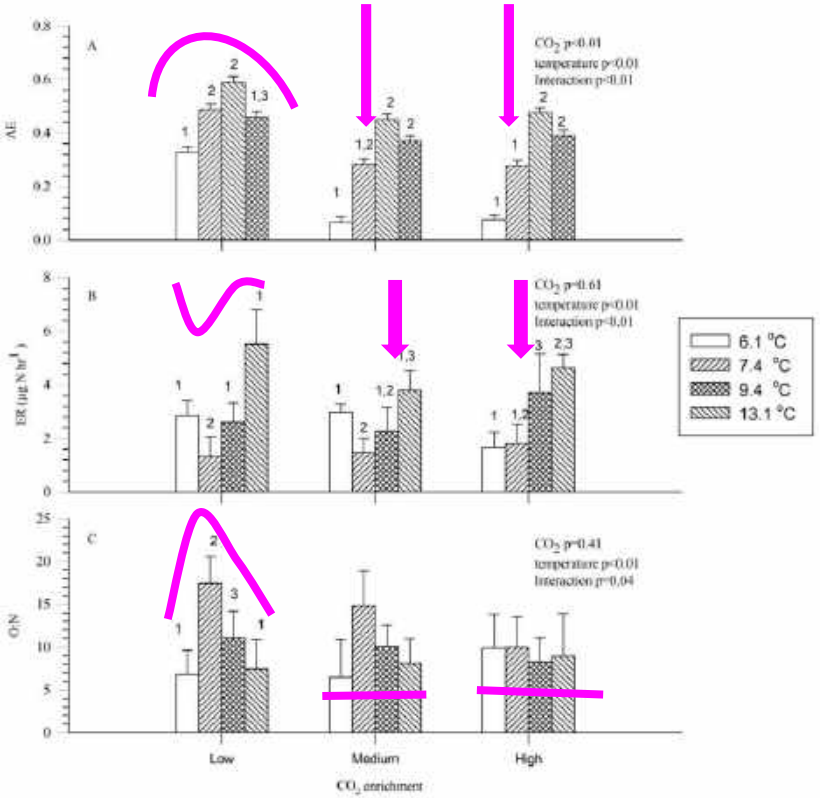


- Feeding rates slowed by CO_2 enrichment
- Feeding rates elevated by temperature
- **Interaction between CO_2 and temperature for feeding**
- Respiration, excretion, and O:N **NOT** affected by CO_2 enrichment
- Respiration, excretion, and O:N affected by temperature
- **Interaction between CO_2 and temperature for ER and O:N ratio**

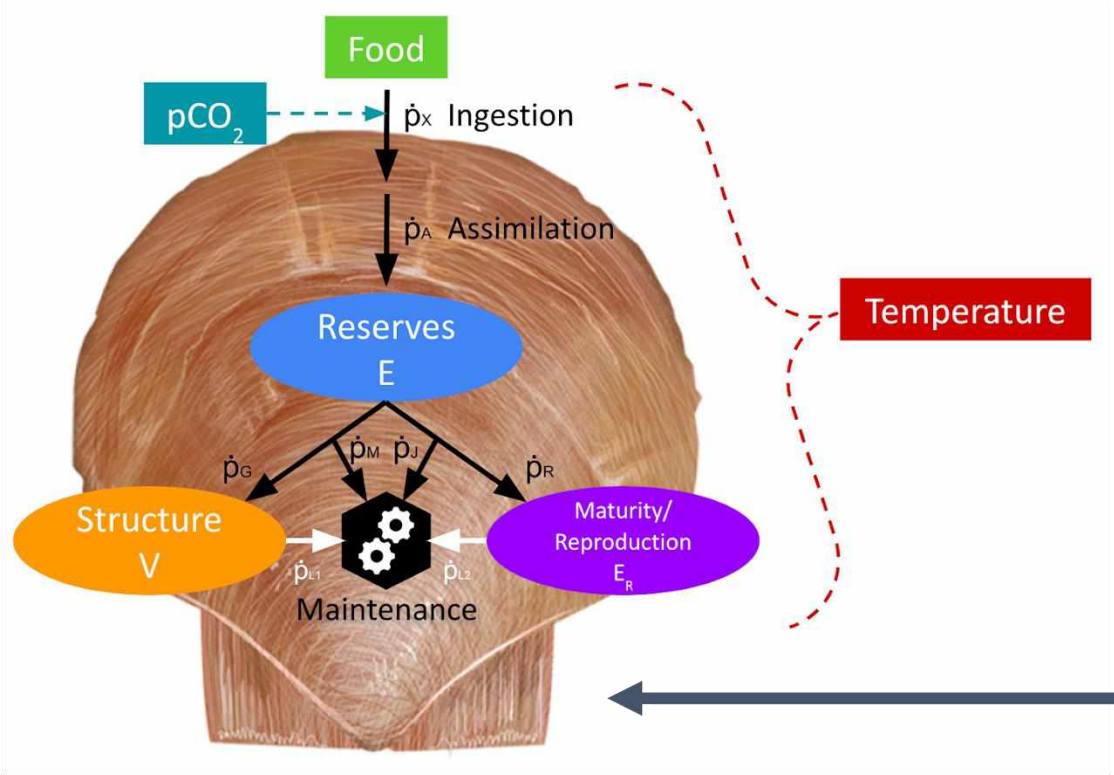
Interaction between CO_2 and temperature

- In low CO_2, AE increased as temperature increased, but delayed for medium and high CO_2
- ER lowest at 7.4°C, similar for all other temperatures for low CO_2; medium and high CO_2 start increasing in ER with temperature
- O:N ratio low CO_2 at lower temperature switches between protein and lipid/carbohydrate catabolism; pure protein catabolism at medium and high CO_2

Change in thermal performance with increased CO_2

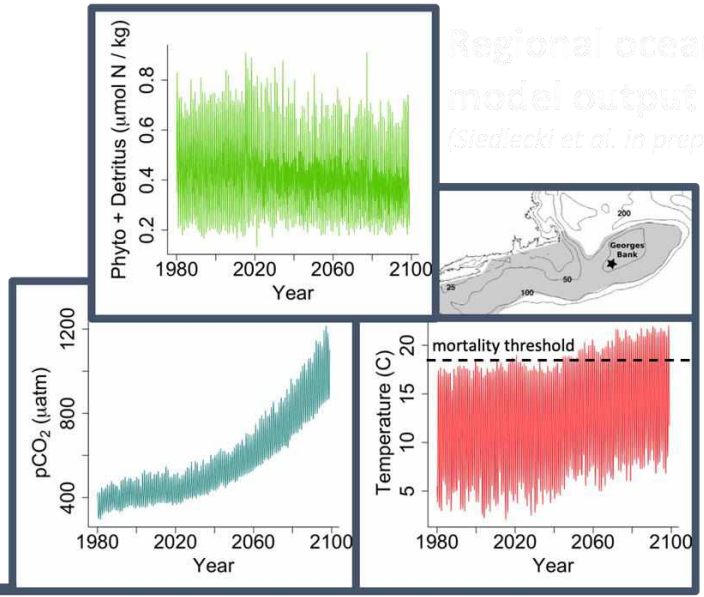


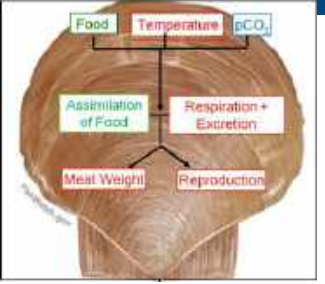
Future directions- DEB Modeling



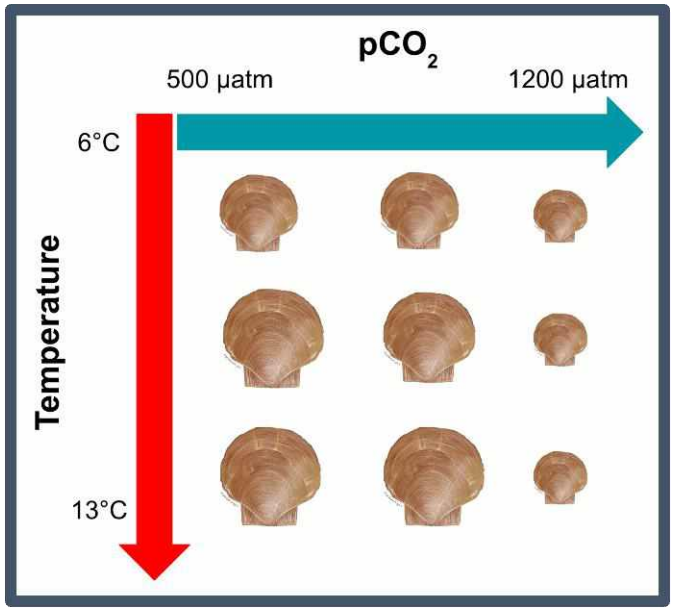
Regional ocean model output

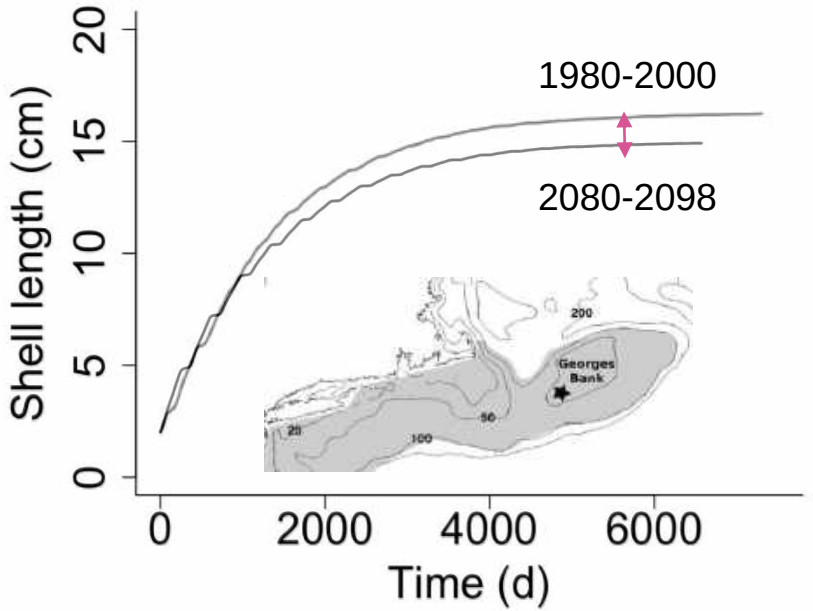
(Siedlecki et al. in prep)





Dynamic Energy Budget (DEB) Model – Future OA & warming cause a decline in shell length





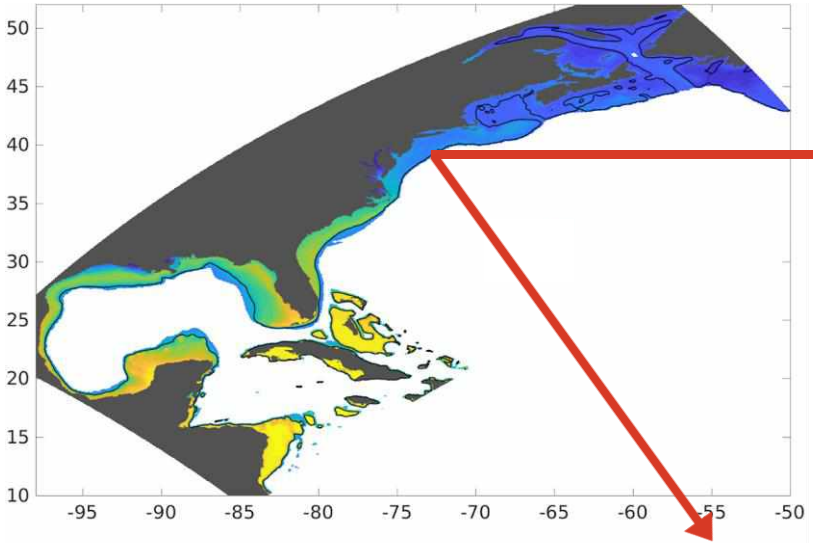
Parameterized based on experimental data (Pousse et al. *2023*)
and the AMP database for *Placopecten magellanicus* (Lavaud & Kooijman *2020*)

Berger et al. (*in prep*)

Natural Science tools applied to the issue – Models

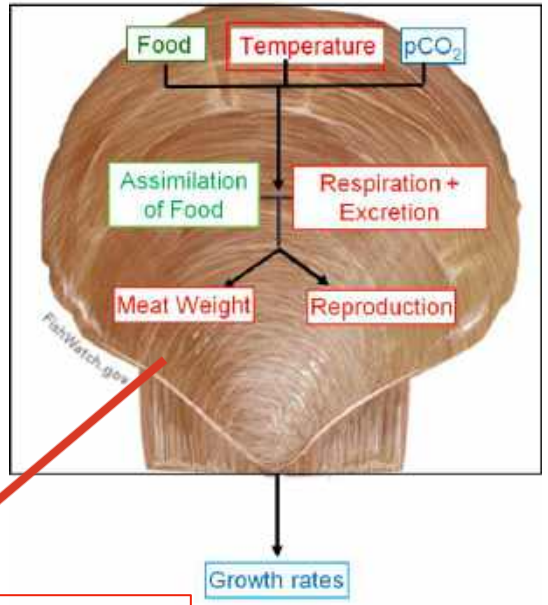
Ocean Conditions

Historical trends & projections using NWA-ROMS



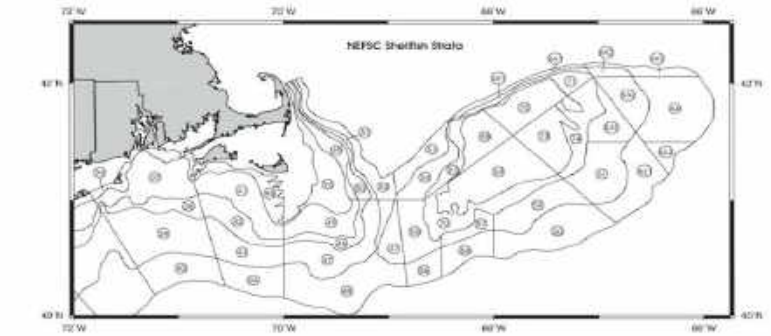
Scallop Biology

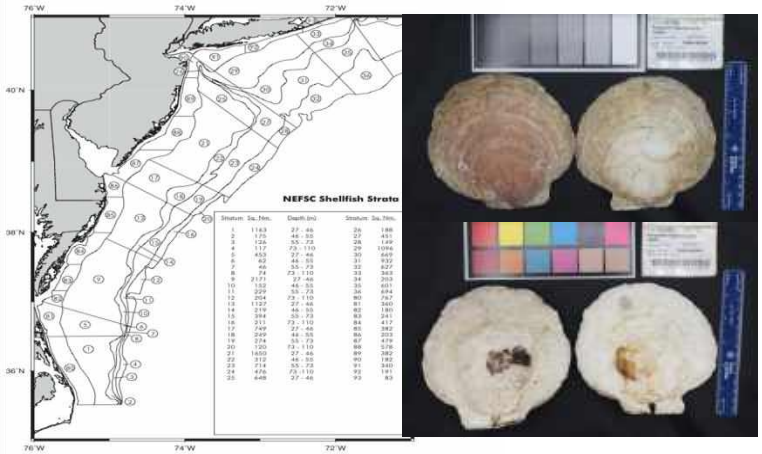
Dynamic Energy Budget Model



Maps of projected growth rate (time to harvest) & recruitment

Historical archive of shells exists in the region maintained by NEFSC and VIMS dating back to 1980





- The data set includes ages/growth increments and meat/gonad weights as well as co-located ocean conditions
- Undergrads at UConn working on additional measurements to add to the archive including thicknesses and pictures (already measured over 3,000 shells!)
- Thicknesses are averaged for every cm across the shell and standardized to the mean shell length

Conclusions

- Projections indicate the majority of the year will experience stressful conditions within benthic habitats by 2050
- Warming & OA may cause benthic habitat compression
  - Potential range shift into deeper waters
- DEB model preliminary results for Georges Bank suggest that future OA & warming will cause scallops to grow slower
- Spatial variability in fishing effort over time will provide us with a footprint of the fishery itself to correspond to changes in the ocean conditions & make the results locally relevant
- Workshops with the engaged fishing community helped identify some key areas of concern for the fishery, provided some educational opportunities, & resulted in a flyer produced to spread the word
- We are planning for our last round of workshops next year…stay tuned!

Understanding fishing industry and community adaptive capacity

Acknowledgements

- **NOAA OAR OA funding**
- Dylan Redman
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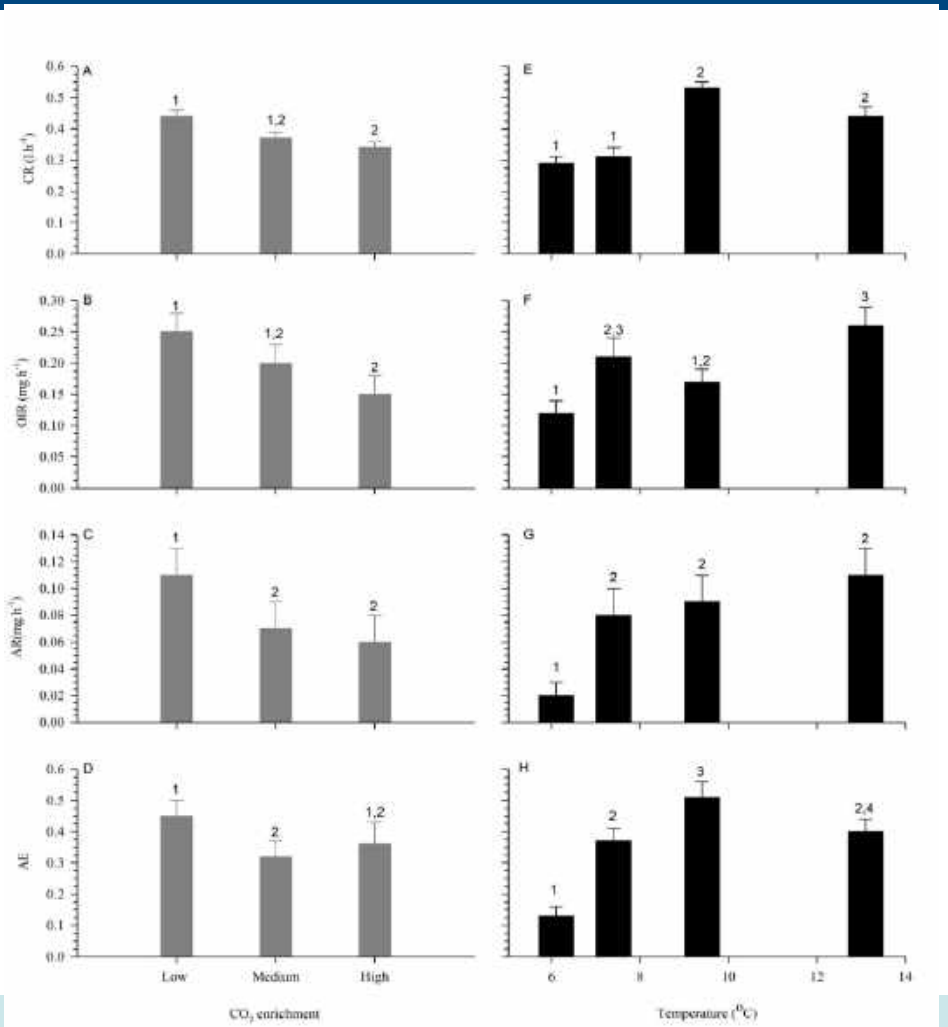
- John Klink
- Daniel Hennen
- Genevieve Bernatchez
- Lisa Guy
- Justin Leonhardt
- Rhadika Shah
- Magali Bassano
- Erin Cuyler

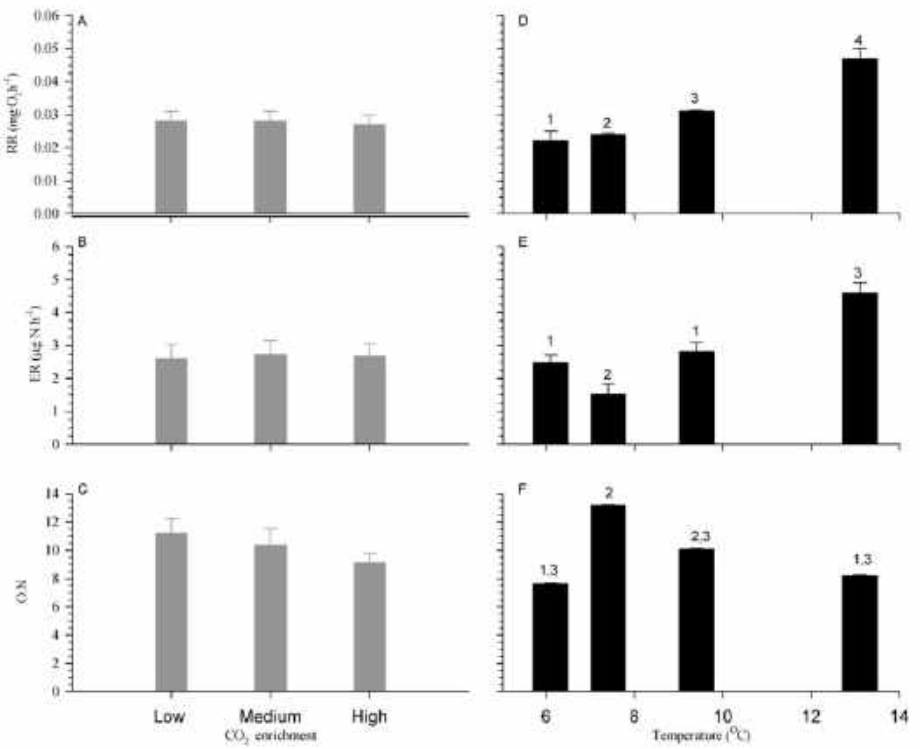
Feeding Rates

- Feeding rates slowed by CO_2 enrichment
  - Decrease in CR (water moved), OIR(organic ingested rate), and AR (assimilation rate) with increase CO_2
- Feeding rates elevated by temperature
  - CR and AE (assimilation efficiency) highest at 9.4°C (agrees with literature)
  - See U shape response by 13.1°C
- **Interaction between CO_2 and temperature for AE**



Catabolic Processes and O:N ratio

- Respiration, excretion, and O:N **NOT** affected by CO_2 enrichment
- Respiration, excretion, and O:N affected by temperature
- **Interaction between CO_2 and temperature for ER and O:N ratio**



Energy- Scope for growth

- Less energy available for growth with CO_2 increase
- More energy available for growth between 9-13 ^oC
  - Literature -- growth from 8-15 ^oC