Impacts of Lab-Induced Acidification and Interannual Changes in Ambient Ecosystem Conditions on Growth and Survival of *Mytilus edulis*

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OA and Blue Mussels

- Ocean Acidification (OA) reduces ocean's pH due to increased CO_2 absorption.
  - The ocean has a pH buffer system[1] (Fig. 1)
  - There is 50% more CO_2 in the atmosphere now than there was before the Industrial Revolution[2]

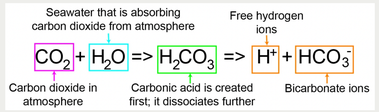


Fig. 1: The ocean's buffer system.

- -Blue mussels are filter feeders found in New England waters[3] that are harvested for food. They also improve water quality via filtration providing benefits to the ecosystem and aquaculture. Mussels are the lead imported bivalve shellfish in the US. There is a large market for offshore mussel farming[4]
- OA has detrimental effects on shell formation
  - Shells are made from $CaCO_3$. Shellfish can expel the H^+ ion from bicarbonate ions for shell formation, but this requires energy and is more difficult in low pH (more acidic) conditions due to the steep concentration gradient[5]
  - Saturation state of calcite and aragonite (Ω C and ΩA respectively) are affected by OA[6]
    - ΩA > 1 = Water is supersaturated, favorable for shell formation
    - Ω A < 1 = Water is undersaturated, corrosive to shells
- OA can change the speciation of metal ions in seawater[7]. Metals that form strong complexes with hydroxide and carbonate will undergo change in speciation, like Cu^{2+} which can be toxic at high conc.
- Coastal and estuarine waters have higher metal concentrations than the ocean.
- Other considerations to mussel aquaculture include harmful algal blooms (HAB's) and pathogens[4]

Fig. 2. Map of NH coast, location of project lab in New Castle, NH marked with star

Goal: Analyze the effects of OA on blue mussels

Implications: Understand how climate change will shape aquaculture in the future

Methods

- The 2023 study builds from similar studies the previous two years (Tab. 1)
- Mussels 28-40 mm in length were collected from local NH waters (Fig. 3)
  - Mussels distributed into 10 tanks (Fig. 3)
  - 1 Additional tank of ambient seawater
- 1 month long acclimation period without CO_2 injection
- Treatment began 07/13/2023 and ended 10/06/23 (87 days total)
  - CO_2 bubblers and pH probes were added to treatment tanks
  - Control tanks were ambient seawater, pH (7.18-7.81) and treatment tanks pH were 0.5 below ambient
- Cohort lengths and mortalities were recorded weekly
  - Note that cohort data only are presented in Results section
  - Measured shell length to nearest 0.01" (convert to mm) using analog calipers
- Metals testing and measurement of all mussel lengths occurred monthly. Control mussel tanks began acclimation period with 50 extra mussels each, and after acclimation period they were removed for testing. Metals tested required 50 mussels per tank
- Shellfish Diet 1800® was pumped into tanks by scheduled peristaltic pumps
  - Feed rate was reduced in proportion to remaining biomass after each mussel sampling
- Sand filtered estuarine Piscataqua River was used in the flow-through tanks (Fig. 2)

Table 1: Summaries of Experiments in 2021-2023

Year	2021	2022	2023
Study Focus	Metals uptake	Growth, crushability, metals uptake	Growth and metals uptake
pH Treatments	2 pH treatments (0.5, 0.25 below ambient) and 1 control	2 pH treatments (0.5, 0.25 below ambient) and 1 control	1 pH treatment (0.5 below ambient) and 1 control
Environmental Parameters and Comments	No feed or cohorts	Feed (TET 3600®) and cohorts	Rainy, different feed, ambient pH lower than 2022
Results: Average Growth Rate and Average Percent Mortality	Little/no growth Relatively high mortalities	Crushability (Fig. 4) **Growth Rate & Mortality:** Control=0.026mm/day; 1.94% 0.25 pH below=0.022mm/day; 2.18% 0.5 pH below=0.018mm/day; 1.76%	**Growth Rate & Mortality:** Control=0.0069 mm/day; 0.15% Treatment=0.0055 mm/day; 0.15%

Fig. 3: (a) Number of mussels distributed into tanks. Teardrop shapes denote the mesh bag that held the cohorts. (b) Tank setup on shelving unit. Mussels were kept in plastic baskets to elevate them from the bottom of the tank. Water inflow tubes, feeding tubes, and feeding pumps are visible

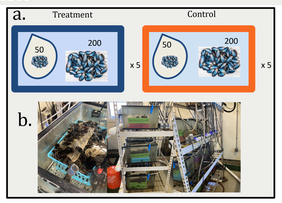
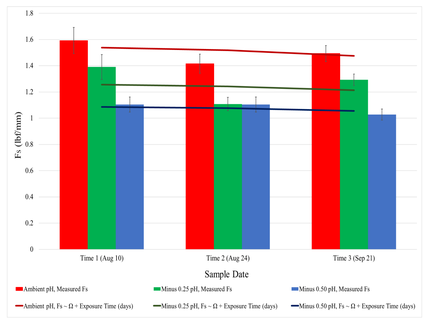
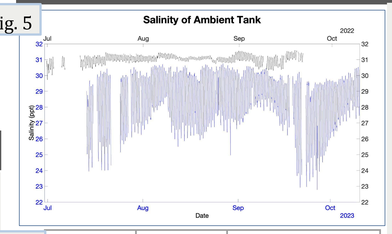


Fig. 4: Crushability of mussels in 2022[8]. Force (Fs) required to crush mussel shell. Resistance to crushing force increased linearly with ΩA.



Environmental Parameters

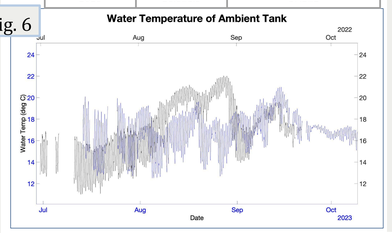
Fig. 5



Tab. 2

Year	Average Salinity (ppt)	Average Water Temp (°C)
2022	31.1±0.2	17±3
2023	28.6±1.5	17.2±2

Fig. 6



- Salinity in 2023 (blue line) was lower and more variable than in 2022 (black line) due to higher total rainfall (Fig. 5 & 7). Total rainfall[9] during the study in 2023 was 22.3 inches compared 16.6 inches in 2022 (Fig. 7).
- Average water temp. was not significantly different between 2022 (black line) and 2023 (blue line) except in July when 2023 was higher (Fig. 6).
- pH of ambient water was significantly higher in 2022 (Fig. 8)

Fig. 7

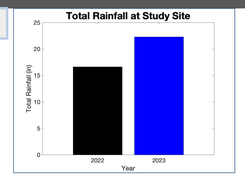
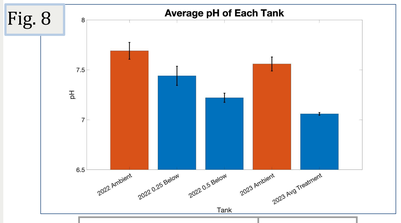


Fig. 8



Tab. 3

Treatment	Avg pH
2022 0.25 Below	7.44±<0.01
2022 0.5 Below	7.22±<0.01
2022 Ambient	7.69±<0.01
2023 0.5 Below	7.06±<0.01
2023 Ambient	7.56±<0.0.7

Mortality and Growth Results

Fig. 9

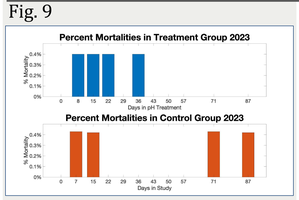
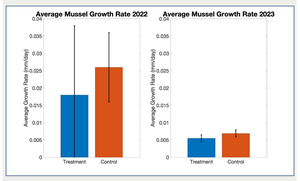
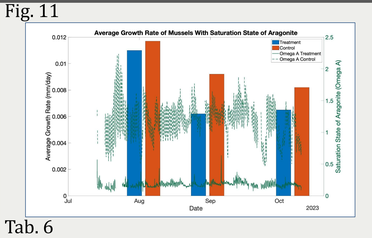


Fig. 10



- Average % mortality over duration of study was 0.15±0.2% for both treatment groups in 2023.
  - Higher mortality observed in treatment group at beginning of CO_2 injection (Fig. 9).
- Higher average mussel growth rate in 2022 than in 2023 in both treatment groups (Fig. 10).
- The aragonite saturation (Fig. 11) was relatively consistent with time and remained >1 in ambient water and much less than 1 in treatment tanks. Average growth rates decreased from Aug to Oct.

Fig. 11



Tab. 6

Average Growth (mm/day)	August	September	October
Treatment	0.011±0.0007	0.006±0.002	0.006±0.002
Control	0.012±0.0003	0.009±0.002	0.008±0.002
Average ΩA			
Treatment	0.16±0.04	0.18±0.03	0.19±0.04
Control	1.18±0.32	1.25±0.17	1.15±0.28

Discussion

- Environmental conditions were significantly different in 2022 and 2023 and impacted study results
- The lower percent mortality in 2023 compared to 2022 could be caused by the change in feed. Lower growth rates in 2023 could be related to the lower and more varied salinity and pH.
  - Mussel growth was consistently lower under the (lower) pH treatment conditions.
  - Mussels prefer salinity between 25-30 ppt. Drastic reduction in growth rates found at salinities less than 10 ppt.

References & Acknowledgements

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