Nature-based Shore Protection to Stabilize Estuarine Sediment

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Background

A section of the Great Bay Estuary, located between the mouths of the Swampscott and Lamprey Rivers, has been exposed to extensive shoreline erosion over time. Due to the location and orientation of the site, it is susceptible to both wind-wave energy and current velocity scour (Fig 1). The largest wind-wave fetch is approximately three miles long, with predominant northeast winds. Scour from currents in the channel could also contribute to erosion by transporting sediments.

Furthermore, byproducts from wastewater treatment plants higher up the watershed are carried downriver, directly past the location of the site. As a result, the portion of Great Bay where the Squamscott and Lamprey rivers empty into Great Bay are closed for aquaculture harvesting.

Though shellfish products harvested from this location are not permitted to be sold in market, they are still able to be grown there and provide ecological benefit to the estuary by filtering out some of the repercussions of wastewater facilities.

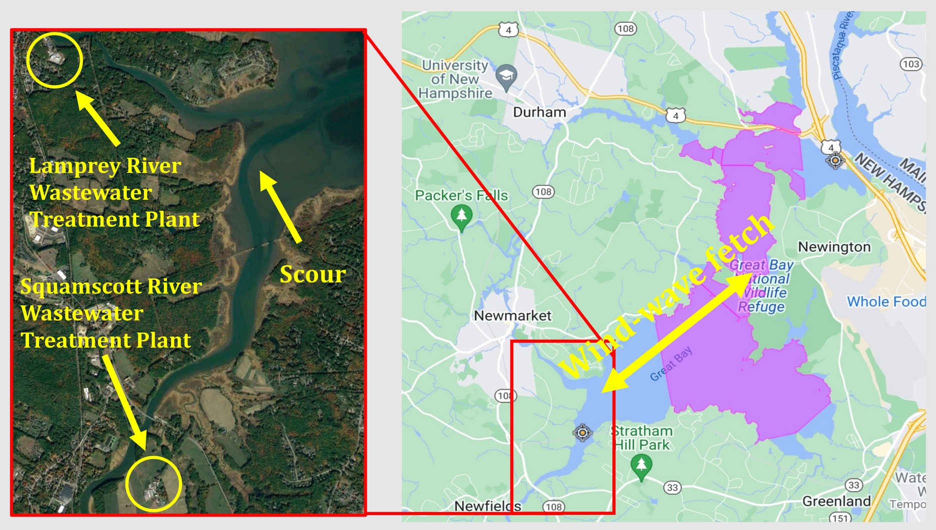

Fig 1. Map of Great Bay, NH region with areas for allowable aquaculture harvesting highlighted.

Objectives

(1) Develop a shoreline erosion strategy using oyster aquaculture structures to attenuate waves and strong currents.

(2) Quantify the ecological benefits of an aquaculture structure.

Once oysters reach a near harvestable size, they would be then relocated for depuration of these elements, removing them from this area of the estuary.

Methodology

1. Field study to determine waves and currents on-site: To get information about the conditions of our site, we deployed pressure and current sensors (Fig. 2) for a total of 28 days.

2. Wind-wave fetch analysis: A wave hindcasting nomogram was used to predict the wave state based on previous wind events.

3. Tow and wave tests to quantify velocity reduction and wave attenuation: Two current sensors were arranged 'fore and aft of the oyster condo to measure incident and reduced velocity through the structure. The wave tests used pressure sensors to measure water surface elevation as a group of waves passed through a full oyster structure (Fig 2.).

4. Estimate benefits of structures to reduce erosion: Data from the tow and wave tank tests was examined for percent reduction in current speed, wave energy, and root mean square wave height.

5. Quantify yearly nitrogen load from the Lamprey River Wastewater Treatment Plant: Monthly nutrient output spreadsheets dating from 2018 through 2021 were obtained from the Newmarket Wastewater Treatment Plant and compiled to procure total nitrogen outputs by year.

6. Estimated number of oysters: Using both the nitrogen output data (Fig 11) and the equation for assimilation (Fig 10), total number of oysters needed was calculated.

7. Oyster Growth Rate as Factor: Assuming a growth rate of 25mm per year, the total number of oysters needed was recalculated to assimilate the nitrogen from the Newmarket treatment plant.

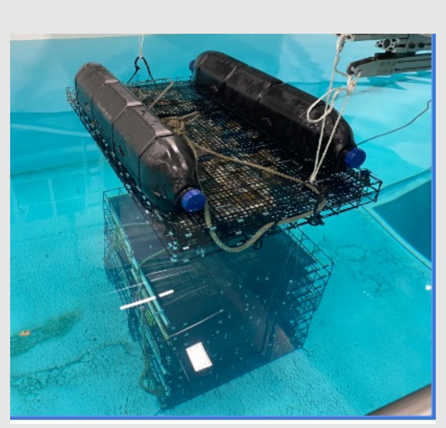

Fig. 2: Full oyster structure, OysterGro (top), two stacked condos (bottom).

Instrumentation and Fall 2022 Deployment

Sensor Arrangement

Fig. 3: Sensor arrangement used in Fall 2022 deployment.

- Developed by former UNH grad student Spencer Marquardt, a Blue Robotics Pressure and Temperature sensor (left, above) uses temperature and hydrostatic pressure sensors, along with a Teensyduino microcontroller and a datalogger to record surrounding pressure in millibars.
- Made by Lowell Instruments, the TCM-4 (right, above) is a shallow water current meter uses magnetic north and angle of inclination to compute current direction and magnitude.

On-Site Deployment

- Timeseries of the tidal data was extracted from the sensors to understand the still water levels.
- Waves were unable to be resolved from this deployment likely due to a low sampling rate chosen to preserve battery life.

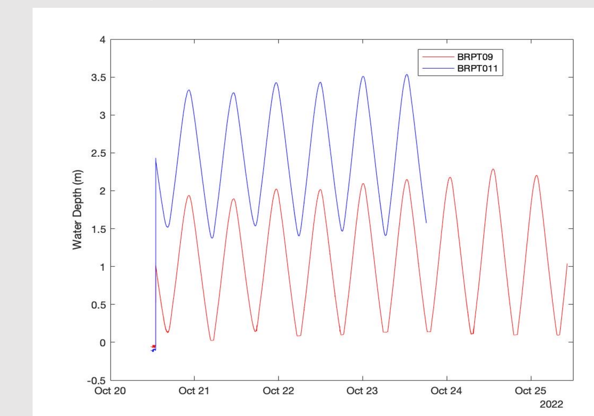

Fig. 4: Tidal timeseries acquired from Fall 2022.

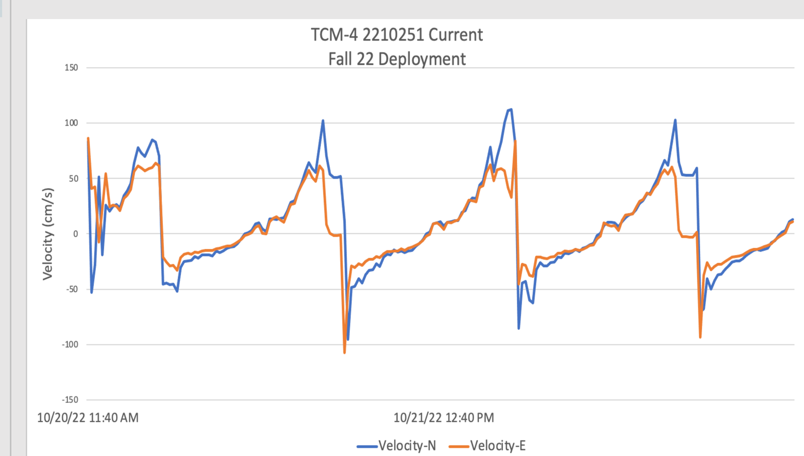

Fig 5: Current data from Fall 2022.

- Typical current velocities at half tide (point during the tidal cycle when maximum currents are observed) were **approximately 1m/s.**

Current and Wave Energy Reduction

Wave-hindcasting

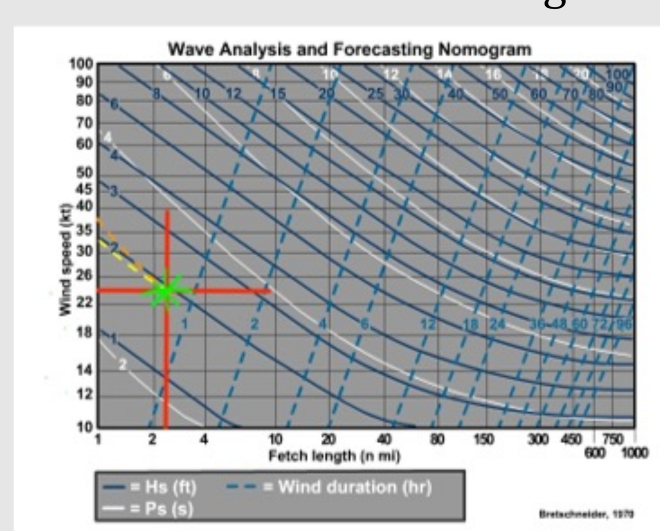

Fig. 6: Wave hindcasting nomogram.

- Using the factors of wind speed and duration, fetch length, the significant wave height and period of a past weather event is predicted.
- Using the maximum wind speed seen during the Fall 2022 deployment (**24 kts**) and fetch length (**2.5nm**), the significant wave height and period were fetch-limited at **1.85ft (0.56m)** and **3 seconds**.
- This wave height is unattainable in the wave tank, so a smaller amplitude will be used for testing.

Wave Attenuation

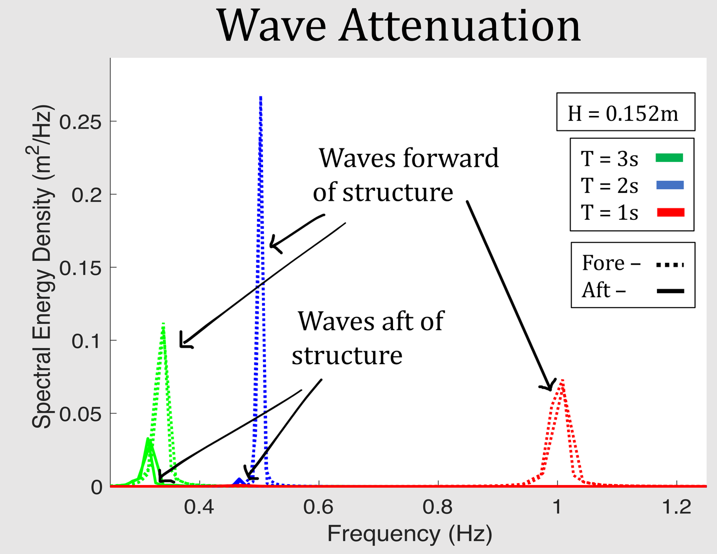

Fig. 7: Wave Energy Spectra, Wave Tests.

- Wave energy spectra was used to determine the significant wave height.
- Due to instrument failure, fore wave spectra were recreated mathematically, assuming no dissipation.

$$E_{wave} = \frac{1}{8}\rho g H_o^2 \qquad (1)$$

H_{input} (m)	Period (s)	ΔH_o (m)	$\overline{\Delta E}_{wave}$ (J/m²)
0.152	3	0.0817	21.27
0.152	2	0.0703	27.66
0.152	1	0.1270	27.81

Table 1: Average Change in Wave Energy.

Current Reduction

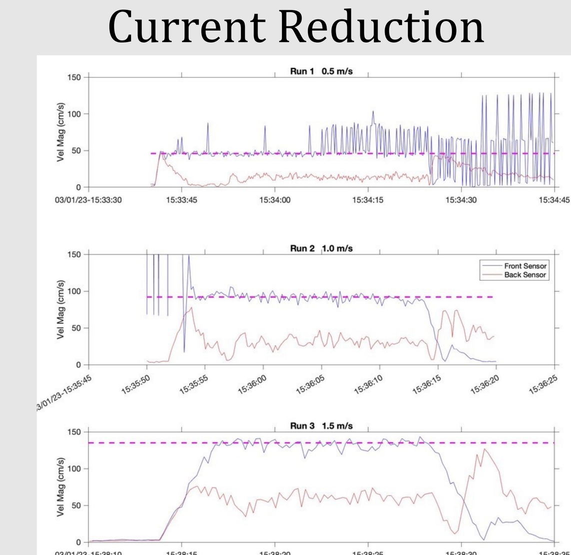

Fig. 8: Current Velocity Magnitude versus Time.

- In total, 3 tow tests each were conducted at speeds of 0.25m/s, 0.5m/s, 0.75m/s, 1m/s, 1.25m/s, and 1.5m/s. Current velocity was reduced by approximately **50% or more** every run.

$$E_{current} = \frac{1}{2}\rho d U^2 \qquad (2)$$

Input Current Speed, U, (m/s)	$\Delta E_{current}$ (J/m²)
0.5	66.64
1.0	368.9
1.5	711.2

Table 2: Change in Current Energy.

Wastewater Treatment Plant Summary and Nitrogen Assimilation Analysis

Mean Bivalve Density (# m-2)	Mean Bivalve Shell Size (mm)	Calculated1 Mean Dry Wt. (g)	Reef/Rack Bottom Surface Area (m2)	**Total # Bivalves in Reef/Rack2**	Total # of Oyster Racks	Mean Water Cross-Section Over Reef/Rack (m2)	Mean Water Depth (cm)	Water Flow Length (m)	Mean Water Flow Speed (cm s-1)	Mean Water Flow Across Reef (m3 h-1)	Riisgård (1988) Predicted Ind. Clearance2 (L h-1)	**% of Water Flow Across Reef Filtered**
884	105.5	0.75	1.5	**1200**	1	2.44	244	1.5	10.0	878	5.5	**0.7**

Fig. 9: Simple Bivalve Filtration Model.

- This above model101 (Grizzle et. al 2008) uses simplest case scenario equations to determine the flow rate across an oyster reef or rack.
- With this model, it is assumed that the oyster racks are oriented in a linear fashion, one behind the other, so to determine the % of water flow filtered across our proposed structures, the calculated number can be multiplied by three.

Total Nitrogen Assimilation by Oysters

$$TN = e^{(-14.1569 + 2.7994 \times \ln(TL))} \quad (R^2 = 0.76; SE = 0.47)$$

Fig. 10: Total Nitrogen Assimilation Equation.

- Using the equation above (Higgins et. Al 2011), the total nitrogen that each individual oyster contained in both their shell and internal tissue could be calculated.
- Using the average size of our sample population, 101mm, we were able to plug this number into the equation as TL.

Wastewater Treatment Plant Nitrogen Output Totals by Year

YEAR	TOTAL NITROGEN (g)
2018	106730.28
2019	130997.48
2020	82962.04
2021	79061.15
2022	47491.12

Table 3: Yearly Nitrogen Outputs in Grams.

- The above data is the total nitrogen output into the Lamprey River by the Newmarket Wastewater Treatment Plant

Biological Results

Nitrogen coming from the WWTP: The average yearly nitrogen output coming from the Newmarket Wastewater Treatment Plant into the Lamprey River between the years 2018-2022 is **89448.42 grams**.

Percent Water Flow: Through a simple model (Figure 9), the % water flow that is filtered over an oyster rack was calculated to be 0.7%. Because this model assumes arrangement in a linear fashion, this number was multiplied by a factor of three to give a total of **2.1% water flow filtered** over one complete structure.

Assimilative capacity of oysters: Using the equation from Figure 10, average length measurements from a sample oyster population, and the 23% nitrogen filtration efficiency, as a result of filtration, biodeposition, excretion, and spawning (Songsangjinda et. Al 2000), an oyster that grows 25mm in length will assimilate **0.0571 grams** of nitrogen over one year.

Conclusions- Design Solution

- One oyster structure (two condos and an OysterGro) filters **205.54 grams** of nitrogen from the water column every year.
- Based on size of site and structures, we could deploy **435 structures** approximately five feet apart from one another to sequester 89,448.42 grams of nitrogen. The number of oysters required to fill these structures totals to **1,566,627 oysters**.
- Hypothetical deployment includes rows of oyster structures spanning the longest dimension of the 2.5-acre site, spaced five feet apart.
- The reductions in wave and current energies will influence scouring and sediment transport behavior, lessening the scale of erosion.

Recommended Future Research:

- Investigate the oyster reefs currently established in Great Bay Estuary and their ability to assimilate nitrogen.
- Determine oyster potential to sequester additional elements such as phosphorous and carbon.
- Study scouring effects and further mitigation possibilities.

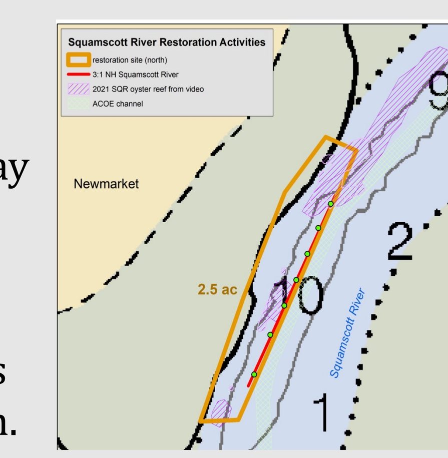

Fig. 11: Hypothetical deployment site (outlined in orange).

Acknowledgements

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