Bottom Water Characterization of Atlantic Surfclam Habitats off New Jersey

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ABSTRACT OF THE THESIS

"Bottom Water Characterization of Atlantic Surfclam Habitats off New Jersey."

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Shellfish aquaculture often occurs in shallow bays, which can have space constraints or unsuitable water conditions for some species. As opportunities to expand shellfish aquaculture into coastal habitats grow, it is important to evaluate the bottom water environmental conditions in those new habitats to assess potential for success. A site off the coast of New Jersey (39.4524 N, 74.2409 W) is being used as a pilot experiment for Atlantic surfclam (*Spisula solidissima*) aquaculture that aims to characterize inter-annual and seasonal patterns in bottom waters at this location. Ocean bottom water is understudied, creating a need for comprehensive coverage of parameters like temperature and dissolved oxygen as it relates to biological needs of the benthos. The goal of this study was to leverage existing datasets to characterize the bottom water conditions in and around a study site to determine if the area had suitable surfclam growing conditions. Parameters including temperature, salinity, density, and dissolved oxygen were sourced from modeled and glider-recorded datasets; model data provides a continuous historical estimated timeseries and the observational data provides observed measurements at isolated points in time.

A literature review was conducted on the Atlantic surfclam to better understand the biological needs of juveniles and adults. The threshold for salinity for the Atlantic surfclam is above 28 ppt. Below 28 ppt, lab experiments have shown stress-induced behaviors, but this was closely related to dramatic salinity drops, which is not anticipated within the study area. Feeding and respiration rates decrease above 23-24 °C, and at 20 °C growth declines and burrowing is inhibited. Dissolved oxygen (DO) below 2.85 mg/L is lethal for surfclams, but oversaturation (DO over 10 mg/L) can also harm them. Physiological stress in mollusks occurs below 4 mg/L, which serves as the DO threshold in this study.

A regional ocean model (Doppio) provided monthly averages of bottom water temperatures from 2007 – 2023 at the study location. The monthly averages were reviewed for seasonal trends and to assess changes across years. Glider observations were made within the bounds of the study area (116 km^2), the center of which is 6 km off the coast of Atlantic City. All glider observations collected in the study area within 5 meters of the bottom were averaged daily to create a multi-year time series of observed bottom water conditions. Glider observations from 22 deployments were available between 2014 – 2023, spanning all seasons, with higher coverage during fall

The combined timeseries of bottom water conditions from the model output and glider observations provide a comprehensive hindcast of the conditions that long-lived surfclams have experienced at that location over recent decades. The summarized bottom water conditions were used in comparison to surfclam biological thresholds and suggest that bottom water temperature tends to exceed 20°C for about 80 days each year. While this is not a lethal threshold for Atlantic surfclams, physiological stress may increase during those times. The other water quality parameters (salinity and DO) remain within suitable levels. This approach, combining modeling and observations, can be utilized as framework in the future for large-scale bottom water mapping to identify suitable aquaculture sites for the Atlantic surfclam.

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Introduction

The Atlantic surfclam, *Spisula solidissima*, is a profitable aquaculture and fishery species that has been well studied, but not over-exploited [1] [2] [3]. As the climate changes and the oceans face more challenges, understanding these challenges and their respective impacts on the Atlantic surfclam is crucial as aquaculture considers moving into coastal habitats [4]. Currently, shellfish aquaculture occurs in intercoastal bays, which can have low water quality index (WQI) parameters and space constraints compared to the coastal ocean [4] [5]. Considering changing marine environments, the need for more research to be done on the coastal oceans has increased. Despite advancements in ocean observing technologies, there are still unknowns about marine benthic conditions in coastal environments.

To better understand what locations are suitable for Atlantic surfclams, water quality parameters may be used to predict areas of optimal growth. Extensive literature on the Atlantic surfclams needs and biological thresholds have outlined the influence of temperature, salinity, and dissolved oxygen (DO) on their metabolic and biological requirements [3] [5] [6].

At 20 °C, Atlantic surfclams have been observed to have low growth rates and inhibited burrowing, while the rates of feeding and respiration decrease if water temperatures exceed 23 °C [3] [7] [8] [9]. The negative consequences of exceeding 20 °C were the driver in declaring the 20 °C threshold for this study. Beyond temperature, low salinities in marine bivalves have been associated with decreased growth and increased mortality [10]. These salinity effects are exacerbated by higher temperatures [10]. Specific to Atlantic Surfclams, lab experiments have demonstrated stress-induced behaviors once salinity dropped below 28 ppt [11].

Low oxygen has been shown to reduce immune function in bivalves [12]. When exposed to low oxygen levels, Atlantic surfclams have been observed to leave the burrow for areas of higher oxygen [11] [13]. Reduced immune function can lead to higher disease susceptibility, potentially leading to higher mortality [12]. Dissolved oxygen (DO) below 2 mg/L is an accepted level leading to mortality in Atlantic surfclams [11] [13]. For this study, 4 mg/L was set as the threshold below which physiological stress may occur.

This paper aims to characterize the bottom water conditions in a specific area off the New Jersey coast relative to the identified biological thresholds of the Atlantic surfclam to gauge the potential of the location for surfclam aquaculture applications. The data collected in this research is not exhaustive but is comprehensive. More research must be done both spatially, and on a wider suite of water chemistry parameters, to understand how this species might perform in this area.

Methodology

Study Area

The study area is about 13 km off the coast of New Jersey and covers an area 5 km wide by 24 km long, running along consistent bathymetry (Figure 1). The latitudinal range of the study area is 39.34 N to 39.55 N; the longitudinal range is 74.13 W to 74.34 W. The study area was selected to centrally encompass the pilot experiment, a site currently being used for an experiment on aquaculture of the Atlantic surfclam, at 39.4524 N, 74.2409 W (Figure 1). Bottom water was characterized in the region surrounding this experiment site using an ocean model and *in situ* data analysis methods.

Model Data

A Regional Ocean Modeling System (ROMS) product called Doppio was used to characterize bottom water conditions within the study site. Doppio's coverage extends from the Gulf of Maine to the Mid Atlantic Bight along latitude, longitude, and depth from 2007 – present [14] [15]. Doppio version 3 is a 7 km horizontal grid resolution that has 40 vertical layers, creating that 3-dimensional output [15] [16]. The model accurately predicts bottom water temperature [15] and was used to determine model-derived temperatures and in the study area (Figure 1).

Model outputs between 7 – 10 m were used to match the depth of the pilot experiment (8 m) and ensure observations were below the thermocline. Monthly temperature averages for 17 years (2007 – 2023) were extracted from the model. The deepest grid point value for the pilot experiment was extracted, and the monthly values were averaged, resulting in one value per month for each of the 12 months across all years. Monthly averages for the 17 years were analyzed and plotted into a time series to allow review of seasonal patterns and annual trends.

Glider Data

Gliders are autonomous underwater vehicles (AUVs) that have environmental sensors that allow for water quality data collection [17]. Every glider is deployed with an integrated CTD (conductivity, temperature, and depth sensor), providing full water column measures of temperature, salinity, and density. Gliders are driven by pumping seawater in or out to change their buoyancy. They can dive to 100 m and swim in a sawtooth pattern, collecting water column data [17]. Glider observations in this study were used to verify Doppio model output and were another method to characterize the bottom water in the study area.

Glider data were retrieved from the Rutgers Marine Glider Portal. Twenty-two gliders collected data within the study area during the study period (Figure 1). Temperature, salinity, density, and dissolved oxygen data from each glider within the study area were averaged daily before being compiled into an annual dataset with all relevant observations from the same year. The dates were then converted into Julian day and plotted into a yearly timeseries (Figure 3).

The literature regarding salinity thresholds used ppt as units, which are equivalent to PSU [18]. PSU was set as the threshold units because those were the units of the glider data. An additional sensor on some of the gliders in this study provided measurements of dissolved oxygen. A note of ‘No Data’ in Table 1 indicates the missions for which oxygen was not measured. Glider based oxygen data was converted to mg/L using the molar mass (16 g/mol) of oxygen to calculate a value of dissolved oxygen. This was done to be consistent with units commonly used in biological studies on farmed shellfish.

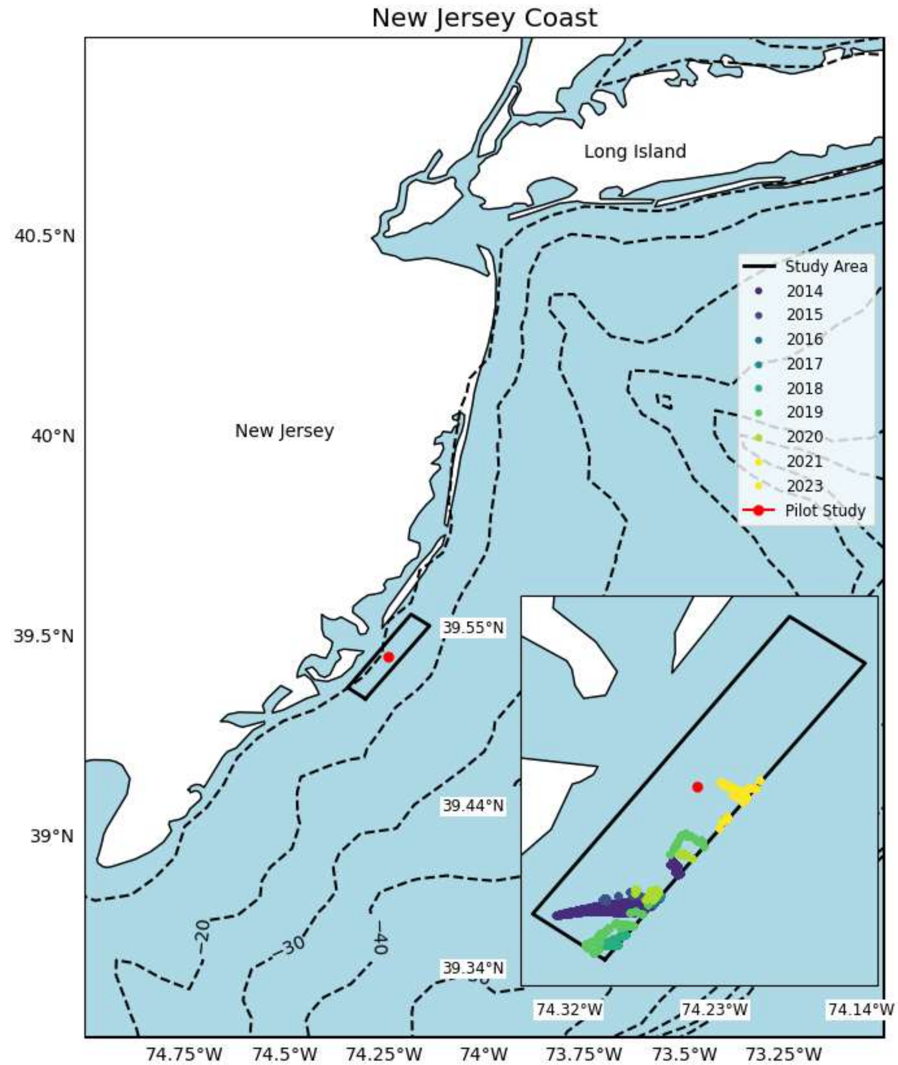

Figure 1: The study site located off the New Jersey coast. The inset shows all glider observations that were collected within the study site, colored by year. The bounds of the study site are shown with the black box, and the central red dot is the location of the pilot experiment. The study site runs parallel to the coast to include similar bathymetry levels.

Results

In the most recent years within the study area, bottom water temperature exceeded the 20 °C biological threshold for about 80 days each year (Figure 2). This is a general estimate of the trends and is consistent in both the modeled and glider observed data.

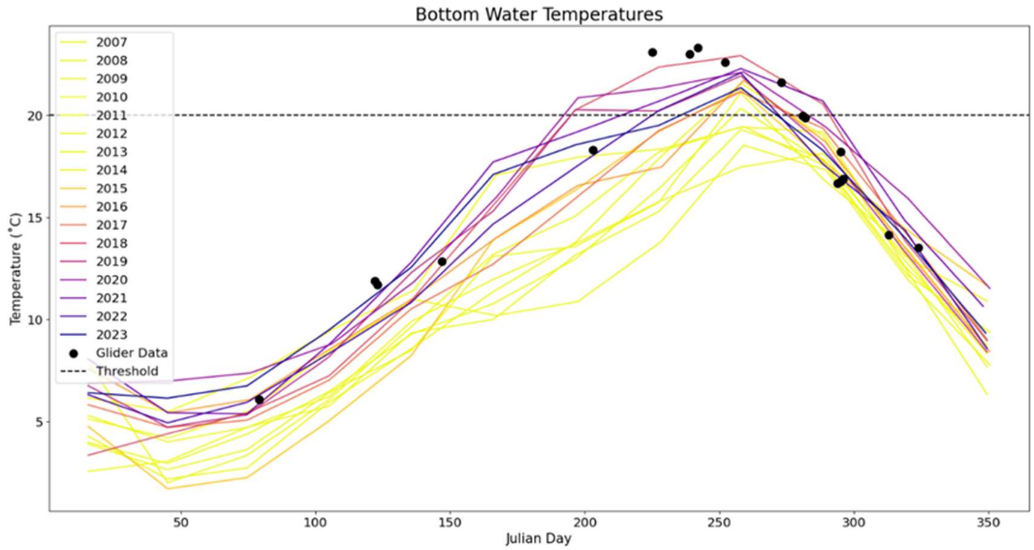

Figure 2: Annual average bottom water temperature trend lines, colored by year, from Doppio showing 2007 – 2023. The black dots are the 22 glider observation temperatures on their respective Julian days.

Twenty-two glider observations were acquired from 2014 – 2023. Data preceding 2014 were limited (Table 1, Figure 3). The data follows expected seasonal trends with the warmest observations, which exceeded the 20 °C threshold, during the summer with a maximum of 24.2 °C (Table 1, Figure 3-D). The coldest observations occurred towards the end of the winter with a minimum of 6.1 °C.

Dissolved oxygen concentrations stayed above the 4.0 mg/L threshold for all observations (Table 1, Figure 3-A). The lowest dissolved oxygen value was 4.8 mg/L, and the highest observation at 9.5 mg/L (Table 1, Figure 3-A). Salinity measurements also stayed above the 28 PSU threshold, ranging from 30.5 – 32.44 PSU (Table 1, Figure 3-B).

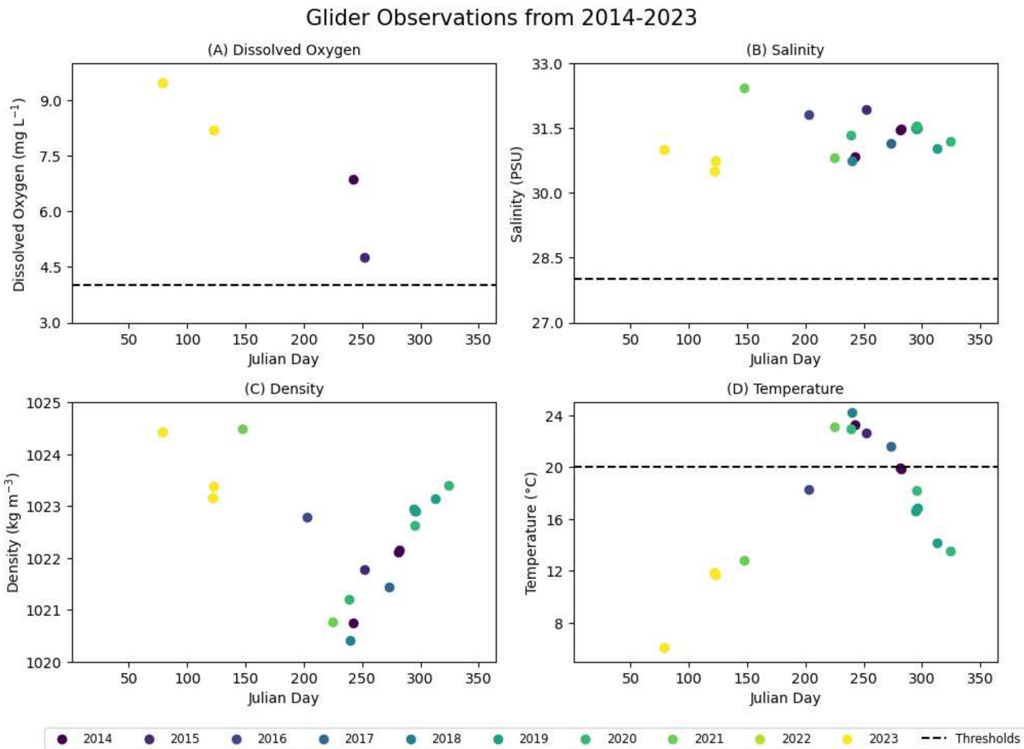

Figure 3: Glider observations of dissolved oxygen (A), salinity (B), density (C), and temperature (D) colored by year. The dashed lines are the biological thresholds of the Atlantic surfclam. There are 22 glider observations summarized by daily average from the study site between 7 - 10 m in depth. Dissolved oxygen (A) has 4 observations above the threshold of 4.0 mg/L. Salinity (B) has 22 observations above the threshold of 28 PSU. Density (C) does not have a threshold and shows the relationship between the variables. Temperature (D) has 22 observations with 6 observations exceeding the 20 °C threshold.

Table 1: Daily aggregated glider observations from the study site from 2014-2017. "No Data" indicates missing data points, most notably in the oxygen columns. This is due to those gliders not collecting oxygen information. Date was converted into Julian day for Figure 2. Oxygen concentration from the glider was in µmol/L but was converted using dimensional analysis into mg/L.

Aggregated Glider Data

Date	Julian Day	Glider	Lat	Lon	Depth m	Conductivity $S\ m^{-1}$	Salinity PSU	Density $kg\ m^{-3}$	O2 $umol\ L^{-1}$	O2 $mg\ L^{-1}$	Temperature °C
2014-08-30	242	ru28	39.383265	-74.266306	8.53	4.58	30.84	1020.74	214.52	6.86	23.3
2014-10-08	281	ru07	39.392954	-74.27071	8.47	4.35	31.45	1022.11	No Data	No Data	19.96
2014-10-09	282	ru07	39.376474	-74.301027	8.5	4.35	31.47	1022.15	No Data	No Data	19.86
2015-09-09	252	ru28	39.384053	-74.290535	8.51	4.66	31.93	1021.77	149.05	4.77	22.6
2016-07-21	203	ru28	39.380588	-74.26768	8.53	4.24	31.81	1022.79	No Data	No Data	18.31
2017-09-30	273	ru28	39.38479	-74.264532	8.49	4.46	31.14	1021.44	No Data	No Data	21.59
2018-08-28	240	ru30	39.356281	-74.295757	8.42	4.65	30.74	1020.41	No Data	No Data	24.19
2019-10-21	294	ru28	39.363794	-74.293567	8.49	4.05	31.5	1022.95	No Data	No Data	16.65
2019-10-22	295	ru28	39.363068	-74.296118	8.48	4.06	31.48	1022.91	No Data	No Data	16.76
2019-10-23	296	ru28	39.356793	-74.298596	8.52	4.07	31.49	1022.9	No Data	No Data	16.87
2019-11-09	313	ru22	39.419875	-74.247896	8.48	3.78	31.02	1023.13	No Data	No Data	14.13
2020-08-26	239	ru34	39.410457	-74.248894	8.4	4.62	31.33	1021.2	No Data	No Data	22.97
2020-10-21	295	ru28	39.43233	-74.224116	8.42	4.2	31.56	1022.64	No Data	No Data	18.19
2020-11-19	324	ru28	39.387057	-74.273672	8.52	3.74	31.2	1023.4	No Data	No Data	13.51
2021-05-27	147	ru30	39.451132	-74.208284	8.48	3.81	32.44	1024.48	No Data	No Data	12.82
2021-08-13	225	maracoos_02	39.451881	-74.220008	8.5	4.56	30.81	1020.77	No Data	No Data	23.09
2023-03-20	79	maracoos_04	39.446103	-74.214159	8.42	3.09	31.01	1024.44	295.79	9.47	6.07
2023-05-02	122	unit_648	39.440253	-74.216171	8.5	3.52	30.49	1023.16	No Data	No Data	11.86
2023-05-03	123	unit_648	39.435255	-74.22103	8.74	3.54	30.75	1023.39	255.86	8.19	11.7
2023-03-20	79	maracoos_04	39.446103	-74.214159	8.42	3.09	31.01	1024.44	295.79	9.47	6.07
2023-05-02	122	unit_648	39.440253	-74.216171	8.5	3.52	30.49	1023.16	No Data	No Data	11.86
2023-05-03	123	unit_648	39.435255	-74.22103	8.74	3.54	30.75	1023.39	255.86	8.19	11.7

Although there is no biological threshold for density (Figure 3-C), it was included to understand what is driving the density gradient in this area.

Discussion

The goal of this study was to characterize the bottom water conditions of the study area to determine if this area could be suitable for Atlantic surfclam aquaculture. While the water temperature is expected to exceed 20 °C for ~80 days each year, this is not a lethal threshold for the species. In terms of water quality, the habitat seems suitable for Atlantic surfclams. However, physiological stress may occur when the temperature exceeds the temperature threshold at this location [3] [7] [8] [9]. The other water quality parameters did not surpass their thresholds and stayed within suitable ranges. When data availability increases, intramonthly variability can be explored to better understand if occasional cold-water events could mitigate the impact exceeding the threshold.

The Doppio model output shows that exceeding 20°C for 80 consecutive days is a recent trend. It was not until the mid-2010's when the temperature values exceeded the 20 °C threshold for extended periods of time. According to the IPCC WGI Interactive Atlas, predictive models that are coupled and averaged show that in these areas mean temperature may increase by 1.5 °C between 2030 and 2040 [19]. Overall warming temperatures could see Atlantic surfclam reproduction, growth, feeding, and respiration decrease [3] [7] [8] [9]. With more observations of bottom water, assimilative models could become more accurate in predicting bottom water temperatures, which would better support aquaculture site decision making.

Although glider data and the model output were similar, the glider temperature data were observed to be warmer by ~1 °C since the mid 2010's. Highest temperatures also occurred slightly earlier in the observations than the model output. These differences could be due to interannual or intramonthly variability, especially if the glider observations favor the fall. Higher spatial and temporal resolution of glider observations at depth would be beneficial to verify if there is truly a degree of disconnect or if there are insufficient observations to determine aquaculture suitability.

Future work for this research could include analysis of data collected by sensors deployed in the pilot experiment with more carbonate chemistry parameters (e.g., pH and pCO2 due to its biological relevance for calcifying organisms) and analyzing within month variability of parameters. Analyzing the instrumentation data will allow for a more in-depth analysis of the temperature differences that were seen between the model and glider data. Collecting more data on water quality parameters will also be able to be leveraged in making a better decision about the future of aquaculture in this area. Monitoring water quality changes, like dramatic drops in salinity or extreme anoxic events, is necessary because these events can be lethal to the Atlantic surfclam [10] [11] [13]. Seasonal trends must be thoroughly assessed when deciding when and where to site aquaculture projects.

More data will support comprehensive and informed decisions regarding the suitability of an area for aquaculture. Such data collection provides a viable research trajectory for future evaluation of aquaculture exploration. Utilizing the methods in this paper provides initial steps to characterizing bottom water in other areas that seem favorable for aquaculture of the Atlantic surfclam, or other benthic species of commercial interest.

Conclusion

This research provides context about bottom water quality in coastal areas being explored for shellfish aquaculture, specifically for the Atlantic surfclam. The species is important in aquaculture and there is growing popularity for coastal applications. Using glider and model data, the study area was found to exceed the surfclams temperature threshold (20°C) for ~80 days a year, with all other parameters staying in their acceptable ranges.

While this research has not been entirely exhaustive, it provides support for surfclam aquaculture at the location reviewed. Using modeled and observed data, this approach can be utilized as a framework for large-scale bottom water research in identifying suitable aquaculture sites for valuable species.

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