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The effectiveness of hypo and hypersaline treatments of the American oyster, *Crassostrea virginica,* to control biofouling by the polychaete worm *Sabellaria vulgaris* and treatment effects on oyster growth in the Great South Bay, Long Island, New York

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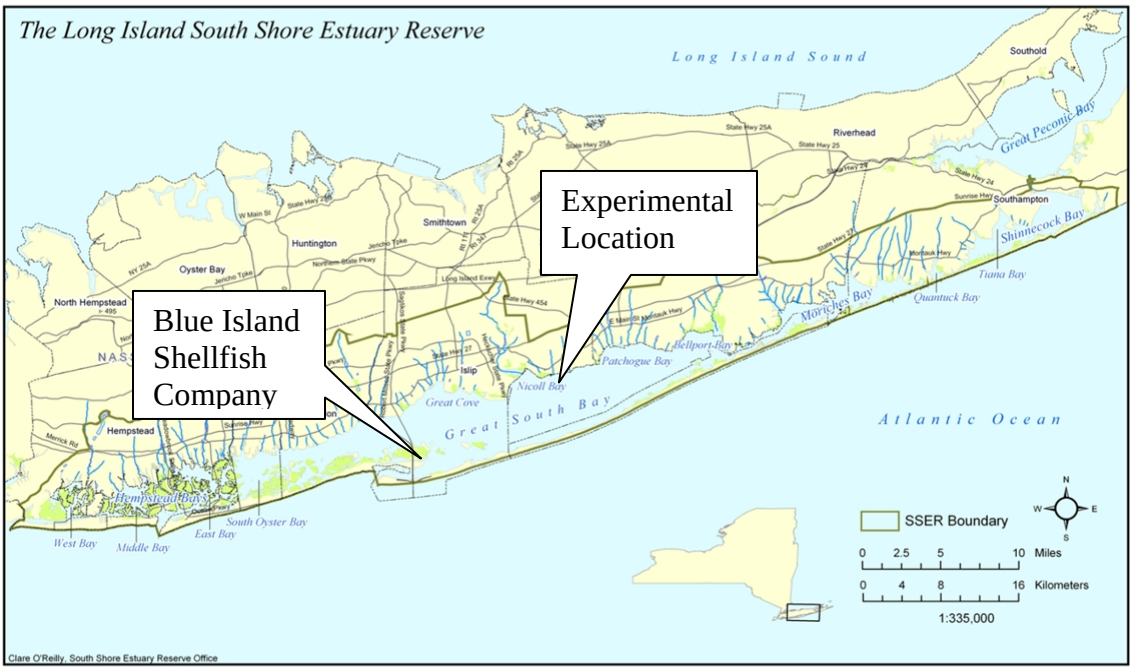


Abstract

The purpose of this project was to test the effectiveness of hypo and hypersaline dipping of the biofouling organism *Sabellaria vulgaris* on the American oyster, *Crassostrea virginica* and to assess oyster growth over a ten-week period. A random sample of 88 oysters reared in the GSB, Long Island, New York was taken from a population grown at the Blue Island Shellfish Company (BISC). The oysters were separated into a control group and two experimental groups and placed in grow-out trays at an experimental location. The experimental groups were exposed to brine dips of 8 parts per thousand (ppt) and 55 ppt. Physical parameters were recorded four times over a ten week period for mass, length, and thickness of oyster shell. Additional measurements for worm mortality (WM) and number of live worms (NLW) were recorded. During each sampling event, water chemistry was measured for temperature, salinity, dissolved oxygen, conductivity, and pH. Abiotic factors including air and dew point temperatures, wind speed, relative humidity, cloud cover, and tidal stage were recorded. Growth rate and descriptive statistics were generated for the data set. The growth of the oysters, NLW and WM of *S. vulgaris* were analyzed using a one-way ANOVA. The statistical tests revealed no difference between groups when NLW and WM were examined. However, the 55ppt group displayed superior shell growth to the other two groups, while the 8ppt group's mass increased by twice the rate of the 55ppt group. The experimental location was situated 15.5 km northeast of the BISC oyster population. While the experimental location did not experience a population explosion of *S. vulgaris*, the BISC location oysters did. The study concluded that: (a) during the time frame of the experiment, there were no statistically significant differences between treatment groups for NLW or WM,

(b) there is a statistically significant difference between groups for oyster growth, (c) confounding variables should be considered for future studies to better understand the flushing rate dynamics in Great South bay (GSB) related to oyster growth and colonization rates of *S. vulgaris*. These studies should be conducted in an effort to establish valuable baseline data to help baymen identify optimal locations for oyster aquaculture in GSB and promote a boost to the regional economics.

Background

The American oyster, *Crassostrea virginica,* is found from the Gulf of Mexico to Cape Cod in estuaries with salinity ranging between 5-30% (Gosner, 1978). The Great South Bay (GSB), part of the South Shore Estuary Reserve, is located along the south shore of Long Island, New York and once supported large populations of *C. virginica* (FWS, 1997). The oyster industry peaked in 1890 to 1910 with over 500 oyster boats and 1,000 oystermen working the bay and five hundred million oysters harvested annually (Small, 2005). However, over harvesting, pollution, and the opening of new inlets from the Hurricane of 1938 were the death knell for the Bluepoints Oyster, the most famous oyster of the GSB (Small, 2005). Oyster populations experienced a severe die-off, augmented by a final great decline in the 1950's that left New York production levels at two million pounds in 1975 (Elston & Relyea, 1981). Since the closure of the former Bluepoints facility in 2003, only one company, Blue Island Shellfish Company (BISC) has established itself as an oyster aquacultural facility in GSB. According to BISC owner, Chris Quartuccio, there is strong interest by local baymen to revitalize oyster production and strengthen the regional economics (Personal communication, June 17, 2007). The need for data collection and analyses to provide baymen with valuable information to

locate potential sites in GSB for oyster aquaculture and help boost the dwindling economic value of goods harvested from the bay is monumental.

Oyster shells commonly serve as hosts for a variety of organisms. In the shellfish industry such organisms can be disastrous for two reasons. First, organisms such as sea stars, oyster drills, and flatworms can kill the oyster by boring into the shell (Gosner, 1978). Secondly, barnacles, tubeworms and other colonizers can 'foul' the shell, making the shells aesthetically unmarketable. Oysters are commonly eaten off the half shell and oystermen are persistently challenged by the colonization of fouling organisms. Therefore, it is vital to determine how best to combat fouling organisms. Traditional methods for ridding fouling organisms from marine surfaces include the use of air drying, brine dipping, and tumbling (Dunphy, Wells, & Jeffs, 2005). Quartuccio asserts that grinding of *S. vulgaris* tubes in a mechanical tumbler is also common for cleaning the shells, but is not 100% effective and is costly and time consuming. Other techniques for biofouling control, include the use of chemicals, but have proven to have adverse effects on oyster health (Mackenzie & Shearer, 1959).

Although extensive research has been done on *C. virginica* for aquacultural purposes across the eastern seaboard, relatively little data has been collected in the GSB related to fouling from *S. vulgaris*. For GSB, oysters are raised in the Town of Islip Shellfish Culture Facility and are then transported to floating cages near the Fire Island Inlet. Here they are grown for two seasons until they reach marketable size. Because the BISC facility is close in proximity to Fire Island Inlet, salinity is high at 28 parts per thousand (ppt) and predation by sea stars, boring worms and encrustation by polychaetes are a common nuisance and render oysters unmarketable, C. Quartuccio (Personal

communication, June 17, 2007). In an effort to reduce tube worm encrustation, BISC has been tumbling and dipping oysters in 55 ppt solutions to kill biofouling organisms once signs of colonization are evident. In order to determine the most effective way to rid the oyster shells of infestations and study the growth rates of the oysters in the GSB, an experiment was implemented for the months of July and August, 2007.

Sabellaria vulgaris has a geographic distribution that ranges from New England to Cape Canaveral, Florida, living in coastal estuaries in the subtidal and intertidal zones and thrives in saline waters ranging from 20-27ppt but cannot survive in entirely marine or fresh water environments (Curtis, 1978). To prevent colonization of *S. vulgaris*, hypersaline or hyposaline treatment may be implemented during or immediately after spawning cycles. According to Waterman (1934), *S vulgaris* spawn primarily during peak water temperature periods in the summer. He has identified two spawning periods: a primary spawning period in late May when water temperature begins to warm, and a brief period in mid-August when water temperature peaks in Massachusetts at 22° C. Alkaline sea water in July can also lead to spawning and subsequent gamete fertilization (Waterman, 1934).

Aquaculture guidelines for dipping oysters have been recommended by Nell (2007), Bataller & Boghen (1999), and Maxwell, (2007). Maxwell (2007) concluded that brine treatments in Louisiana adversely affected oyster health and size. Therefore, oyster growth and mortality are two essential factors that warrant consideration.

The aquaculture industry is experiencing a boom, as world aquaculture grew by 9% per year between 1984 and 2001 (Olin, 2001). As the world population increases, global and local fisheries become more stressed. As a result, access to these resources

will continue to become limited. With reports predicting a complete collapse of world commercial fisheries by 2050 (Mackenzie, 2006), the move towards more sustainable practices to access food sources must be achieved at the local and global levels.

Experimental Methods

Experimental Design Methods

American oysters in their second year of residence at BISC (40° 38.645'N, 073° 14.901'W) were randomly selected from two sets of three-tier grow-out trays on July 8, 2007. The aquaculture facility is situated near the confluence of the GSB and Fire Island Inlet immediately offshore of Captree Island and Jones Beach Island. The trays immersed in 2 meters of water were hoisted for the selection of the experimental sample population. A pre-determination of sample size was calculated by the choice to conduct statistical tests with a power of .80 and effect size of .30. This resulted in 27 oysters per group. It was determined that there would be a control group and two experimental groups, bringing the sample size to 81 (3x27). Oysters were chosen randomly from a population that supported at least two adult polychaete annelids (*S. vulgaris)*. Ninety oysters were collected to account for mortality during transport and acclimation to the experimental site.

Abiotic measurements were taken at BISC when the oysters were removed initially and one time per week for ten weeks at the experimental location. A YSI-85 meter was used to measure water temperature, salinity, dissolved oxygen, conductivity, and percent saturation. An Oakton pH meter measured pH. A Kestrel 3000 measured air and dew point temperatures, relative humidity, and average wind speed (Plate 1). Cloud cover was estimated visually. A secchi disk was used to measure water transparency.

Oysters were placed into pails with bay water and transported via car 20 minutes away (15.5 km by water) to a location in Sayville, New York (40° 43.338'N, 73° 05.275'W) on July 8, 2007. Oysters were placed in a bi-level grow out tray. Each tray was divided into nine sections using plastic fencing material (Plate 2). The two experimental groups (which were named 8ppt and 55ppt based on brine concentrations) and one control group each had five oysters per section, fifteen per tray layer, thirty overall per experimental group and thirty in the control group. Oysters were placed randomly into an experimental or control group. The tray was submerged in 1.2 meters of water anchored off of a bulkhead, situated 0.2 meters off of the bay bottom. This depth was determined based on .09m fluctuation in tides between cycles (Tides and Currents, 2007).

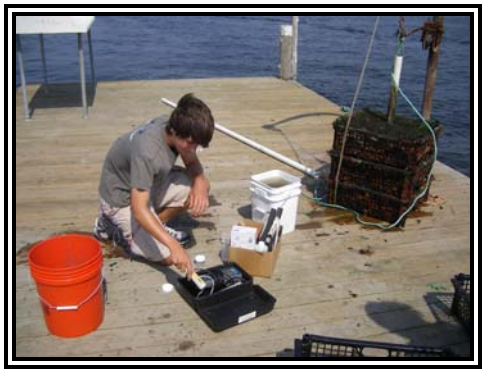


Plate 1: Water testing and BISC grow out trays

Plate 2: Experimental grow out tray

Oysters acclimated to new environmental conditions over a six day period. During this time, two oysters from the control group were lost during a storm on July 10, 2007. On July 14 oysters in each group were labeled 1-30 using wire markers and a waterproof, nontoxic adhesive. Mass, length, and thickness were measured. Oyster length was measured with calipers as the straight line distance from the posterior end to the anterior end of the oyster. Oyster thickness was measured at the greatest distance from

surface of the left valve to surface of the right valve. Mass was measured using an Ohaus electronic balance. All adult colonizing worms were counted by visual inspection and recorded. After the oysters were measured, marked, and photographed, they were placed in pails with bay water (Plate 3). All oysters were placed back into the grow-out trays and submerged into the bay after each data collection event. On Sunday, July 15, the oysters were removed from the bay and each group was placed into a pail without water (Plate 4). All three groups remained out of water for thirty minutes to ensure valve closure prior to dipping. Solutions of 8.0 ppt and 55.0 ppt were made from chemical-free salt and non-chlorinated fresh water using pre-determined ratios of salt mass to water mass and were held in three separate pails. A YSI-85 meter was used to ensure that the concentrations were correct and fell within plus or minus 0.1 ppt salinity for accuracy.

Plate 3: Oysters in control solution

Plate 4: Oyster in drying pail

All oysters were rapidly transferred from the dry pail to their respective experimental pails. The control group oysters were placed in bay water (25.0 ppt), the hyposaline experimental group placed in 8.0 ppt, and the hypersaline experimental group placed in 55.0 ppt. The oysters were submerged for fifteen minutes in their respective solutions, after which they were rapidly removed and placed back into dry pails for one hour to allow biofouling organisms affected by the dipping to die. They were then

returned to grow out trays and placed back in the bay water. This experiment was repeated two weeks later on July 21, 2007 and again on August 4, 2007. Thereafter, the oysters were placed in grow-out trays and left untouched for a period of four weeks during the period of peak water temperature when polychaete spawning was expected to be greatest. Oysters were removed from the trays a final time on September 8th 2007, measured, photographed, and then returned to BISC. All data were entered into Microsoft Excel.

Hypothesis Testing and Statistical Methods

In an effort to determine the best statistical analyses to interpret the data, a set of hypotheses were created. Steps to hypothesis testing were established to evaluate the data, review assumptions, select and calculate a test statistic, and state the decision rules for rejecting or accepting the null hypothesis (H_0).

A random sample size of 90 American oysters whose data are continuous with no fixed limits and are on a ratio scale (per 100 in an oyster population) were evaluated to: (a) determine whether a difference exists in NLW for those oyster shells that are not subjected to brine dipping (N=28, M = 1.69, SD = 1.57 compared to those dipped at 8ppt (N= 30, M = 1.69, SD = 1.33) and 55ppt (N= 28, M= 1.49, SD = 1.51), (b) determine whether a difference exists in WM for those oyster shells that are not subjected to brine dipping (N= 28, M = 0.59, SD = 0.60) compared to those dipped at 8ppt (N= 30, M =0.6, SD = 0.90) and 55ppt (N= 28, M = 0.70, SD = 0.93), (c) determine whether a difference exists in mass over a 10 week period for *C. virginica* that are not subjected to brine dipping (N= 28, M = 47.48, SD = 11.72) compared to those dipped at 8ppt (N=30, M= 45.69, SD = 14.08) and 55ppt (N= 28, M = 51.57, SD = 15.88), (d) determine whether a

difference exists in length over a 10 week period for *C. virginica* that are not subjected to brine dipping (N= 28, M= 7.98, SD=0.88) compared to those dipped at 8ppt (N= 30, M= 7.82, SD=1.20) and 55ppt (N= 28, M = 8.20, SD=1.18), and (e) determine whether a difference exists in thickness over a 10 week period for *C. virginica* that are not subjected to brine dipping (N= 28, M = 1.97, SD = 0.28) compared to those dipped at 8ppt (N=30, M=2.03, SD = 0.26) and 55ppt (N=28, M=2.12, SD=0.39).

The assumptions for conducting a one way ANOVA included: (a) the dependent variables are continuous and are normally distributed, (b) groups are mutually exclusive (independent of each other), and (c) groups display homogeneity of variance.

The following Null Hypotheses (H_0) and Alternative Hypotheses (H_A) were established to guide the statistical tests: (a) H_0 #1 - There will be no difference in NLW for those oyster shells that are not subjected to brine dipping when compared to those dipped at 8ppt and 55ppt. H_A #1 - There may be a difference which does not occur by chance between the groups in total NLW for oysters that have received brine dipping at 8ppt, brine dipping of 55ppt, or no brine dipping in the sample population, (b) H_0 #2 - There will be no difference in WM for those oyster shells that are not subjected to brine dipping when compared to those dipped at 8ppt and 55ppt. H_A #2 - There may be a difference which does not occur by chance between the groups in total WM for oysters that have received brine dipping at 8ppt, brine dipping of 55ppt, or no brine dipping in the sample population, (c) H_0 #3 -There will be no difference in mass over a 10 week period for *C. virginica* that are not subjected to brine dipping when compared to those dipped at 8ppt and 55ppt. H_A #3 - There may be a difference which does not occur by

chance between the groups in total mass for oysters that have received brine dipping at 8ppt, brine dipping of 55ppt, or no brine dipping in the sample population, (d) H_0 #4 - There will be no difference in length over a 10 week period for *C. virginica* that are not subjected to brine dipping when compared to those dipped at 8ppt and 55ppt. H_A #4 - There may be a difference which does not occur by chance between the groups in total length for oysters that have received brine dipping at 8ppt, brine dipping of 55ppt, or no brine dipping in the sample population, and (e) H_0 #5 -There will be no difference in thickness over a 10 week period for *C. virginica* that are not subjected to brine dipping when compared to those dipped at 8ppt and 55ppt. H_A #5 - There may be a difference which does not occur by chance between the groups in total thickness for oysters that have received brine dipping at 8ppt, brine dipping of 55ppt, or no brine dipping in the sample population.

The Critical F Test statistics of the ANOVA with 2 degrees of freedom were calculated to be: (a) 3.02 at $p = 0.05$ level, and (b) 4.66 at $p = 0.01$. The Decision Rules for H_0 are: (a) Reject H_0 if $F>3.02$ at .05 level and (b) Reject H_0 if $F>4.66$ at .01 level.

To determine differences among group means for factor variable, a one way ANOVA test was run using the EXCEL Tool Pack. Using the partitioning of the sum of squares, the ANOVA measures the variance both within a group and between groups. According to Munro (2005), when: between group variance > within group variance, the groups are said to be different in a statistically significant way and when: between group variance = within group variance, the means between groups are not statistically different. Gotelli & Ellison, (2004) assert that the F-ratio, which is the between group

variance mean square divided by the within group variance mean square, is a measure of the validity of H_0 (p. 299). They continue to state that if H_0 is true, the F-ratio will be near 1.0 and if the F-ratio is substantially larger than 1.0, the effect of the experiment is said to be very large (p. 299). This allows for the rejection of H_0. For a variation to be statistically significant, the F-ratio has a critical value which will allow H_0 to be rejected 95% of the time in this experiment (p=.05) or 99% of the time (p=.01).

To evaluate growth rate, for the three experimental groups over a period of ten weeks, rate analysis was conducted for mass, length and thickness using the following formula: Rate of change = final-initial/time

Results

The Descriptive Statistics for the three groups are presented below in tables 1-5

Table 1. Mass of Groups

	Mass (g) control	*Mass (g) 8ppt*	*Mass (g) 55ppt*
Mean	47.47526786	46.45783333	52.24342
Standard Error	1.107357298	1.164187321	1.362454
Median	46.365	47.73	52.825
Standard Deviation	11.71916809	12.75303313	14.92494
Skewness	0.377337061	-0.020381106	0.767242
Count	112	120	120
Confidence Level(95.0%)	2.194302342	2.305207142	2.697795

Table 2. Length of Groups

Length (mm) control	*Length (mm) 8ppt*	*Length (mm) 55ppt*
Mean	7.975625	7.828916667	8.201833
Standard Error	0.082951	0.109513618	0.106512
Median	7.995	7.91	8.155
Standard Deviation	0.877873	1.199661574	1.166782
Skewness	-0.00217	-0.797414566	-0.14833
Count	112	120	120
Confidence Level(95.0%)	0.164373	0.216847898	0.210905

Table 3. Thickness of Groups

	Thickness (mm) control	Thickness (mm) 8ppt	*Thickness (mm) 55ppt*
Mean	1.96625	2.032917	2.123167
Standard Error	0.026546	0.023762	0.034954
Median	1.965	2.005	2.05
Standard Deviation	0.280935	0.260302	0.382899
Skewness	1.670454	0.194565	2.003459
Count	112	120	120
Confidence Level(95.0%)	0.052602	0.047051	0.069212

Table 4. # Worms in Groups

# worms control		*# worms 8ppt*	*# worms 55ppt*
Mean	1.696429	1.691667	1.475
Standard Error	0.148371	0.121727	0.134395
Median	1	1	1
Standard Deviation	1.570214	1.333447	1.472222
Skewness	3.175794	1.990456	2.476194
Count	112	120	120
Confidence Level(95.0%)	0.294008	0.241031	0.266115

Table 5 Mortality in Groups

	Mortality Control	*Mortality 8ppt*	*Mortality 55ppt*
Mean	0.598214	0.6	3.400568
Standard Error	0.080678	0.095857	1.987566
Median	0	0	0.011881
Standard Deviation	0.853818	0.909377	23.1788
Skewness	2.030766	1.620958	9.358097
Count	112	90	136
Confidence Level(95.0%)	0.159869	0.190465	3.930793

The results of the one way ANOVA are presented on the next page in Tables 6-10.

Table 6

Anova: Single Factor Mass

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Mass (g) control	112	5317.23	47.47527	137.3389
Mass (g) 8ppt	120	5574.94	46.45783	162.6399
Mass (g) 55ppt	120	6269.21	52.24342	222.7538

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2276.94666	2	1138.473	6.502213	0.001688	3.021595
Within Groups	61106.4601	349	175.0901			
Total	63383.4068	351				

Table 7

Anova: Single Factor Length

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Length (mm) control	112	893.27	7.975625	0.770661
Length (mm) 8ppt	120	939.47	7.828917	1.439188
Length (mm) 55ppt	120	984.22	8.201833	1.36138

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.46466973	2	4.232335	3.526854	0.030449	3.021595
Within Groups	418.810912	349	1.200031			
Total	427.275582	351				

Table 8

Anova: Single Factor Thickness

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Thickness (mm) control	112	220.22	1.96625	0.078925
Thickness (mm) 8ppt	120	243.95	2.032917	0.067757
Thickness (mm) 55ppt	120	254.78	2.123167	0.146612

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.44304888	2	0.721524	7.347778	0.000749	3.021595
Within Groups	34.2705008	349	0.098196			
Total	35.7135497	351				

Table 9

Anova: Single Factor Number of Worms

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
# worms control	112	190	1.696429	2.465573
# worms 8ppt	120	203	1.691667	1.778081
# worms 55ppt	120	177	1.475	2.167437

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.793398	2	1.896699	0.890678	0.411308	3.021595
Within Groups	743.1952	349	2.129499			
Total	746.9886	351				

Table 10

Anova: Single Factor Mortality

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*	
Mortality Control		112	67	0.598214	0.729006
Mortality 8ppt	90	54	0.6	0.826966	
Mortality 55ppt	120	81	0.675	0.843067	

ANOVA

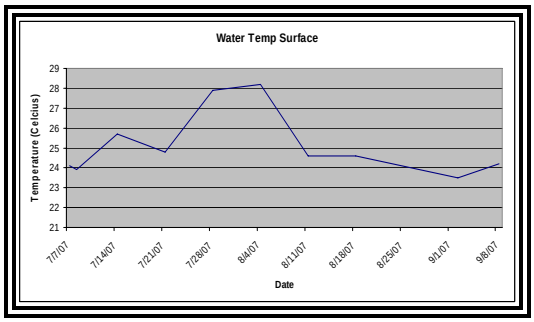
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.43486	2	0.21743	0.272167	0.761904	3.024042
Within Groups	254.8446	319	0.798886			
Total	255.2795	321				

The null hypothesis was accepted or rejected based on the F-statistic and rules established in the statistical methodology of this report and are summarized in Table 11.

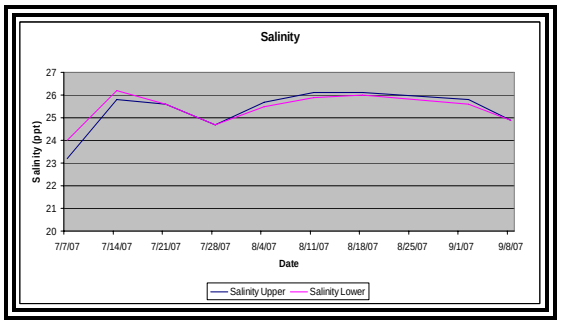
Table 11. Acceptance/Rejection of Null Hypothesis

H_0 Number	**Factor**	**Accept**	**Reject**	**F-Statistic and Rule**
1	Number of worms	X		F= 0.89; *Accept H_0 if F<3.02 at .05 level*
2	Mortality	X		F = 0.27; *Accept H_0 if F<3.02 at .05 level*
3	Mass		X	F= 6.50; *Reject H_0 if F>4.66 at .01 level*
4	Length		X	F= 3.53; *Reject H_0 if F>3.02 at .05 level*
5	Thickness		X	F= 7.35; *Reject H_0 if F>4.66 at .01 level*

Water chemistry was collected over the experimental period and is presented in the graphs below.



Water Temperature ° C vs Time (weeks)



Salinity (ppt) vs Time (weeks)

Measurements of the sample oysters were compared for percent change in mass, length, and thickness over a ten week period to determine whether brine treatments had an effect on oyster growth. The results are presented in Table 12 below.

Table 12: Percent change in oyster size

	Mass	**Length**	**Thickness**
Control	10.11	0.03	6.12
8 ppt	13.06	1.17	5.60
55 ppt	6.85	1.48	6.74

Discussion and Conclusion

The ANOVA accepted two of the null hypotheses and rejected three. H_0 #1 (NLW) was accepted as the F ratio was lower than F crit at the .05 level. Although within group variance was slightly lower than total variance, the difference between the two groups does not appear to be statistically significant. The acceptance of the H_0 means that

the differences in salinity when the oysters were dipped had no effect on tube worm survival or colonization. H_0 #2 (WM) was also accepted, as its F-ratio was lower than F crit at p=.05. Although there was some variation among groups, with the 55ppt group experiencing the highest WM, the variation between groups and the resultant F-value were extremely low (0.27). For all three hypotheses regarding the oysters' physical dimensions (mass, length, thickness), the H_0 was rejected. For H_0 #3 (mass), the F-value (6.50) exceeded F-crit for p=.05 (3.02) and p=.01 (4.66). For H_0 #4 (length) the F-value exceeded F-crit for p=.05 but was below F-crit at p=.01. For H_0 #5 (thickness) the F-value (7.34) significantly exceeded F-crit for p=.05 and p=.01. In contrast to Munro (2005), every case that H_0 was rejected, variation between groups was lower than variation within groups, which implies that a Type I Error may exist. When H_0 is rejected at p=.05, there is a 5% chance that the H_0 was falsely rejected. The Type I Error could be attributed to the assumption of homogeneity of variance not being met. This assumption was screened initially by generating box plots. To further evaluate whether the means in the data meet this assumption, Levene's Test of Equality of Error Variances could be conducted (Munro, 2005).

Type I Error could also be attributed to differences in sample size between groups due to oyster mortality or a problem related to how normal the data is actually distributed. Quinn & Keough assert that transformations for (+) skewed distributions may be necessary (p.206). The descriptive statistics show some (+) skewness for mass, NLW, and WM in the control group; thickness, NLW, and WM in 8ppt group; and mass, thickness, NLW, and WM in the 55 ppt group.

Worm mortality and NLW showed no significant difference between groups. These results do not agree with Maxwell (2007), or Bataller & Boghen (2000). The data from this experiment also do not support an isolated event that occurred at BISC during the week of August 5, 2007, when a population explosion of *S. vulgaris* occurred at the aquaculture facility. This explosion was not observed at the experimental location. Explanations for these difference may be related to, but not limited to, the following confounding variables based on differences in geographic location (spatial distribution) between experimental location, BISC, and other study locations: (a) water temperature and salinity, (b) tidal flushing, and (c) relative abundance of oysters per grow out tray (crowding). The need for further studies related to tidal flushing are supported by the water chemistry data which indicate a water temperature peak was reached in early August concurrent to the *S. vulgaris* population explosion at BISC. According to Waterman (1934), *S. vulgaris* spawn at 22° C in Massachusetts. Water temperature was measured to be above this critical value at the onset and for the duration of this experiment with peak water temperature at 28.2 ° C. This study concurs with Maxwell (2007) where brine dipping is associated with longer shell length over time. This study also indicates that brine dipping is associated with a thicker shell over time. Bataller, Boghen, & Burt (1999) confirm that optimal temperature and salinity variations are due to varied weather patterns and tidal prism. Their study does not address tidal flushing.

In an effort to promote long term economic growth in GSB and to support the scientific needs for successful implementation of oyster aquaculture, future studies should include a replication of this study using BISC as a control site and experimental locations further from Fire Island Inlet in GSB to: (a) study and evaluate tidal flushing

rates on oyster growth and *S. vulgaris* colonization, (b) study water nutrients related to tidal flushing and potential effects on oyster growth and colonization of *S. vulgaris*, and (c) study oyster density in grow out trays related to fouling from *S. vulgaris* at various locations in GSB.

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