The Effect of Fishery Pressure on Oyster Reefs in the South River

By Chloe Obara

A Capstone Study Submitted to the Chesapeake Bay Trust in Partial Fulfillment of the Requirements of the Chesapeake Conservation Corps Program

August 2021

Host Site: Arundel Rivers Federation

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ABSTRACT

Five understudied oyster reefs (reefs) in the South River were sampled throughout the 2020-2021 year to uncover the biological and physical differences between reefs in a fairly homogeneous environment that experience a wide variety of fishery pressure. Reefs were sampled for presence of disease on-reef and above-reef habitat, and oyster size and spat size/survivorship. There was a large amount of variability between the parameters measured, so a definitive conclusion as to the effect of fishery pressure on reef health cannot be drawn. However, the high resolution data collected provide an insight into four reefs for which little to no data was previously available and build upon the existing data base for one well studied reef. Additionally, this study develops methodology for sampling a variety of parameters in reefs for which access by diver is not available and funding is limited. Replication of this study is recommended to determine if significant trends exist across years of data.

INTRODUCTION

The current population of the Eastern Oyster (*Crassotrea virginica*) in the Chesapeake Bay is >2% that of the late 1800s [1]. Decades of volunteer restoration efforts have been dedicated towards reviving this threatened population and implementing best management practices [2]. Early oyster restoration efforts on the South River were initiated by John Flood, who devised "flood buckets" or five gallon buckets with holes drilled into the sides, which were filled with spat and hung from pilings on volunteers' docks until the oysters matured. Other methods of raising spat were also developed, such as oyster floats (PVC floats with a metal cage in the middle) or oyster cages that are hung from pilings. The Chesapeake Bay Foundation (CBF) and partners have built and periodically replenished oyster reefs in Selby Bay, Glebe Bay, the mouth of Crab Creek, the mouth of Glebe Bay, Duvall Creek, Aberdeen and Little Aberdeen Creeks, off Brewer's Point, off Edgewater Beach, Ferry Point, off Turnbull Estates, Harness Creek, off Larrimore Point, off Sheckell's property, and Libby's Bar since 1998 [3]. Since 2008, the Arundel Rivers Federation, then South River Federation, has run a branch of the Marylander's Grow Oysters Program in communities on the South River. This program engages homeowners who raise spat in cages hanging off their pilings and release the mature spat on the sanctuary reef at Glebe Bay.

Organizations such as the Arundel Rivers Federation, Smithsonian Environmental Research Center, and CBF are invested in monitoring the success of oyster restoration efforts to understand their effectiveness. The need for this study was identified through discussion with principal investigator Dr. Matthew Ogburn and postdoc Allison Tracy of the Smithsonian Environmental Research Center Fisheries Conservation Lab (SERC FCL) regarding their current oyster monitoring efforts and goals for future research. In 2019, the lab identified the Glebe Bay and Ferry Point reefs on which to begin a long-term monitoring effort with funding from the Marine Global Earth Observatory program (Marine GEO), a worldwide network of researchers studying and working to mitigate climate change of coastal environments. In 2020, the SERC FCL collected data on habitat structure, disease presence, size distribution, and associated species at the Glebe Bay and Ferry Point reefs. Previously, in 2018, Chesapeake Conservation

Corps Member Shayna Keller conducted a dive survey on the Glebe Bay reef to quantify oyster size and spat health. Despite this extensive localized monitoring at Glebe Bay, there are over a dozen known oyster reefs in the South River, as listed above, that are either understudied or for which no data exists. Furthermore, given the complicated regulatory framework that governs the oyster population, fishery pressure varies greatly from reef to reef [4]. For the purpose of this study, "fishery pressure" is defined as the localized impacts of commercial or recreational oyster harvesting on an oyster reef.

This study aims to address this gap in knowledge and provide data that will benefit the Arundel Rivers Federation, SERC FCL, CBF, and other organizations that monitor, restore, and advocate for the preservation and expansion of healthy oyster populations in the Chesapeake Bay. To conduct this study, five oyster reefs in the South River were sampled that fall into each of the following fishery pressure categories: 1. sanctuary; 2. public shellfish harvest; 3. open access, limited harvesting due to high bacteria levels; and 4. independently owned aquaculture. Parameters to be monitored are: 1. presence of disease (specifically *Perkinsus marinus*, commonly referred to as Dermo, a parasite that causes mortality in oysters [5]); 2. on-reef and above-reef habitat and 3. oyster size and spat size/survivorship. It is predicted that oyster reefs with higher fishery pressure will have reduced habitat structure, biodiversity, spat count, and oyster size as compared to sanctuary oyster reefs, but disease presence will not vary.

Goals:

1. Compile and analyze data from 2020-21 on five oyster reefs in the South River.

2. Identify physical and biological variation between the reefs studied and place this variation context of fishery pressure.

STUDY SITE

To conduct this study, one well studied reef and four understudied oyster reef locations in the South River were selected: 1. Glebe Bay- well studied (sanctuary); 2. off Persimmon Point (public shellfish harvest); 3. off Brewer Point (public shellfish harvest); 4. Duvall Creek (limited harvesting due to high bacteria levels); and 5. off Quiet Waters Park (independently owned aquaculture) (Table 1, Figure 1). In this paper, these sites will be referenced by their site ID as follows:

Site ID	Reef Location	Coordinates	Description
WP68	Off Brewer Point	38.927112, -76.517439	Restored, open to public harvest
WP69	Off Persimmon Point	38.93512, -76.519027	Restored, open to public harvest
Duvall	Duvall Creek	38.929348, -76.482764	Restricted harvest due to high bacteria levels
QW	Off Quiet Waters Park	38.929449, -76.508728	Privately owned and harvested

Glebe	Glebe Bay	38.931652, -76.537481	Restored, in sanctuary zone

Table 1. Site ID, GPS location, and description of fishery pressure for the five oyster reefs selected for this study.

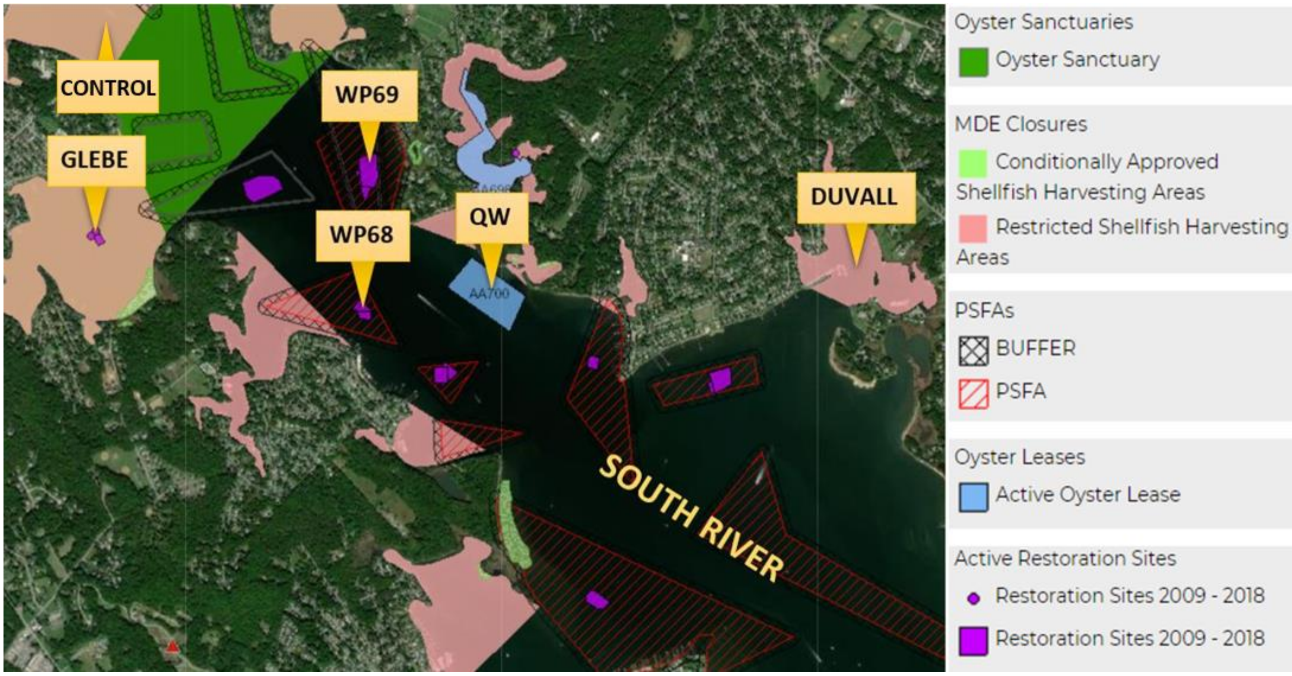

Figure 1. Study sites noted on map of the South River overlaid with fishery zones. Basemap and legend borrowed from Maryland Department of Natural Resources. For complete map visit: http://gisapps.dnr.state.md.us/Aquaculture/index.html.

Data from CBF shows that Glebe, Duvall, and WP68 have been seeded with spat on shell and year-old oysters over the past decade [3]. WP68 has only received one batch of 1,485,000 spat in 2006. Duvall has received 27 batches of spat/oysters from 2004 through 2016, totaling 3,121,762 oysters, but none in the past 5 years. Glebe has received 25 batches from CBF from 2005-2020 totaling 5,978,046 oysters, and also receives about 120,000 year-old oysters each year from the Maryland Grows Oysters Program, which began in 2008, and has run every year since except 2018 due to poor spat growth conditions. WP69 does not have a record of oyster replenishment from CBF but is marked as restored on the MDNR Aquaculture Siting Tool, and QW is independently maintained without public data.

MATERIALS

This list is included for ease of replication in future studies.

I. *Locating Study Sites*
   - Long sturdy rod ex. boat hook, oyster tongs
   - Hand tongs

- 20 foot Carolina Skiff
- In-boat or handheld GPS unit

II. *Collecting Samples*
- Hand tongs
- Labeled bags or oyster cages for each sample site
- Hydrolab HL7 Mulitparameter Probe
- 20 foot Carolina Skiff
- In-boat or handheld GPS unit

III. *Reef Survey*
- 0.5m x 0.5m x 0.55m PVC quadrat rig with a weighted base and 3 mounted GoPro cameras
- Hydrolab HL7 Mulitparameter Probe
- White board and markers

IV. *Shell Analysis*
- GoPro camera
- Caliper

V. *Trawl Survey*
a) Otter trawl (trawl)
b) 1-2 Small hand nets
c) 2 aerators
d) 2 bins
e) Measuring tape
f) Measuring board

METHODS

I. *Locating Study Sites*
a. Potential target locations are identified though referencing the MDNR Aquaculture Siting Tool for approximate location of all historic and modern reefs.
b. In field, hard bottom, indicating reef presence is identified. Water clarity in the South River is too poor to see oyster shell on the river bottom, so a long, sturdy rod is used to poke bottom, feeling for change in substrate that would indicate hard bottom.
c. Once hard bottom is identified, a few sample grabs are taken with hand tongs to confirm presence of oyster shell.
d. Once oyster reef is located, location is marked on boat GPS or hand-held GPS unit

II. *Collecting Samples*
a. Hand tongs are used to collect oysters from bottom until at least 15 live oysters are acquired from each study site. Samples were only taken at QW once, for disease testing, due to private ownership restrictions.
b. Samples are placed in pre-labeled bags or oyster cages.

c. Water quality is sampled at site using a Hydrolab HL7 Multiparameter Probe to record temperature, pH, salinity, conductivity, and dissolved oxygen at .25m depth intervals.

III. *Disease Testing*

a. Conducted by Shellfish Pathology Lab by Virginia Institute of Marine Science (VIMS). See attached lab report for methods.

IV. *Reef Survey**

a. Two cameras are fitted to opposite sides of the base pipe and are pointed outward at a slight downward tilt of approximately 20 degrees off of vertical. A third camera is mounted on the middle of the top pipe and is angles straight down. The rig is attached to a 6m line with a buoy for deployment and retrieval. Base cameras are set to record continuous footage, while the top camera takes a still image every 3 seconds.

b. After navigating to a pre-selected GPS point, cameras are turned on and a white board with a unique station/run# identifier is held in front of each base camera. The image number on the top camera is also recorded.

c. Once over the desired reef location the rig is carefully lowered so it sits upright on the bottom and the deployment GPS location is recorded. The rig is left for 2 minutes before it is recovered, during which the boat moves away from the location to allow sediment to settle in the area. Once recovered, cameras are turned off and image number of the top camera is recorded.

d. Steps b-c are repeated four additional times for a total of five deployments at each site.

e. In-lab, each bottom camera video footage is observed from start to finish, with observations recorded such as visible fauna/algae, oyster structure, oyster coverage, and water clarity. In ideal conditions, the top images can be overlaid by a grid to conduct a percent coverage analysis. In this study, the water quality was too murky to allow for a clear top image, so this analysis was not included.

*Adapted with borrowed language from methodology devised by SERC FCL [6].

V. *Shell Analysis*

a. For each oyster:

- Two to three pictures are taken of oyster next to white board labeled with sample ID ex. 1.3
- Length, height, and width of oyster are measured in mm with caliper
    - Length = longest hinge to lip distance
    - Width = longest distance roughly perpendicular to length
    - Height = thickest part of oyster measured vertically when lying flat
- Number of spat (live), boxes (dead), and scars (no shell remains, only discoloration) on oyster are counted
- Length of spat, boxes, and scars are measured in mm with caliper
- Presence organisms/discoloration on shell is observed

VI. *Trawl Survey**

a. Trawls are conducted before any other surveys/collections as to not scare away organisms.
b. Starting location for the first trawl is devised so that the trawl occurs mostly within or immediately adjacent to the target habitat.
c. Trawl is deployed over side of boat. Depth, starting time, and starting location (GPS coordinates) are recorded.
d. Boat is throttled forward at low speed (3-4 knots) to keep doors open for designated amount of time. Trawls taken at two, three, or four minute intervals. Total time of trawling pull and ending GPS location are recorded.
e. Trawl is pulled onto boat and net is opened. All organisms are transferred into a holding bin with water and an aerator. A hand net is used to catch organisms from the holding bin. Species and length (cm) of all organisms is recorded. Fish are measured by total length (tip of the snout to tip of the caudal fin); invertebrates are measured by carapace width or total length. Organisms are returned to the water as rapidly as possible to minimize handling time.
f. Any unidentifiable species are photographed for later identification.
g. Steps a-f are repeated until at least two properly deployed and retrieved trawl runs are conducted at each site.

*Adapted with borrowed language from methodology devised by SERC Marine GEO [7].

RESULTS

I. *Disease Testing*

BEGIN REPORT

VIMS | WILLIAM & MARY
VIRGINIA INSTITUTE OF MARINE SCIENCE

Shellfish Pathology Laboratory • Virginia Institute of Marine Science • William & Mary

PATHOLOGY REPORT

5 January 2021

Case numbers: 7812, 7813, 7814, 7815
Requested by: Chloe Obara, Arundel Rivers Federation
Collection date: 21 December 2020

Date processed: 30 December 2020

Species: Eastern oyster *Crassostrea virginica*

Background: Oysters were from four reefs in the South River, Maryland. All were adult oysters, with size ranges (shell heights) in the four samples of fifteen oysters as follows: Bag 1, 102.9-143.9 mm; Bag 2, 67.9-120.8 mm; Bag 3, 99.8-122.9 mm; and Bag 4, 70.9-119.0 mm.

Methods: Live oysters were processed for *Perkinsus marinus* (dermo) detection by Ray's fluid thioglycollate method (RFTM), specifically the tissue method analyzing gill and mantle tissue and rectum from each oyster. Observed infections were to be rated heavy, moderate, light, or rare.

Findings:
***Gross observations*:** No gross signs of disease were observed in tissues or shells.
***RFTM for Perkinsus marinus*:** *Perkinsus marinus* was detected in all four samples as follows:

Duvall: Bag 1 (case 7812): 8/15 positive (53.3%), 3 *light-moderate*, 3 *light*, and 2 *rare* in intensity
WP69: Bag 2 (7813): 10/15 positive (66.7%), 1 *moderate*, 1 *light-moderate*, 5 *light*, 3 *rare*
QW: Bag 3 (7814): 11/15 positive (73.3%), 1 *moderate-heavy*, 4 *light-moderate*, 5 *light*, 1 *rare*
Glebe: Bag 4 (7815): 7/15 positive (46.7%), 1 *moderate*, 2 *light-moderate*, 4 *light*

Remarks: The oysters in these samples appeared generally healthy. *Perkinsus marinus* is of course a ubiquitous and highly prevalent pathogen, and many oysters are infected without displaying serious disease. In this case, the weighted prevalences we would calculate based on the prevalence and intensity distributions would be 0.87, 0.83, 1.50, and 0.87 for Bags 1-4, respectively, indicative of a very modest level of dermo disease. (Weighted prevalences > 2 are conventionally regarded as being associated with serious mortality.) Looking at the data another way, only 0%, 6.7%, 6.7%, and 6.7% of oysters, respectively, had infections exceeding light-moderate in intensity—thus reaching advanced, more physiologically consequential intensities. Most of these oysters across the samples were healthy in dermo disease terms. While we did not evaluate *Haplosporidium nelsoni* (MSX), our other major pathogen, we know that this pathogen is scarcely detectable in Virginia due to inhospitable salinities over recent years, so MSX is likely absent or present only at very low prevalence in the South River as well.

I offer two additional notes for additional context. First, analyses for *P. marinus* in December may be regarded as somewhat past the peak of the seasonal outbreak, which may raise the question of how accurately these figures would portray *P. marinus* at its worst in 2020 at these locations. I'd argue that if December is past peak for *P. marinus* it's not far past, and we know that December infection levels can be as high as, or higher than, infection in October. It is safe to assume that October infection levels may have been a bit higher in prevalences and intensities, but not much higher—not high enough to alter the conclusion based on this sampling that dermo impacts at the studies sites were not great. Second, is it possible that we were looking at survivors of a significant mortality event, which if sampled earlier would have revealed abundant advanced and lethal infections? This very is unlikely, as Fall Survey analyses for the Virginia part of Chesapeake Bay are complete and describe a very light dermo disease year, near historical lows for the time period dating back to 1989. We have every reason to expect that 2020 was a light dermo year in Maryland too, including in the South River.

Records of these analyses will be retained should they be needed in the future.

Pathologist:
Ryan B. Carnegie, Ph.D.
Research Professor

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804/684-7713 • carnegie@vims.edu

END REPORT

Water Quality for Disease Testing:

WP69 was in 3m of water, QW was in 1.75, Duvall was in 1m and Glebe was in 1.25. Dissolved oxygen was very consistent across all sites, ranging from 12.31-12.98 mg/L. Salinity ranged from 10.04-10.64. pH ranged from 7.11-7.96. Temperature ranged from 5.4-5.64. Duvall has the highest water temperature at 5.64 degrees Celsius and lowest pH at 7.11.

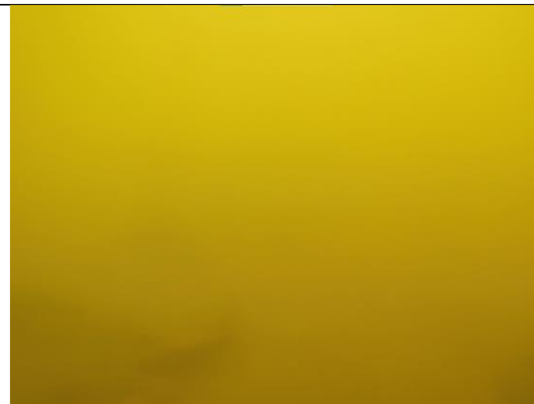
Reef	Date / Time	Temperature [°C]	pH [Units]	Conductivity [µS/cm]	Salinity [ppt]	Depth [meters]	Dissolved Oxygen [mg/l]
WP69	12/21/2020	5.43	7.96	18055	10.64	3	12.31
QW	12/21/2020	5.4	7.81	17903	10.54	1.75	12.72
Glebe	12/21/2020	5.61	7.88	17115	10.04	1.25	12.84
Duvall	12/21/2020	5.64	7.11	18032	10.62	1	12.98

Table 2. Water quality at bottom depth measured with a Hydrolab Mulitparameter Sonde.

II. *Reef Survey*

Observations from GoPro Footage	Reef Image
Duvall Run 1 Side A: • Lots of particulates suspended and debris on oysters • 2:22 → possible oyster spawn release circled in blue • Uniform coverage of oysters, very clumped • Silty bottom appearance	
Duvall Run 1 Side B: • Too murky to see anything	
Duvall Run 2 Side A: • Very murky, lots of particulates in water column • Patches of clumped oysters and patches of open, silty bottom	

Duvall Run 2 Side B: • Very murky, lots of particulates in the water column • Bottom 90% covered with flat-lying shell	
Duvall Run 3 Side A: • Somewhat clear • Shells mostly un-clumped, but video shows a glimpse of greater surroundings as GoPro was lifted off bottom that align with Duvall Run 1 and 2 descriptions	
Duvall Run 3 Side B: • Somewhat clear • Silty sediment with clumps of oysters • Oysters covered with layer of debris	
Duvall Run 4 Side A: • Very murky • Mostly silty bottom visible with one oyster clump	

Duvall Run 4 Side B: • Too murky to see • One shell fragment in foreground	
QW Run 1 Side A: • Fairly clear • One live barnacle in foreground, circled in blue • Dense clumping of oysters, no bottom visible	
QW Run 1 Side B: • Somewhat murky • Shells covered in debris • Only clumped shells in foreground are visible, no bottom visible	
WP 68 Run 1 Side A: • Very clear • 70% bottom sediment visible with a few shell fragments scattered • Great shot of a live barnacle filtering, circled in blue	

WP 68 Run 1 Side B: • Silty bottom primarily visible with small shell fragments and 4 barnacles • Fairly clear	
WP 68 Run 2 Side A: • At least 25 active barnacles visible • Very clear • Bottom mostly covered with unclumped shells lying flat or barnacles	
WP 68 Run 2 Side B: • Somewhat murky • 12 living barnacles visible • Bottom mostly covered with unclumped shells lying flat with sandy bottom sediment with shell hash in between	
WP 68 Run 3 Side A: • Sandy/silty bottom with some curves, some debris on bottom in background • Seven barnacles in action on the bottom visible • Somewhat clear	

WP 68 Run 3 Side B • Mostly silty bottom visible with few oyster fragments visible • Fairly murky • Three barnacles visible filtering	
WP 69 Run 1 Side A • 14 active barnacles visible • Very clear • Bottom mostly covered with unclumped half shells lying flat with sandy bottom sediment with shell hash in between • Small grass shrimp seen at 1:50 and 3:00	
WP 69 Run 1 Side B • Fairly clear • Two live barnacles visible • Bottom mostly covered with unclumped ½ shells lying flat with sandy bottom sediment with shell hash in between	
WP 69 Run 2 Side A: • Isopod or shrimp spotted at 2:12, circled in blue • One live barnacle visible • Somewhat murky • Soft sediment and shell fragments with one clump of live oysters visible	

<table>
<tr><td>WP 69 Run 2 Side B:
Soft sediment with a few shell fragments
Somewhat murky</td><td></td></tr>
<tr><td>WP 69 Run 3 Side A:
Soft sediment with a few shell fragments
Somewhat clear</td><td></td></tr>
<tr><td>WP 69 Run 3 Side B
Fairly murky
Soft sediment with a few shell fragments</td><td></td></tr>
<tr><td>GB Run 1 Side A:
Camera got flipped down after first 10 seconds of video
Sandier sediment, no plume formed when camera was placed
Very clear</td><td></td></tr>
</table>

GB Run 1 Side B: • Camera got flipped down after first 10 seconds of video • Sandier sediment, no plume formed when camera was placed • Somewhat clear	
GB Run 2 Side A: • Very clear • Lots of filamentous algae • Camera got flipped sideways after first 10 seconds • Bottom composed of dense shell fragments and whole shells	
GB Run 2 Side B • Very clear • Lots of filamentous algae • Camera got flipped sideways after first 10 seconds • Significant amounts of clumped oysters and structure in view • No plume formed when camera was placed	
GB Run 3 Side A: • Very clear • Mostly soft sediment with shell hash • Few oysters visible lying at an angle to bottom • Four active barnacles visible on shells, algae present on oysters and bottom	

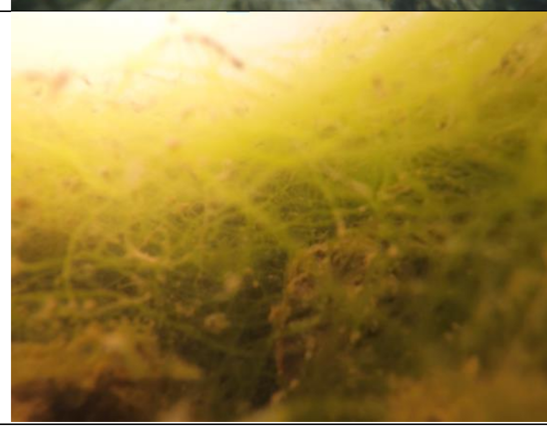
GB Run 3 Side B: • Fairly clear but lots of particulates in water column • Mostly sandy sediment with shell hash, with some oyster clumps in background • Small algae visible on bottom • No plume formed when camera was placed	
GB Run 4 Side A: • Good video of algae • Very clear • Bottom composed of shell fragments and algae • Large clump of oysters in background • Lots of algae and particulates present in water column	
GB Run 4 Side B: • Only filamentous algae and an oyster visible due to camera placement	

Table 3. All images represent the clearest still point in each two minute video. Side A and Side B denote the two GoPro cameras mounted on opposite ends of the quadrat facing outwards. Run denotes a single two minute sampling event.

III. *Shell Analysis*

Shells lengths ranged from 57mm to 141mm (excluding one outlier at WP68 of 191mm), with an average interquartile range from 92.9 to 116. Median values were 103 for WP68, 94 for WP69, 108 for Glebe, and 97 for Duvall, a range of 14. Mean values were 113.3 for WP68, 96.1 for WP69, 105.1 for Glebe, and 104.7 for Duvall, a range of 17.2 (Figure 2).

Shell widths ranged from 45mm to 94 mm (excluding an outlier of 29.5mm at WP69 and 99mm at Glebe) with an average interquartile range from 61.1 to 74.5. Median values were 69 for

WP68, 66.5 for WP69, 67 for Glebe, and 70 for Duvall, a range of 3.5. Mean values were 71.1 for WP68, 64.5 for WP69, 68.6 for Glebe, and 68.4 for Duvall, a range of 6.6. (Figure 3)

Shell Heights ranged from 17mm to 50mm (excluding an outlier of 14 at WP69) with an average interquartile range from 30.25 to 39.75. Median values were 41 for WP68, 33 for WP69, 31 for Glebe, and 35.5 for Duvall, a range of 10. Mean values were 40.7 for WP68, 30.4 for WP69, 32.7 for Glebe and 35.3 for Duvall, a range of 10.3 (Figure 4).

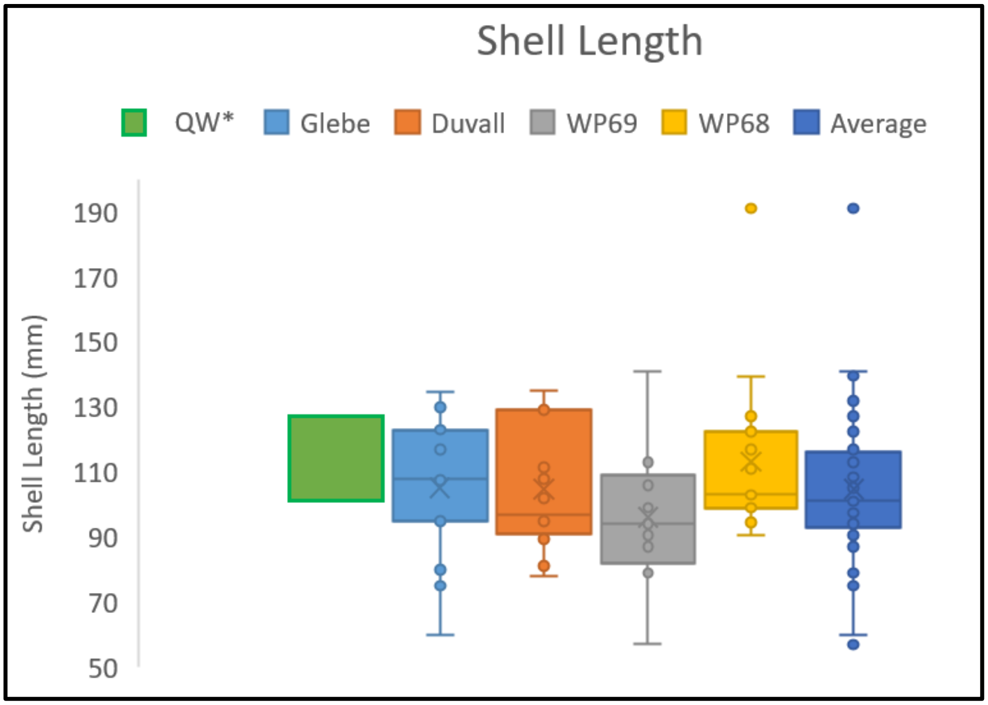


Figure 2. Shell lengths represented as box plots. *Range data provided by VIMS: shell lengths ranged from 99.8-122.9 mm.

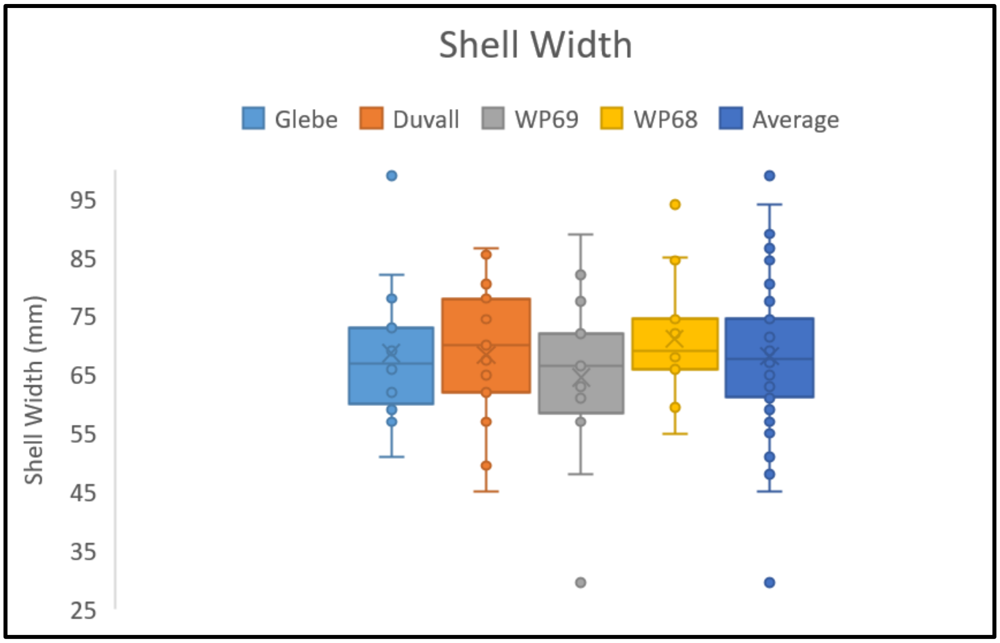


Figure 3. Shell widths represented as box plots. Width data not given in VIMS analysis.

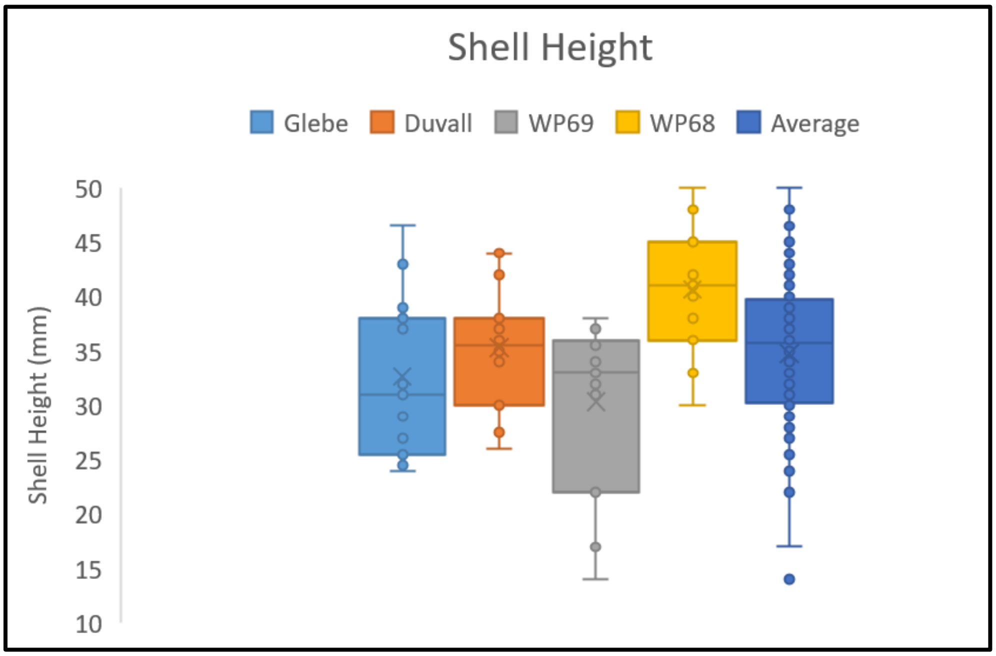


Figure 4. Shell heights represented as box plots. Height data not given in VIMS analysis.

Additional Observations:

Biota: Species diversity was fairly uniform across all four reefs, ranging between five and six species identified. All samples contained bay barnacles, mussels, bryozoans, and isopods. Only one blenny and one mud crab were identified, at Glebe and Duvall respectively. Blood worms were sited in all samples except Glebe. Only Glebe oysters were covered in green filamentous algae.

Spat: At WP 68, one 63mm long live spat was observed. Three scars were observed, with lengths of 67mm, 89mm, and 47mm. At WP69, three boxes and 20 scars were recorded. At Glebe, one box and nine scars were recorded. At Duvall, one box and four scars were recorded.

Shell Edges: All shells at WP68 had thick, layered, rounded edges, and were un-clustered while at the other three reefs, all shells had thin, sharp edges and at least 1/3 of the oysters were part of a cluster. At WP69, 12/15 of the oysters were clustered. At Glebe, 9/15 were clustered. At Duvall, 5/15 were clustered.

Water Quality for Shell Analysis:

WP69 was in 2.75m of water, WP68 was in 3.5m, QW was in 0.5m, Duvall was in 1.25m and Glebe was in 0.75 (Table 4). pH at Glebe was notably higher than the other sites. WP69 had the deepest reef, highest salinity, and lowest dissolved oxygen. Dissolved oxygen was at a high enough level that any native fish or invertebrate species could survive.

Reef	Date / Time	Temperature [°C]	pH [Units]	Conductivity [µS/cm]	Salinity [ppt]	Depth [meters]	Dissolved Oxygen [mg/l]
WP69	3/31/2020	13.03	7.89	11808	6.81	2.75	11.22
WP68	3/31/2020	10.71	7.4	14558	8.55	3.5	9.77
QW	3/31/2020	12.63	7.7	11974	6.92	0.5	11.09
Glebe	3/31/2020	13.68	8.48	11336	6.52	0.75	11.49
Duvall	3/31/2020	12.5	7.4	12603	7.31	1.25	10.33

Table 4. Water quality at bottom depth measured with a Hydrolab Mulitparameter Sonde.

IV. *Trawl Survey*

Duvall had by far the highest catch per efforts of the four sites tested with 20.42, followed by Persimmon Point 1.5 and Glebe with 0.83 (Figure 5). Trawling at Duvall also recorded the most species with 7, followed by Persimmon Point with 4 and Glebe with 2 (Tables 5-8). Trawling over no reef (control) yielded no catch.

Of all the trawling runs used in this analysis the most abundant species were the spot (69 total), white perch (22 total), and croaker (14 total). Less common but still frequently caught were the hog choker (8) and blue crab (6) (Table 9). Rare species caught only once were the weakfish and terrapin. White perch and blue crab were the only species caught at all 3 reef sites. Spot and hog choker were caught at 2 sites. Though very abundant at Duvall creek, croaker were only found at that one site.

Note: This survey was taken over the course of two days of similar conditions (Appendix A). Nine trawl runs were thrown out for one of the following reasons: trawl net improperly deployed, trawl became tangled in water, trawl bag opened during run, trawl run stopped due to encountering obstruction in water. The below tables are a compilation of data taken from only the nine correct trawl runs over the course of the two sampling days. With 2-3 replications per site, this data is meant to give a general insight into fish community overtop the reefs.

Control				
Run	#species	#individuals	time (mins)	individuals/minute
1.1	0	0	2	0
2.1	0	0	3	0
total	**0**	**0**	**5**	**Average: 0**

Table 5. Trawl catch data at a control site (no oyster reef below) on the South River.

Glebe				
Run	#species	#individuals	time (mins)	individuals/minute
1.1	1	2	2	1
1.2	2	2	2	1
2.2	1	2	4	0.5
total	**2**	**6**	**8**	**Average: 0.833**

Table 6. Trawl catch data at Glebe.

Duvall				
Run	#species	#individuals	time (mins)	individuals/minute
1.1	4	33	2	16.5
2.1	7	73	3	24.33333
total	**7**	**106**	**5**	**Average: 20.42**

Table 7. Trawl catch data at Duvall.

WP69				
Run	#species	#individuals	time (mins)	individuals/minute
1.1	0	0	2	0
2.1	4	9	3	3
total	**4**	**9**	**5**	**Average: 1.5**

Table 8. Trawl catch data at WP69.

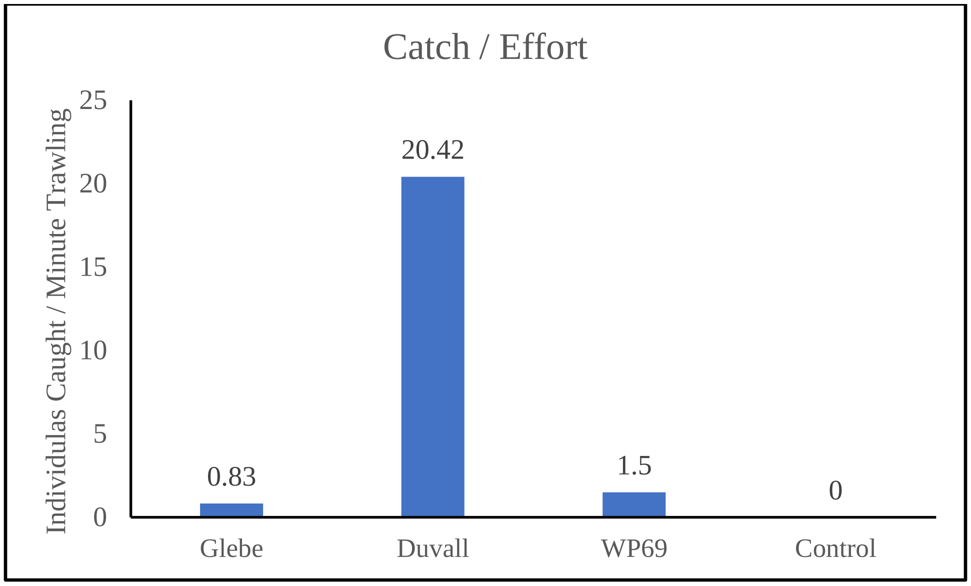


Figure 5. Catch per trawling effort for each reef.

Species Diversity					
	Glebe	Duvall	WP69	Control	Other
White Perch	X	X	X		
Croaker		X			
Spot		X	X		
Blue Crab	X	X	X		
Hog Choker		X	X		
Summer Flounder					X
Brown Bullhead Catfish		X			
Terrapin		X			
Weakfish		X			

Table 9. Species diversity at each reef location. Note: Brown Bullhead Catfish and Summer Flounder were caught during runs omitted from the data, so are not included in Tables 5-8 or Figure 5.

DISCUSSION

The goal of this study was to identify differences between oyster reefs under differing levels of fishing regulation. Glebe is the only reef located in a sanctuary zone and has been replenished most frequently with oysters and spat on shell. Duvall is also protected from fishing due to high levels bacteria and is most frequently with oysters and spat on shell, though less so than Glebe. QW is independently owned and hand tonged to harvest oysters. WP68 and WP69 are open to public shellfish harvest. It was expected that Glebe would have the healthiest reef across all parameters, followed by Duvall.

I. *Disease Testing*

All four reefs sampled for disease reflected a very modest level of Dermo disease. Glebe had the lowest positivity rate, followed by Duvall, then WP69, then QW. Calculated as intensity distributions, WP69 had the lowest, followed by Duvall and Glebe equally, then by QW. Though QW clearly had the highest Demo intensity, the percentage of oysters sampled having infections exceeding light-moderate intensity was fairly uniform across the reefs, at 6.7% for all Duvall which had 0%. Though there was some variability between reefs, the results were, as hypothesized, fairly uniform.

The salinity of the water when the samples were taken (10.04-10.64 ppt) was at the lower end of the survivable range for Dermo, which thrives in above 12 ppt [5]. Temperature may also have decreased the presence of Dermo in the samples, as it spreads most rapidly above 25 degrees Celsius, so is more prevalent in summer months [5]. Though prevalence decreases during winter months, the disease is capable of surviving through freezing water temperature [5]. Dr. Carnegie concludes that though the Dermo concentrations represented in the samples may have been slightly past their peak intensity, the results are unlikely to have been substantially different should this sample have been taken in October. To further confirm this assertion, these data were compared to data collected by the SERC FCL at Glebe in early fall of 2020, about 3 months prior to the sampling conducted in this study, during peak bacteria survival conditions [8]. The prevalence of Dermo in this sample was 40%, 6.7% lower than found in this study. Furthermore, oyster lengths had a comparable range to that of the oysters sampled in this study. The parallels in these data indicate that the results of the disease testing in this study likely reflect prevalence at similar or higher levels to that of peak disease survivability for fall of 2020.

II. *Reef Survey*

Glebe footage indicated a sandy bottom composition with shell hash that, unlike the other sites, did not form a sediment plume when GoPro was lowered onto bottom. This more stable bottom may be an indicator for a healthier reef environment. Footage at WP68 and WP69 indicated a softer sediment bottom composition that did create a plume when GoPro was lowered. Many live barnacles were observed from both these videos. Oysters at QW appeared the most clumped since the GoPro perched on top of the oysters high enough that the bottom was not visible. However, only one video was taken at this site because the reef was so small, so more footage is necessary to confirm this observation. It is possible that the waterman that owns this reef manually piles the oysters for ease of collection. Visibility seemed to track with depth, as the more shallow reefs at Glebe and QW had better clarity than WP68 and WP69. However, Duvall footage was murkier then expected for having the shallowest depth. Duvall oysters appeared to be very clumped and was the only footage that showed an oyster releasing a cloudy white substance into the water column.

Presence of biota on and around the oyster reefs was fairly uniform across all reefs, with the exception of filamentous algae which was only present on Glebe reef. This observation does not have a clear cause and could be a source for further study in future monitoring.

III. *Shell Analysis*

Shell length was the measurement that varied most significantly by reef and within reef, followed by height, then width. The thicker, blunter edges on the shells at WP68 could be an indication of a slower growth rate of those oysters compared to those at the other reefs sampled having thin, sharp-edged shells. Though the distributions of shell parameters were fairly uniform, WP68 had the highest mean shell length, width, and height. WP69 had the lowest mean shell length and width, and median shell length, width, and height. WP69 had the most clustered oysters, while WP68 had the least clustered oysters. One possible explanation for this pattern could be that oysters that are not clumped grow longer because there are no nearby attached oysters to limit their space. However, based on GoPro footage, Glebe, Duvall, and QW oysters appeared more densely concentrated as compared to WP68 and WP69 which appeared sparsely distributed in clumps or single oysters. This leads to an interpretation that WP68 and WP69 have sparse reefs with few clumps of oysters that were easier to pick up with the hand tongs then the loose shell, skewing the results to make the oyster composition on the reef appear more clumped than in reality. An oyster usually reaches maturity at 1-3 years of age, or 25-75mm in length [9]. All of the oysters measured in this study fall into or above this range, so are likely to be sexually mature. Despite this, almost no live spat were observed, which may indicate unfavorable conditions in the South River for oyster reproduction.

IV. *Trawl Survey*

Results indicate that Duvall has the most diverse and abundant population of fish above its reef. Persimmon Point has the second most diverse and abundant population of fish, followed by Glebe. The catch per unit effort values also reflect this trend.

V. *Comparisons Across Multiple Parameters*

When scored across seven measured parameters, WP69 had the lowest, or healthiest, score, followed by Duvall, Glebe, and then QW and WP68 equally (Table 10). However, there is a large amount of variability between the parameter scores, so a definitive conclusion as to the effect of fishery pressure on reef health cannot be drawn. Though the results of this study do provide high resolution insight into the dynamics of oyster reefs in the South River, there was not a consistent trend in which reef was most healthy across the parameters.

	Disease Intensity	Positivity Rate of Disease	Largest oysters	Total spat count	Clumping %	Catch/unit effort	Diversity/ Abundance	**Average Score**
Glebe	2	1	4	2	2	3	3	**2.71**
Duvall	2	2	3	3	3	1	1	**2.14**
WP68	N/A	N/A	1	4	4	NA	N/A	**3**
WP69	1	3	4	1	1	2	2	**2**
QW	4	4	1	N/A	N/A	NA	N/A	**3**

Table 10. Parameters are scored as following: Disease Intensity (1= lowest, 4=highest). Positivity Rate of Disease (1=lowest, 4=highest). Largest oysters (1=largest, 4=smallest). Total spat count (live/boxes/scars) (1=most, 5=least). Clumping % (1=highest, 4=lowest). Catch/unit effort (1=highest, 4=lowest). Diversity/ Abundance (1=highest, 4=lowest).

CONCLUSION

This study provides methodology for sampling a variety of parameters in oyster reefs in which access by diver is not available and funding is limited. Rarely can a single year of data uncover a clear trend or definitive conclusion. Replication of this study is recommended to determine if more significant trends emerge across years of data. Areas of future study could include an investigation into spat survivability and *in situ* reproduction, as few to no spat were observed on the oysters sampled in this study. Based on the results of this study, I would recommend Duvall reef for continued monitoring, as it showed evidence of more developed reef structure and fish community than other study reefs.

Monitoring data is pivotal in the greater science community as we continue to better understand oyster survivorship and restoration effectiveness. This research is compiled for use by institutions and environmental organizations in the implementation of oyster restoration projects and decisions on future management/policy. For example, a living shoreline project is being considered on the Hillsmere Marine shoreline adjacent to this reef, and these data may be useful in the planning of the project. It is important to continue improving knowledge of how fishery pressure affects reefs in order to make informed adjustments to fishery regulations and preserve oyster habitat for the health of the bay and its inhabitants.

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REFERENCES

[1] Chesapeake Bay: Oyster Restoration. NOAA. https://www.fisheries.noaa.gov/topic/chesapeake-bay#oyster-restoration

[2] Schulte, David M., (2017). History of the Virginia Oyster Fishery, Chesapeake Bay, USA. Frontiers in Marine Science. 4.

[3] CBF Spat on Shell Spreading Data 1998-2020. (2020) Oyster Restoration Center, Chesapeake Bay Foundation.

[4] Maryland DNR Aquaculture Siting Tool. http://gisapps.dnr.state.md.us/Aquaculture/index.html

[5] Ewart, John W., and Ford, Susan E., (1993). History and impact of MSX and Dermo diseases on oyster stocks in the Northeast region. Northeastern Regional Aquatic Center. 1-8.

[6] GoPro Camera System Specifications & Methods. (2020) Fisheries Conservation Lab, Smithsonian Institution.

[7] Fish Trawls. (2020) Tennenbaum Marine Observatories Network, Marine GEO, Smithsonian Institution.

[8] SERC VIMS MSX Pm Disease Data. (2020) Fisheries Conservation Lab, Smithsonian Institution.

[9] The Oyster Life Cycle. Florida State University. https://marinelab.fsu.edu/absi/commengage/aboutoyster/lifecycle_anatomy/

APPENDIX A: Trawling Conditions

Sample Date 1: 6/14/21

Tides: High- 8:03 am; Low- 3:16 pm. All trawls taken at ebb tide.

Cloud Cover: Partial

Rain: None

Wind Speed: 1-10 knots

Wave Height: <1ft

Sample Date 1: 6/21/21

Tides: High- 2:25 pm; Low- 9:25 am. All trawls taken at flood tide.

Cloud Cover: Overcast

Rain: None

Wind Speed: 1-10 knots

Wave Height: <1ft