EVALUATING HYDRUALIC PATENT TONG EFFICIENCY TO ESTIMATE OYSTER DENSITY ON RESTORED OYSTER REEFS

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Table of Contents

List of Tables

List of Figures

1. Introduction

Oysters are temperate reef-building bivalves that provide an array of ecosystem services. As filter-feeding organisms, oysters are able to reduce suspended sediments from the water column and can increase water clarity and light penetration for seagrasses (Newell and Koch 2004). Additionally, created oyster reefs have been shown to reduce shoreline retreat and stabilize sediments (Meyer et al. 1997, Piazza et al. 2005). Fishes and decapod crustaceans benefit from the three-dimensional structure provided by oyster reefs (Tolley and Volety 2005).

With a substantial decline in oyster populations worldwide (Beck et al. 2011), more and more efforts have been aimed at restoring oyster reefs and the ecosystem services they provide. In Maryland's portion of the Chesapeake Bay, over 780 acres of habitat have been restored under the 2014 Chesapeake Bay Watershed Agreement. Using ArcGIS analysis, historic population data, bathymetry information, and site inspection with divers and hydraulic patent tongs, areas are selected for various types of restoration. Efforts include planting spat on shell in areas deemed already suitable (with firm substrate and existing oyster densities) and by rebuilding habitat using primarily oyster shell and granite before planting spat. Restored reefs are then monitored three and six years after completion.

Monitoring progress towards this target has been conducted using hydraulic patent tongs in areas where only spat on shell plantings were conducted and by divers in areas where spat on shell were planted over constructed granite reefs. In both cases, oysters are sampled from a known area (1.33 m^2 in the case of the hydraulic patent tongs and 1 m^2 for divers) and oyster densities are estimated by dividing the number of oysters caught in the sample by the area sampled. For this approach to provide unbiased estimates of density, both sampling methods must collect and retain all of the oysters in the area swept. Previous studies on natural reefs under commercial harvest conditions have determined that hydraulic patent tongs and diver sampling do not produce significantly different estimates of oyster densities on harvest bars (Chai et al. 1992).

In recent monitoring, estimated densities of oysters were substantially higher on the granite reefs that were sampled by divers than on the reefs where spat on shell was placed directly on the bottom. This difference could be caused by two potential mechanisms: 1) oyster survival, and thus density, was higher on the granite reefs, or 2) differences in sampling efficiency between divers and hydraulic patent tongs. Our objective was to estimate the efficiency of hydraulic patent tongs for estimating oyster density on restored oyster reef habitat in one large-scale restoration tributary, Harris Creek.

2. Methods

2.1. Study Site

Harris Creek is a mesohaline tributary located on Maryland's Eastern Shore situated near the mouth of the Choptank River. Harris Creek was designated as an oyster sanctuary in 2010 and initial restoration on 351 acres of oyster reefs was completed in 2015. For this study, we focused on 14 reefs representing a mix of three- and six-year-old restored reefs originally planted with spat-on-shell (SOS) in either 2012 or 2015 (Figure 1). Twelve of the reefs received SOS on top of existing natural oyster shell and two reefs received a mixed shell base prior to deployment of SOS. Reefs ranged in size from approximately one acre to over 15 acres (Table 1 and Appendix A-Table 1).

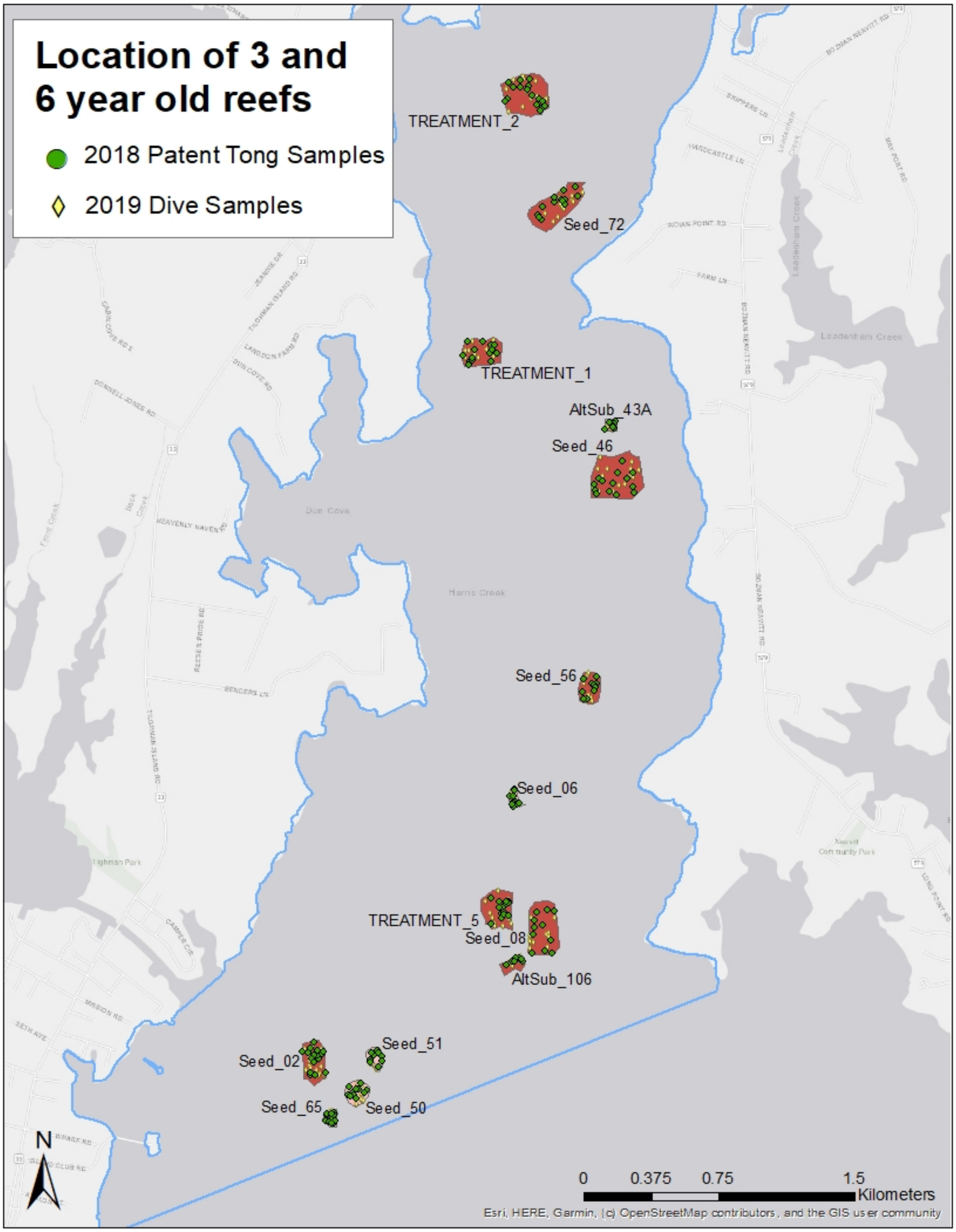

Figure 1. Sites sampled using patent tongs and diver quadrats in Harris Creek.

2.2. Data Collection

All study reefs were part of an existing annual reef monitoring program scheduled to assess the health and condition of three- and six-year-old reefs. Each reef was sampled using hydraulic patent tongs to satisfy the objectives of the annual monitoring survey. Subsequent dive sampling was conducted in late June through August 2019, approximately 3 months after reefs had been sampled with hydraulic patent tongs. Due to logistical constraints and changes to dive personnel, dive operations could not be initiated while hydraulic patent tong sampling occurred. The time difference between sampling dates was not expected to influence the comparability of data because no major changes to reef characteristics were expected.

Table 1. Harris Creek sites sampled with divers in summer 2019, after being sampled by hydraulic patent tongs as part of three- and six-year post-restoration survey.

Site ID	Area (acres)	Yates Bar Name	Cohort Year	Material	N
H02	2.14	Change	2012	Mixed shell	7
H72	1.02	Mill Point	2015	Mixed shell	7
H03	6.56	Tilghman Wharf	2012	Spat on shell only	16
H81	1.27	Eagle Point	2015	Spat on shell only	11
H04	11.24	Change	2012	Spat on shell only	11
H05	15.65	Mill Point	2012	Spat on shell only	14
H76	3.65	Tilghman Wharf	2015	Spat on shell only	11
H77	2.32	Tilghman Wharf	2015	Spat on shell only	9
H06	4.62	Turkey Neck	2012	Spat on shell only	9
H84	1.40	Tilghman Wharf	2015	Spat on shell only	11
H07	10.95	Lodges	2012	Spat on shell only	13
H08	7.34	Seths Point	2012	Spat on shell only	14
H09	12.29	Walnut	2012	Spat on shell only	16
H12	7.83	Change	2012	Spat on shell only	14

ArcGIS (ESRI 2019) was used to create random sampling points on each reef. A buffer with 5m radius was placed around points where patent tong grabs had previously been collected. Additionally, we created a 5m buffer from the edge of each reef to ensure we were sampling areas that had been treated. The number of samples per site ranged from seven to 16 with the number of samples proportional to area of the site. To maintain a balanced design the number of dive samples was equal to the number of hydraulic patent tong samples in all reefs except H03.

During dive operations a laptop with GPS capabilities was used to navigate to each random sampling point, and a waypoint was created to mark where the diver quadrat was deployed. At each point, the diver descended to the quadrat to collect a sample. All material (live oysters, shell, and surface substrate) inside the quadrat excavated and placed into a basket to be pulled to the surface. The diver also estimated the depth of material excavated before reaching sediment. Equal samples sizes were used between gear types on each site.

Once each sample was onboard the vessel, crew recorded the dominant substrate type, presence of fouling organisms, and enumerated all live and dead oysters. A subset of at least 30 individuals was measured. For each clump of oysters, the number of oysters in each clump and substrate they were attached on was recorded. Crew also assessed the percent of the sample that was anoxic (black shell). Graduated buckets were used to estimate the volume of shell and live oysters in the sample.

2.3. Data Analysis

Because sampling did not occur at the same time for hydraulic patent tongs and divers, the population size may have been different due to recruitment or natural mortality. We compared the distribution of shell heights of live Eastern Oysters to evaluate if there had been recruitment in the period between the two surveys. In addition, we calculated the mean and standard deviations of shell heights for each gear type. Generally, recruitment of Eastern Oysters in Chesapeake Bay occurs later than our diver sampling period, and most natural mortality is thought to occur in the fall.

To estimate differences in efficiency between the two gears, we used generalized linear mixed effects models to estimate the number of live oysters or boxes observed in a sample as a function of gear type,

$$E(Y_{G,S}) = e^{\alpha + \beta_G + \beta_S + A},$$

where E was the expected value of the number of oysters in a sample (*Y*), α was the intercept, β_G was the gear effect (effect of hydraulic patent tongs relative to divers), and β_S was a normally distribute random effect for site, $\beta_S \sim N(0, \sigma_S^2)$. The model included a negative binomial distribution and a log link function. The model also included an offset variable for the area sampled by each gear (A). We originally included a factor for years since restoration, but it was not significant (p=0.35), and the simplest model was the best according to the Akaike Information Criterion. Therefore, we dropped the years since restoration from our model for parsimony.

We calculated the median and approximate 95% confidence interval (*95%CI*) for the efficiency of hydraulic patent tongs for sampling oysters assuming that divers were 100% efficient as

$$95\%CI = e^{\beta_G \pm 1.96\sigma_{\beta_G}},$$

where σ_{β_G} was the estimated standard error of β_G.

3. Results

The distribution of shell heights was very similar between the diver and hydraulic patent tong samples (Fig. 2). The mean and standard deviation (SD) of shell heights were very similar with a mean = 76.3 mm and SD = 24.5 mm for divers and a mean = 77.1 mm and SD = 27.4 mm for hydraulic patent tongs. Because additional small oysters were not present in the diver samples, differences in density were not caused by recruitment to the study area in the time between sampling events.

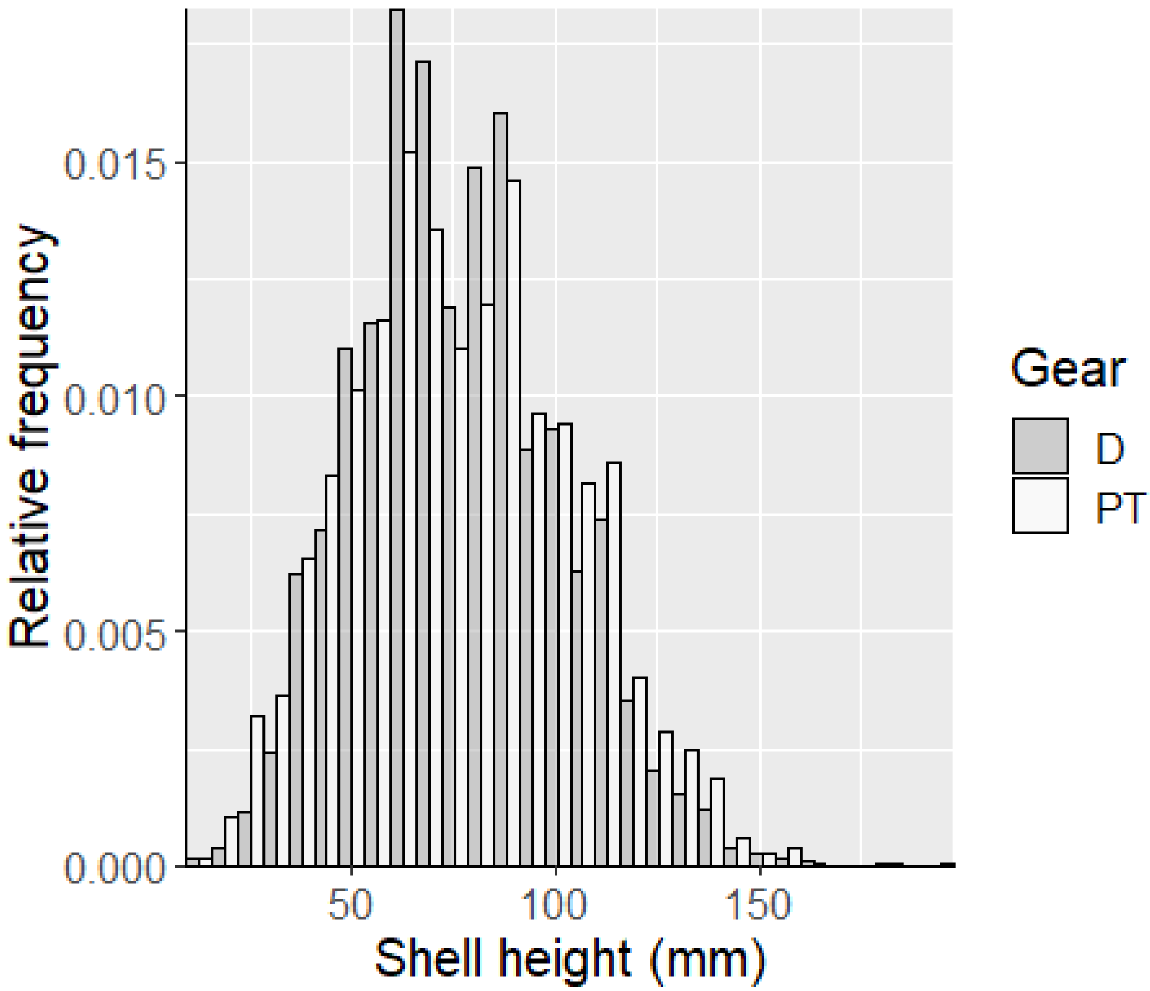

Figure 2. Histogram of shell heights of live oysters collected using divers (D) and hydraulic patent tongs (PT).

The mean density was 119 oysters per m^2 for diver samples and 33 oysters per m^2 for hydraulic patent tongs (Table 2). Estimates of density from divers were significantly higher than those from hydraulic patent tongs (Table 3; Figure 3). Reef level oyster density estimates from hydraulic patent tong sampling is presented in Appendix A. Estimated densities of oysters were substantially different between hydraulic patent tongs and divers, with divers being substantially more efficient than hydraulic patent tongs. On average, the estimated efficiency of hydraulic patent tongs was 0.30 (95% CI 0.24-0.37). The densities estimated by divers were 3.35 times higher than those from hydraulic patent tongs, on average. If this correction factor is applied to previous hydraulic patent tong monitoring data (NCBO 2018), the average density of oysters on the seed only sites that were sampled in 2017 would be 130.8 per m^2 in comparison with the uncorrected density estimate of 39.0 oysters per m^2.

Table 2. Site level results for the 2019 diver sampled reefs.												
Site ID	**Sample Date**	**Area (acres)**	**Year Planted**	**N**	**# live oysters counted**	**# dead oysters counted**	**% of oysters that were dead**	**Ave. live density across reef (#/ m²)**	**Standard error of live density (#/ m²)**	**Ave. Shell volume across reef (L/m²)**	**Standard Error of volume across reef (L/m²)**	**Ave. % black shell**
H02	7/18/2019	2.14	2012	7	424	40	8.62	123.62	31.33	36.01	8.60	45
H72	7/25/2019	1.02	2015	7	893	60	6.30	260.35	49.21	61.37	7.35	56.43
H03	7/10/2019	6.56	2012	15	639	154	19.42	86.94	14.19	41.8	5.90	19.3
H81	7/31/2019	1.27	2016	11	454	44	8.84	84.23	35.37	34.32	11.76	68.18
H04	8/14/2019	11.24	2012	11	419	52	11.04	77.74	14.96	48.42	8.50	72.27
H05	7/18/2019	15.65	2012	14	803	77	8.75	117.06	12.78	37.24	4.34	85
H76	7/3/2019	3.65	2015	11	212	26	10.92	43.37	9.02	21.47	3.35	72.27
H77	6/26/2019	2.32	2015	9	279	32	10.29	80.04	21.2	57.09	11.45	73.222
H06	7/17/2019	4.62	2011	9	717	84	10.49	162.59	41.93	50.34	6.36	60
H84	7/17/2019	1.40	2015	11	497	42	7.79	92.21	19.21	33.07	6.66	47.27
H07	8/1/2019	10.95	2012	13	837	159	15.96	131.4	14.5	60.91	6.10	83.08
H08	7/25/2019	7.34	2012	14	1410	264	15.77	205.54	30.66	71.68	10.42	71
H09	8/14/2019	12.29	2012	16	1120	131	10.47	142.86	20.37	52.3	6.82	63.44
H12	7/10/2019	7.83	2012	14	667	105	13.60	97.23	22.73	46.92	9.89	62.14

Table 3. Estimates of the intercept (α), effect of hydraulic patent tongs relative to divers (β_G), and the variance of the site effect (σ_S^2) for a negative binomial generalized linear mixed model of estimated oyster density as a function of gear and site. The estimated overdispersion parameter of the model was 1.09.

Parameter	**Estimate**	**Standard Error**	**P**
α	3.51	0.12	<0.001
β_G	-1.2100	0.11	<0.001
σ_S^2	0.13		

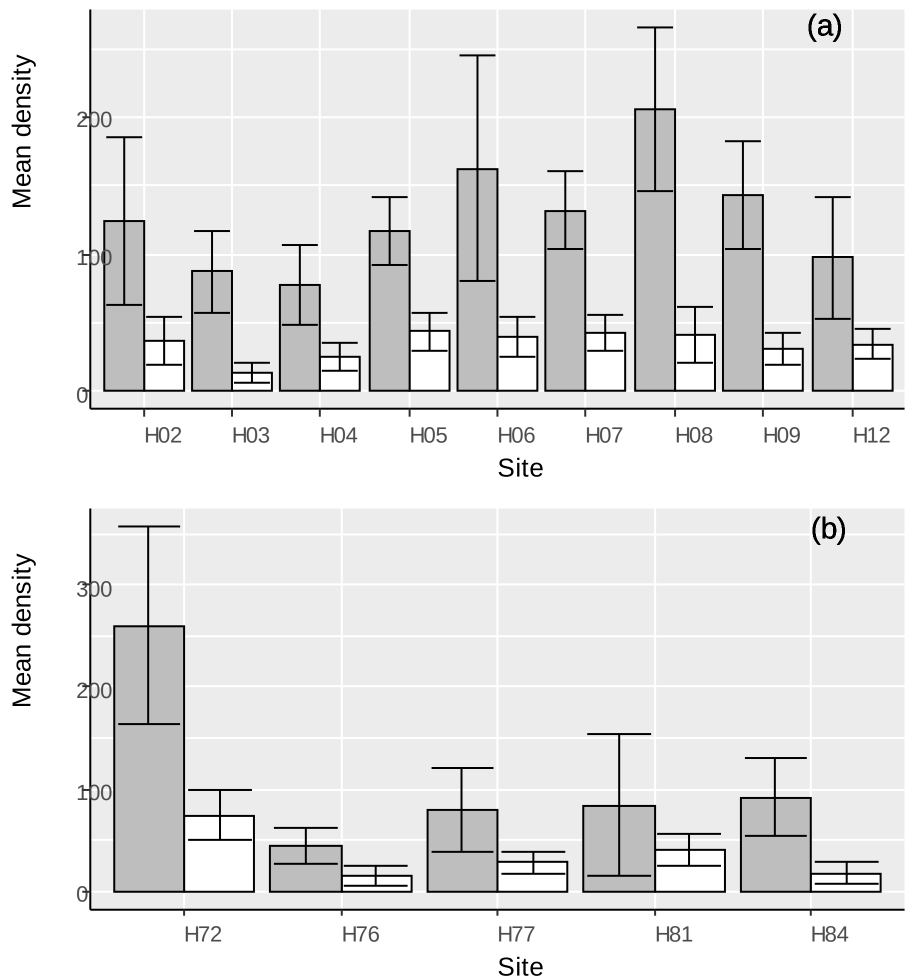

Figure 3. Comparison of mean live oyster densities (number per m^2) sampled by divers (gray bars) or using hydraulic patent tongs (white bars). Panel (a) is live Eastern Oyster density at sites six years post restoration, and panel (b) live Eastern Oyster density three years post planting. Whiskers on the plots represent 95% confidence intervals for mean density.

4. Discussion and Conclusions

Hydraulic patent tongs and dive surveys are two primary gear types used in Chesapeake Bay to assess the status and condition oyster resources. Both gears are used in commercial oyster fisheries and have been adapted for use in resource assessment due to their performance in fisheries operations. Diving gear allows harvesters the ability to process oysters during harvesting and select for superior product, but the gear is labor intensive and inefficient. Hydraulic patent tongs are deployed directly from a commercial vessel and the gear grabs a layer of oysters and shell from the surface of an oyster reef. Hydraulic patent tonging is very time and cost efficient, and hundreds of grabs can be conducted each day. Both gear types have their advantages in a monitoring context, but the preference in Maryland has been to use patent tongs due to its perceived cost efficiency for collecting samples.

Some work has occurred to compare the effectiveness of patent tong gear to sample oyster density. Chai et al. (1992) found that density estimates from divers and hydraulic patent tongs were not significantly different, and average densities derived from each gear type were similar. This study assumed that diver gear was 100% efficient at collecting oysters. Schulte et al. (2018) compared mechanical patent tongs to video images from an ROV to ensure that no oysters remained in the sampling location. Results from this study suggested that mechanical patent tongs were 76% efficient at collecting oysters in the area of the sample.

Results from our study found that estimated densities of oysters were substantially different between hydraulic patent tongs and divers, with divers being substantially more efficient than hydraulic patent tongs. The densities estimated by hydraulic patent tongs were 30% of those estimated by divers (95% CI 24-37%). These results disagree with results from previous studies evaluating patent tong efficiency. The work by Chai et al. (1992) has been used to form the basis of assumptions for ongoing sampling efforts to evaluate the status and condition of restored oyster reefs in Maryland. The large differences in estimated oyster densities by gear type indicates that previous assumptions of similar sampling efficiencies by these gears may be substantially more complicated than previously realized. It is likely that there are more oysters in restoration areas, at least on reefs sampled solely by patent tongs, than previously thought.

These results also present possible management implications because of the widespread use of hydraulic patent tongs in other oyster assessment survey work in Maryland. However, the body of research available to compare results and draw conclusions is very limited. Differences in survey design, techniques and habitat studied exist between our study and the two studies referenced in this discussion. In addition, our study was incorporated into an existing annual survey with a goal of determining whether further research was required if differences in gear efficiency were detected. These results suggest large differences, but additional work is required to improve and refine the application of these results to assist in the interpretation of previously collected data and for future monitoring. For example, similar studies of dredge efficiency in the Delaware Bay, New Jersey, have found substantial complexities in the efficiency of oyster dredges for estimating densities (Morson et al. 2018). Similar effects of habitat on the efficiency of sampling gear may be expected for hydraulic patent tongs. We recommend the following:

- Incorporate paired sampling of diver and patent tong gear with ongoing monitoring efforts to refine the understanding of differences in gear efficiency with habitat or other bottom characteristics and to potentially develop robust correction factors, and

- Assess hydraulic patent tong gear efficiency by directly observing patent tong grabs.

5. Acknowledgments

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6. References

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7. Appendix A

Appendix A-Table 1. Reef level characteristics, restoration details, and previous monitoring information for 14 study reefs in Harris Creek. Multiple SOS planting dates can represent second year class seeding conducted after three years.

Site ID	Area	SOS Planting Dates	Treatment type	Total SOS deployed (millions)	Planting density (millions SOS/acre)	Total Shell deployed (bushels)	Shell density (bushels/acre)	Avg Live Density in 2018 Monitoring	SE Live Density in 2018
H02	2.14	2012, 2017	Mixed shell	21.38	9.99	1920	897.2	36.73	9.04
H72	1.02	2015	Mixed shell	3.39	3.32	800	784.3	74.36	12.22
H03	6.56	2012, 2017	Spat on shell only	36.37	5.54	5120	780.5	13.04	3.58
H81	1.27	2016	Spat on shell only	7.23	5.69	800	629.9	39.81	8.16
H04	11.24	2012, 2017	Spat on shell only	61.73	5.49	5920	526.7	25.07	4.99
H05	15.65	2012, 2017	Spat on shell only	85.13	5.44	8000	511.2	43.57	7.16
H76	3.65	2015, 2016	Spat on shell only	15.26	4.18	2720	745.2	14.74	5.13
H77	2.32	2015	Spat on shell only	15.99	6.89	3200	1379.3	27.61	5.6
H06	4.62	2011, 2013, 2017	Spat on shell only	69.88	15.13	5120	1108.2	39.89	7.57
H84	1.40	2015	Spat on shell only	5.96	4.26	1280	914.3	17.22	5.66
H07	10.95	2012, 2017	Spat on shell only	73.89	6.75	9600	876.7	42.95	6.74
H08	7.34	2012, 2017	Spat on shell only	64.97	8.85	4480	610.4	40.73	10.21
H09	12.29	2012, 2017	Spat on shell only	70.63	5.75	9600	781.1	31.17	6.01
H12	7.83	2012, 2017	Spat on shell only	47.84	6.11	4480	572.2	34.29	5.28