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An Investigation of Utilizing Ripraps as Substrate for Oyster Stocking within Delaware Coastal Bays

Brian A Reckenbeil[1,2] and Gulnihal Ozbay[1]*

[1]Department of Agriculture and Natural Resources, Delaware State University, Dover, DE 19901, USA
[2]Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, Marathon, FL 33050, USA

Abstract

Numerous resources are required to re-construct oyster reefs, which make oyster enhancement projects difficult, and are not always successful. Riprap has increased the complexity of shorelines in developed regions, thus providing a suitable substrate for oyster stocking at no extra cost to managers. Two year-old oysters were planted between rock crevices, and after one year in the riprap, showed 50% survival. Medium sized ripraps (0.4-0.6 m rock diameter) are ideal for conducting survival experiments and general oyster stocking. It is important to note that all riprap is not homogeneous in nature, as size and depth of boulders vary, which will influence site selection depending on the goals of the oyster restoration program.

Keywords: Oyster reefs; Oyster restoration; Oyster stocking; Riprap; Rock crevices

Introduction

The decline of *Crassostrea virginica* populations over the past century is well known. Two basic restoration techniques exist: restore substrate (large programs) or increase broodstock (smaller programs). Millions of dollars are spent yearly on oyster restoration practices, yet small community-based restoration programs are still an effective technique [1]. Creating a patchwork of oyster habitats throughout an estuary, such as placing oysters in multiple riprap locations, may be the best method to effectively restore ecosystem functionality to the Delaware Inland Bays (DIB) [2]. The Delaware Oyster Gardening Program increases broodstock by growing oysters in floating aquaculture gear. In order to make room for a new oyster cohort biennially, oysters are collected from the volunteer gardener's floats every spring. These oysters are either utilized for research or restoration efforts, as the oysters are not eaten or sold.

Original restoration practices in Ocean View, Delaware used two-dimensional trays to create an artificially oyster reef at the James Farm Ecological Preserve. Poor survival results generated the idea to place oysters into riprap crevices, possibly providing a 3-Dimensional (3D) structure similar to oyster reefs [2,3]. However, no one has monitored these efforts to determine if stocking oysters in riprap is advantageous.

Riprap is a shoreline armoring technique comprised of various sized rocks and boulders. These intertidal areas potentially serve as a good settling substrate, as oysters and other shellfish live on riprap worldwide [4-7].

Within estuaries such as the DIB, artificial hard substrate is most often observed as riprap, bulkhead, docks, or pilings. Shorelines within the Inland Bays have been extensively modified; with dead end lagoons comprising over 75.6 km of bulkhead [8], and 157 km of shoreline riprap in IRB in 2006. It is anticipated that riprap may serve as a good restoration location for several reasons, including:

i. Riprap has the capability to engulf countless bushels of aqua culturally produced oysters in a 3 dimensional habitat.

ii. Riprap is abundant and frequently found near populated areas in altered habitats. Therefore, accessing armored shorelines is easily achieved from land, which reduces associated costs and strains of visiting sites by boat, and requires a small workforce. Limited resources need to be spent to establish "base" material (i.e. several inches of shell or stone) like those involved on recreating oyster reefs through shell planting.

iii. Placing broodstock in locations with nearby hard substrate is important. The abundance of oyster spat which settled on loose shell nearby a restored oyster reef was higher than in locations farther from the reef [1]. Rough surfaces with more surface area allow more space for potential settlement of spat.

iv. Silt deposits on cultch prevent larvae from settling [9]. Constant wave and wind action, along with fluctuating tide levels, should keep intertidal boulders clean of silt, allowing larvae to settle.

v. It is a difficult and dangerous habitat for humans to explore, so oyster theft should not be a problem.

This experiment was conducted to see how well oysters survive, remain, and grow in riprap. Impressive results may highlight the potential of utilizing riprapped shorelines for oyster restoration in the future.

Materials and Methods

In August 2009, researchers at Delaware State University and The University of Delaware Sea Grant Program selected and established four sites (A, C, E, and G) as riprap testing locations (Figure 1). Each riprap site contained three experimental quadrats, where 25 living oysters of known shell heights were planted between rock crevices in each quadrat. Quadrats were outlined on rocks using PVC mainly to geographically mark which rock crevices the oysters were placed. Quadrat positions were marked with plastic stakes, and photographs were taken so

***Corresponding author:** Gulnihal Ozbay, Department of Agriculture and Natural Resources, Delaware State University, Dover, DE, 19901, USA, Tel: 1+(302) 857 6476; E-mail: gozbay@desu.edu

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Figure 1: Locations of riprap study sites. Each site was comprised of three quadrats, each with 25 oysters, for a total of 75 oysters per site.

relocation of our exact planting site was achieved. An additional two sites were established in 2010 (sites C and G), and five in 2011 (B, D, E, F, and H) (Figure 1) with oysters produced from each year's oyster gardening crop. Most oysters produced in 2010 were utilized in another experiment. Oysters varied from single individual oysters to clusters containing up to five or six oysters. The oyster height, width, and thickness were recorded with digital calipers to the nearest 0.1 mm for all 25 oysters placed in each quadrat. Oysters were planted during low tides, and it took several days to set up this study. No containment gear (i.e. mesh bags) was employed, as we wanted to mimic our program's restoration procedure of placing oysters individually into rock crevices. We returned to each location roughly one year after establishing each quadrat. During low tide, we searched by hand all rock crevices within each quadrat (approximately 1 m^2 for the planted oysters. We combed each quadrat for 10 minutes, or until all 25 oysters were retrieved. Each oysters' fate (alive or dead), height, width, and thickness was recorded. Cluster size, width, and thickness data are unique to the 2010 and 2011 data sets. Dead oysters were counted when boxes were retrieved. Shell disarticulation rates were deemed superfluous in this study because oysters were retrieved within one year of planting. Boxes remain articulated for about one year in Delaware Bay [10], and less than two years in Chesapeake Bay [11]. The DIBs are located between these two large estuarine systems, so these rates should be a good example for DIB oysters. Datum was analyzed with a Chi-Square Test of Association to reveal if frequencies of oyster fate differed by site.

Results

Out of 825 planted oysters for the study (Table 1), 296 (35.88%) were found alive, 292 (35.39%) were found dead, and 237 (29.73%) could not be found. Survival of the oysters found after one year was 46%, 70%, 50% in 2010, 2011, and 2012, respectively. The cumulative survival was 50.3% across the entire study.

Site	Initiated	Water Body	Town	A	D	T	L	S	Obs. R	Riprap Size
A	2009	Lewes Canal	Rehoboth Beach	38	65	103	-28	36.9%	X	Large
B	2011	Torquay Canal	Rehoboth Beach	36	34	70	5	51.4%		Small
C	2009	Potnets	Indian River Bay	6	2	8	67	75.0%	XX	Large
C	2010	Potnets	Indian River Bay	20	9	29	46	69.0%	XX	Large
D	2011	Sunset Harbor	Ocean View	38	31	69	6	55.1%	XX	Small
E	2009	Jefferson Creek	South Bethany	27	23	50	25	54.0%		Medium
E	2011	Jefferson Creek	South Bethany	31	28	59	16	52.5%	X	Medium
F	2011	Strawberry Landing	South Bethany	33	26	59	16	55.9%		Medium
G	2009	Lighthouse Cove	Fenwick Island	26	24	50	25	52.0%	X	Small/Medium
G	2010	Lighthouse Cove	Fenwick Island	15	6	21	54	71.4%	X	Small/Medium
H	2011	S. Schultz Canal	Fenwick Island	26	44	70	5	37.1%	X	Medium
		Totals		296	292	588	237	50.3%		

(A) = The number of alive oysters found
(D) = The number of dead oysters found
(T) = The total number of oysters found (A+D)
(L) = The number of lost/missing oysters. (Calculated by subtracting the total found (T) from the initial 75).
(S) = The survival rate (A/T)
(Obs. R) = Observed natural recruitment.
(X) = recruitment of oysters were found on nearby riprap, oysters, or in the quadrat area.
(XX) = much greater recruitment abundance (>25 oysters)

Table 1: Fate of oysters in riprap study. Data is geographically referenced from north to south on the fate of oysters established in quadrats after approximately 1yr.

As shown in Table 1, the number of oysters that have been re-found after one year can vary per site. At the Potnets IRB site established in 2009, only 8 of the original 75 oysters were found, yet survival (75%) was high, but a small sample size existed. The remaining two sites in South Bethany and Fenwick Island had nearly identical results, just over 50% survival and a 67% relocation rate.

An extra 28 oysters were found at the Lewes Rehoboth Canal site initiated in 2009. As the oysters were not naturally attached to substrate, we assumed that extra oysters not intended to be part of this study were stocked into riprap crevices along the jetty, and inadvertently were placed in or directly around the third quadrat. Due to this mistake, this site was not used in further data analysis as oysters may have been dead at the time of stocking. Even with the additional oysters, survival was the poorest at this site (36.9%), but was similar to the canal site in Fenwick Island (37.1%; Table 1).

A Chi-Square (X^2) Test of Association was run using frequencies of the categorical variables alive or dead by 7 sites. At sites where the study site was tested more than one year (i.e. Jefferson Creek, Potnets, and Lighthouse Cove), data was combined per site over years. There is no difference in oysters being alive or dead among sites (X^2= 12.531, df=6, P=0.051), and that an even frequency of alive to dead oysters should be found after one year at any site. However, when the missing oyster counts were analyzed in a 3×7 table, results indicated location was a significant factor (X^2=226.892, df=12, P<0.001. Therefore, there is a relationship between site and oyster fate, but only when the missing or lost oysters are taken into account.

Discussion

Riprap size

We observed that large boulders (>0.6 m diameter) occur more often along large open waters which are prone to increased wave action due to increased fetch (distance of open water) [12]. Constant water exchange along the shoreline supplies nutrients and oxygenated water to the shoreline for shellfish to feed upon. These large ripraps provide adequate crevices to place thousands of bushels of oyster clusters; however, they are also prone to oyster dislodgment from heavy wave action. Therefore, determining true survival is difficult when oysters disappear from the study site. However, if pure restoration is a program's goal, and yearly monitoring is not realistic, sites with large boulders and constant water exchange may be adequate for the goals of the program.

Small ripraps (0.1-0.3 m diameter) occur in slower moving water bodies. Because the rocks are small, crevices to place oysters into are difficult to find, so oysters are often placed on top of rocks. This has a negative influence on studies because oysters are easily displaced either by waves, wind, or predators. However, shorelines consisting of smaller rocks may bode well as study sites because researchers can personally modify the rocky shoreline. The rocks are of manageable size and weight to lift into different positions, in which researchers can almost guarantee the oysters will not be washed away. A disadvantage to this is that it is time-consuming.

Medium sized ripraps (0.4-0.6 m diameter) are beneficial to both riprap stocking and scientific experimentally designed restoration studies. The rocks create natural crevices large enough to easily stock oysters, yet are small enough to contain oysters from easily being displaced. As rocks always vary by size and weight, researchers are still able to modify the rock layout if needed. Locations with medium sized ripraps were often observed in locations with moderate water flow and were accessible from land (Table 2).

Location

The ability for riprap to be utilized as a substrate for oyster restoration is evident. The overall combined oyster survival rate of 50.3% was higher in this study across three years (2009-2011) than a previous local study utilizing an artificially oyster reef which had a 20% survival after two years (John Ewart, Delaware Sea Grant Marine Advisory Program, pers. comm.). Even though some sites may be more advantageous than others, survival was not significantly different based on location within the DIB (X^2=12.531, df=6, P=0.051). However, the analysis utilizing lost oysters did make a significant difference, which may be an effect of site location or riprap quality (Table 2).

Lewes Canal (Site A): The geography at the Lewes-Rehoboth Canal entrance site is slightly different from all the other riprap sites. This riprap is comprised as a jetty sticking out into the northern part of Rehoboth Bay, running perpendicular to the shoreline of the bay. The

	Riprap Size and Quality		
Characteristics	**Small**	**Medium**	**Large**
Size	<0.3m	0.3-0.6m	>0.6m
Application	Easy to move	Manageable to move	Impossible to move
Features	Few crevices Poor oyster retention Containment gear	Several crevices Good for research and oyster stocking	Abundant crevices Great for oyster planting Poor oyster retention
Study Sites	Sites D, G Shallow sites Easy access Small rocks fit uniformily together not producing many crevices	Sites E, F, G, H Open and closed water Easy access	Sites A, C Open water More remote locations-High wave energy sites
			

Table 2: Characteristics of riprap used in this study and corresponding pictures of those riprap (Pictures taken by Brian Reckenbeil).

riprap outlines the boundaries of the canal entrance which eventually connects northern Rehoboth Bay to the southern portion of Delaware Bay through Lewes, Delaware. All other riprap sites are part of the shoreline.

Unexpectedly, a surplus of oysters was found within the 1 m^2 quadrats which were established in July 2009 at the Lewes-Rehoboth Canal site. Besides being an original study site with three quadrats, the riprap was utilized for general oyster restoration purposes. Unfortunately, some additional oysters were accidentally stocked in or directly adjacent to the quadrats for general oyster stocking efforts. This resulted in a greater abundance than the original 75 oysters being found one year later. Even though we found more than the original 75 oysters set up for this study, it is interesting to note the differences in mortality of these three quadrats. The near-shore quadrat had a 9% (1/11) survival, middle quadrat 3% (1/29) survival, and farthest quadrat had a 57% survival (36/63). Quadrats were spaced approximately 15 m apart. In the two quadrats closest to the shoreline, the water was inundated with thick mats of algae. The far quadrat was mostly clear of any algae, and the water was deeper.

Torquay Canal (Site B): A study site was established in the entrance to Torquay Canal in 2011. This site had small riprap, which had been densely filled with mussels. Bald Eagle Creek [13] connects Torquay Canal to Rehoboth Bay and contained several hundred meters of shallow small riprap. Several fish kills have occurred within Torquay Canal and Bald Eagle Creek as a result of anoxia, H_2S, and storm events. Multiple stressors can affect the dissolved oxygen (DO) concentration, including anthropogenic sources. Poor survival results from another study [14] near this site also confirm that this is a poor location to continue oyster restoration efforts.

Potnets (Site C): The Potnets site in IRB is a high wave energy environment with large boulders (Table 2). We suggest that the abundant waves washed the oysters out of the 1 m^2 quadrat locations. Low abundances make conclusions about oysters' survival difficult since the sample size was small (8 of 75). Therefore, the study was repeated at this location in 2010. Predation also could have caused death and disappearance of some oysters. Some oysters may have not been found due to sedimentation, however, seems unlikely since the sediment in each crevice was trolled with hand several times until no bivalve shells or small rocks could be excavated from the hole. Additional searching of crevices immediately surrounding the quadrat area did not reveal any of the missing oysters. At this site, several naturally set oysters were seen attached to the riprap, which is a promising sign for the future.

Sunset Harbor (Site D): The riprap site in Ocean View at Sunset Harbor had evidence of several naturally recruited oysters. Oyster survival was 55%; however the small riprap (0.1-0.3m) is not suitable for oyster restoration purposes (Table 2). Riprap had to be manipulated to create crevices, which would be ineffective for general oyster restoration, as it would be extremely time consuming when needing to plant dozens of Bu. of shellfish. Bottom sediment was comprised of very soft dark mud. Tidal waters enter IRB from only three locations: Indian River Inlet, the Lewes Rehoboth Canal, or the Little Assawoman canal. Due to this fact, water current is strong at this site because it is <150 m from the northern entrance to Little Assawoman Canal which empties into White Creek and then IRB.

Jefferson Creek (Site E): The Little Assawoman Canal empties 5km to the south at Jefferson Creek. Two study sites were established within Jefferson Creek. The areas surrounding Jefferson Creek have been highly developed, yet many shoreline habitats were left natural. However, many ripraps bordering the edges of Jefferson Creek are of medium size, and oysters had a 53% survival rate. Water conditions were suitable, but at times had low DO levels (1.38 and 1.55 mg/L). Surface water runoff from rain events can drastically reduce salinity, which may help suppress mortality from parasites which thrive in high temperature and high salinity environments.

Strawberry Landing (Site F): This site at Strawberry Landing in South Bethany was discovered in 2011 and is part of the Assawoman Wildlife Area. It has medium sized riprap and is accessible by truck from the western side of the DIB. From the five study sites in 2011, oyster survival was highest here at 56%, and would bode well for future restoration activity.

Lighthouse Cove (Site G): The riprap site on Lighthouse Cove in Fenwick Island was comprised of small to medium sized riprap in shallow water. This location is ideal, as water quality conditions were best throughout the study. However, slightly deeper and larger riprap would be preferred. Additional suitable riprap may be present just past the Rt. 54 Bridge heading into Maryland waters. Natural recruitment, higher survival, and best growth rates were found in oysters grown in Fenwick Island [15].

S. Schultz Canal (Site H): This site is in Fenwick Island, but within a canal. The riprap was medium sized and was located at the end of a street which dead-ended into the canal and was <100 m from the opening to Lighthouse Cove. Other ripraps occurred further into the canal system and also displayed similar depths and riprap size, suggesting potential substrate for oyster stocking. However, oyster survival was very poor at this site, 37%, and is confirmed by poor oyster survival in the Fenwick Island canal in a separate study. Thick algal mats were observed on these rocks, which may be an indication of eutrophied waters [16].

Conclusions

Riprap comes in various shapes and sized boulders. Therefore, classifying all riprap as a homogenous similar habitat is erroneous, as not all riprap is suitable for stocking oysters. The analogy of goldilocks and the 3 bears is a good rule of thumb for determining the potential of riprap to be a suitable oyster stocking location, with medium sized ripraps 'being just right'. Containment gear may increase the odds of relocating all subjects in future studies. Plastic mesh bags are often utilized in the shellfish restoration field to contain cultch or oysters [17]. Containment gear would calculate survival and mortality rates more accurately, yet would not mimic the DIB programs oyster restoration methods.

To improve oyster survival, placing loose cultch into crevices prior to stocking with live clusters may prevent oysters from sinking into anoxic mud conditions, detrimental to the oyster health. Many of the dead oysters found in crevices were pulled out of the bottom of the hole with black mud surrounding the shell. Additionally, loose shell could be placed in front of riprap for the same effect in case oysters are washed out of the riprap. In addition, cultch would provide habitat and substrate for other organisms.

We would recommend managers to continue oyster restoration efforts at Potnets, Jefferson Creek, Strawberry Landing, and Lighthouse Cove. We would not recommend the Lewes Canal entrance due to poor oyster survival and inadequate site accessibility, Torquay Canal and Sunset Harbor due to small riprap size, or S. Schultz canal due to low survival. As we have not explored the entire shoreline of the DIB, many other suitable locations may exist, and sites with medium sized ripraps on open water would be best, since locations with moderate current are ideal locations to grow bivalves [18].

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