FAUNAL COMMUNITY USE OF ENHANCED AND NATURAL OYSTER REEFS IN DELAWARE BAY: A FIELD STUDY AND CLASSROOM INQUIRY

By

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ABSTRACT OF THESIS

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In addition to its value as a fisheries resource, the eastern oyster *Crassostrea virginica*, is a reef building, cornerstone species that provides ecosystem services to the environment. Oysters provide habitat for associated resident and transient species. With widespread declines in oyster populations, restoration efforts have focused on improving oyster stocks and enhancing the ecosystem services they provide. Community-based oyster restoration programs engage the public and local community in planning, construction and/or monitoring of restoration projects. Since 2007, a K-12 student centered community-based restoration venture, Project PORTS, *Promoting Oyster Restoration Through Schools*, has been working to educate students, promote stewardship values, and enhance oyster habitat in the Delaware Bay. The overarching goals of the present study were to (1) assess fish and macroinvertebrate utilization on the Project PORTS community-created, subtidal, low-relief oyster restoration area in the Delaware Bay, and (2) convert the data collected into a STEM (Science, Technology, Engineering and Mathematics) activity that can be implemented in the classroom.

I examined six subtidal natural oyster reefs of varying oyster densities and one community-based restoration reef as habitat for fishes and invertebrates. Sampling methods on these low-relief reefs consisted of otter trawl tows and benthic habitat tray collections. Results revealed that the enhancement area supported a diverse faunal community consistent with nearby, natural oyster habitats. Data collected during the field study were then transformed into an educational lesson plan, "*One Fish, Two Fish-Assessing Habitat Value of Restored Oyster Reefs*", that fulfilled national and state (NJ) curriculum standards. The lesson was piloted in a middle school classroom and student learning was evaluated through summative assessments pre and post-participation in the activity. Results of the assessments indicated that students made strong gains in knowledge of oyster ecology and improved analytical skills by graphing data. This dual interest study demonstrated that a novel education program with a local, real-world connection positively enhanced crucial estuarine habitat while expanding STEM knowledge and skills of participating students.

PREFACE

The eastern oyster (*Crassostrea virginica*) is an estuarine, filter-feeding bivalve that ranges in distribution along the east coast of North America from the Gulf of St. Lawrence to the Gulf of Mexico (Kennedy *et al*. 1996). They currently are, and historically were harvested as an important food item throughout most of their range. Although immobile for most of their lives, oysters form gregarious communities that create hard structure in estuaries (e.g. Jones *et al*. 1994). *Crassostrea virginica* will settle subtidally or intertidally depending on habitat conditions, but their overall ecosystem functions remain the same (Coen *et al.* 2007). Some of these functions include water filtration, concentration of bio-deposits, enhancement of estuarine biodiversity, and supply of habitat for associated resident and transient species (Wells 1961, Tolley *et al.* 2005). With widespread declines in oyster populations due to over-fishing, habitat loss, pollution and disease (e.g. Kennedy *et al*. 1996), many restoration programs exist to improve oyster stocks and enhance the ecosystem services they provide.

Eastern oyster habitat restoration efforts that once focused exclusively on fisheries stock enhancement now routinely focus on ecological function (Brumbaugh *et al.* 2010, Coen and Luckenbach 2000). Oyster reefs have been successfully constructed by community-based programs that aimed for ecological restoration (e.g. Brumbaugh *et al*. 2000 and Hadley *et al.* 2010), however, in subtidal conditions, the habitat benefits of these projects have not often been investigated. Quantitative post-restoration monitoring efforts are needed to determine the success of a project and to identify effects on the local ecosystem. Community-based programs offer a unique opportunity and an ideal platform to communicate relevant scientific information to the public. Since 2007, a K-12 student

centered community-based restoration venture, Project PORTS, *Promoting Oyster Restoration Through Schools*, has been working to educate students, promote stewardship values, and enhance oyster habitat in the Delaware Bay. The overarching goals of the present study were to (1) assess fish and macroinvertebrate utilization on a community-created, subtidal oyster restoration area in the Delaware Bay, and (2) convert the assessment into a STEM (Science, Technology, Engineering and Mathematics) activity that can be implemented in the classroom. To reach these goals, I examined six subtidal, low-relief, natural oyster reefs of varying oyster densities and one enhanced reef as habitat for fishes and invertebrates. Sampling methods on these reefs consisted of otter trawl tows and benthic habitat tray collections. The single enhancement area studied was constructed over a five year period by Project PORTS which transplanted seeded shell to the area each year.

The educational outreach portion of the program uses the oyster as a vehicle to introduce students, educators and the local public with the Delaware Bayshore and acquaint them to the science of an authentic restoration project. Hands-on work building shell bags for the foundation of the reefs is complemented by in-class education programming. Data collected during the field study were transformed into an educational lesson plan, "*One Fish, Two Fish- Assessing Habitat Value of Restored Oyster Reefs*", that fulfilled national curriculum standards and provided the students with a more complete understanding of their efforts. Moreover, the lesson plan provides an active engagement in STEM education. Students at a local middle school were engaged in that lesson and student learning was assessed via summative assessments pre and post-participation in the activity.

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I would like to express my sincere gratitude to my advisor, Dr. David Bushek, for his encouragement, support and patient guidance, from when I first accepted a summer internship at the Haskin Shellfish Research Laboratory six years ago, through the completion of this degree. I would also like to thank Lisa Calvo, for seeing the potential in me and fostering my enthusiasm for community outreach. Advice and guidance from committee members Drs. Thomas Grothues, Rebecca Jordan and Olaf Jensen certainly helped to strengthen this research. The Geraldine Dodge Foundation, NJ Sea Grant and Dupont Clear into the Future provided financial support for this research. Generous scholarships received from BAC Union Local 7, Manasquan River Marlin and Tuna Club, and the NJ Water Environment Association assisted me during my academic pursuits.

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To my Mom, Dad and family, thank you for teaching me to never lose sight of the important things in life. Your love and unwavering support over my graduate school career and throughout my life allowed me to achieve my goals.

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CHAPTER 1: A Field Study

INTRODUCTION

Decreases in eastern oyster populations over the last century have been documented in many estuaries along the North American Atlantic and the Gulf of Mexico coasts (e.g. Rothschild *et al.* 1994). This striking trend has expanded interest in oyster restoration for both fishery and ecological benefit. Eastern oysters *Crassostrea virginica* (Gmelin, 1791) are a valuable fishery and provide numerous ecosystem services to the environment (Coen *et al.* 2007). Some of these services include water filtration, concentration of bio-deposits, enhancement of estuarine biodiversity, and supply of habitat for associated resident and transient species (Wells 1961, Tolley *et al.* 2005). The aim of this study was to compare the diversity of nekton and benthic macroinvertebrates on an oyster restoration area with nearby unenhanced bottoms containing low or high densities of oysters as a means to evaluate the effect of the "restoration effort".

Eastern oysters form intricate reef systems and can be called "ecosystem engineers" because they modify the environment in ways that influence the health of organisms around them (Jones *et al.* 1994). Oysters form gregarious communities that alter the bay bottom structure. Oyster larvae initially settle on hard substrate, usually shell, and once grown, their shells provide substrate on which new larvae settle. Over time, this process creates living hard structures in an otherwise soft-bottom environment. Oyster bottom can range from high relief reefs with significant three-dimensional structure to low relief, cultch bottom beds. The structure of the reef may be different based on the estuary's climate or the oyster's habitat within the estuary (intertidal vs. subtidal etc). From southern North Carolina to northern Florida, oysters are predominantly found in the intertidal zone and further north, they are predominantly

subtidal (Bahr and Lanier, 1981). Over time, these structures are colonized by an array of species. Lenihan and Peterson (1998) demonstrated that temperate oyster reefs are analogous to tropical coral reefs in terms of their ecological diversity. This rich habitat provides reproduction, nursery and foraging grounds for a variety of estuarine species and refuge from predation (Coen & Luckenbach 2000, Harding & Mann 2001). Wells (1961) identified 303 species utilizing *C.virginica* beds in Newport River, North Carolina. Plunket and LaPeyre (2005) described 23 transient and resident fish species that assembled over flat, cultch oyster bottom of Barataria Bay, Louisiana. Although not high relief, they found that oyster bottom provided critical habitat for many estuarine fish species.

Habitat restoration is a recent concept in human history; however, consuming oysters is not (e.g. Claassen 1998). Oyster restoration efforts have been expanding throughout the coastal United States, most concentrated in the last couple decades, but industry driven shell-planting efforts have been occurring for the last 70 years in some areas such as the Delaware Bay (Ford 1997). Because oysters are a foundation species in the estuary, restoration efforts should benefit reef associated species. While fishery-based shell planting is designed to increase oyster abundances, the enhanced oyster reefs may result in the return of important services to the environment (Coen *et al.* 2007). The goal of ecological restoration is to re-establish, initiate or speed the recovery of an ecosystem that has been disturbed (Vaughn 2010). This recovery takes time that may not be realized until restoration is well underway. The time it takes for a natural ecosystem to recover delivers a great diversity of responses and often elicits ecological succession. Thus, successful restoration must be evaluated in the broader ecological context of succession

(Walker *et al.* 2007). This research was conducted six years after the first shell plantings and therefore, multiple recruitment events and epifaunal shell colonization had occurred.

Field experimentation and modeling efforts have shown that a restored oyster reef can enhance production of fish and large crustaceans during its functional lifetime (Peterson *et al.* 2003). Brown *et al.* (2014) looked at the effect of artificial reef substrate on nekton and benthic invertebrate use in the Gulf of Mexico and determined that a restored reef can provide certain ecosystem services, such as, refuge from predation and provision of macroinvertebrate habitat, even if spat recruitment is low. Studies in Virginia, Maryland, Louisiana and the Carolinas have quantified increases in species diversity and abundance associated with oyster reefs (Coen *et al.* 1999, Coen & Luckenbach 2000, Breitburg *et al.* 2000, Luckenbach *et al.* 2005). The results of these and other studies reflect an enhanced abundance of fish and encrusting species within the areas of native and restored reefs.

This study asks whether cultch-based oyster restoration efforts on a small scale, subtidal area in the Delaware Bay altered species abundances relative to unenhanced bottom. In other words, has oyster reef restoration occurred? To answer this question, I (1) delineated seven sites in the Delaware Bay based on benthic habitat characteristics, (2) sampled fishes and invertebrates on the enhancement site, the high density oyster bottom, the low density oyster bottom, then (3) compared species diversity among these three different areas to characterize the community structure of benthic invertebrates, transient fishes and resident fishes. The null hypothesis was there was no difference in community assemblages across sites. I hypothesized that the faunal community assemblage on the restoration site would be different from unenhanced, natural reefs.

MATERIALS AND METHODS

Study site description

The Gandy's Beach Oyster Restoration Enhancement Area (GBOREA) is a ten acre plot located in the upper Delaware Bay (Latitude N 39°16', Longitude W 79°14') nestled inshore of natural oyster beds (Figure 1). It was established by the New Jersey Department of Environmental Protection in 2007 in conjunction with Rutgers University's Project PORTS (Promoting Oyster Restoration Through Schools). Project PORTS is a community-based oyster restoration program that engages local school children in stewardship by building shell bags that provide substrate for oyster larvae. Pre-manipulation, the NJDEP conducted a dredge survey to confirm that the oyster abundance on the proposed area was scarce and primarily consisted of muddy sand (pers. comm. Lisa Calvo).

Shell planting began at this 10-acre site in 2007 with the placement of crushed surf clam shells and oyster spat-on-shell along a 2-acre plot at the northwestern corner of the reserve. This plot is referred to as GBOREA-1 (Fig. 1a). A 2-acre plot immediately east of the initial planting site, referred to as GBOREA-2, received surf clam shell and oyster spat-on-shell in 2008. Subsequently, GBOREA-1 received spat on shell additions in odd years while GBOREA-2 was planted in even years (Fig.1a). The level of planting was substantially greater on GBOREA-2 with almost double the total surf clam shell planted (Table 1) and nearly 21 million total oyster seed placed as spat-on-shell versus just over 5.5 million for GBOREA-1 (pers. comm. Lisa Calvo). In 2012, 2013 and 2014, seeded shell was planted on a third 2-acre site, referred to as GBOREA-3. GBOREA-1 and GBOREA-2 were sampled as the "restoration area" in this study between 9 July 2013

and 11 November 2013. Maximum tidal amplitude in this region of the bay is 2.35 meters. High tide depth ranges from 3- 5.5 meters across sites.

Study design

To determine how nekton and macroinvertebrate assemblages change with bottom type, six sites were chosen in close proximity to the GBOREA (Fig.1b). Sample locations were chosen based on field exploration and bed data collected for the New Jersey oyster stock assessment (Bushek and Ashton-Alcox 2012). Sample sites also followed a depth contour (3-5.5 m). The New Jersey oyster stock is managed on a grid system and that nomenclature initially served as site names for this study. Field exploration consisted of sampling bottom substrate using oyster tongs and a dredge to assess bottom composition. Bottoms chosen were found to exhibit a gradient of oyster abundance from low to high with the GBOREA falling into the middle of the distribution. A rectangular sampling area of 34,500 m^2 was mapped on the GBOREA and each of the following grids using Google Earth: Nantuxent 19, Strawberry 23, Strawberry 28, Hawk's Nest 26, Hawk's Nest 28 and Hog Shoal 18. The rectangular area was 300 meters long by 115 meters wide (equivalent to 3.45 hectares, 8.5 acres). The GBOREA is in close proximity to natural oyster beds included in the fishery (Fig. 1b).

Bay floor mapping

High resolution side scan sonar images (600 kHz) were collected from a propeller-driven Remote Environmental Measuring Units (REMUS-100) AUV, and used to map bottom features and shell distribution on the GBOREA. REMUS is an autonomous underwater vehicle used to perform hydrographic reconnaissance (Grothues *et al.* 2008). The vehicle was operated by the Jacques Cousteau National Estuarine

Research Reserve in Tuckerton, New Jersey. The entire 10-acre GBOREA as well as a 30 meter perimeter around the area was surveyed. The altitude over the bottom was 3.0 meters and the speed was set at 3.0 knots. The swath width was 30 meters to each side of the AUV for a total of 60 meters total and the boustrophedonic survey pattern had line spacing between the rows of 15 and 45 meters. Chesapeake Technology's SonarWiz 5.0xxxxxx software was used to process the side scan imagery for mosaic development and target information.

Benthic habitat tray sampling

Bottom temperature and salinity were measured each sampling day using a YSI® multi-probe meter. Benthic habitat trays, similar to those used by Lenhert and Allen (2002) in the North Inlet estuary, South Carolina were constructed to sample mobile, epibethic invertebrates and resident fishes. Plastic (Nestier) aquaculture trays (0.36 m^2 x 9.5 cm deep) were lined with 2 mm plastic-coated fiberglass mesh, outfitted with 12 kg of weight (concrete), a polypropylene rope bridal with a buoy line and buoy (Fig.3). Trays were filled with 11 liters of bottom substrate collected from the respective sampling site using an oyster dredge (lined with 3 mm mesh). Once filled with benthic material from that site, each tray was immediately deployed into the water. The trays were deployed once each month from July to November, and retrieved one week later by steadily pulling them to the surface using the attached buoy line and a capstan winch. Soak times varied from 7-11 days due to weather and scheduling constraints. Two trays were deployed on each site once a month.

Retrieved trays were rinsed thoroughly on site with ambient water using a deckwash pump. Contents were carefully removed by hand and placed into labeled

buckets for transport back to the laboratory where they were refrigerated until processed. Organisms were separated and sorted by species or lowest possible taxon. Non-sessile individuals (excluding isopods and worms) were measured with a ruler and each taxon weighed collectively. The following organisms were rated on a scale of absent, present or abundant: *Molgula sp.*, *Nereis sp.*, anemones (primarily *Diadumene lineate*), *Balanus sp.*, *Synidotea laticauda* (invasive isopod) and *Sabellaria spp*. Barnacles were classified as abundant if overall shell coverage was 30% or greater. Tunicates were classified as abundant if the volume of tunicates in the tray was 0.5 L or greater. Anemones, worms and isopods were classified as abundant if there were more than 10 individuals present.

Four characters of physical habitat properties were measured: volume and number of oysters (including spat), volume and number of oyster boxes (dead oysters with valves still articulated), volume of debris (rocks, mud, sand, detritus, *Sabellaria* tubes, etc.) and volume of cultch per tray. The height of each oyster was also measured. The oysters themselves compose the physical reef structure and therefore, the density of live oysters can be a direct measure of habitat quality (Rodney & Paynter 2006). Additionally, boxes and cultch (loose shell) provide shelter and nesting areas for several species of resident fishes and crabs and are therefore considered to be an important element of reef habitat (e.g. Runyan 1961).

Species accumulation curves, similar to those created by Marenghi and Ozbay (2010), were plotted based on the cumulative number of species collected in each tray and fitted with Michaelis-Menten model curves (Clench 1979). Examination of species accumulation curves provides: a measure of species richness and an indication of sampling effort rigor in capturing species utilizing a habitat.

Pre and post-deployment tray comparison experiment

A pre and post-deployment tray comparison experiment was conducted in November during the routine monthly sampling. The intent of this small experiment was to answer ad-hoc questions that arose during the study: (1) Do the repeated dredge tows used to collect bottom substrate artificially alter the density of animals in the trays? For example, a soft bottom habitat required more dredge tows than a bottom with dense oyster coverage to collect the 11 liters of substrate needed, thus, additional animals might have been incidentally collected and put into the trays. (2) Do abundances of animals change over time from tray deployment to collection? To answer these questions, bottom material sufficient to fill a replicate tray was collected at each site and returned to the lab for processing instead of getting deployed back on the site. Three replicate samples were collected from the enhancement area to allow for averaging. The same metrics and methods discussed above were used to process the pre-deployment samples.

Otter trawl sampling

Transient and resident fishes were sampled bi-weekly with an otter trawl (width between otter boards = 2.44 m, stretched net mesh diameter = 3.5 cm, stretched cod end mesh diameter = 1 cm, otter boards = 40.64 x 22.86 cm, tow rope ~ 22.25 m). The trawl was deployed off of the 24 foot *R.V. Veliger* and towed over each of the seven sites three times each sampling day across the tidal cycle. The net was towed against the current for better efficiency. Each tow was two minutes long. The following data were recorded for each tow: GPS start location, GPS end location (using the vessel's Garmin® GPS device), depth and tidal direction. Each individual caught was indentified and measured (total length for fishes and carapace width for crabs) using a fish board. Weights were

taken collectively as species per tow, not individually unless a single animal surpassed the limit of the scale or comprised more than ~50% of total biomass. Tubular spring scales were used to measure weight in the field. Small animals were placed in thin mesh bags to obtain weights.

DATA ANALYSIS

Benthic habitat tray sampling

Oysters in the tray after the soak time were counted for abundance. A two-way analysis of variance (ANOVA) ($\alpha = 0.05$) was used to test for differences in oyster abundance across sites. The two factors used in the ANOVA were location (seven sites) and sampling month (July-November). An interaction term between location and month was also included in the ANOVA. Tukey's honest significant difference (HSD) post-hoc comparisons followed for any tests that were globally significant.

Simpson's Index of Diversity (SID) was calculated following McIntosh (1967) on the cumulative tray data from each of the seven sites using the following equation:

$$D = \sum (n / N)^2$$

Where n is the total number of organisms of a particular species and N is the total number of organisms of all species. The eleven most abundant species collected in the trays were included in these calculations.

Canonical Correspondence Analysis (CCA) was used to identify relationships between community composition and explanatory variables, which were the benthic habitat properties (box count, oyster count, debris volume). Eigenaxes were restricted to those for which linear combinations of explanatory variables significantly explained

species abundance (ter Braak & Šmilauer 2012). Each tray was treated as an individual sample; i.e., trays from the same site over time were not combined (n=70). Canonical correspondence analyses were performed in CANOCO (CANOCO, Version 5). A generalized linear model (GLM) was constructed to determine if site was a predictive variable in naked goby, *Gobiosoma bosci*, abundance. Naked gobies were identified a priori as characteristic reef residents because they rely on oyster reefs for nesting sites (Harding and Mann 2000), refuge from predation and foraging habitat (Nelson 1928).

Principal components analysis (PCA) was used to quantify variability in faunal tray composition of the three bottom habitat types (high oyster density, GBOREA and low oyster density). All nineteen species collected in the trays were used in the PCA. Each tray was treated as an individual sample; i.e., trays on the same site over time were not combined (n=70). Catch data was classified by both location and month to view distribution of fauna.

Otter trawl sampling

Simpson's Index of Diversity (SID) was calculated following McIntosh (1967) on cumulative trawl data from each of the seven sites. Excluding *Anchoa mitchili*, the ten most abundant species collected in the trawl were included in these calculations. PCA was used to investigate variability in faunal composition of the three bottom habitat types (high oyster density, GBOREA and low oyster density). Cumulative catch abundances from each sampling day (composite of 3 tows) were used in the analyses and data were log transformed. PCA was performed in CANOCO (CANOCO, Version 5). Catch data was classified by both location and month to view distribution of fauna.

RESULTS

Over the course of this study (16 July 2014 to 21 November 2014), salinity ranged from 11.7 to 19.5 ppt and temperature ranged from 8.3 to 29.6°C (Table 2). Seventy trays were deployed and retrieved (2 trays x 7 sites x 5 months) with soak times ranging from 7 to 11 days (Table 2). Two hundred ten trawl tows were completed (6 tows x 7 sites x 5 months) during the study.

Benthic habitat tray sampling

After collecting the trays from each site, the substrate materials present were processed for oyster abundance. The number of oysters per tray (Fig. 2a) varied across sites. Oyster abundance was not significantly different among months (mean = 16.39 oyster per tray, SD = 23.51, $F = 0.314$, $p = 0.867$) suggesting two things: (1) benthic sampling was fairly consistent over time and (2) there wasn't strong monthly variation in oysters at each site. The interaction term (location:month, $p = 0.0124$) in the analysis was statistically significant (Fig. 2b) and oyster abundance was highly significant ($P<0.00001$) between sites (Table 3). Tukey's HSD post-hoc comparisons ($\alpha = 0.05$) revealed 3 groupings based on oyster abundance in the trays (Fig. 2a). These significant differences denoted the nomenclature for discussion of results (Table 4). Oysters were most abundant in H1 and H2, followed by GBOREA, and then L2, L1, L3 and L4 (Fig. 2a).

New species collections in the benthic habitat trays (Fig. 4) begin to level off asymptotically, after 4 samples, indicating that sampling ten trays per site was adequate to estimate richness of each site. Richness was greatest on high oyster density sites (12

and 13 species). Richness on low oyster density sites was 9-13 species, with the enhancement area containing 12 species (Fig. 4).

A total of 2211 individuals representing 19 species were collected in the trays (Table 5). The Atlantic mud crab *Panopeus herbstii* was by far the most abundant species captured with 834 individuals composing almost a third of the entire catch. After the Atlantic mud crab, the three most abundant species were the eastern mud snail *Ilyanassa obsoleta* (321 individuals), the marsh grass shrimp *Paleomonetes vulgaris* (282 individuals), and the estuarine mud crab *Rhithropanopeus harisii* (268 individuals). The eastern mud snail, Atlantic mud crab and daggerblade grass shrimp (*Paleomonetes pugio*) were on average most abundant at low oyster density sites, high oyster density sites and the GBOREA, respectively. *Tellina agilis*, *Pagarus longicarpus* and *Mulinia literalis* were collected exclusively on low oyster density bottom. One species, *Polinices duplicatus*, was only collected on the GBOREA. *Crangon septemspinosa* and *Eurypanopeus depressus* were unique to high oyster density habitats (Table 5). Site was a significant predictor of naked goby abundance (H1 mean = 2.1, SD = 5.95, $p = 0.0029$, H2 mean = 2.4, SD = 3.10, $p = 0.0019$, GB & L1-L4 means ≤ 0.6, p-value range = 0.097-1.0). This analysis was not conducted for all species. Naked gobies were identified a priori as characteristic reef residents because they rely on oyster reefs for nesting sites (Harding and Mann 2000), refuge from predation, and foraging habitat (Nelson 1928).

Median abundance of all animals (excluding oysters) was greatest on site H2, nearing 40 and least on site L2, under 20 (Figs. 5a & 5b). Highest richness overall was found on the enhancement area (GB) with 9 species per tray. Median richness was

greatest on H2 (6.5 species), lowest on L2 (3.5 species) and equal on GBOREA, L1, L3 and L4 with 5 species each.

There was no constant pattern in the Simpson's index of diversity (SID). Site H2 had the highest diversity overall (SID = 0.799). This means there is ~80% chance that two individuals randomly selected from the tray samples will belong to a different species. The other scores ranged from 0.696 to 0.791 and the restoration area had the 4th highest SID (Fig. 6a).

Bottom habitat parameters accounted for only 11% of cumulative variation exhibited in catch data (CCA, Eigenvalues 1 = 0.085, 2 = 0.067, 3 = 0.0323, 4 = 0.0121, canonical coefficients axis1 = 0.6021, axis2 = 0.6187, $P < 0.005$) (Table 6). Oyster count and box count were highly correlated (Fig. 7), but little variation was explained by these properties.

Pre and post-deployment tray comparison experiment

There were no consistent trends between tray catch pre-deployment number of animals collected in November only and average post-deployment samples from November as well as all other months (Table 7). The number of animals per tray was quite variable (range = 2-96, mean = 32.07, SD = 17.30) over time. Interestingly, blue crabs *Callinectes sapidus* were only collected during pre-deployment. No blue crabs were found post-deployment over the course of the study.

Cultch volume remained relatively constant throughout deployment at a mean value of 3.42 liters (Fig. 8a). However, debris volumes decreased at each of the sites over the soak period (Fig. 8b). This trend was particularly striking for the low oyster density sites. It is unclear whether the sediments were lost while the trays were lowered down

from the boat, during the 7-11 day soak time or during retrieval of the trays from the bottom of the bay. With the exception of one anomaly on L2, pre and post-deployment oyster abundances (pre mean = 1.15 L, pre SD = 1.01, post mean = 0.99 L, post SD = 0.98) remained relatively unchanged throughout deployment (Fig. 8c).

Otter trawl sampling

A total of 1609 individuals representing 30 different species were collected in the trawl (Table 8). Collections were probably close to, but not saturated with respect to estimated richness (Fig.9). The two high oyster density sites had the greatest overall richness (19 and 20 species), while the faunal assemblages on GBOREA (13 species) and L1 had the lowest richness (11 species).

Overall, the three most abundant species were the bay anchovy *Anchoa mitchili*, Atlantic croaker *Micropogonias undulatus,* and weakfish *Cynoscion regalis*. The majority of croaker and weakfish individuals collected were juveniles. Of the 30 species caught, five were found in highest abundances on the GBOREA: *Trinectes maculatus, Opsanus tau, Menticirrhus saxatilis, Chilomycterus schoepfi and Morone saxatilis* (Table 8). *Micropogonias undulatus* had the highest abundance on the low oyster density sites, while *Pogonias cromis, Morone americana* and *Centropristis striata* exhibited the highest abundances on high oyster density sites.

The number of individuals caught per tow ranged from 0 to 52 with a median value of 5. Fish abundance varied greatly across sites, but had similar medians of 2-8 species per tow caught over each site (Fig. 10a). The maximum number of species caught in a tow was 9 (Fig. 10b). The number of species caught increased with the number of individuals (Fig. 11), however, this linear relationship was not significant (t = 0.9330).

Species richness varied among sites with median values of just 2 or 3 per tow at each site (Fig. 10b).

The GBOREA site was the most diverse (SID = 0.845) of any other site (Fig. 6b). This means there is ~85% chance that two individuals randomly selected from a trawl sample will belong to different species. The other SID scores ranged from 0.751 to 0.837 with only one low density oyster site having a higher index than the high density oyster sites.

Nineteen out of the thirty species collected were used in the PCA. The species excluded were those that were rare (< 2 individuals collected) and those whose habit is not vulnerable to sampling by the otter trawl, such as, *Ophidion marginatum* (burrow dweller) and *Anchoa mitchelli* (planktivorous schooling fish). Two groups of species closely associated with each other were: the group aligned with axis 1 that contained species such as *Centropristis striata, Opsanus tau, Bairdiella chrysoura* and *Chilomycterus schoepfi*, and the group aligned with axis 2 including *Pogonias cromis, Mustelus canis* and *Syngnathus fuscus*. Neither *Micropogonias undulatus* or *Morone saxatilis* were positively correlated with above mentioned species. The major trends in fish composition among sites were that *T.maculatus* and *C.sapidus* most commonly co-occurred across sites (with the exception of H1), while *C.regalis* and *O. Tau* co-occurred on all sites in relatively high abundances. *C. striata* was collected only on H1 and H2. *M. saxatilis* was most commonly collected on L3. These trends related to 51% of the total variation (Table 9). Fish assemblage changed with season (Fig. 13).

Bay floor mapping

Weather and other logistics prevented side scan mapping of all sites, but the GBOREA was mapped. The GBOREA consisted of patchy hard substrate (shell and oysters) surrounded by sand in defined waves with a wave length of approximately 1.2 to 1.4 meters and height of 0.14 to 0.18 meters (Fig. 14). Fish schools were also detectable from the side scan images (Fig. 15). The schools were fairly common and appeared to be more densely distributed over the more recently planted portions of the enhancement area.

DISCUSSION

Karl Möbius, a pioneering ecologist, was one of the first scientists to describe an oyster bed as a community (Möbius 1877). He observed that oyster beds were home to a host of other animals and that they were richer in species than other areas of the sea-floor. He coined the term "biocoenosis" in 1877 to describe a community of interacting living beings that find everything necessary for survival in one habitat. A biöconose is akin to our modern term, ecological community. Furthermore, a given community would be transformed if the number of a particular species (e.g. oysters) increased or diminished through the actions of man (Möbius, 1883). Progressing the observations Möbius noted almost 150 years ago, this study documented the fish and motile fauna utilization on a subtidal oyster restoration area in a mid-Atlantic estuary.

The shell on the portions of the restoration area sampled have been in the Bay for 1-6 years based on the year planted and thus were in various stages of colonization. The original design plan for this experiment was to select three sites that contain abundant

live oysters and three sites that contain few or no live oysters to compare to the GBOREA. The sites were chosen based on stock assessment data from previous years that contain information such as the number of oyster per square meter and the estimated number of times that area was covered by a fishing dredge (Bushek & Ashton-Alcox 2012). Post-hoc analyses revealed only two sites contained relatively high live oyster abundances and four of low abundances. As a result, sampling effort was equal across each of the seven sites, but, sample sizes were not distributed evenly among the three oyster density groups. Ideally, an additional restoration area similar to the GBOREA would have been included for sampling rigor and statistical analyses, but only one such area currently exists in Delaware Bay.

The otter trawl captured a very different community than the benthic habitat trays. Of the 47 species collected during this study, only two: *Gobiosoma bosci* and *Opsanus tau*, were caught in both the trays and trawl. The trawl was intended to collect resident and transient fishes, while the shell trays were geared to collect mobile, benthic invertebrates and resident fishes. The gear performed quite well in meeting these goals and despite common concerns, the trawl net did not get snagged on the oyster reef as most of the beds in that portion of the bay are low relief. More specifically, current state and federal policies for the Delaware Estuary prohibit the construction of reefs for restoration with a vertical relief greater than 6 inches. In their comparison of gear for sampling nekton in shallow estuarine habitats, Rozas and Minello (1997), note three advantages to using an otter trawl: they are easy to use, they provide clean samples, and they sample a large unit area. On the other hand, they also list disadvantages including low and variable catch efficiency coupled with numerous attributes that influence catch

efficiency. Catch efficiency for the otter trawl used in this study was not calculated, but was assumed to be consistent across sites and sample dates because the relief is low at all sites relative to the trawl mouth. Trawl tows were also rotated across sites throughout the tidal cycle to avoid tide sampling bias.

During October sampling, the question arose that perhaps collecting the bottom substrate (and by default some animals) with a lined oyster dredge could be artificially altering the number of animals in the trays. Dredge tows were conducted on each site until there were 11 liters of substrate to fill each of the two trays. On some sites, that only took 2 dredge tows, on others it took 4 or more tows to collect the 11 liters placed in each tray. It took more effort to collect fine sediments like sand or lose silt than it did cultch and oysters. Presumably, the fine sediments washed through the 3 mm mesh of the dredge, but large animals were retained in the mesh and included in the overall tray volume. In this manner increased dredge tows and effort on some sites may have added more animals to some trays before deployment, possibly biasing the post-deployment data. The results of the pre and post-deployment experiment seem to demonstrate that the dredge and bottom substrate collection methods were not artificially altering the density of fauna put in the trays. Fish and invertebrates may be attracted to the structure of the trays themselves, so tray catches may be higher. Since all trays are structurally identical, this bias should be similar.

There was a disparity between the interpretation of richness and rarefaction patterns. Boxplots demonstrated that there were no distinct differences between sites when plotted in context of number of species per tow. In contrast, the species accumulation curves showed obvious differences in overall richness. Sites rank in order

from least to greatest cumulative richness by the end of the sampling period. A likely explanation is that at any given time (each individual tray or trawl tow), there wasn't a high diversity of species, but over time, the differences in species richness become more clear.

A species' life history and ecology can be a strong determinant of where it is found within an estuary, or any other ecosystem. Behind Atlantic silversides, the most numerous species captured was the Atlantic croaker; most of which were young-of-the-year (YOY) and juveniles. By autumn, juvenile croakers in New Jersey waters are not yet 100 mm (Hare & Able 2007). The average size collected in this study was 48.7 mm TL with a minimum length of 10 mm and a maximum of 225 mm TL; thus, at least two year classes were present. They were found in greatest numbers on the low oyster density sites which had higher debris/sediment content than the other sites. Most of the sediment consisted of smooth, fine mud or sandy mud. This trend has been observed in other studies. For example, Miller *et al.* (2003) concluded that, in the deeper waters of the lower Delaware Bay, YOY croakers were most abundant over areas with mud sediments. Perhaps these observations reflect croaker feeding habitats. In a study of nearshore croaker near Beach Haven, NJ, nearly 70% of gut content consisted of poychaete worms and detritus (Vasslides & Able 2008).

Weakfish were the third most abundant fish collected in this study and, like croakers, most were juveniles. Based on similar comparisons, weakfish at age-1 are less than 200 mm TL (Able & Fahay 1998). The average total length of fish collected was 94.2 mm with a minimum of 10 mm and a maximum of 190 mm. According to Paperno *et al.* (2000), the heaviest recruitment of juvenile weakfish in the Delaware Bay occurs in

areas of less than 20 ppt salinity. The salinity range on site during this study was 11.7-19.5, which falls in the ideal range for optimal recruitment.

Black sea bass were found exclusively on H1 and H2 (high oyster density sites). Black sea bass are considered "reef fishes" attracted to structure (e.g. Steimle *et al.* 1999). In a study conducted on oyster shell plantings in Chincoteague Bay, Maryland, Arve (1960) reported the abundance of black sea bass captured in traps was much higher on planted areas than un-planted areas. Furthermore, Lehnert and Allen (2002) suggest subtidal shell bottom may be essential fish habitat for black sea bass based on their study in North Inlet Estuary, South Carolina. It is unclear whether the hard structure of the oysters themselves or the increase in prey (encrusting organisms, benthic invertebrates, small fish) utilizing the shells may have increased black sea bass abundance in Lehnert and Allen's study.

With only one mission completed with REMUS there were not enough data on the fish schools to make definitive conclusions about distribution or size (Fig. 15). Based on side scan sonar results from REMUS, the GBOREA consists of patchy hard substrate (shell and oysters) surrounded by well formed sand waves. In this somewhat new shallow water application, REMUS was a useful tool to map the bottom characteristics and shell coverage of the area. Unfortunately, logistical issues and weather precluded taking full advantage of this powerful tool.

Species composition with regards to the 14 most abundant trawl species and the 11 most abundant tray species was similar for all seven sites. However, the abundances of these species varied (greatly, for some species) among the bottom habitats. Differences in species abundances and diversity may be attributed to the habitat created by growing

oysters and thus, the benthic properties present at each site. The addition of spatted shell to the GBOREA resulted in a faunal community consistent with natural oyster habitat. Cumulative diversity of fish species was greatest at the enhancement site. Average species abundance and richness were, however, highest on sites of high oyster density.

Species diversity includes measures of both evenness (relative number of species) and richness (number of species in a community). Communities with a large number of species that are relatively evenly distributed are more diverse than communities with a few species that are dominated by one or two. One possible explanation for the increase in species diversity on the enhancement area is the intermediate disturbance hypothesis. The intermediate disturbance hypothesis described by Connell (1978) reasoned that the highest species diversity is present under conditions of intermediate disturbance. He proposed that in newly disturbed communities a few early colonizing organisms dominate; similarly after long periods without disturbance, competition occurs and a few dominant species prevail. In both cases, diversity is low. Diversity would therefore be greatest at intermediate points when several species had colonized a habitat but competitive exclusion had not yet taken place. Annual shell plantings disturb the GBOREA and thus, might have caused increased species diversity compared to undisturbed sites. Alternatively, the sites exhibited habitat variability which may have also played a role in the subtle differences observed. Variability, in the form of patchiness, was not measured in this study.

Overall, the enhancement area was intermediate to the other habitats in terms of oyster abundance and faunal utilization, and thus, it appeared to represent a transitional stage between degraded natural oyster habitat and high oyster density natural habitat.

Species richness and total abundance observed are summarized by the following: high oyster density reefs > GBOREA ≥ low oyster density reefs. This habitat utilization study demonstrated subtidal, cultch bottom, oyster enhancement efforts can (1) establish a living, multi-generational oyster reef (2) provide habitat and other ecosystem services to a diversity of animals (3) attract a similar faunal community as natural oyster reefs in the Delaware Bay.

Tolley and Volety (2005) compared residents collected in trays filled with either clean, articulated shell or live oyster clusters and found little evidence to conclude any of the fishes or decapod crustaceans found were solely selecting habitat with live oysters present (see also Brown *et al*. 2014). Live oysters don't necessarily need to be present to attract species; the addition of shell alone can add habitat value for many species (even if oyster recruitment is not successful over time). In regards to faunal utilization, planted shell can simultaneously perform several ecological roles such as providing nesting habitat, creating concealment from predators, providing substrate for encrusting organisms, as well as creating foraging habitat for juveniles and adults of mobile species (Lenihan *et al*. 2001, Coen *et al*. 2007).

Although the enhancement area did not rival or surpass the high oyster density areas in terms of species abundance, the efforts of Project PORTS were successful in providing habitat to the local ecosystem. The GBOREA did exhibit the highest species diversity, but excluding a few rare species, all sites shared the same overall faunal community. Because all of the sites sampled in this study were in relatively close proximity to each other (< 2 km distance measured parallel to shore), it is likely that there was connectivity and movement between them, resulting in similar communities.

Additionally, degraded habitats stressed from disturbances most likely require recovery time that extends beyond sampling rigor in many scientific studies (Bagett *et al.* 2014). Restoration efforts should include an ecosystem-wide view since the persistence of the desired species depends on the system's recruitment source, and furthermore, on the species interactions once the community is established (Palmer *et al.* 1997). With a recent surge in oyster restoration projects along the east coast, gaining a greater understanding of how small shell planting efforts impact the local faunal community have practical implications. Results from this study provide a valuable baseline for future restoration and enhancement efforts along the Delaware Bayshore.

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CHAPTER 2: Classroom Inquiry

ABSTRACT

Project PORTS: Promoting Oyster Restoration Through Schools is a unique environmental stewardship program that engages K-12 students in southern New Jersey in the restoration of critical oyster habitat in the Delaware Estuary. The program was developed in 2007 as an outreach initiative of the Haskin Shellfish Research Laboratory of Rutgers University to expand educational opportunities. Project PORTS' education program facilitates a series of learning activities that utilize the oyster as a vehicle to improve science literacy, acquaint school children with the Delaware Estuary, and promote stewardship.

The community-based restoration project, the core of Project PORTS, extends lessons from the classroom to a real-world application. Students construct shell bags that are deployed in the Bay to serve as cultch for oyster spat. Student-stewards have constructed 14,000 shell bags supporting the placement of more than 20 million oysters on a 5-acre oyster reef at the Gandy's Beach Oyster Restoration Enhancement Area (GBOREA).

In 2013 we compared the diversity and abundance of resident fishes, transient fishes and benthic macroinvertebrates on the GBOREA with nearby habitats. Data from that study were converted into a classroom activity entitled Activity 3.7: "*One fish, Two Fish- Assessing Habitat Value of Restored Oyster Reefs*". The activity was geared towards grades 6-10 and taught students to define habitat restoration, graph and interpret data and describe how species abundances might change in different environments.

Assessments including a learning task were administered to a group of students (n=21) grades 6-8 pre and post-participation in the activity. Students made strong gains in knowledge of oyster ecology and improved analytical skills by graphing data. Utilizing data from a relatable research study to initiate problem-based learning and review complex ecological concepts improved science and math literacy in middle school students.

INTRODUCTION

In addition to conducting relevant research, communicating science to the public is an important function of a scientist (e.g. Tocci 1986). Youth are often the target public audience for outreach efforts. How can communicators effectively disseminate scientific information to children, both inside and outside of the classroom? Best practices suggest a combination of knowledge integration and learning environment (e.g. Zimmerman 2005), use of technology in the classroom (Neiss 2005) or inclusion of real-world applications (Fortus *et al.* 2005). The overall goal of this study was to convert data collected in a scientific study into a classroom activity. Two study tasks followed that goal: implement the activity at a local school, demonstrate the activity is teaching students targeted information and meets national science standards.

In order to investigate how real-world scientific research can be transformed for use in classrooms, this study employed a newly developed activity that used actual experimental data and a local theme, to promote data interpretation skills and science literacy in middle school students. Transforming experimental data from a study into a tool to teach K-12 students about key concepts in science and mathematics provides real-

world scientific practices in the classroom; an important feature in relevant science standards (e.g., NGSS 2013). Pertinent, relatable material delivered to students for application to science topics, has proven to be beneficial for learning (Fortus *et al*. 2005, Nicosia *et al*. 2014).

Using scientific research as a teaching tool in the classroom to improve learning was introduced several decades ago (Schwab 1962) and still has contemporary validation (e.g. Nicosia *et al*. 2014). In his classic essay entitled, "The Teaching of Science as Enquiry", Schwab (1962) described a number of potential instructional approaches that included organizing laboratory investigations to deliberately demonstrate the difficulties involved in making sense of raw data to students. Schwab also advocated the use of scientific papers in the classroom to provide students with instances of valid research questions that yielded scientific knowledge (Rudolph 2011). Below I will introduce a classroom intervention and then discuss evidence for learning gains following this intervention.

The intervention

Our model for introducing "real-world" science in the classroom is Project PORTS: *Promoting Oyster Restoration Though Schools*; developed by Lisa Calvo at the Haskin Shellfish Research Laboratory, Rutgers University in 2007. The goals of Project PORTS are: (1) increase awareness and understanding of the oyster as a cornerstone species and a significant natural resource of the Delaware Bay; (2) to promote an understanding of important scientific concepts and stewardship values; (3) to enhance Delaware Bay oyster habitat; and (4) to evaluate success and natural value of enhanced

oyster reef habitat (Calvo 2008). These goals continue to be pursued through a series of activities including community-based oyster habitat enhancement efforts, habitat assessments (e.g. see Chapter 1: A Field Study), and school enrichment programs. The Project PORTS education program facilitates a series of learning activities that utilize the oyster as a vehicle to improve science literacy, acquaint school children with the Delaware Estuary, and promote stewardship.

Most Project PORTS school enrichment programs are led by Rutgers University scientists in the classroom. The school enrichment programs vary in delivery and scope, but usually include at least one in-class activity led by scientists and followed by a complementary shell bagging event. Teachers are encouraged to present students with additional activities provided in the Project PORTS Curriculum and Activity Guide (Calvo 2008) to build on the initial introduction delivered by the program. All lessons are designed to address and supplement current national and state curriculum standards, including the Next Generation Science Standards (NGSS 2013) and the former, but still widely used, New Jersey Core Curriculum Content Standards in Social Studies (NJ Dept. of Education 2014).

The Project PORTS Curriculum Guide offers a suite of cross-curricular activities and is divided into three main chapters: (1) the Delaware Estuary, (2) the history of the Delaware Bay oyster fishery, and (3) oyster biology and ecology. Each chapter begins with a primer that presents background information for the educator. The primer is followed by a series of classroom oriented activities and lessons (Calvo 2008). Copy-ready student worksheets are printed at the end of each chapter. Frequently requested

classroom activities include, a Delaware Estuary mapping scavenger hunt, oyster dissection, and an experiment to demonstrate filter feeding in bivalves.

The culminating event to the classroom programs is building shell bags. For this activity students construct shell bags that are subsequently deployed in the Bay to serve as cultch for oyster spat. Whole and fragmented surf clam shells are delivered to the school yards where 7/8 inch mesh bags are filled by students. The bags are assembled to hold about 11 liters of shell. The bags are then deployed onto the intertidal sand flats in Delaware Bay (near Green Creek, NJ) with the help of community volunteers. Shell bags are delivered by a barge at high tide and subsequently redistributed into piles of four bags on the sand bars at low tide in mid-summer.

Forty 5th grade students from a Project PORTS partner school came out into the field and assisted in redistributing the bags this past deployment in 2014. At the end of the summer the bags are collected, again with the help of about 30 community volunteers, and moved up-bay to the Gandy's Beach Oyster Restoration Enhancement Area (GBOREA) and offloaded by a commercial waterman. Through this process, students have constructed 14,000 shell bags supporting the restoration of more than 20 million oysters on a 5-acre oyster reef at the GBOREA since 2007. Engagement of students in the field activity is limited by timing, funding and other logistical constraints; however, students have been engaged on several occasions as mentioned above.

Utilizing the school enrichment programs and the oyster habitat enhancement efforts that Project PORTS delivers, I designed a classroom activity that included data from a scientific study that I lead to exhibit a real-world connection in the classroom. Termed *One Fish, Two Fish- Assessing Habitat Value of Restored Oyster Reefs*, this

activity is printed in the Project PORTS Curriculum and Activity Guide as Activity 3.7 (Appendix A). The goals of the activity are to: introduce students to ecological restoration, acquaint them with common Delaware Bay oyster reef inhabitants, graph and interpret data from a local scientific study. Below I describe a small study aimed at evaluating student learning gains as a result of participating in this activity.

MATERIALS AND METHODS

Project PORTS Activity 3.7*: One Fish, Two Fish- Assessing Habitat Value of Restored Oyster Reefs* was conducted with three groups of students from a public middle school in Cumberland County, New Jersey on 21 July 2014. The students, grades 6-8th, were participating in the 21st Century Community Learning Centers summer Program funded by the Cumberland County Empowerment Zone Corporation. In an effort to quantify potential impacts of the activity, students were asked to complete assessments before and after their participation. The time-frame to complete a pre-activity assessment and Activity 3.7 was one 40 minute session. The criterion-referenced assessments administered were summative surveys that consisted of four multiple choice questions, one true/false question, and two performance tasks (Fig. 17). The assessment was designed to measure student performance and learning progress against a fixed set of activity objectives (outlined in Activity 3.7, see Appendix A).

Criterion-referenced tests are the most widely used type of test in American public education (Abbott 2014). The first task prompted students to read a data table of tree abundances from different habitat types and draw a bar graph of one species' abundance across the three habitat types. The accompanying short answer question, asked

"based on your graph, what is one conclusion you can make about the species you chose?" The final performance task focused on data interpretation using a provided graph about tree seedling growth.

Students worked independently on the assessment and it was collected immediately after completion. Afterwards, the students were shown a brief power point presentation that provided a basic overview of oyster ecology and oyster reef inhabitants before the formal activity began. Each student was then given paper copies of the handouts from the Curriculum Guide (Figs. 18a and 18b). Instructions were presented for each task in the activity and students worked independently and in small groups to complete them. Calculators were provided for the mathematical calculations needed to compute the diversity indices. At the end of the activity, the short answer questions located on the back of the hand-out were discussed (Figs. 18a and 18b). The students also had the opportunity to ask questions about the information covered in the introductory presentation or activity during and after the session. The same assessment was administered again on 24 July 2014 post-participation in the activity. Students worked on the follow-up assessment independently and it was collected immediately upon completion.

Each pre and post-activity assessment was scored from 0 to 13 points using a rubric. The rubric score included the number of correct multiple choice/true false questions and completeness in understanding the performance tasks (Fig. 19). For example, for question 7a which prompted students to create a bar graph, the rubric included accuracy of drawn bars and overall completeness of graph using data presented in the in the score. The null hypothesis was that pre-Activity 3.7 assessment scores were

equal to post-Activity 3.7 assessment scores. In other words, there would be no effect of the activity on knowledge targeted in the assessment.

DATA ANALYSIS

A dependant, two-tailed t-test was performed on assessment scores from each student that took both the pre and post-activity assessment (n=21). Dependent sample t-tests for correlated means are appropriate if each of the two samples can be paired on a particular characteristic. In this study, the same student offers two assessment scores. Given an alpha level of 0.05, when a calculated t-value is larger than the critical t-value, for dependant samples, the null hypothesis will be rejected.

Similar to that of Nicosia *et al*. (2014), ANOVA tests were performed on each category of the pre and post-activity assessments (Fig. 17). The categories defined were: ecology multiple choice questions (question #2-6), create bar graph (questions #7a-b) and interpret line graph (questions #8a-b). Both the dependent samples t-test and ANOVA assume normal distribution. The assumption of normality was examined with a Shapiro-Wilks test for normality.

RESULTS

Twenty nine students took the pre-activity assessment and 24 students took the post-activity assessment, but only 21 students participated in both and the entire activity. Therefore, only those 21 student scores were included in the analyses. The Shapiro-Wilks test conducted on the pre and post-activity scores indicated that the data were normally distributed (pre-activity scores $p = 0.6569$, post-activity scores $p = 0.0739$). Based on the

assessments completed by the participating students and the results of the t-test, Project PORTS Activity 3.7 positively affected student assessment scores, $t=5.342$, $\alpha < 0.05$. Pre-activity assessment scores across all grades (6-8) ranged from 1 to 13 and had an average of 7.17 (SD=3.28). The highest possible total assessment score was a 13. Post-activity assessment scores across all grades ranged from 5 to 13 and had an average of 10.02 (SD=2.4). (Fig. 20).

Scores from pre and post-activity assessments were statistically significant (Table 10). Mean scores were greater for the ecology multiple choice questions ($p = 0.011$) and creating the bar graph task ($p = 0.009$) after participation in Activity 3.7 (Table 10). Post-activity scores of the line graph interpretation task were greater than the pre-activity scores, however, that difference was not statistically significant ($p > 0.286$) (Table 10). The highest possible score for the line graph task was a 2.

DISCUSSION

Activity 3.7*: One Fish, Two Fish- Assessing Habitat Value of Restored Oyster Reefs* significantly improved students' assessment scores. Therefore, students learned targeted information in the areas of oyster biology, restoration ecology and graphing. These results have implications for designing science lessons to include authentic research information for enhanced science literacy and data interpretation skills. It is likely that multiple sessions would have been more effective than a single session in teaching students basic methods for data interpretation and then successfully applying those methods to new, unfamiliar data. Multiple classroom sessions to help reinforce the

newly introduced information might have yielded more drastic results and potentially aid in information retention, which was not studied in this experiment.

Elements of Activity 3.7 are closely aligned with problem-based learning theory. Problem-based learning (PBL) is an instructional method that facilitates problem solving to teach targeted concepts (Hmelo-Silver 2004). Most problems the students attempt to solve do not have a sole correct answer. The application of the students' knowledge to attempt to solve the complex problem and reflection on lessons learned is the focus of PBL (Hmelo-Silver 2004). Determining community composition on restored habitats is a difficult task with complicated interpretation. There is no one correct answer or solution that stays constant through time. Students worked in small collaborative groups to apply a provided equation and basic knowledge about a research project to work on a real-world problem. According to Hmelo-Silver, developing flexible knowledge involves integrating information across multiple disciplines. In this case, some of those disciplines were algebra, ecology and biology. Students were engaged in a learning experience organized around the examination, explanation and outcomes of a locally relevant problem. Traditional science teaching has tended to exclude students who need to learn from contexts that are authentic, graspable and meaningful (Kolodner *et al.* 2003).

IMPLICATIONS

Goals of the activity were achieved through the single classroom session, but could certainly be enhanced with additional teacher directed follow-up activities and discussion. Few teachers have had firsthand experiences with scientific research or contact with professional scientists until collaborating with Project PORTS. Science is

often an impersonal activity to teachers "which poses a challenge to developing, and indeed teaching, ideas about the nature of science" (Hanuscin and Lee 2007). Activity 3.7 and the program as a whole may help to bridge such gaps by identifying science happening in the local community and giving students a more familiar frame of reference. Lemke (1990) recommends that educators emphasize that science consists of real activities being conducted by real human beings, perhaps most sincerely conveyed when the educators are scientists themselves. Contrary to the stereotypical lab coat clad male scientist with crazy hair and bubbling test tubes in hand, the personal characteristics of local scientists, with which students can identify, are gleaned by students from participation in Project PORTS.

By teaming with educators, Project PORTS brings together content knowledge and classroom experience in a developmentally appropriate curriculum. This study demonstrated that a novel education program with a local, real-world connection can expand participating students STEM knowledge in alliance with national science priorities. *National efforts including those lead by The American Association for the Advancement of Science (AAAS) released Benchmarks for Science Literacy that noted students in grades 6-8 should be helping in data analysis and preparing tables and graphs (AAAS 2009). This activity supported those benchmarks and more largely, Project PORTS also enhances the Association's goals to foster education in science and science careers. By interacting with Project PORTS scientists, students learn that scientists' interests, careers and appearances are widely diverse.*

President Obama declared Science, Technology Engineering and Math (STEM) education a national priority for the next decade. He identified three overarching

priorities, including; increasing STEM literacy so all students can thinking critically in science, technology, engineering and mathematics (Metheny 2009). The objectives of Activity 3.7 and more largely, Project PORTS, are in alignment with STEM national priorities and I therefore recommend that scientists increase their engagement with teachers to design activities based on authentic science.

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Table 1. Number of oyster seed on shell and estimated volume of shell planted at the GBOREA, plots 1, 2 and 3 from 2007-2014 (Lisa Calvo, unpublished work)

	GBOREA-1		**GBOREA-2**		**GBOREA-3**	
	Seed count	**Shell volume***	**Seed count**	**Shell volume***	**Seed count**	**Shell volume***
2007	2,320,500	4,000				
2008			17,300,000**	11,000		
2009	1,375,000	1,500				
2010			3,625,200	4,000		
2011	2,018,415	5,200				
2012					2,528,000	10,000
2013					182,400	6,000
2014					200,000	4,000
TOTAL	**5,713,915**	**10,700**	**20,925,200**	**15,000**	**2,962,400**	**20,000**

*Shell volume measured in NJ bushels (equal to a standard US bushel) which is 37 "liquid" quarts = 35.24 L = 2150 in^3

**Spat number includes approximately 15,000,000 microscopic individuals that set just prior to transplant. No other counts included microscopic analysis.

Table 2. Trawl and tray sampling dates with corresponding temperatures (°C) and salinities (ppt). Temperature and salinities for the trays reflect data collected at tray deployment.

Trawl date	Temperature	Salinity	Tray deployment	Tray retrieval	Temperature	Salinity
7.16.13	28.5	12.2	7.18.13	7.25.13	28.4	13.1
7.31.13	26.0	14.7				
8.15.13	23.4	17.8	8.2.13	8.12.13	25.5	15.6
8.23.13	25.2	16.1				
9.9.13	23.1	17.4	9.20.13	9.27.13	16.2	16.6
9.18.13	16.4	16.1				
10.16.13	18.3	19.5	10.4.13	10.14.13	15.6	18.9
10.28.13	13.0	17.7				
11.6.13	8.3	18.6	11.5.13	11.16.13	12.2	18.5
11.21.13	8.3	19.2				

Table 3. Results of the two-way ANOVA testing for differences in oyster abundance across locations, months and an interaction between location: month.

	Df	Sum Sq.	Mean Sq.	F value	Pr (>F)
location	6	24312	4052	17.656	1.39e-11***
month	4	289	72	0.314	0.867
location:month	24	8275	345	2.292	0.0124
residuals	35	5266	150		

Table 4. Sampling site designations and abbreviations based on oyster stock assessment nomenclature and results of post-hoc analyses (ANOVA and Tukey's HSD) For example, the sampling site located on Hawk's Nest 26 (bed and grid name used for NJ stock assessment) is a high oyster density site abbreviated by H1. Sites were compared as individuals as well as in the context of their post-hoc categories (high oyster density, GBOREA and low oyster density).

Sample locations*	Bottom type classification	Site abbreviation
Hawk's Nest 26	High oyster density	H1
Hawk's Nest 28		H2
GBOREA	GBOREA	GBOREA
Hog Shoal 18	Low oyster density	L1
Nantuxent 19		L2
Strawberry 23		L3
Strawberry 28		L4

* Except GBOREA, all names are based off of bed names and grid numbers designated for the New Jersey oyster stock assessment (Bushek and Ashton-Alcox 2013).

Table 5. Summary table of all catch collected in the benthic habitat trays. Data for each sampling displayed in terms of number of individuals as well as cumulative averages for each of the three habitat types.

Species	Common Name	H1	H2	High density average (n=2)	GBOREA (n=1)	L1	L2	L3	L4	Low density average (n=4)	Grand Total
Panopeus herbstii	Atlantic mud crab	154	145	149.5	128	164	82	100	61	101.75	834
Ilyanassa obsoleta	eastern mudsnail	21	8	14.5	4	53	12	57	166	72	321
Paleomonetes vulgaris	marsh grass shrimp	34	79	56.5	49	18	29	32	41	30	282
Rhithropanopeus harisii	estuarine mud crab	36	40	38	22	64	47	51	8	42.5	268
Panopeus sayi	Say mud crab	31	62	46.5	18	35	21	10	20	21.5	197
Paleomonetes pugio	daggerblade grass shrimp	4	25	14.5	27	15	12	7	21	13.75	111
Ischadium recurvum	hooked mussel	10	12	11	31	0	5	16	1	5.5	75
Gobiosoma bosci	naked goby	21	24	22.5	1	2	0	1	6	2.25	55
Geukensia demissa	ribbed mussel	1	1	1	1	0	8	8	0	4	19
Crepidula convexa	slipper snail	1	10	5.5	2	2	0	1	0	0.75	16
Opsanus tau	oyster toadfish	2	4	3	2	1	1	0	2	1	12
Mulinia literalis	dwarf surf clam	0	0	0	0	4	0	0	3	1.75	7
Pagarus longicarpus	long-clawed hermit crab	0	0	0	0	0	0	4	1	1.25	5
Polinices duplicatus	shark eye moon snail	0	0	0	2	0	0	0	0	0	2
Urosalpinx cinerea	Atlantic oyster drill	1	0	0.5	0	1	0	0	0	0.25	2
Tellina agilis	northern dwarf tellin	0	0	0	0	0	0	0	2	0.5	2
Eurypanopeus depressus	flat back mud crab	0	1	0.5	0	0	0	0	0	0	1
Crangon septemspinosa	sand shrimp	1	0	0.5	0	0	0	0	0	0	1
Anguilla rostata	American eel	0	0	0	0	0	0	0	1	0.25	1
Grand total		317	411		287	359	217	287	333		**2211**

Table 6. Eigenvalues and correlations of species abundances for principal components 1-4 of the CCA conducted on tray catch.

	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**
Eigenvalues	0.0846	0.0674	0.0323	0.0121
Explained variation (cumulative)	4.72	8.49	10.30	10.97
Pseudo-canonical correlation	0.6021	0.6187	0.4839	0.3959
Explained fitted variation (cumulative)	43.05	77.37	93.82	100.00

Table 7. Catch summary of pre and post-deployment tray experiment conducted in November, 2013. The table values for pre-deployment samples (except for those from the GBOREA) and post-deployment values from November are actual counts. Post-deployment values representing collections from the entire study are averages.

	Number of animals collected			
	Pre-deployment November only	**Post-deployment November only**		**Post-deployment entire study***
H1	18	39	35	31.7
H2	20	37	34	41.1
GBOREA	26.7*	34	30	28.7
L1	41	48	96	35.9
L2	32	10	24	21.7
L3	4	14	42	28.7
L4	47	39	49	33.3

*average

Table 8. Summary table of all catch collected in the trawl. Data for each sampling displayed in terms of number of individuals as well as cumulative averages for each of the three habitat types (continued on the following page).

Species	Common Name	H1	H2	high oyster average (n=2)	GBOREA (n=1)	L1	L2	L3	L4	low oyster average (n=4)	Grand Total
Anchoa mitchili	bay anchovy	52	117	84.5	28	24	14	176	76	72.5	487
Micropogonias undulatus	Atlantic croaker	22	32	27	44	21	39	75	69	51	302
Cynoscion regalis	weakfish	45	41	43	22	3	17	31	43	23.5	202
Trinectes maculatus	hogchoker	3	21	12	27	16	24	15	48	25.75	154
Callinectes sapidus	blue crab	18	18	18	14	13	15	23	23	18.5	124
Opsanus tau	oyster toadfish	35	11	23	24	30	13	1	3	11.75	117
Morone americana	white perch	21	14	17.5	17	3	8	5	5	5.25	73
Menticirrhus saxatilis	northern kingfish	1	0	0.5	7	0	6	11	3	5	28
Bairdiella chrysoura	silver perch	9	3	6	6	1	6	0	0	1.75	25
Leiostomus xanthurus	spot	1	6	3.5	2	0	0	9	2	2.75	20
Pogonias cromis	black drum	4	4	4	1	0	4	3	0	1.75	16
Limulus polyphemus	horseshoe crab	2	2	2	0	3	5	0	0	2	12
Paralichthys dentatus	summer flounder	1	3	2	0	0	0	1	3	1	8
Chilomycterus schoepfi	striped burrfish	1	2	1.5	2	0	1	0	1	0.5	7
Centropristis striata	black sea bass	3	3	3	0	0	0	0	0	0	6
Alosa pseudoharengus	alewife	0	2	1	0	0	1	1	1	0.75	5
Brevortia tyrannus	Atlantic menhaden	1	1	1	0	0	0	0	1	0.25	3
Morone saxatilis	striped bass	1	0	0.5	1	0	1	0	0	0.25	3
Ophidion marginatum	striped cusk-eel	0	0	0	0	0	1	1	0	0.5	2
Syngnathus fuscus	northern pipefish	0	0	0	0	0	1	1	0	0.5	2
Prionotus carolinus	northern sea robin	1	0	0.5	0	0	0	1	0	0.25	2
Peprilus triacanthus	butterfish	0	1	0.5	0	0	0	1	0	0.25	2

Species	Common Name	H1	H2	high oyster average (n=2)	GBOREA (n=1)	L1	L2	L3	L4	low oyster average (n=4)	Grand Total
Mustelus canis	smooth dogfish	0	1	0.5	0	1	0	0	0	0.25	2
Libinia emarginata	spider crab	0	0	0	0	1	0	0	0	0.25	1
Astroscopus guttatus	northern stargazer	0	0	0	0	0	0	0	1	0.25	1
Malaclemys terrapin	diamondback terrapin	0	1	0.5	0	0	0	0	0	0	1
Gobiosoma bosci	naked goby	1	0	0.5	0	0	0	0	0	0	1
Penaeus aztecus	brown shrimp	0	0	0	0	0	0	0	1	0.25	1
Scophthalmus aquosus	windowpane flounder	0	1	0.5	0	0	0	0	0	0	1
Alosa mediocris	hickory shad	0	0	0	0	0	0	0	1	0.25	1
Grand Total		222	284		195	116	156	355	281		**1609**

Table 9. Eigenvalues and cumulative variation of species abundances for principal components 1-4 (axes 1-4) of PCA performed on trawl catch data. 19 of the 30 different species collected were included in the analysis.

Statistic	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**
Eigenvalues	0.3436	0.1666	0.1103	0.1062
Explained variation (cumulative)	34.36	51.02	62.05	72.67

Figure 10. ANOVA comparison of mean responses collected from student assessments pre and post-involvement in the Project PORTS activity.

	Pre mean (sd)	Post mean (sd)	df	F	P-value
Ecology multiple choice	2.76 (1.00)	3.71 (1.31)	1	7.04	0.011 *
Create bar graph	2.95 (2.38)	4.55 (1.22)	1	7.48	0.009 **
Interpret line graph	1.54 (0.81)	1.81 (0.60)	1	1.17	0.286

* Significant at the 0.05 level

** Significant at the 0.01 level

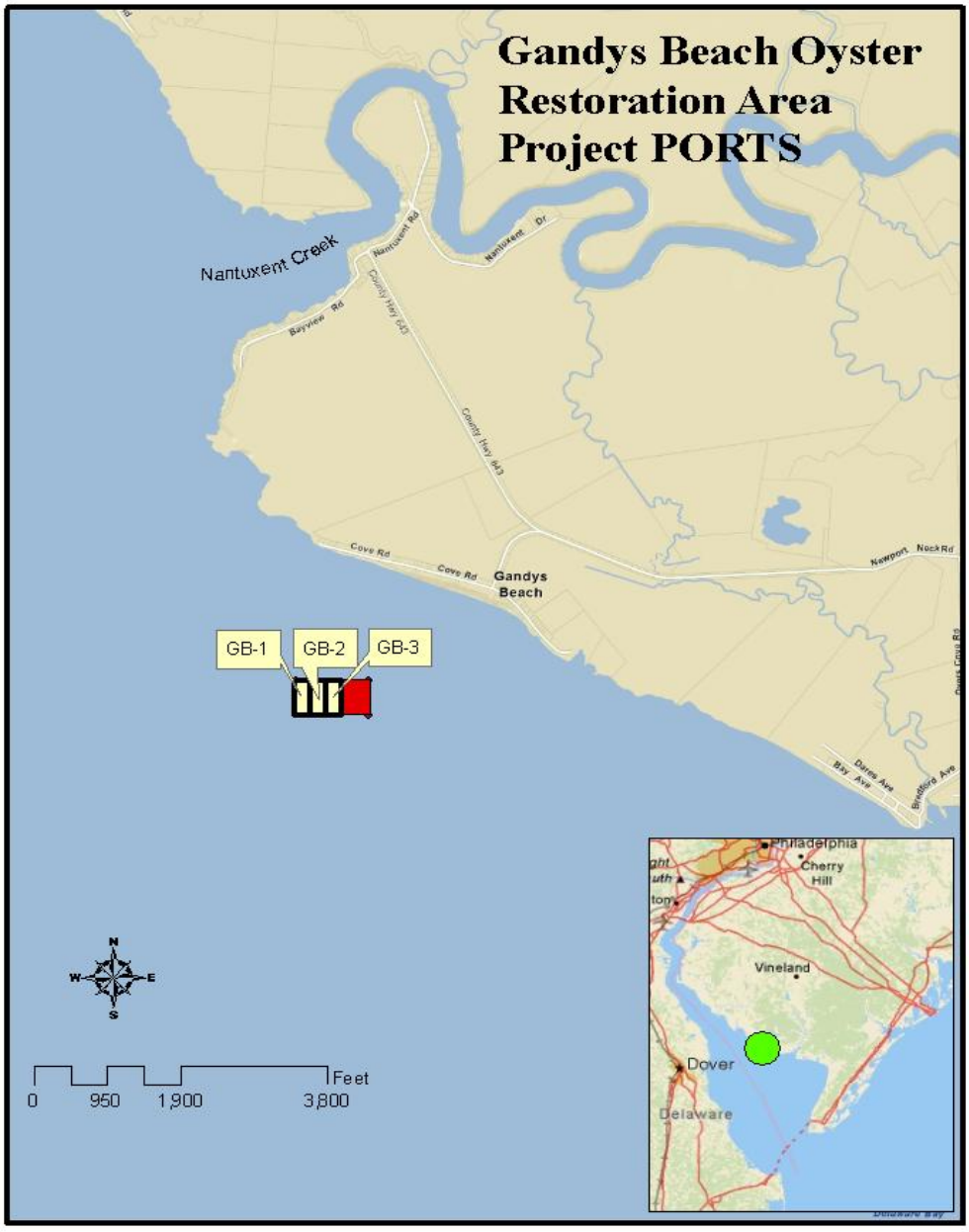


Fig. 1a. Map of the Gandy's Beach Oyster Restoration Enhancement Area (GBOREA) in Delaware Bay denoting each planted portion of the area (Figure credit: Lisa Calvo)

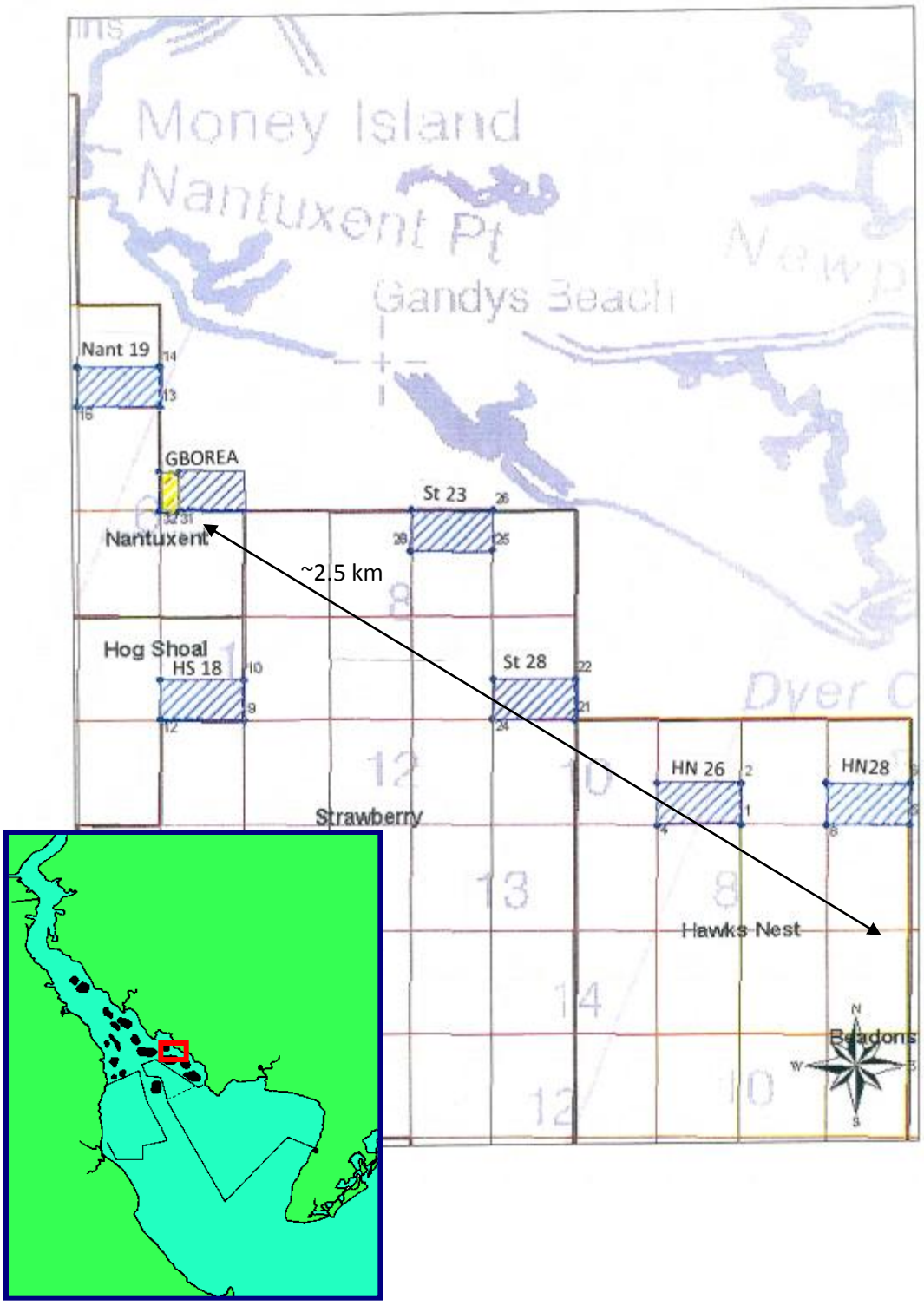


Fig. 1b. Map of the Gandy's Beach Oyster Restoration Enhancement Area (GBOREA) and the six other sampling sites in Delaware Bay. Each grid outlines is approximately 25 acres and each cross-shaded sampling site is approximately 8 acres. Site names are abbreviations of bed and grid names. Inset map: General location of the GBOREA relative to natural oyster beds (Map courtesy of: Craig Tomlin, NJDEP)

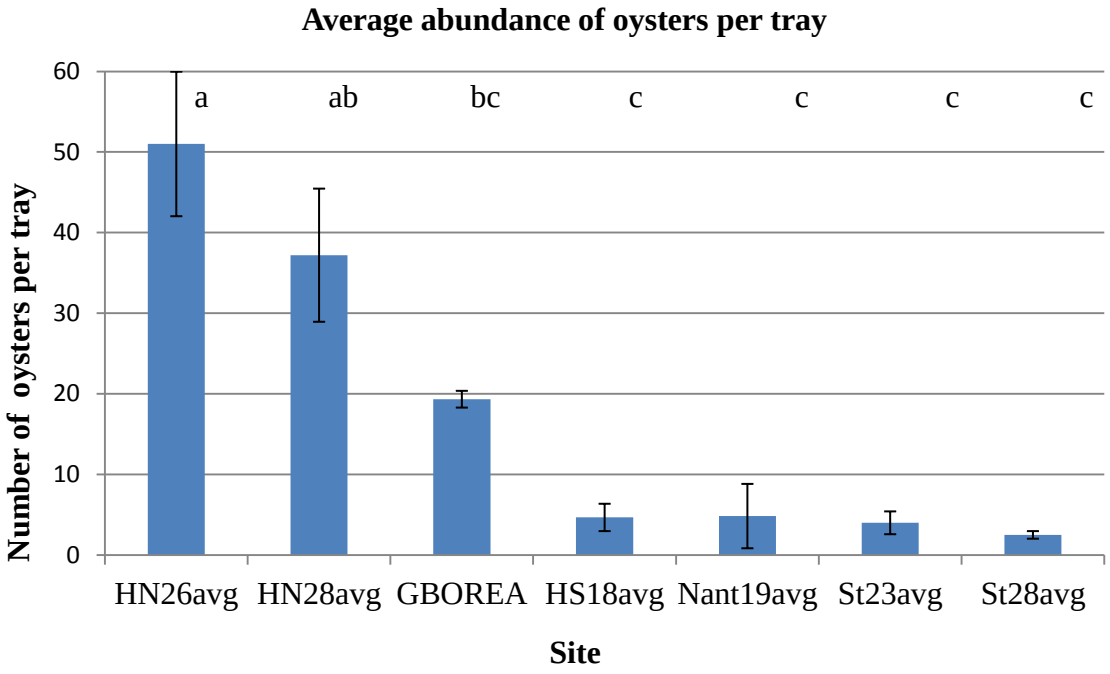


Fig. 2a. Bar plot of average count of oysters per benthic habitat tray across all seven sites. Data are means ± 1 SE from trays (0.36 m^2 x 9.5 cm, 11 liters of bottom material) N= 10 trays per site. Letters denote significant differences $P \leq 0.05$, Tukey's HSD. See table 3 for site name abbreviation descriptions ("avg" indicates average).

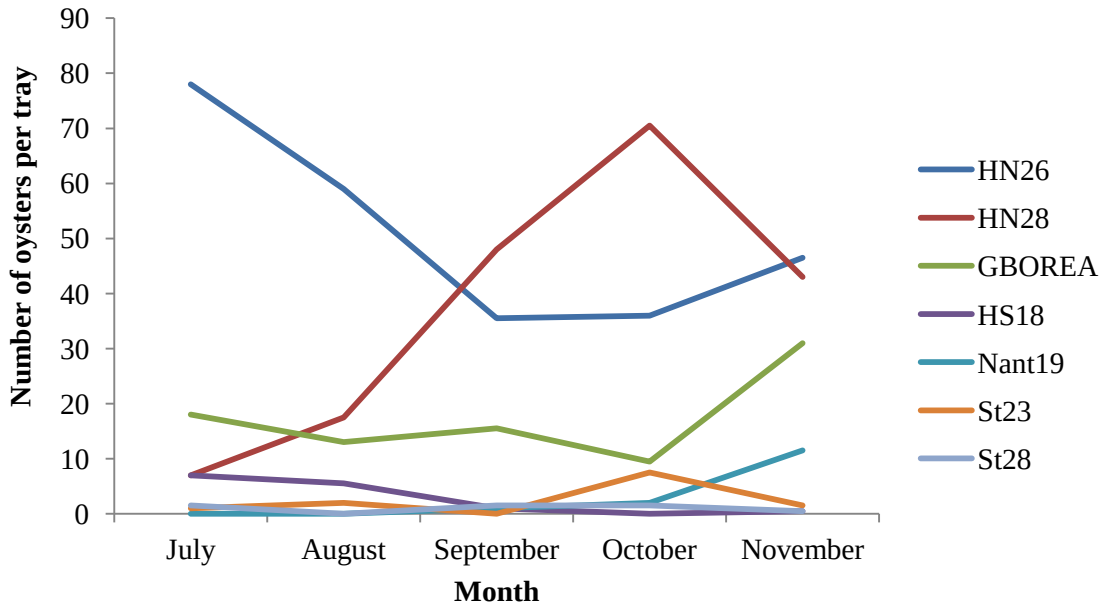


Fig. 2b. Average abundance of oysters per tray on each site over the sampling period showing the interaction between site and month. N= 2 trays per site per month. See table 3 for site name abbreviation descriptions.

Fig. 3. A benthic habitat tray (0.36 m^2 x 9.5 cm high) filled with substrate post-deployment. Weights are concrete cylinders zip-tied to the sides of the plastic, lined trays.

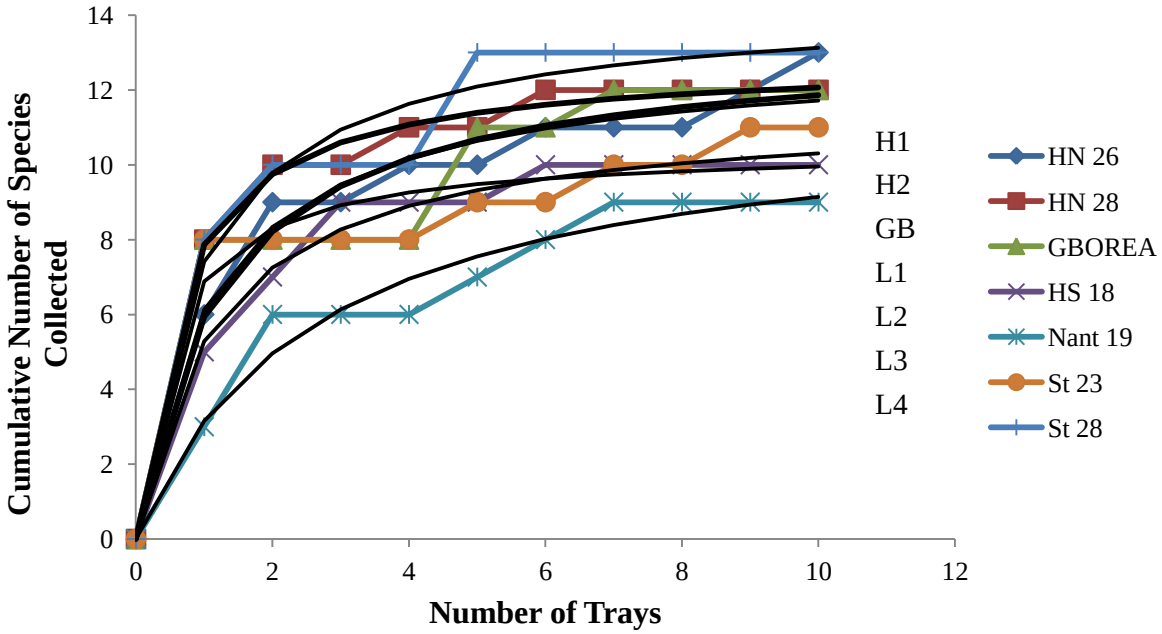


Fig. 4. Species accumulation curves of motile fauna collected in benthic habitat trays for each sampling location. Solid lines are the Michaelis-Menten model curves fit to the data for each site.

a. b.

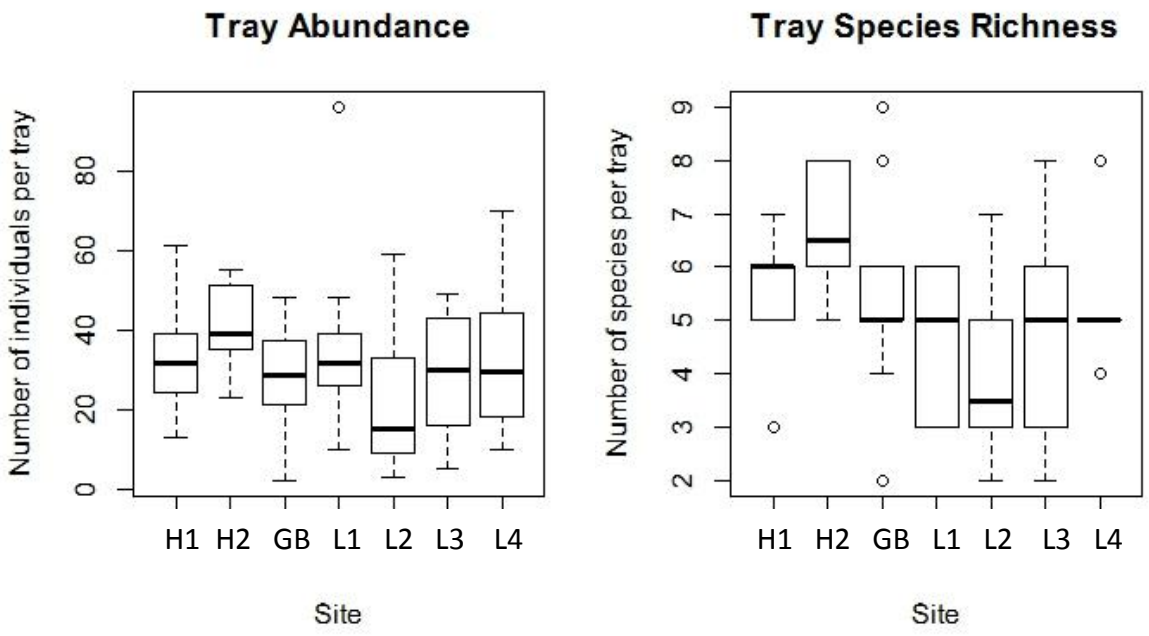
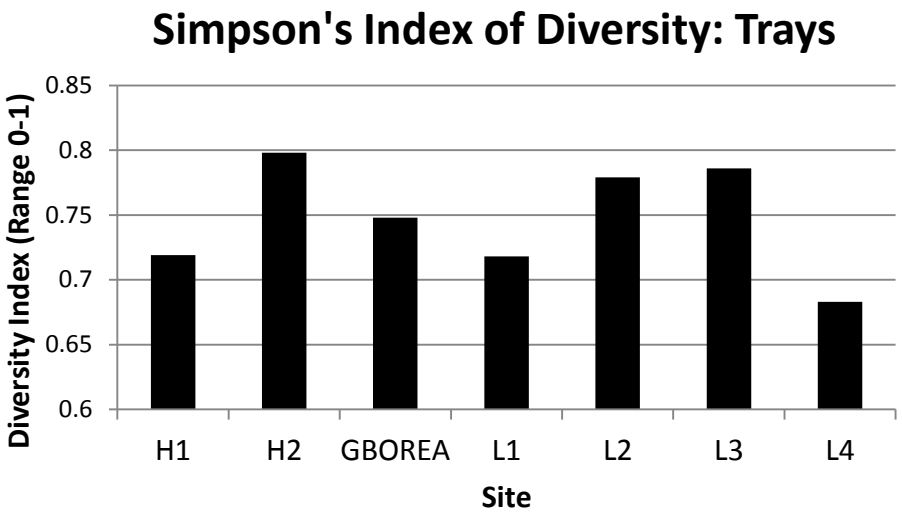


Fig. 5. Boxplots representing number of (a) individuals caught per tray (n = 10 trays/site) and (b) species richness in terms of number of species per tray. Thick black lines denote the median of the data set.

a.



b.

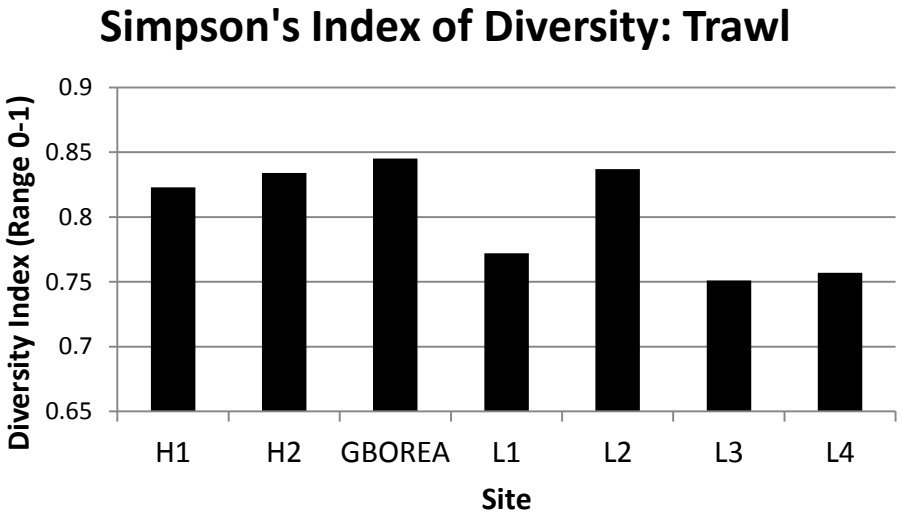


Fig. 6. Bar graphs of Simpson's Diversity Indices calculated from cumulative catch data. Scores are represented by D-1 and range from 0 to 1 for (a) cumulative tray data from the eleven most abundant species and (b) cumulative trawl data from the ten most abundant species, excluding *Anchoa mitchelli*. The closer the index values to 1, the greater the species diversity.

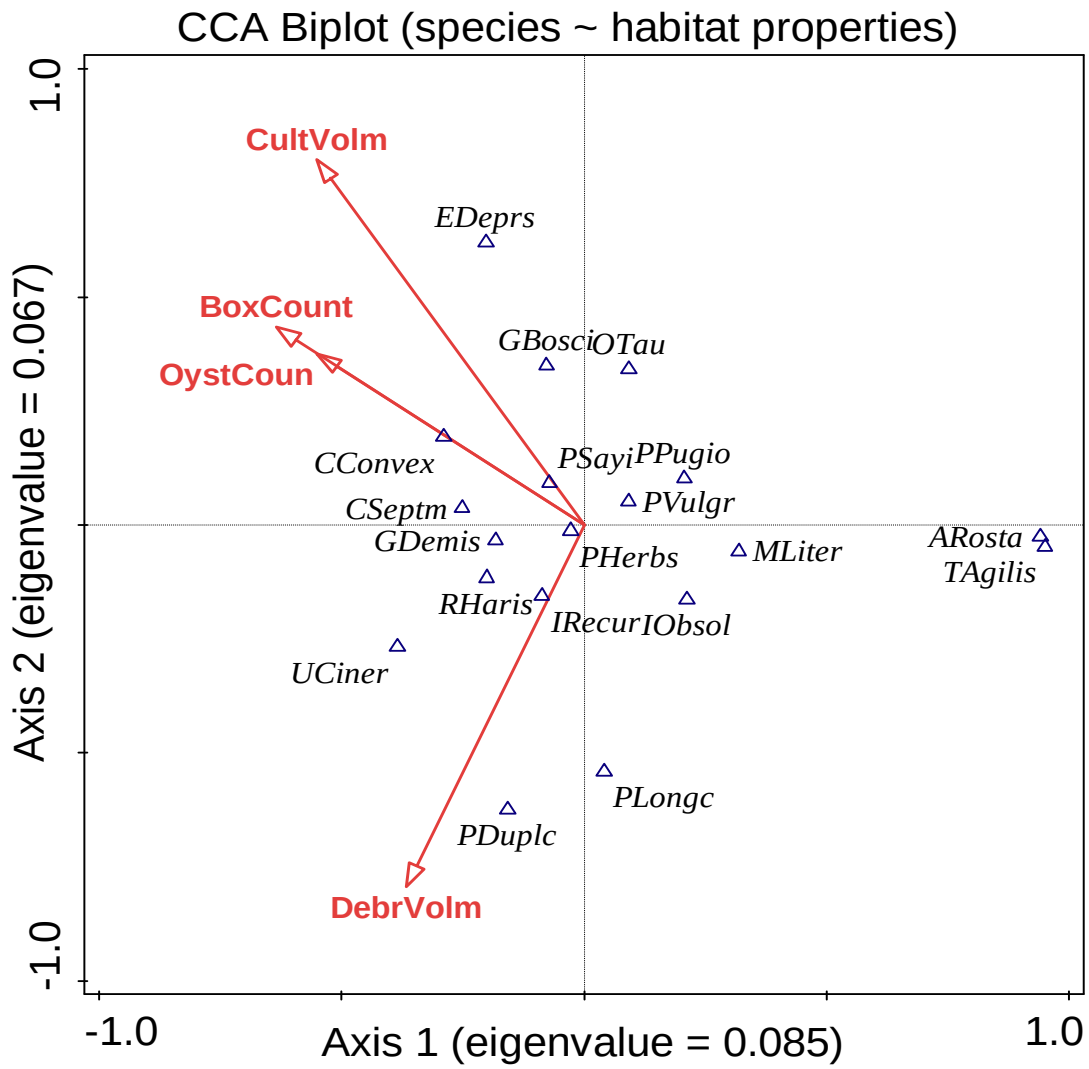


Fig. 7. Canonical Correspondence Analysis (CCA) bi-plot of bottom habitat properties (explanatory variables) and tray catch. Explanatory variables account for 11.0% of the variation exhibited in catch data. (P<0.005). Habitat properties are: DebrVolm(debris volume), OystCoun (number of oysters), BoxCount (number of boxes), CultVolm (cultch volume). See table 4 for full species names.

a.

b.

c.

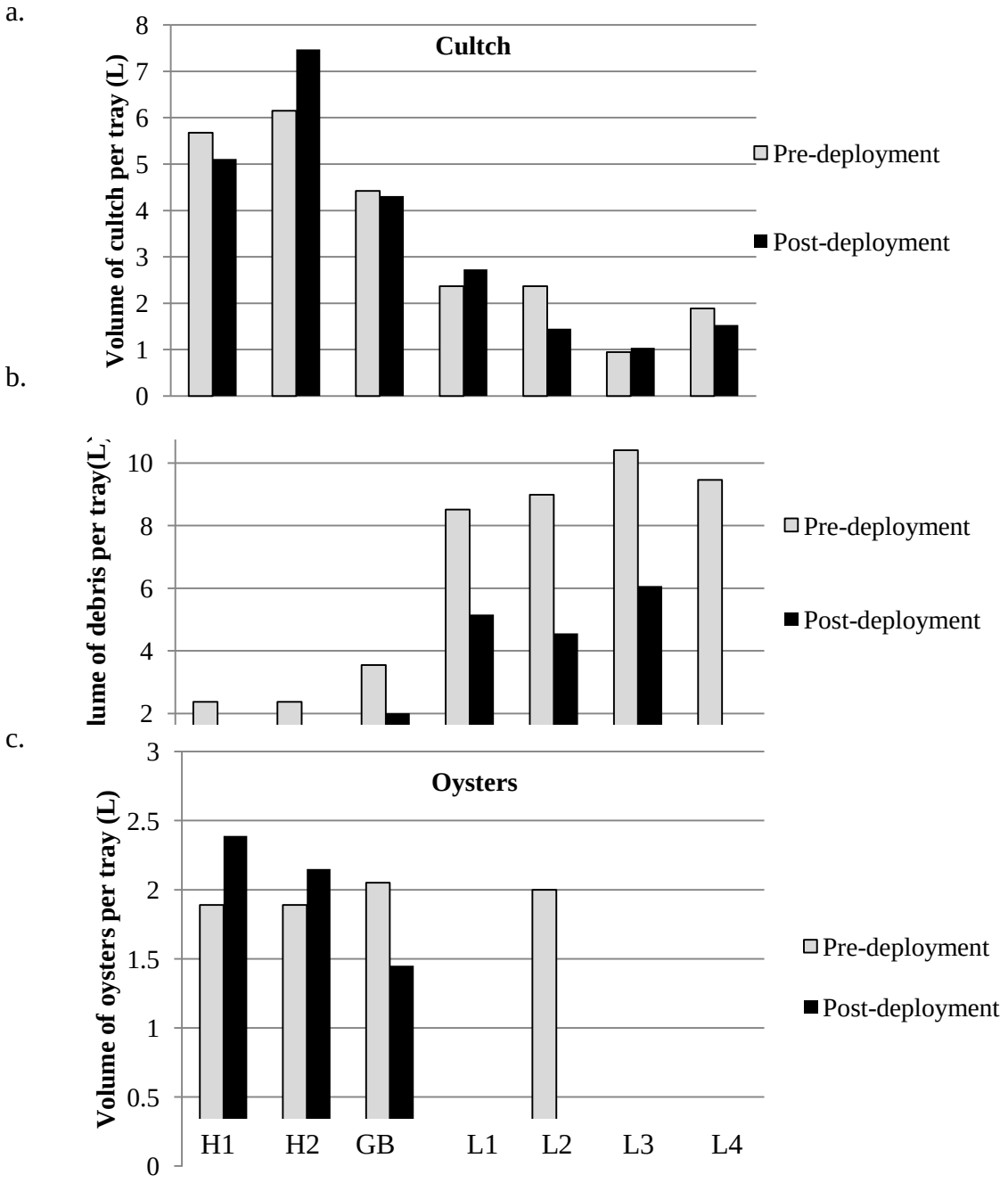


Fig.8. Bar graphs of pre and post-deployment tray contents from the November 2013 samples. Dark bars represent post-deployment results and light bars represent pre-deployment results. Each graph displays a different bottom habitat parameter: (a) volume of cultch, (b) volume of debris and (c) number of oysters.

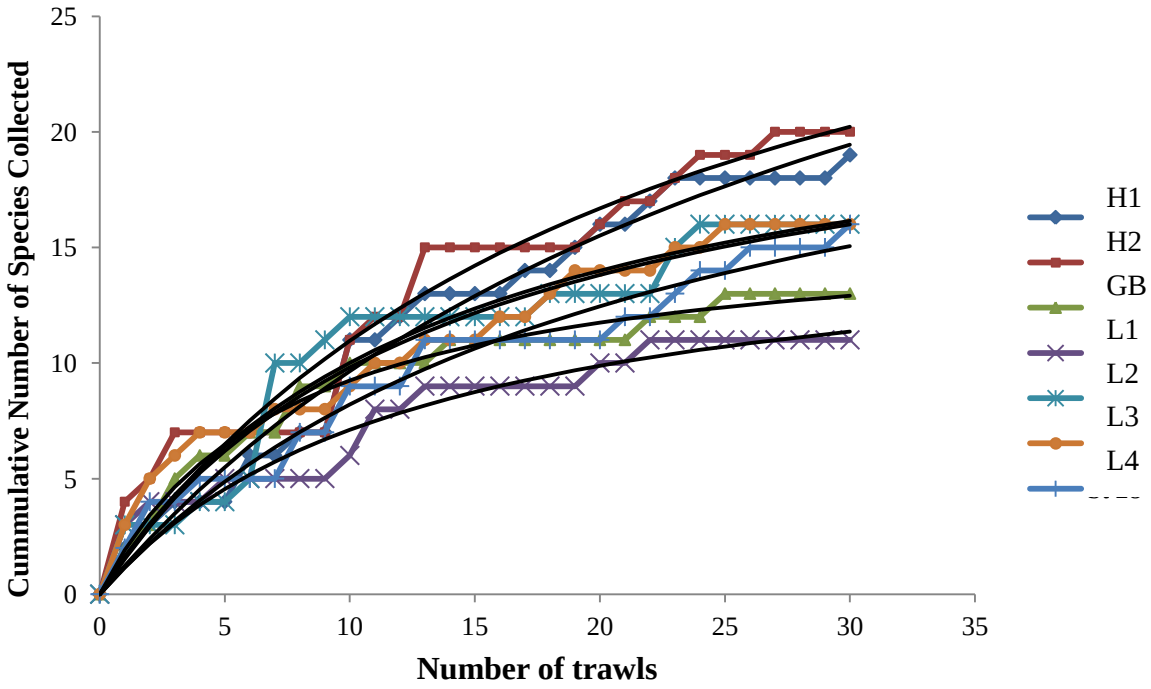


Fig. 9. Species accumulation curves of resident and transient fishes collected in the trawl for each sampling location. Solid lines are the Michaelis-Menten model curves fit to the data for each site.

a. b.

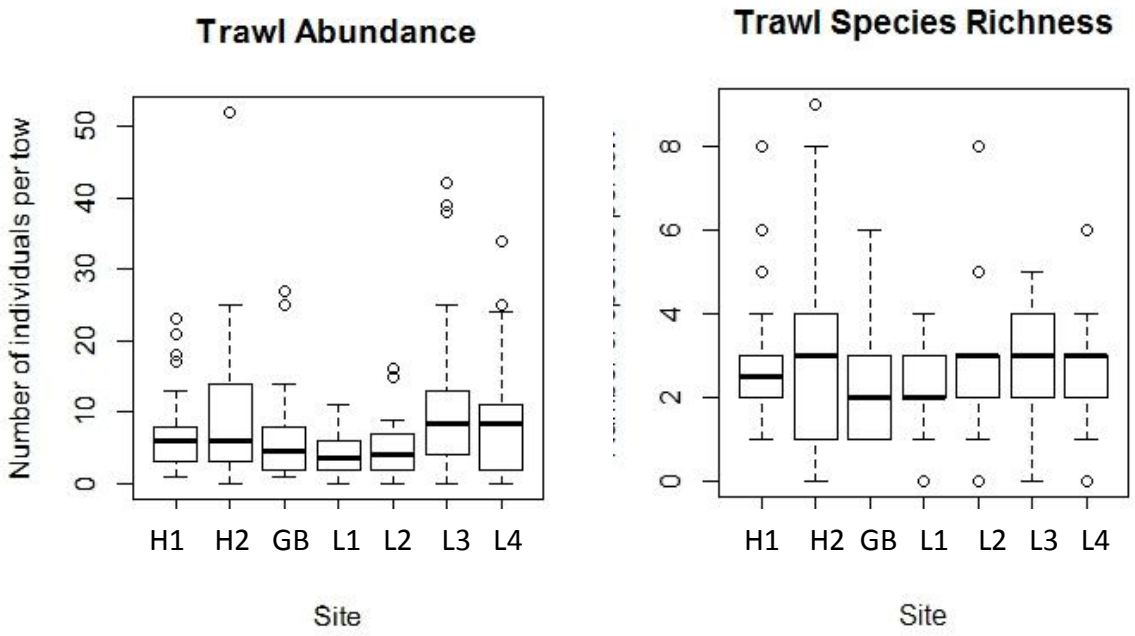


Fig.10. Boxplots representing number of (a) individuals caught per trawl tow (n=30 tows/site) and (b) species richness in terms of number of species per tow. Thick black lines denote the median of the data.

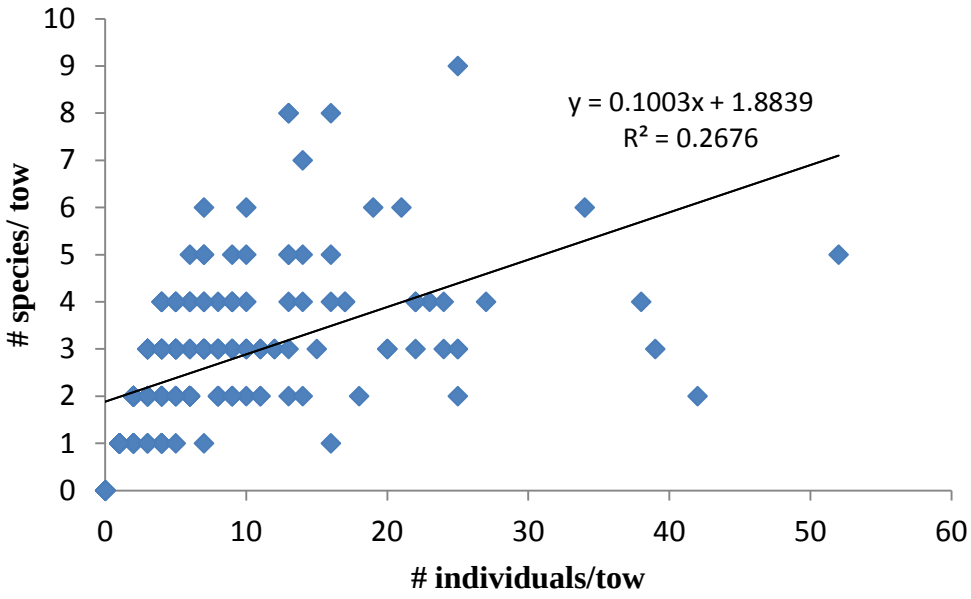


Fig. 11. Plot displaying number of individuals per tow against number of species per tow collected in the trawl. The trendline, line equation and R^2 value demonstrate the linear relationship.

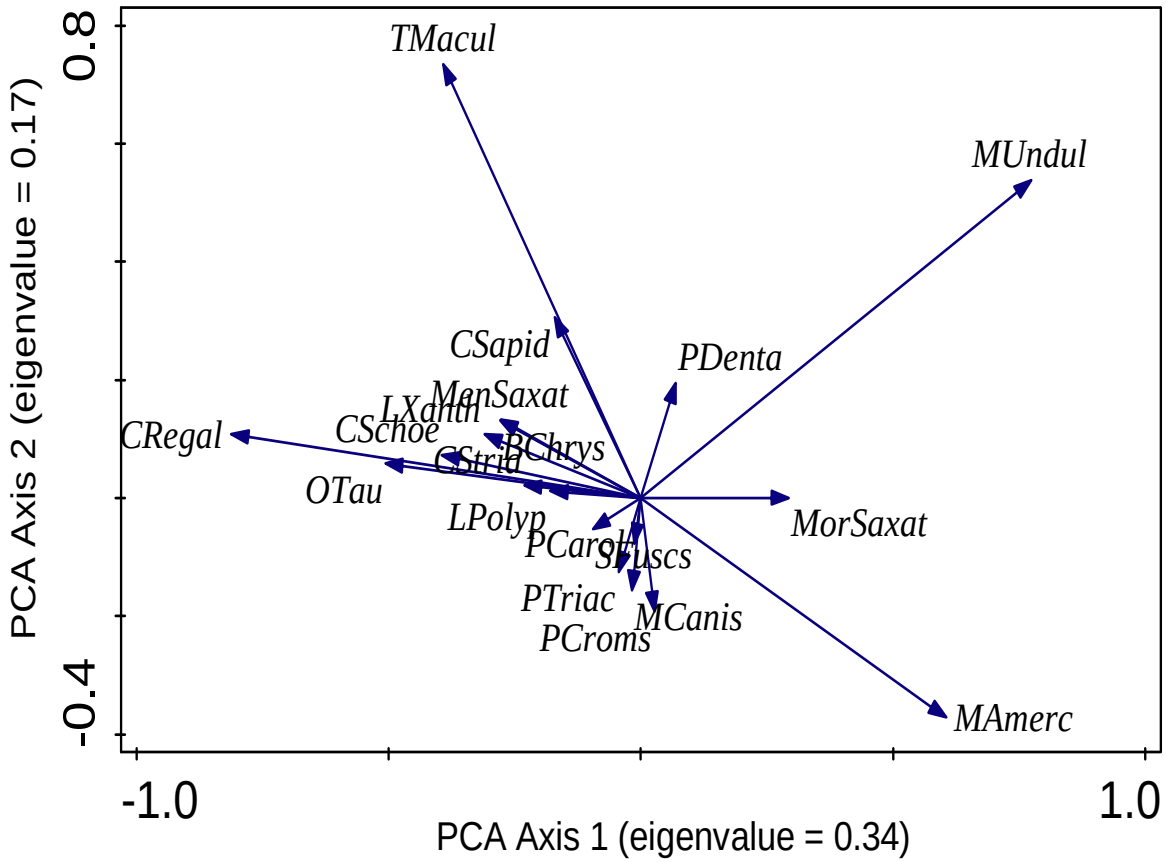


Fig. 12. Principle Component Analysis (PCA) bi-plot of species collected in the trawl. See table 7 for full species names. The distribution along PC1 was most distinct. Envelopes were drawn around data classified by location and the envelopes indicated that the observed fish communities occurred across all seven sites (envelopes not shown).

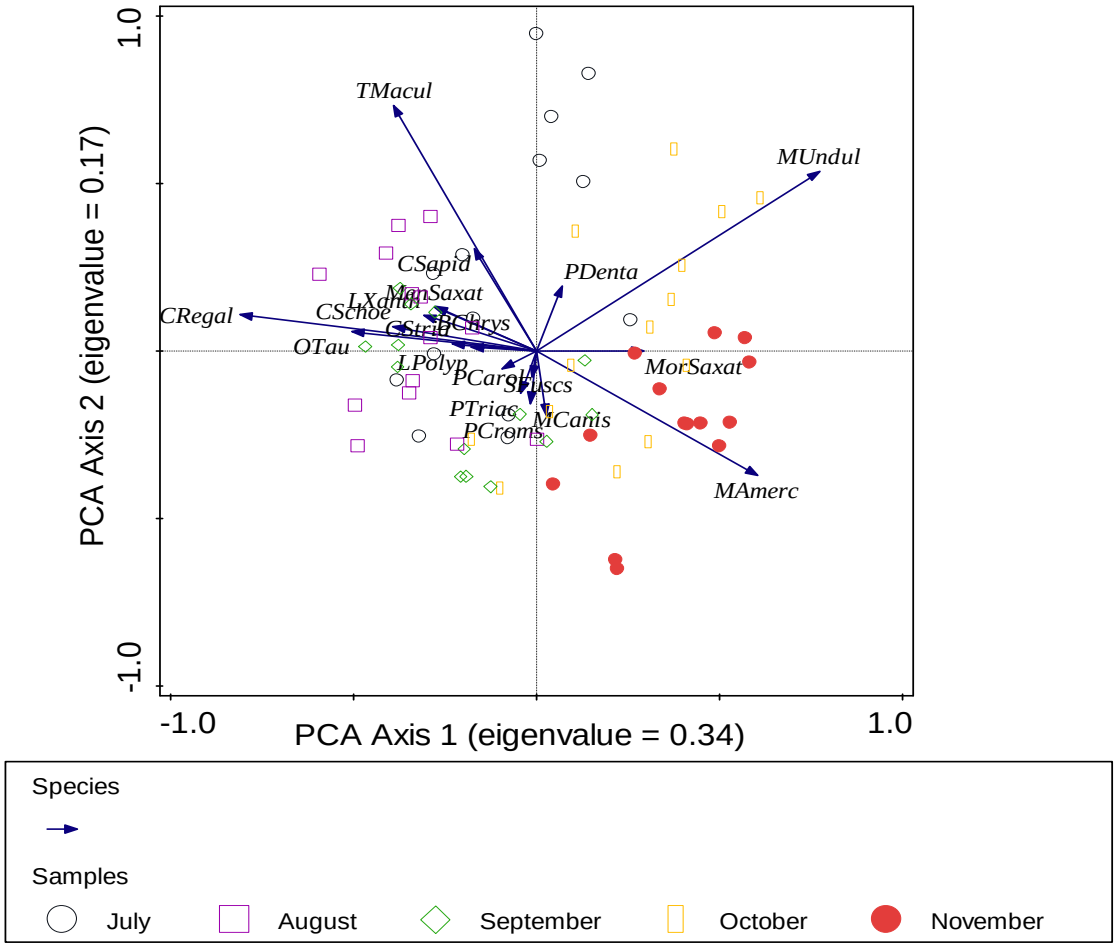


Fig. 13. PCA bipot of trawl catch with locations classified by month to view seasonality effects on species assemblages. See Table 7 for full species names.

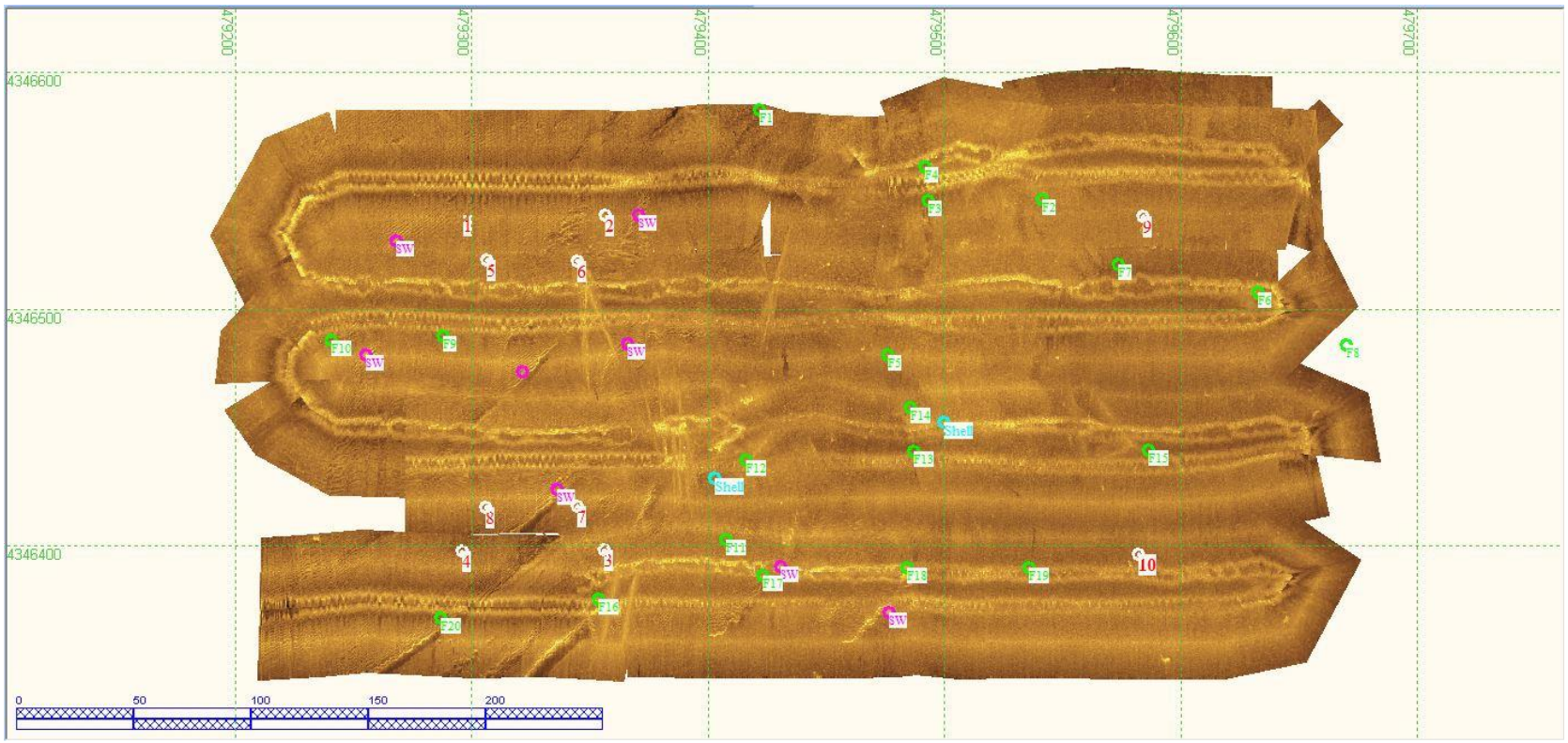


Fig. 14. Side scan sonar (600 kHz) mosaic of the GBOREA. Marked areas identify targets of either fish schools (F), clumps of hard substrate (Shell), and sand waves (SW). The points marked numerically represent the corners of planted areas. The nadir area has been cropped out of the mosaic. The grids are defined by NAD83/UTM zone 18N projections and each grid is 100m^2. The scale bar on the bottom left hand corner is in meters.

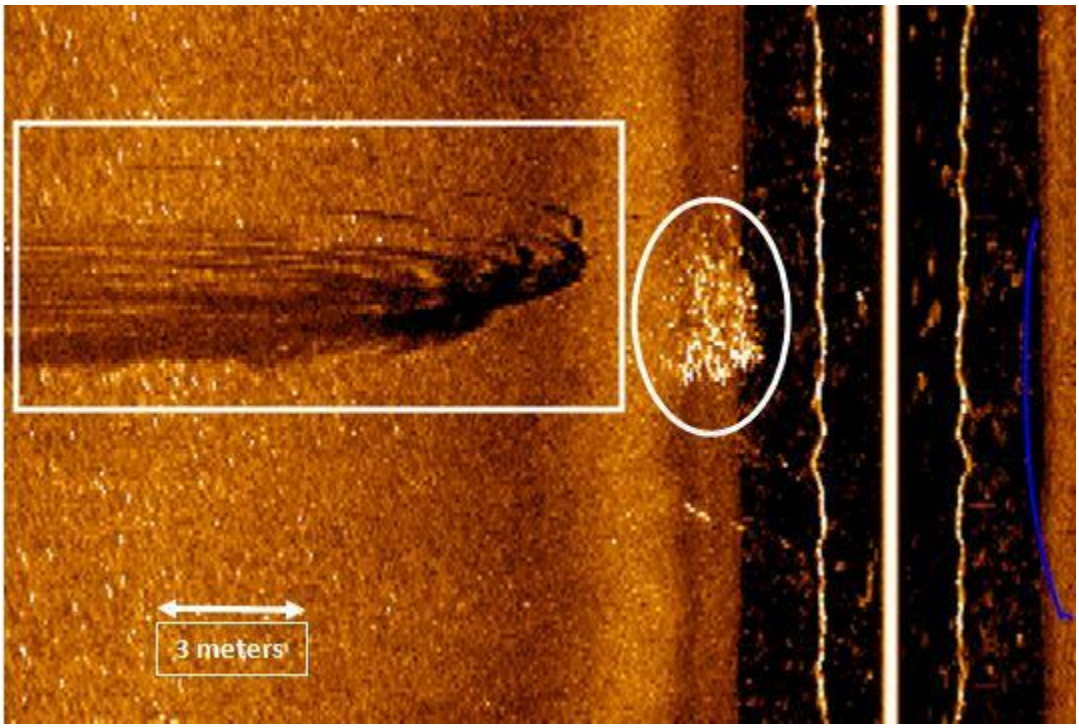
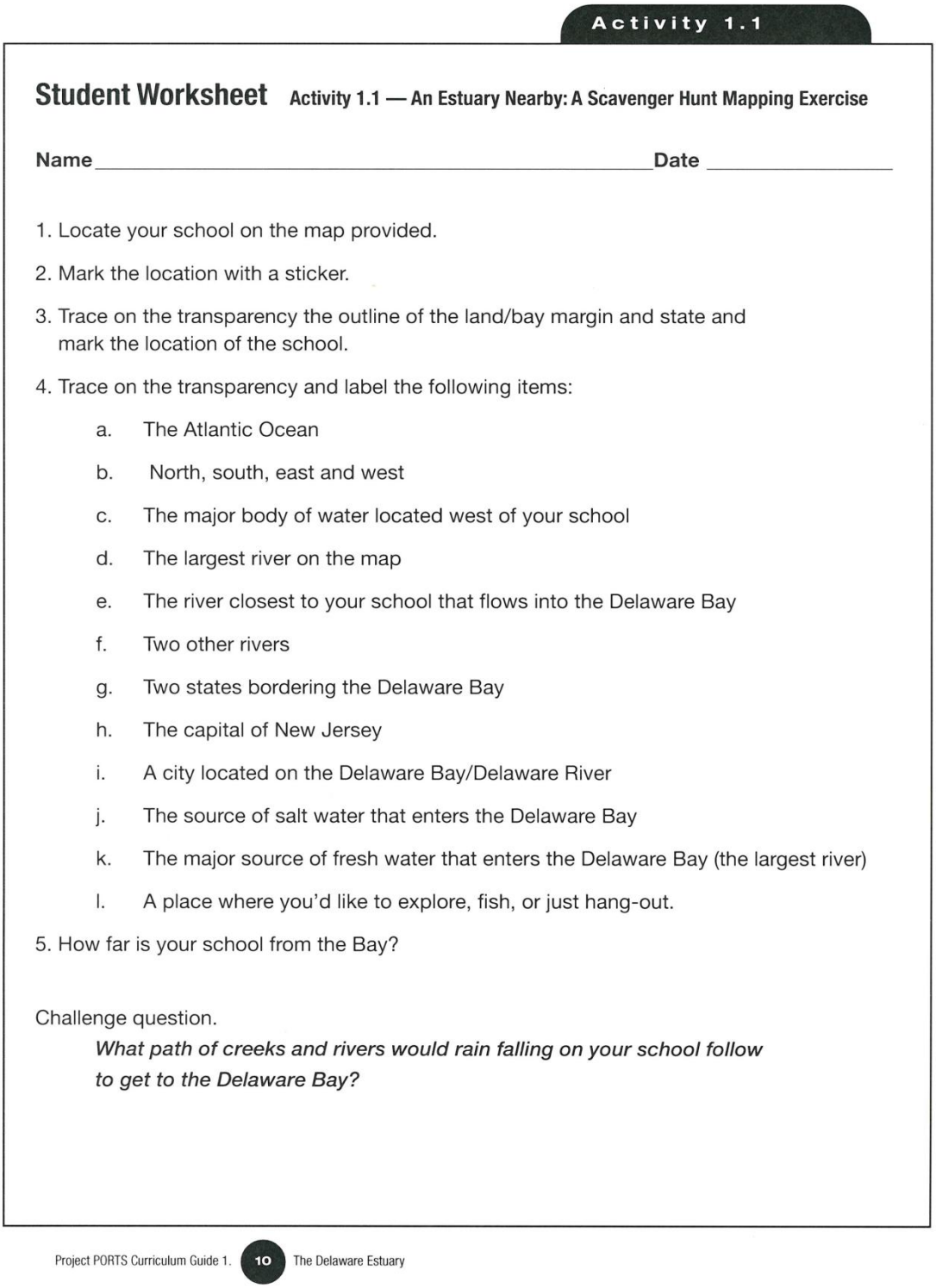


Fig. 15. Image of fish school detected using REMUS's side scan sonar. The figure in the oval shape is the hard return from the fish school itself and the figure in the rectangle is the shadow created by the fish swimming in the water column. Scale bar is shown below.



Activity 1.1

Student Worksheet **Activity 1.1 — An Estuary Nearby: A Scavenger Hunt Mapping Exercise**

Name_____ **Date** _____

1. Locate your school on the map provided.
2. Mark the location with a sticker.
3. Trace on the transparency the outline of the land/bay margin and state and mark the location of the school.
4. Trace on the transparency and label the following items:
   a. The Atlantic Ocean
   b. North, south, east and west
   c. The major body of water located west of your school
   d. The largest river on the map
   e. The river closest to your school that flows into the Delaware Bay
   f. Two other rivers
   g. Two states bordering the Delaware Bay
   h. The capital of New Jersey
   i. A city located on the Delaware Bay/Delaware River
   j. The source of salt water that enters the Delaware Bay
   k. The major source of fresh water that enters the Delaware Bay (the largest river)
   l. A place where you'd like to explore, fish, or just hang-out.
5. How far is your school from the Bay?

Challenge question.

What path of creeks and rivers would rain falling on your school follow to get to the Delaware Bay?

Project PORTS Curriculum Guide 1. 10 The Delaware Estuary

Fig. 16. An example of a student worksheet printed at the ends of the activities in the Project PORTS Curriculum and Activity Guide. This worksheet is part of Activity 1.1, *An Estuary Nearby: A Scavenger Hunt Mapping Exercise*.

Project PORTS, Activity 3.7
One Fish, Two Fish- Assessing Habitat Value of Restored Oyster Reefs

Circle the letter of the answer you think is correct, there will only be one correct answer per question. If you're not sure about an answer, just select "I'm not sure".

1. Please fill in the following information:
   Name _____ Date_____
   Grade _____

2. What is habitat restoration?
   a. To help the environment come back to a former condition
   b. To build parks
   c. To relocate human populations
   d. I'm not sure

3. What is species diversity?
   a. It describes what part of the world a plant or animal lives in
   b. Measure of how many offspring and animal can have
   c. Measure that includes the number species and their relative abundances in a community
   d. I'm not sure

4. Which of the following most closely defines species richness?
   a. The "value" a species brings to a community
   b. The number of species in a community
   c. The number of individuals in a square meter
   d. I'm not sure

5. Oysters are important because:
   a. They are good to eat
   b. They clean the water
   c. They provide habitat for other animals
   d. All of the above

6. Habitat restoration can only be attempted on land.
   a. True b. False

Fig. 17. Summative assessment administered to students before and after participation in Activity 3.7 (continued on following page)

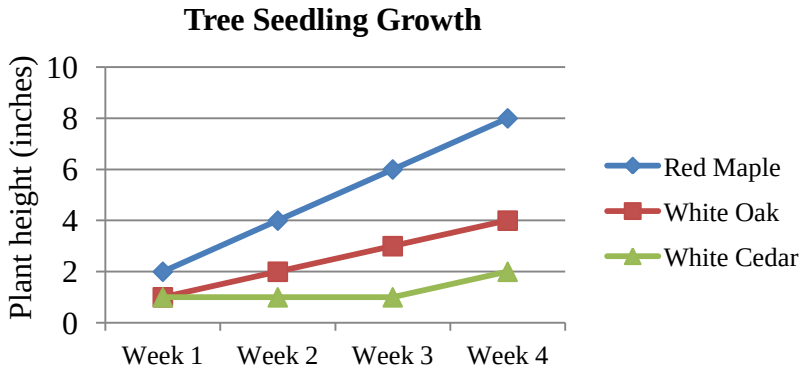
The following data were collected in an experiment to study trees in different southern New Jersey habitats:

	Number of trees/plot		
	Forest (most dry)	**Meadow (part wet)**	**Swamp (most wet)**
Red Maple	10	6	7
White Oak	17	0	3
White Cedar	0	2	20

7a. Create a bar graph of a tree of your choice. _____

7b. Based on your plots, what is one conclusion you can make about the species you chose?

8. Use the line graph to answer the following questions.



a. Which seedlings were the fastest growers? _____

b. Which seedlings were the slowest growers? _____

Activity 3.7

Student Worksheet Activity 3.7—Assessing Habitat Value of Restored Oyster Reefs

Name _____ Date _____

TABLE 1

Common Name	Scientific Name	Restoration Area	Non-oyster	Mature oyster
Atlantic croaker	*Micropogonias undulatus*	44	50	21
Weakfish	*Cynoscion regalis*	22	30	29
Hogchoker	*Trinectes maculatus*	27	28	8
Oyster toadfish	*Opsanus tao*	24	6	24
Blue crab	*Callinectes sapidus*	14	19	14
Northern kingfish	*Menticirrhus saxatilis*	7	7	0
Silver perch	*Bairdiella chrysoura*	6	2	4
Spot	*Leiostomus xanthrus*	2	4	2
White perch	*Morone americana*	17	2	7
TOTAL		163	148	109

A. Using the chart below and the data in Table 1, choose three fish species and create a bar chart showing their abundance at each habitat. Color or pattern the bars for each species and create a legend to denote each species. Note: each site should have three bars (one for each species)

GRAPH 1

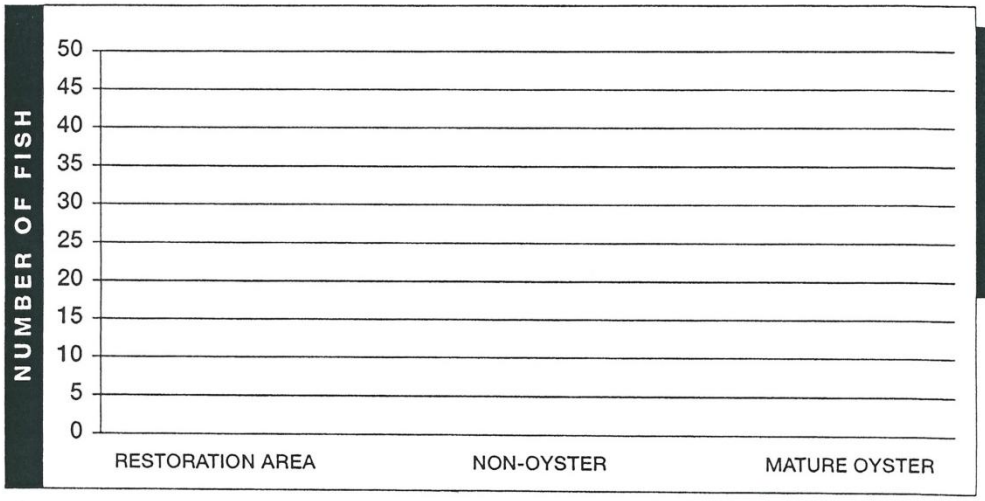
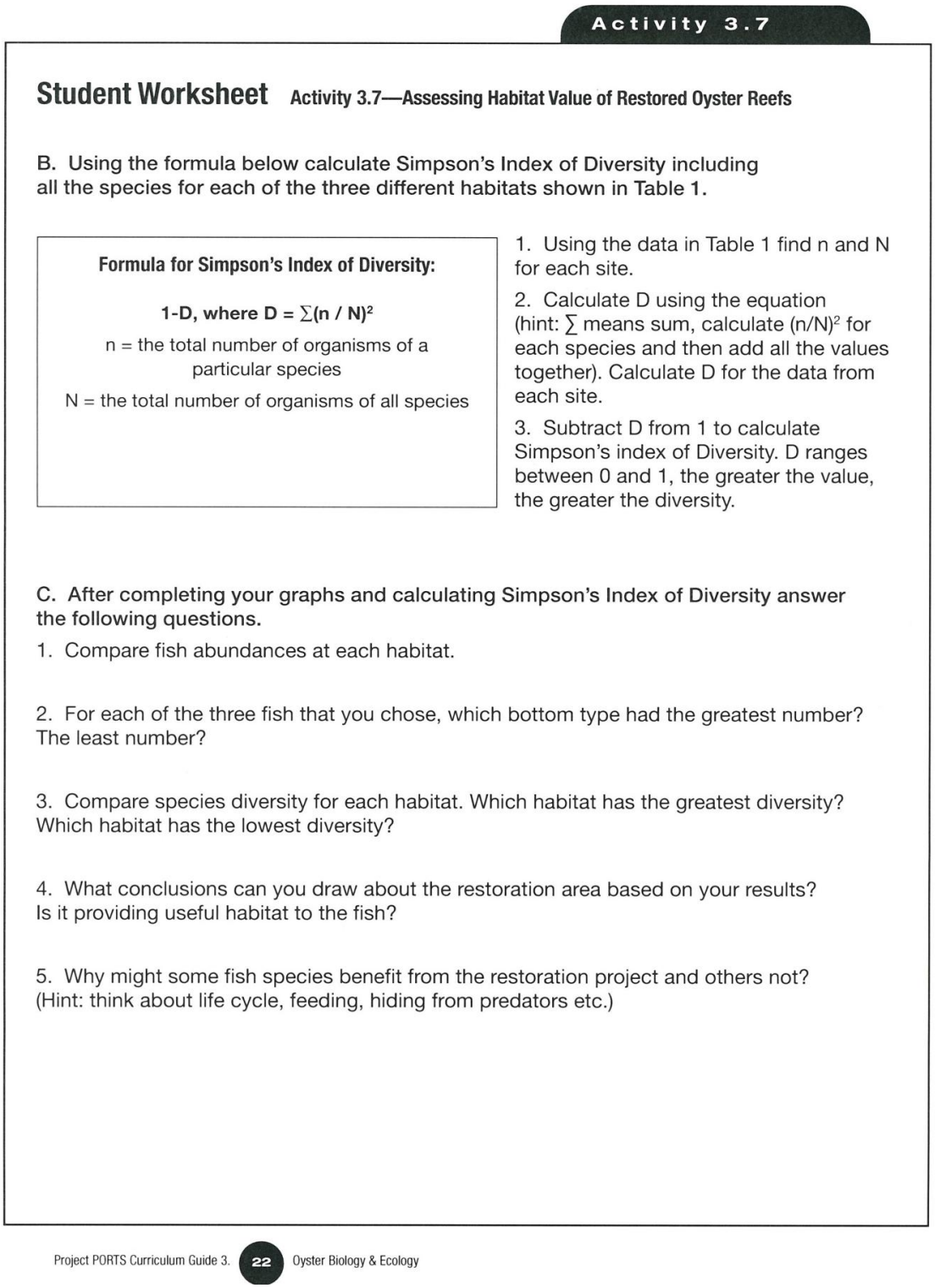


Fig. 18a. Activity 3.7 worksheet that prompts students to read a data table and create bar graphs. It is published in the Project PORTS Curriculum Guide and was used in the classroom activity during this study (Calvo 2008).



Activity 3.7

Student Worksheet Activity 3.7—Assessing Habitat Value of Restored Oyster Reefs

B. Using the formula below calculate Simpson's Index of Diversity including all the species for each of the three different habitats shown in Table 1.

Formula for Simpson's Index of Diversity:

1-D, where D = $\sum(n / N)^2$

n = the total number of organisms of a particular species

N = the total number of organisms of all species

1. Using the data in Table 1 find n and N for each site.
2. Calculate D using the equation (hint: $\sum$ means sum, calculate $(n/N)^2$ for each species and then add all the values together). Calculate D for the data from each site.
3. Subtract D from 1 to calculate Simpson's index of Diversity. D ranges between 0 and 1, the greater the value, the greater the diversity.

C. After completing your graphs and calculating Simpson's Index of Diversity answer the following questions.

1. Compare fish abundances at each habitat.

2. For each of the three fish that you chose, which bottom type had the greatest number? The least number?

3. Compare species diversity for each habitat. Which habitat has the greatest diversity? Which habitat has the lowest diversity?

4. What conclusions can you draw about the restoration area based on your results? Is it providing useful habitat to the fish?

5. Why might some fish species benefit from the restoration project and others not? (Hint: think about life cycle, feeding, hiding from predators etc.)

Project PORTS Curriculum Guide 3. 22 Oyster Biology & Ecology

Fig. 18b. Activity 3.7 worksheet that leads students through the formula to calculate the diversity index and subsequently interpret data. It is published in the Project PORTS Curriculum Guide and was used in the classroom activity during this study (Calvo 2008).

Assessment Score Rubric

	0	**1**	**2**	**3**
7a. Bar graph	Did not plot graph at all, no effort shown	Draws on graph, but does not create bars (uses lines, dots, etc)	Draws bars, but not plotted on graph correctly: wrong values, missing bars etc.	Draws all bars accurately
7b. Conclusion question	Did not write in an answer	Answer does not demonstrate understanding of data	Answer demonstrates some understanding of data, but does not include moisture characteristic	Answer includes all information provided (tree species, habitat and moisture), clear understanding of data table

Notes:	Multiple choice:	/ 5
	Create a bar graph:	/ 6
	Interpret a line graph:	/ 2
	TOTAL	**/ 13**

Fig. 19. Assessment rubric that was used to score each student on completeness and correctness of questions and performance tasks.

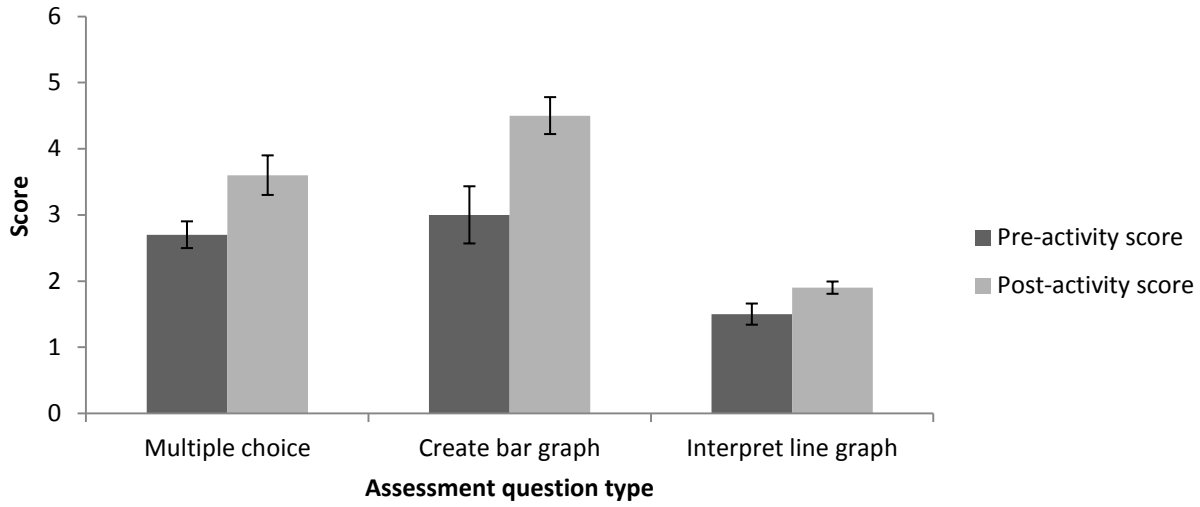


Fig. 20. Bar plot of pre and post-activity assessment scores for the three different question/learning task categories students completed.

Appendix A

Activity 3.7

One Fish, Two Fish—Assessing Habitat Value of Restored Oyster Reefs

- Grade Level
  6-9
- Subject Areas
  Science, Mathematics
- Duration
  One to two 40 minute class sessions
- Setting
  Classroom
- Skills
  Graphing, interpreting, explaining, hypothesizing
- Vocabulary
  Habitat, restoration, diversity, species richness
- Correlation with Next Generation Science Standards
  MS-LS2-1, MS-LS2-4, MS-LS2-5, MS-ETS1-1, HS-LS2-1, HS-LS2-2, HS-LS2-6, HS-LS2-7, HS-LS4-5, HS-LS4-6

Materials:

- ☐ Student Worksheet-Activity 3.7
- ☐ Computer graphing program (optional)
- ☐ Calculator

Charting the Course

In this exercise students will examine data collected in a real scientific study conducted by Rutgers University. Students will analyze data and make conclusions about potential results of the experiment. Using this study as a model, students will develop a clearer understanding of aspects of the scientific method: analyze data, make conclusions and communicate the results.

Background

The Gandy's Beach Oyster Restoration Enhancement Area (GBOREA) is a subtidal ten-acre plot located in the upper Delaware Bay. The GBOREA was established by the New Jersey Department of Environmental Protection to provide a target site for community-based oyster restoration efforts. Since 2007, Rutgers University's outreach program Project PORTS (Promoting Oyster Restoration Through Schools) has engaged school children in restoring the area. Participating students have built more than 8,000 shell bags, which have provided substrate for oyster larvae settlement (see activity 3.4 for more information on the oyster life cycle). More than 20 million spat (newly settled juvenile oysters) have been planted at the enhancement site as a result of these efforts.

Simply put, environmental restoration is the act of returning an area to a former condition. Scientists examine various parameters when evaluating the success of a restoration project. Since oyster reefs are important habitat for many estuarine fish species, determination of the abundance and diversity of fish species at a restored reef can be one way to measure the ecological value of the reef.

This activity focuses on an examination of data collected in 2013 by Rutgers University scientists to examine fish and invertebrate utilization of the GBOREA site in comparison to that at a natural mature oyster reef and at a non-oyster bottom (rocks, sand, mud) site. Scientists deployed habitat trays (trays filled with material collected from the site) monthly to collect resident fishes and invertebrates living on the bottom. They also used an otter trawl (weighted net towed behind a boat) to collect both resident and transient fishes twice a month. Each animal captured was identified, measured and weighed before being released back into the Delaware Bay.

In addition to counting each individual and comparing abundances directly, scientists compare communities by calculating species richness, an index relating to the diversity of species in an area. Species richness is the number of different species present in a community. For example, the species richness for a habitat containing a striped bass, weakfish and toadfish is 3. Diversity indices are commonly used to measure richness while also reflecting the evenness of the species distributed amongst habitat types. In this activity, students will employ The Simpson Index of Diversity (Figure 1) to examine and compare species use of the three types of habitats sampled. Based on this examination, your students should discuss whether Project PORTS efforts have been successful.

Appendix A (continued)

Objectives / Students will be able to:

1. Define restoration
2. Graph and interpret data
3. Describe how species abundances change in different environments in the study areas
4. Show how the restoration efforts may have impacted habitats in the estuary

Procedure / Warm Up

Introduce habitat restoration using the GBOREA as an example in a class discussion. Briefly describe the study and site types. Query, what is the purpose of habitat restoration? What benefits can it provide to the environment, animals and humans? Explain that scientists can use the number of species (diversity) in a habitat to better understand the animal community. Introduce Simpson's Index of Diversity and discuss how this might be a valuable tool. Ask students to make a prediction of how species numbers will differ between sites.

The Activity

1. Divide the class into teams of restoration scientists assigned with the project of studying the effects of the Gandy's Beach Oyster Restoration Enhancement Area on native fish species.
2. Each team will receive a copy of the data set on Student Worksheet – Table 1 (page 21).
3. Students should graph the data (either by hand or using excel if proficient in it). They should graph the abundances of three fish species of their choice.
4. Using their bar graphs, students should:
   a. Compare their selected species abundance across bottom types
   b. Determine which species were most abundant and least abundant on each habitat type
5. Calculate Simpson's Index (D) for each of the three bottom types using the equation in Figure 1 (example below).

Figure 1. Formula for Simpson's Index of Diversity:

1-D, where $D = \sum(n / N)^2$

n = the total number of organisms of a particular species

N = the total number of organisms of all species

Example: Calculating D for the restoration area would look like this:

$D= (44/163)^2 + (22/163)^2 + (27/163)^2 + (24/163)^2 + (14/163)^2 + (7/163)^2 + (6/163)^2 + (2/163)^2 + (17/163)^2 = 0.17$

Simpson's Index of Diversity: 1-D = 1-0.17 = 0.83

6. Using the calculated ranges from 0 to 1, low to high, determine which bottom type hosts the highest diversity of fishes.

   note: -Simpson's Index (D) measures the probability that two individuals randomly selected from a sample will belong to the same species.
   -Simpson's Index of Diversity (1 – D): ranges between 0 and 1, the greater the value, the greater the sample diversity.

7. Ask students what conclusions they can draw about the restoration project?

Extensions / Complement this activity with Activity 1.3, Life in the Estuary, to continue learning about some of the same species in this study.