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Integrated assessment of oyster reef ecosystem services: Fish and crustacean utilization and trophic linkages

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INTEGRATED ASSESSMENT OF OYSTER REEF ECOSYSTEM SERVICES

3/16/2016

Fish utilization and trophic linkages

A final report to:
National Oceanic and Atmospheric Administration's
Chesapeake Bay Office

Prepared by:
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VIMS | William & Mary
Virginia Institute of Marine Science

Integrated assessment of oyster reef ecosystem services

FISH UTILIZATION AND TROPHIC LINKAGES

Award Information

Project Title:	Integrated assessment of oyster reef ecosystem services: Fish and crustacean utilization and trophic linkages
Principal Investigators:	M. Lisa Kellogg, Virginia Institute of Marine Science Mark W. Luckenbach, Virginia Institute of Marine Science Paige G. Ross, Virginia Institute of Marine Science
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Abstract

Using a regression design that encompassed the continuum of oyster reef biomass density in Harris Creek, MD, from unrestored reefs to those restored reefs with the greatest oyster biomass, we examined finfish and crustacean utilization of these habitats. Of the eight sites studied, three had not been subject to any restoration activities and five had been planted in 2012 with juvenile oysters set on oyster shell. All sites were sampled in April, June, August, and October 2015. During each sampling period, we assessed abundance, total length and biomass of finfish and examined gut contents to assess the diets of selected finfish species. Of the species collected that were likely to use reefs as habitat or a foraging ground, only striped bass and white perch were sufficiently abundant to support robust statistical analyses.

Regression analyses found no clear relationship between oyster biomass density and catch per unit effort, total length or biomass for striped bass or white perch. Analyses of the effects of sampling period and restoration status (restored versus non-restored sites) on fish utilization frequently found an effect of sampling period but rarely found

an effect of restoration status. In all cases where differences were detected, they suggested greater utilization of non-restored sites. Overall, data were sparse and the power of statistical analyses was low.

Analyses of striped bass and white perch diets suggest that they are using oyster reefs as a foraging ground. Although comparisons of the proportion of striped bass and white perch that contained prey in their stomachs found no difference between those caught on restored sites versus non-restored sites, gut contents of both species contained prey taxa that are likely more abundant on restored oyster reefs than non-restored sites. As a percentage of total prey wet weight, polychaete worms were the most important component of striped bass diets in both April (50%) and August (47%). Of the polychaete worms identifiable to species, 100% were *Alitta succinea*, a species found in much greater abundance and biomass on restored oyster reefs than on comparable non-restored sites (Kellogg et al. 2013, Rodney and Paynter 2006). White perch diets were dominated by the ascidian *Molgula manhattensis* (52%), a species generally found in greater abundance on hard substrates including oyster reefs. Of the identifiable species of fish found in the stomachs of striped bass, 93% by weight were naked gobies (*Gobiosoma bosc)* or striped blennies (*Chasmodes bosquianus*), two species found in greater abundance and biomass on restored oyster reefs than non-restored sites in Chesapeake Bay (Kellogg et al. 2013, Rodney and Paynter 2006). For white perch, naked gobies accounted for 95% of the identifiable fish species by weight.

Direct comparisons of white perch and striped bass diets to the prey fields at each sampling site will be conducted as part of a companion project also funded by NOAA Chesapeake Bay Office (Award #: NA13NMF4570209: Integrated assessment of oyster reef ecosystem services: Macrofaunal utilization, secondary production and nutrient sequestration). This companion project will also provide data on abundance, biomass and distribution of small, reef-associated species including naked gobies, striped blennies, and oyster toadfish (*Opsanus tau*).

Rationale

An important factor motivating conservation and restoration of oyster reefs over the past two decades has been their role in supporting production rates of higher trophic levels (primarily fish and crustaceans) that are greater than rates for unstructured benthic habitats (Lenihan et al. 1998, Coen et al. 1999, Luckenbach et al. 1999, Peterson et al. 2003, Plunket and La Peyre 2005, zu Ermgassen 2015) and comparable to or greater than rates for marsh edge habitats (Shervette and Gelwick 2008, Stunz et al. 2010). Field and laboratory studies have invoked several mechanisms to account for this enhancement, including availability of spawning substrate (Breitburg 1999, Lenhert and Allen 2002), refugia from predation (Posey et al. 1999, Stunz and Minello 2001) and greater food availability (Harding and Mann 2001, Peterson et al. 2003, Wong et al. 2011). In a study of annual secondary production for macrofaunal and epifaunal communities across a variety of natural and anthropogenic estuarine habitats in North Carolina, Wong et al. (2011) found the highest annual rates on oyster reefs and suggested that secondary production within a habitat is an appropriate metric of food web support for higher trophic levels. Thus, enhanced secondary production attributable to reef restoration can be viewed as a food web subsidy for higher trophic levels, a quantifiable ecosystem service.

Quantifying food web subsidy in a specific restoration application requires that we not only know (i) the amount of secondary production enhancement resulting from the restoration, but also (ii) the utilization of the restored and non-restored habitats by higher trophic levels and (iii) the direct trophic linkages between these levels and the habitat-specific prey assemblages. Although several recent studies have assessed finfish utilization of oyster reef habitats (e.g. Harding and Mann 1999, Peterson et al. 2003, Tolley and Volety 2005, Stunz et al. 2010, Pierson and Eggleston 2014), to our knowledge none have included detailed assessments of trophic links between finfish and restored reef habitats or assessed how finfish utilization changes either through time or with oyster biomass density on subtidal oyster reefs restored using hatchery-produced juvenile oysters settled on adult oyster shell (hereafter "spat on shell"). Our observations suggest that finfish utilization is enhanced almost immediately after placement of spat on shell and increases as the oyster reef and associated macrofaunal community develops and the reef matures, but quantitative relationships between easily-determined oyster reef metrics (e.g. reef age, oyster abundance, oyster biomass density, reef complexity) and ecosystem functions (e.g. provision of habitat, secondary production) are largely lacking (but see Luckenbach et al. 2005 and Gregalis et al. 2009). Identification of these relationships will ultimately allow estimation of the ecosystem services provided by a broad range of ongoing oyster reef restoration activities and help justify the expenses associated with these restoration efforts.

Fig. 1. Location of Harris Creek Oyster Sanctuary in the Maryland portion of Chesapeake Bay.

Project Narrative

Our overarching objective was to quantify the utilization of restored oyster reefs as habitat and foraging grounds for transient finfish and larger size classes of resident demersal finfish and crustaceans. All studies were conducted within the Harris Creek Oyster Sanctuary in the Maryland portion of Chesapeake Bay (Fig. 1). Using a variety of techniques, restoration activities have been implemented on >300 acres of historic oyster bottom (i.e. areas identified as viable oyster habitat at some point in the past) within this sanctuary. Within Harris Creek, we studied five restoration sites and three control sites that were suitable for restoration but were not subject to any restoration activities (hereafter "non-restored"). To control for the influence of the restoration method employed, we limited our study to sites where juvenile oysters set on oyster shell (i.e. "spat-on-shell") were planted directly on the bottom (i.e. areas with substratum conditions suitable for oyster survival and growth without adding hard substrate prior to planting). To control for the influence of oyster age, we selected only sites that were planted in 2012. Prior to site selection, a patent tong survey of potential sites was conducted in 2014 by the Paynter Lab at the University of Maryland. Based upon the resulting data, we delineated eight 1.25-ha study sites for our work (Fig. 2). The selected areas provided biomass densities ranging from 2.7 to 98.4 g dry weight (DW) oyster tissue per square meter at the time of initial surveys (Fig. 3). These same study sites were used by two complementary NCBO-funded projects focused on assessing the relationships between oyster biomass density and provision of habitat for macrofauna (Award #: NA13NMF4570209: Integrated assessment of oyster reef ecosystem services: Macrofaunal utilization, secondary production and nutrient sequestration), and biogeochemical fluxes (Award #: NA14NMF4570275: Integrated assessment of oyster reef ecosystem services: Quantifying denitrification rates and nutrient fluxes).

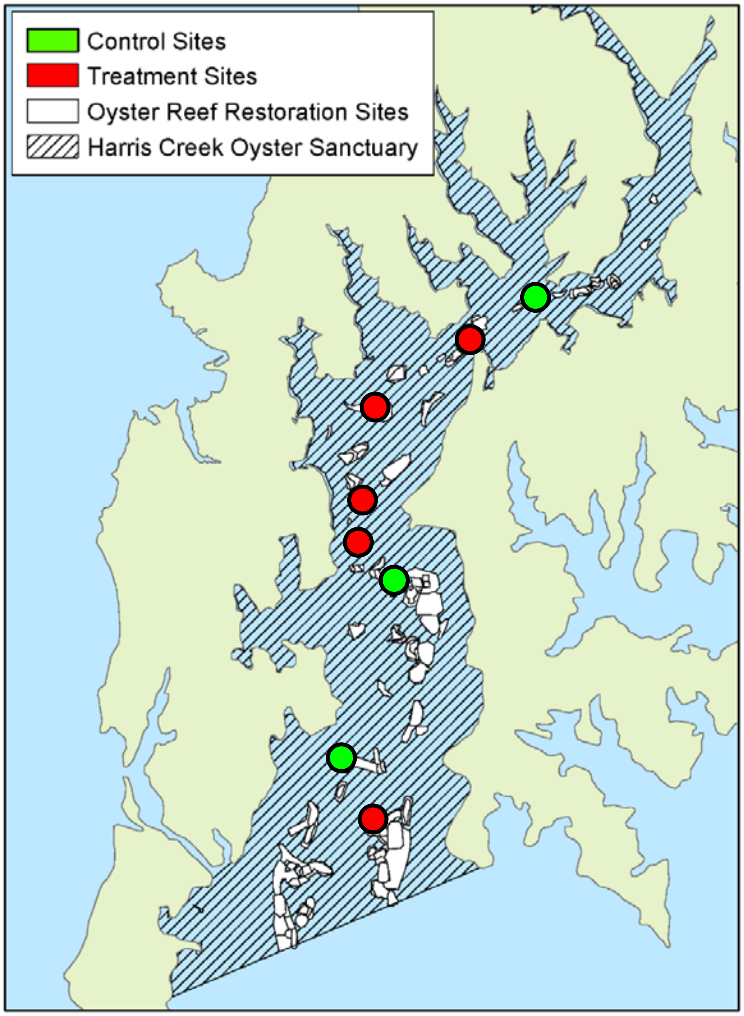

Fig. 2. Location of control (non-restored) and treatment (restored) sites within the Harris Creek Oyster Sanctuary in relation to the larger oyster reef restoration effort (white polygons).

Objective 1:

Compare utilization of non-restored and restored oyster reefs (encompassing a range of oyster biomass density) by transient finfish and large size classes of resident finfish and crustaceans

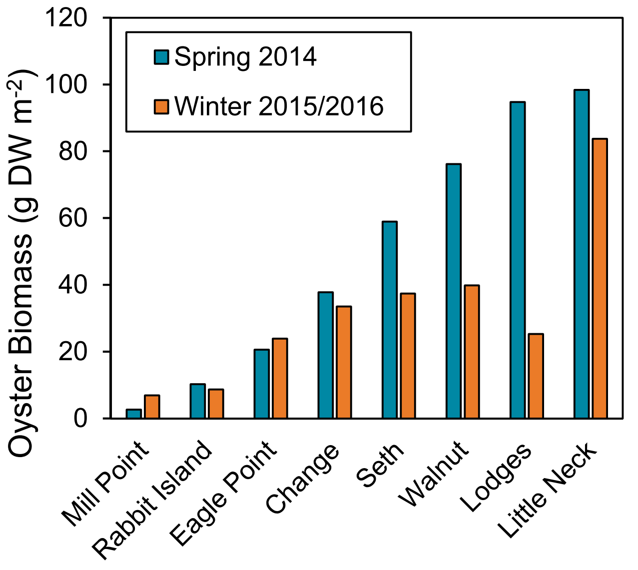

Fig. 3. Oyster biomass density (DW = dry weight of oyster tissue) at study sites based upon patent tong surveys in spring 2014 and winter 2015/2016 (Paynter, unpublished data).

Fig. 4. Virginia Institute of Marine Science's Eastern Shore Lab (VIMS-ESL) staff deploying fish traps (top), and collecting fish from a gillnet (bottom).

Methods: Finfish and crustacean utilization at each site was assessed using a combination of baited crab pots, baited fish traps (trap type specifically selected to complement ongoing studies by NCBO staff elsewhere in the Choptank River complex) and multi-panel gill nets (Fig. 4). This combination of sampling gear was chosen to sample a broad spectrum of organism sizes and feeding habits and to complement NCBO plans for sampling in the Choptank River complex. Both the crab pots and the fish traps were deployed inside a large encircling seine (area encompassed: ~160 m^2), allowing us to calculate the abundance and biomass of resident species per unit area. In our crab pots (lined with ≤ 1-cm mesh) and fish traps, we anticipated catching blue crabs (*Callinectes sapidus*), demersal finfish unlikely to be captured by gillnetting (e.g. eels [*Anguilla rostrata*] and toadfish), and small size classes (< 10cm) of other transient and resident finfish species. Recognizing that our chosen gear was unlikely to efficiently catch the smallest size classes and species of resident finfish (e.g. gobies, blennies, small size classes of toadfish and other resident species), we coordinated our sampling design with complementary macrofaunal studies also funded by NCBO. Once complete, those studies will provide additional data on smaller size classes and species of resident fish. To assess reef utilization by larger finfish and crustaceans species, we utilized 90-m sinking rigged monofilament gill nets composed of three 30-m panels of differing mesh sizes (2.5, 7.6, and 12.7 cm).

During April, June, August and October 2015, we collected four gillnet samples from each of the eight sites for a total of 32 samples per sampling period. As per our permit from the Maryland Department of Natural Resources, gillnets were deployed for one hour per set. Species, total length and biomass (wet weight) were determined for all individuals of interest in each sample. In April and June 2015, six crab pot samples and six fish trap samples were collected from each site. Traps and pots were deployed for 2.5 hours per set. All catch data were standardized using deployment and retrieval times to determine catch per unit effort (CPUE) as number of individuals caught per hour of sampling.

Results: In April and June 2015, no fish or crabs were caught in pots or traps during either sampling effort (despite observations suggesting reasonably abundant crab populations in Harris Creek at the time of sampling). After the June sampling period, these gear types were deemed to be inefficient, and this type of sampling was terminated.

A total of 619 fish were collected during gillnet sampling (Table 1). Atlantic menhaden (*Brevoortia tyrannus*) was the most abundant species, followed by striped bass, American gizzard shad (*Dorosoma cepedianum*) and white perch. Fewer than 10 individuals were captured for any other species. Based on known feeding habits (i.e. likely to consume organisms inhabiting oyster reefs) and number of individuals collected, detailed analyses were limited to striped bass and white perch only.

Table 1. Seasonal gillnet catch of finfish for 2015.

Species	Total # of Individuals				
	Apr	Jun	Aug	Oct	Total
Atlantic menhaden *(Brevoortia tyrannus)*	57	56	182	35	330
Striped bass *(Morone saxatilis)*	35	4	24	55	118
American gizzard shad *(Dorosoma cepedianum)*	6	11	17	54	88
White perch *(Morone americana)*	7	1	22	45	75
Weakfish *(Cynoscion regalis)*	0	0	3	0	3
American shad *(Alosa sapidissima)*	1	0	0	0	1
Atlantic croaker *(Micropogonias undulatus)*	0	1	0	0	1
Atlantic herring *(Clupea harengus)*	1	0	0	0	1
Bluefish *(Pomatomus saltatrix)*	0	1	0	0	1
Spot *(Leiostomus xanthurus)*	0	0	1	0	1

During winter 2015/2016, the Paynter Lab again conducted patent tong surveys of our sites; these data were used to update our estimates of oyster biomass density for each of our sites. To examine potential relationships between oyster biomass density and finfish utilization, we performed linear and quadratic regression analyses of CPUE, total length and biomass for striped bass and white perch during each sampling period against 2015/16 oyster biomass density. These analyses did not reveal any clear relationship between oyster biomass density and fish utilization of these sites (Fig. 5; for brevity only CPUE regressions are shown).

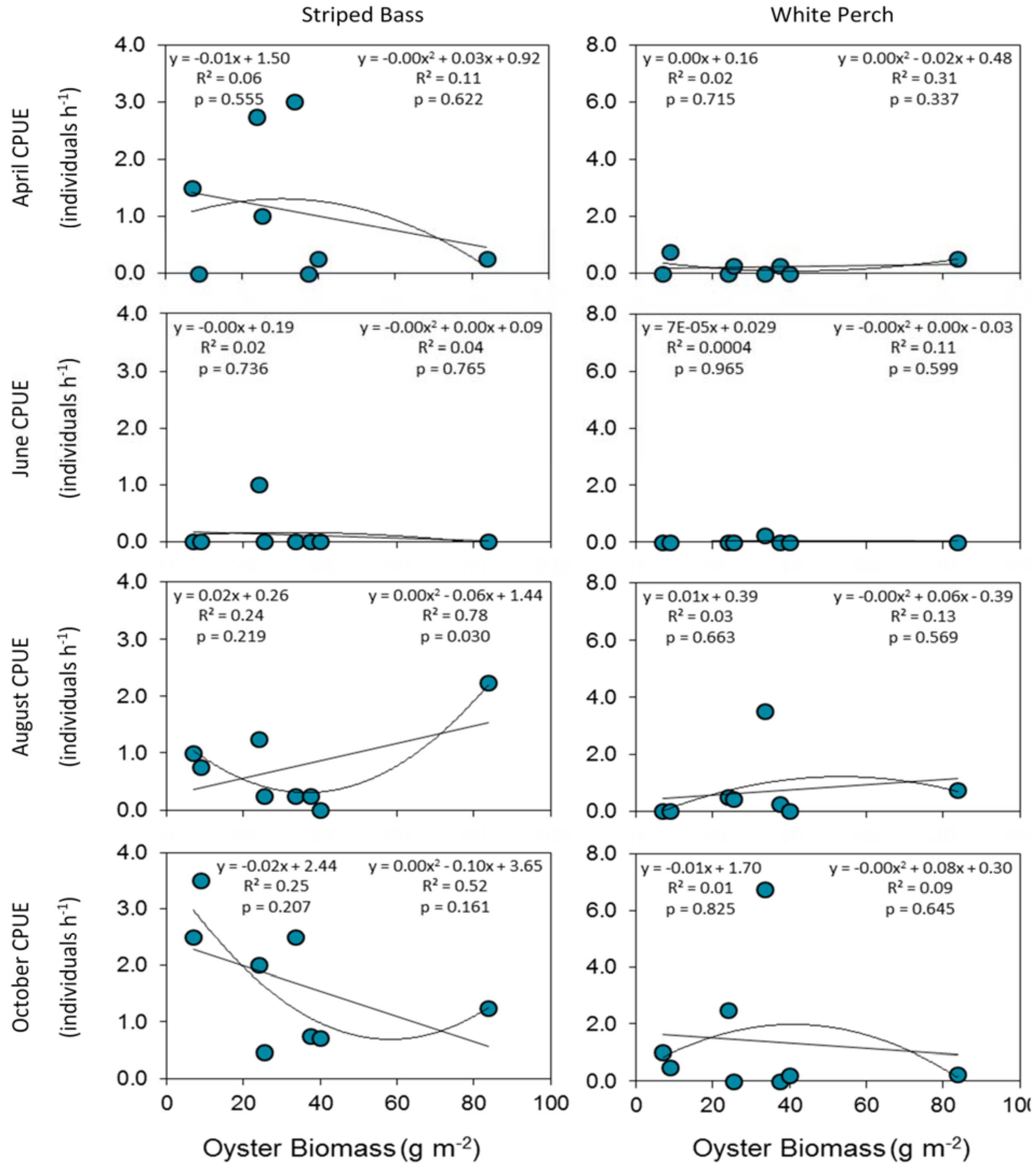

Fig. 5. Regression analyses of catch per unit effort (CPUE) of striped bass and white perch by season.

Because our catch rates were low and included many zeros, we pooled data from the four individual sets within each site and examined the effects of restoration status and sampling period on fish utilization using two-way fixed-factor Analysis of Variance (ANOVA) models with sites serving as treatment replicates (five for restored and three for unrestored). Data were transformed as needed to meet assumptions of normality and equal variance. For total length and biomass, the available data were insufficient to test for an interaction between sampling period and restoration status.

STRIPED BASS

Catches of striped bass were highly variable across sampling periods and sites (Fig. 6). Both sampling period and restoration status had significant effects on striped bass CPUE (Table 2). Holm-Sidak post hoc analyses indicated that catches of striped bass were higher in October than in June ($p < 0.001$) but that there were no other significant differences between any other seasons. These analyses also indicated that catches were higher on non-restored sites than restored sites ($p = 0.040$).

Analyses of striped bass total length and biomass both found significant effects of season and no effect of restoration status (Fig. 7, Table 2). Striped bass length data were not normally distributed and were resistant to transformation. However, ANOVA models are generally robust to violations of the assumption of normality and analyses were continued despite failing to meet this assumption. Both total length ($p = 0.040$) and biomass ($p = 0.016$) were significantly greater in April than in August. No other seasons differed significantly from each other.

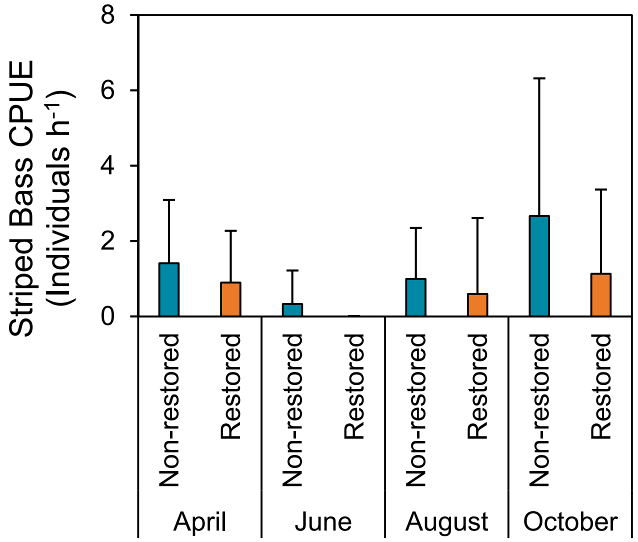

Fig. 6. Catch per unit effort (CPUE) of striped bass at restored and non-restored sites in Harris Creek. Error bars represent standard deviation.

Table 2. Summary of p-values associated with 2-way ANOVAs for the effects of sampling period and restoration status on striped bass captured in gillnets. * = Failed normality and resistant to transformation. † = Low catch rates prevented analysis of interaction between sampling period and restoration status.

	Sampling Period	Restoration Status	Interaction
CPUE	0.001	0.040	0.889
Total length*,†	0.031	0.462	
Biomass†	0.017	0.387	

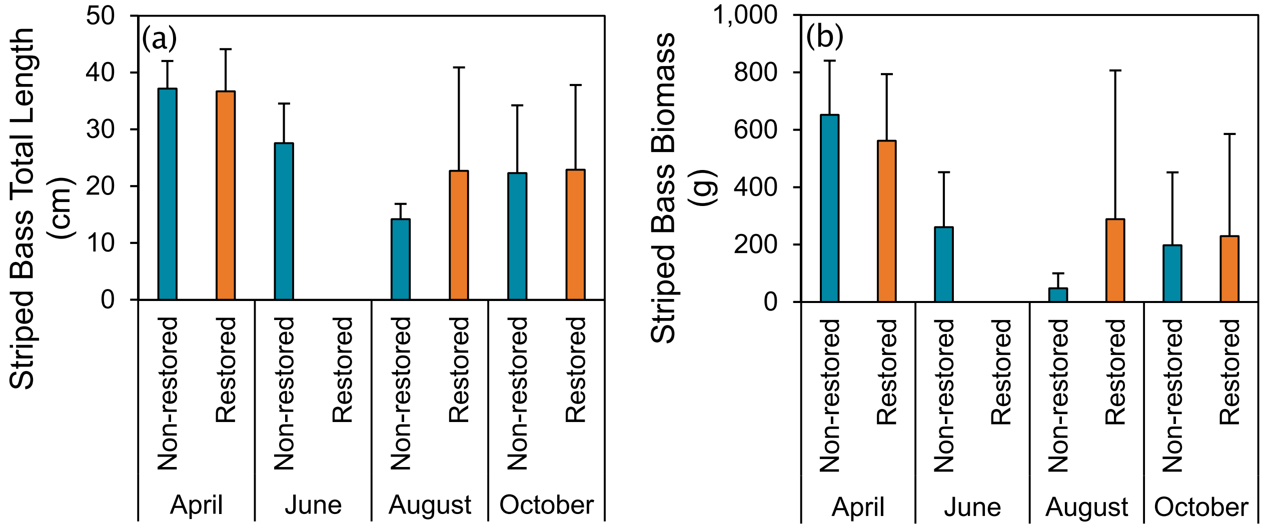

Fig. 7. Striped bass average total length (a) and biomass (b) at restored and non-restored sites in Harris Creek for each sampling period. Error bars represent standard deviation.

WHITE PERCH

Catches of white perch were also highly variable across sampling periods and sites (Fig. 8). Analysis of white perch CPUE found that sampling period had a significant effect but reef restoration status did not (Table 3). Holm-Sidak post hoc analyses indicated that catches of white perch were higher in October than in June (p = 0.029) but that there were no other significant differences among other seasons.

Average white perch total length and biomass were less variable than those for striped bass (Fig. 9). Two-way ANOVA found no effect of sampling period or restoration status on white perch total length or biomass (Table 3).

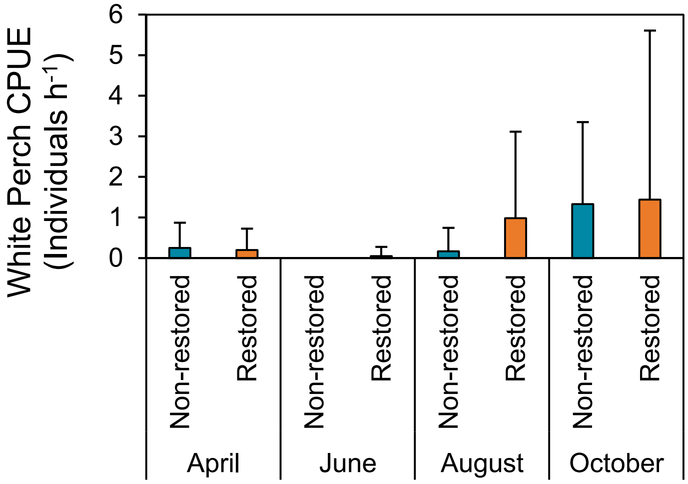

Fig. 8. Catch per unit effort (CPUE) of white perch at restored and non-restored sites in Harris Creek. Error bars represent standard deviation.

Table 3. Summary of p-values associated with 2-way ANOVAs for the effects of sampling period and restoration status on white perch captured in gillnets. † = Low catch rates prevented analysis of interaction between sampling period and restoration status.

	Sampling Period	Restoration Status	Interaction
CPUE	0.036	0.671	0.346
Total length†	0.080	0.721	
Biomass†	0.120	0.616	

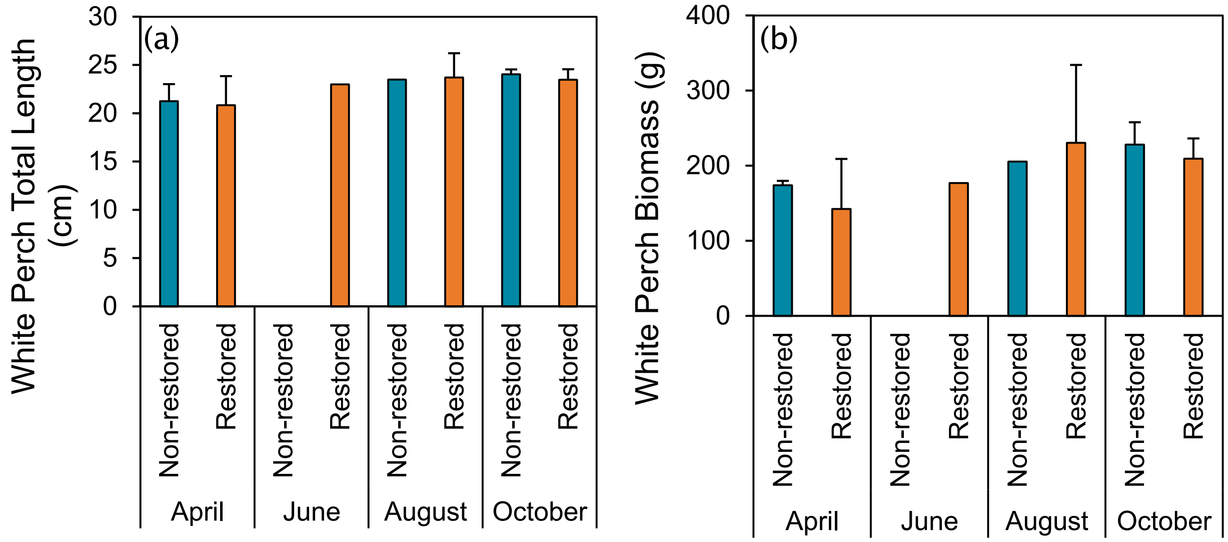

Fig. 9. White perch average total length (a) and biomass (b) at restored and non-restored sites in Harris Creek for each sampling period. Error bars represent standard deviation.

Objective 2:

Assess the diet of finfish species utilizing each reef type

Methods: During gillnet sampling in April, June, August and October 2015, individuals of each species from each site (representing as broad of a range of size classes as possible) were sacrificed for gut content analyses to establish dietary composition during each sampling period. For large individuals, samples were collected by excising the esophagus and stomach of individual fish in the field and immediately immersing them in Normalin for fixation. For smaller individuals, a slit was made in the body cavity and the individual was preserved whole for later laboratory excision of esophagus and stomach (Fig. 10). After a minimum of 48 hours, samples were transferred to 70% ethanol prior to processing. During processing, all diet components were identified to the lowest practical taxa, measured (when possible and appropriate), and weighed (wet weight) using standard

Fig. 10. After extracting stomach from fish (top), VIMS staff identify and count all prey items (bottom).

methods (Hyslop 1980). All diet analyses were based upon the wet weight prey taxa as a percentage of the wet weight of all prey within each sample.

Results: A total of 168 gut content samples were analyzed. However, only samples collected from white perch and striped bass were sufficiently abundant to allow detailed analyses.

STRIPED BASS

The percent of striped bass that had prey items in their stomach was highly variable (Fig.11). Data were insufficient to allow testing for the effects of restoration status and sampling period simultaneously. However, a series of Fisher's Exact tests within sampling period found no effect of restoration status.

Striped bass diet was highly variable among individuals (Fig. 12). Based on the percentage of total prey items by wet weight, mysids were the most abundant prey (34%), followed by polychaete worms (21%) and bivalves (12%). All other prey formed <10% of total striped bass diets by weight. Of the polychaete worms identifiable to species, 100% were *Alitta succinea*. Of the fish identifiable to species, 93% by weight were naked gobies or striped blennies.

Striped bass diet varied across seasons (Fig. 13). In April, they were feeding primarily on crustaceans and polychaetes. By August, they were feeding primarily on polychaetes, and in October they were consuming primarily crustaceans and fish. Polychaete worms were the most important component of striped

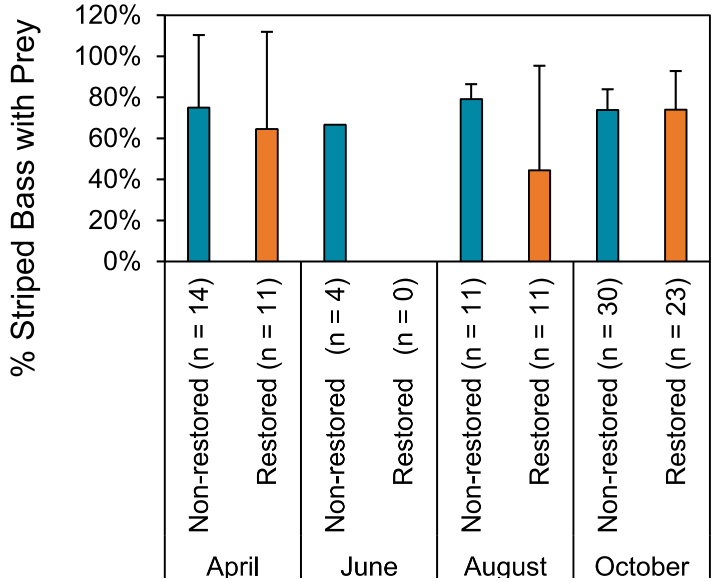

Fig.11. Percent of striped bass with prey in their stomachs at restored and non-restored sites in Harris Creek. No significant effect of reef type was detected in any of the four sampling seasons. Error bars represent standard deviation.

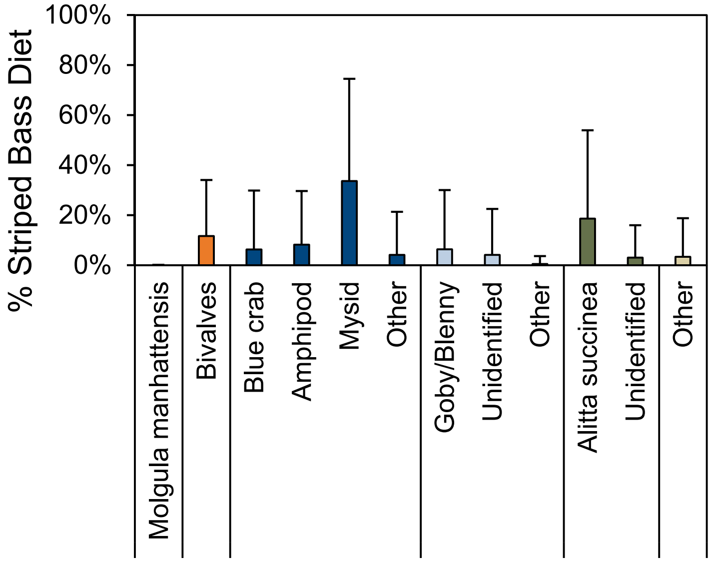

Fig. 12. Striped bass diet as percentage of total gut contents by weight. Error bars represent standard deviation.

bass diets in both April (50%) and August (47%). Because fewer than ten samples of gut contents were collected in June, data were deemed too sparse to give a reasonable estimate of striped bass diet during that time period.

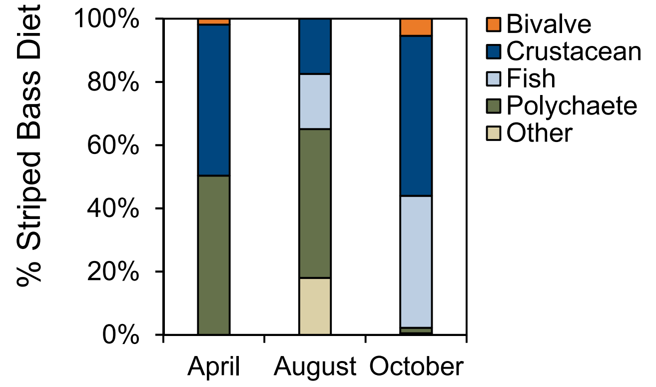

Fig. 13. Striped bass diet as proportion of total gut contents by weight for April, August and October 2015.

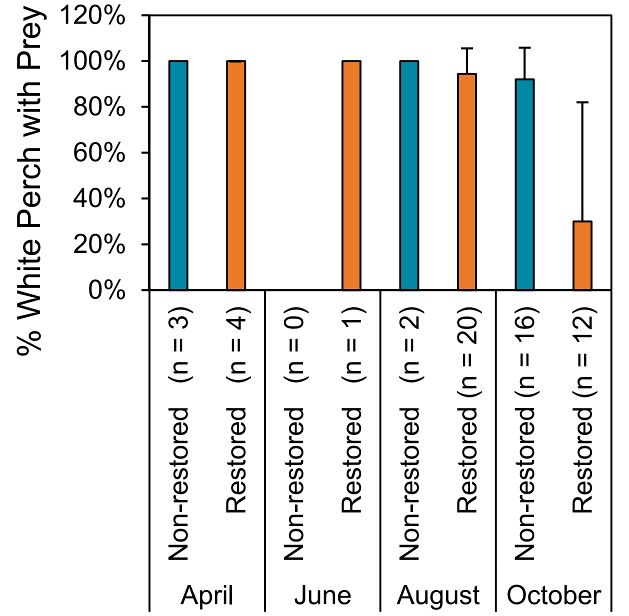

Fig.14. Percent of white perch with prey in their stomachs at restored and non-restored sites in Harris Creek. No significant effect of reef type was detected in any of the four sampling seasons. n = total number of fish stomachs analyzed. Error bars represent standard deviation.

WHITE PERCH

The percentage of white perch that contained prey in their stomachs was far less variable than for striped bass (Fig. 14) and the majority of fish analyzed contained prey. Data were insufficient to allow testing for the effects of restoration status and sampling period simultaneously. However, a series of Fisher's Exact tests within sampling period found no effect of restoration status.

As for striped bass, analyses of white perch diets found that diet was highly variable among individuals (Fig. 15). Based on the percentage of total prey items by wet weight, the sea squirt, *Molgula manhattensis,* was by far the most abundant prey (52%). All other prey formed <10% of total white perch diets by weight. Of the polychaete worms identifiable to species, 100% were *Alitta succinea.* Of the fish identifiable to species, 95% were naked gobies.

Analysis of seasonal samples suggests that white perch diet varies across seasons (Fig. 16). In April, they were feeding primarily on crustaceans (68%). Their diet shifted to feed primarily on *Molgula manhattensis* by August (46%) and October (61%). Because fewer than ten samples of gut contents were collected in June, data were deemed too sparse to give a reasonable estimate of white perch diet during that time period.

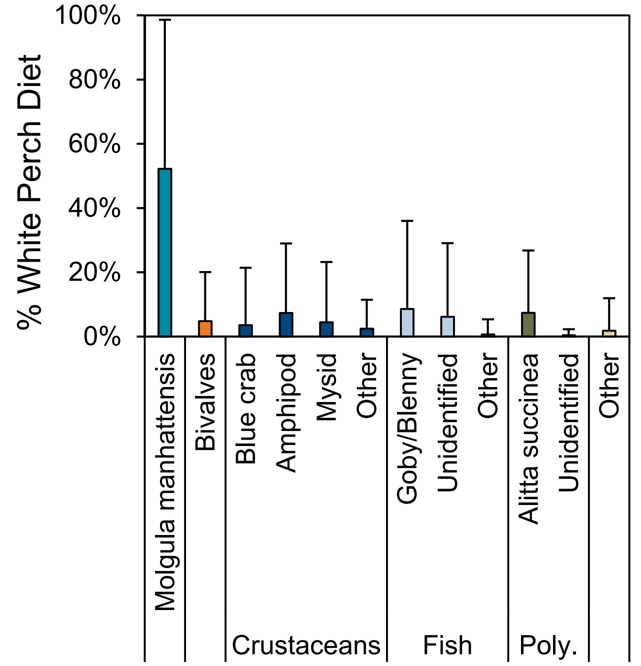

Fig. 15. White perch diet as proportion of total gut contents by weight. Error bars represent standard deviation.

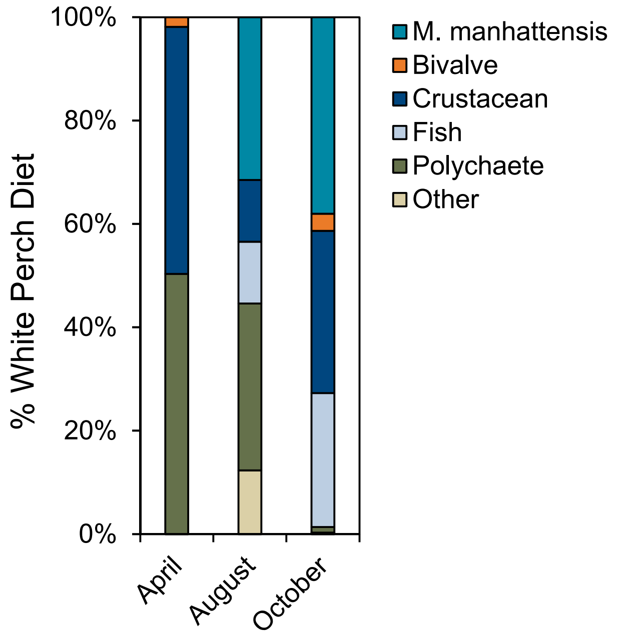

Fig. 16. White perch diet as proportion of total gut contents by weight for April, August and October 2015.

Objective 3:

Estimate secondary production and nutrient sequestration for appropriate resident finfish and crustacean species

Results: Estimates of secondary production and nutrient sequestration are only useful if they are scaled per unit area, or some other unit, that is reasonably comparable across sites. Unfortunately, our plan to scale secondary production data from crab trap and fish pot catches per unit area (using the area enclosed by the encircling seine within which they were deployed) was unsuccessful due to lack of catch using these types of sampling gear.

Ongoing collaborative work: Data on smaller reef resident species will be forthcoming as part of two related, ongoing NCBO-funded projects (Award #: NA13NMF4570209: Integrated assessment of oyster reef ecosystem services: Macrofaunal utilization, secondary production and nutrient sequestration and Award #: NA14NMF4570275: Integrated assessment of oyster reef ecosystem services: Quantifying denitrification rates and nutrient fluxes). Both of these projects have collected 0.1m^2 samples of substratum from each site during five sampling periods (early May, early June, late July, late October and mid-December 2015). Despite some losses due to boat strikes and other incidents, almost 200 samples have been collected to date and analyses are ongoing. Samples include small fish species (e.g. *Gobiosoma bosc*) that use the oyster reef as their primary habitat. Because fish abundance, biomass and nutrient content from these samples can be scaled per unit area, we will be able to calculate secondary production for small, resident fish species once sample analyses are complete. These projects will also supplement the diet analyses in the present study by providing estimates of abundance and biomass per unit area of many of the prey species found in striped bass and white perch stomachs (e.g. *Molgula manhattensis*, *Alitta succinea*, and *Gobiosoma bosc*).

Objective 4:

Determine the relationship between easily measured oyster reef parameters (e.g. biomass) and both finfish secondary production and nutrient sequestration in appropriate finfish and crustacean species

Results: As noted above, the lack of catch in crab pots and fish traps precluded calculation of the secondary production and nutrient sequestration rates of larger size classes of reef resident species.

Ongoing collaborative work: As described under Objective 3, samples from two related projects will provide data on secondary production and nutrient sequestration for small, resident reef species. We will use those data along with data on easily measured reef metrics to determine whether significant relationships exist. These analyses will be provided as part of the report for the project “Integrated assessment of oyster reef ecosystem services: Macrofaunal utilization, secondary production and nutrient sequestration” (Award #: NA13NMF4570209) due in May 2015.

Discussion

Our studies provide some evidence that both striped bass and white perch may benefit from oyster reef restoration via a prey subsidy. Both white perch and striped bass diets included species previously documented to occur in higher abundances on restored oyster reefs (e.g. *Alitta succinea, Molgula manhattensis, Gobiosoma bosc,* etc.). Our companion study focusing on provision of habitat for macrofauna by restored oyster reefs will provide data on the abundance per unit area of these species for all of our study sites and seasons.

Our failure to find significantly higher abundances of striped bass or white perch at restored sites compared to non-restored sites is not without precedent. In a much more intensive sampling effort, Pierson and Eggleston (2014) found either similar amounts of finfish on restored and non-restored sites or greater amounts at the non-restored sites, depending on location. Without a more detailed understanding of finfish movements in relation to habitat types, it is difficult to determine the relationship between CPUE and finfish utilization of reefs.

Of the gear types we used in our studies, gillnets proved the most useful but were still subject to relatively low catch rates and a large proportion of samples collected no fish, likely due in part to permit requirements that necessitated a maximum one-hour soak time. Crab pots and fish traps failed to catch any fish or crabs, despite the observation of a relatively abundant crab population in the area during several sampling efforts. It is worth noting that Pierson and Eggleston (2014) failed to find differences in CPUE using crab pots and fish traps even at sites where gillnet sampling did find differences. At present, it is unclear how the presence of the trap might interact with the surrounding environment to influence the catch rates of this type of gear. Placement of a trap on unstructured substratum represents a greater relative increase in structure than placement on an oyster reef. It is also unclear whether there are interactions between the attractiveness of bait in an unstructured habitat where biomass density of potential prey items is relatively low compared to a structured habitat where prey items are generally more abundant.

The gear in the present study did not sample the smallest size classes of transient fish species. The smallest striped bass and white perch in our samples had total lengths of 12 cm and 18 cm, respectively. Given that it is most often the smallest size classes of fish that require structured habitats for refuge from predation and provision of prey, it is possible there are relationships between the smaller size classes of transient fish species and oyster biomass density that could not be identified by our sampling program.

White perch consumption of the sea squirt, *M. manhattensis,* was the most surprising finding in the present study. Two recent analyses of finfish diets in Chesapeake Bay (Buchheister and Latour 2015; Ihde et al. 2015) do not indicate significant consumption of this species by white perch. Both of these studies included thousands of samples from white perch. The finding that white perch in Harris Creek appear to be using *M. manhattensis* as a primary food source in some seasons warrants further investigation. The significant roles of both the polychaete worm, *A. succinea*, and the naked goby, *G. bosc*, also warrant further investigation. Both of these species have been found in much greater abundances on restored oyster reefs than in adjacent non-restored areas in Chesapeake Bay.

Conclusions and recommendations

- Gillnet sampling of one-hour duration proved a relatively effective method for collecting finfish for gut content analyses. We were able to identify many prey items to species, including many species that are known to occur in higher abundances on restored oyster reefs than on adjacent, non-restored areas. However, this short sampling duration resulted in low overall catch rates.
- Gillnet sampling did not catch white perch smaller than 18 cm total length or striped bass smaller than 12 cm total length. This precluded diet studies of individuals in the smallest size classes. Given that the juveniles of many fish species are more likely to feed on invertebrates than larger size classes, diet studies of smaller transient fish collected from oyster reef environments would be a valuable addition to our understand of the potential food web support provided by oyster reefs.
- Sampling using crab pots and fish traps within encircling seines was unsuccessful. Trials in which half of the traps and pots were deployed inside the seines and half outside the seines also failed to catch anything. This, combined with observations of

relatively high abundances of blue crabs in the system, suggest that these gear may not be the most appropriate for determining the relative abundances blue crabs and larger resident fish species in this system. We suggest investigating other sampling approaches for quantifying these species.

- *Molgula manhattensis* was a primary component of white perch diets. Because the importance of this prey species to white perch has not been documented previously, it is unclear whether this was unusual or whether previous studies have failed to find this relationship because of the locations in which samples were taken or because of the methods used to collect samples. Additional studies are needed to more fully determine the importance of this species to the diet of white perch and its effects on fish production.
- Both *M. manhattensis* and *A. succinea* were found in our gut content samples. These species likely differ in amount of time required for them to be digested by predatory fish species. If this is indeed the case, then we could be significantly overestimating the importance of *M. manhattensis* and/or significantly underestimating the importance of *A. succinea* to local predators. Studies of the gut passage times of dominant prey species would allow evaluation of the scale of these potential biases.

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Outreach Activities

Data from or information about this project have been presented at a variety of meetings attended by resource managers, restoration practitioners and researchers. Presentations to date include:

Kellogg ML, Cornwell JC, Owens MS, Ross PG, Dreyer JC, Paynter KT, Luckenbach MW (2015) Integrated assessment of ecosystem services provided by tributary-scale oyster reef restoration in Chesapeake Bay. Coastal and Estuarine Research Federation's 23rd Biennial Conference, Portland, Oregon

Kellogg ML (2015) Measuring the benefits of oyster reef restoration: Quantifying denitrification rates and other ecosystem services. NC State Center for Marine Sciences and Technology, Morehead City, NC

Kellogg ML, Paynter KT, Cornwell JC, Ross PG, Owens MS, Handschy AV, Dreyer JC, Luckenbach MW (2014) Integrated assessment of oyster reef ecosystem services: Harris Creek, MD. 16th International Conference on Shellfish Restoration, Charleston, SC