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A comparison of the habitat value of sub-tidal and floating oyster (*Crassostrea virginica*) aquaculture gear with a created reef in Delaware's Inland Bays, USA

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Abstract The culture of the Eastern oyster (*Crassostrea virginica*) in containment gear has become a viable component of restoration programs in many states on the East Coast of the United States, and it has been suggested that these operations may provide many of the same ecological services as natural or restored reefs. Our two-part study comparing the diversity and abundance in macro-epifaunal communities associated with a sub-tidal-created oyster reef and 'modified rack and bag' cage system (Part I) and floating oyster cages for restoration (Part II) occurred over the summer and fall of 2006 and 2007, respectively. In Part I, a greater total abundance and species richness ($P < 0.05$) was found to be associated with the cages, but greater evenness ($P < 0.05$) was found on the reef. No significant difference ($P > 0.05$) was found in species diversity according to Simpson's index by habitat type, but it was significant ($P < 0.05$) by month. These samples were dominated by naked goby (*Gobisoma bosc*) and Atlantic mud crab (*Panopeus herbstii*). Spaghetti worm (Ampharetidae, $P < 0.01$), sheepshead (*Archosargus probatocephalus*, $P < 0.01$), blue crab (*Callinectes sapidus*, $P < 0.01$), grey snapper (*Lutjanus griseus*, $P < 0.05$), gag grouper (*Mycteroperca microlepis*, $P < 0.01$), and Atlantic oyster drill (*Urosalpinx cinera*, $P < 0.05$) were unique to the cages, while the skilletfish (*Gobiesox strumosus*) was unique to the reef. Part II revealed that the floating cages supported 13 species of fish and invertebrates, although no significant differences in species richness, evenness, or diversity were found by month or by bay area ($P > 0.05$). These results suggest that created reefs in conjunction with 'rack and bag' cage systems, as well as floating cage systems, support ecologically and economically important macro-epifauna, even at very small scales.

Keywords *Crassostrea virginica* · Delaware's Inland Bays · Eastern oyster · Habitat value · Macro-epifauna · Oyster aquaculture

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Abbreviations

SAV	Submerged aquatic vegetation
MSX	Multinucleated sphere X
CIB	Center for the Inland Bays
PVC	Poly-vinyl chloride
USDA	United States Department of Agriculture

Introduction

The dramatic decline of the Eastern oyster (*Crassostrea virginica*) population in the Mid-Atlantic and along the Gulf Coast of the USA since the late 1800s has been well documented to be a result of overharvesting, habitat degradation, reduced water quality, and increased mortality from Dermo and multinucleated sphere X (MSX) diseases (Rothschild et al. 1994; Kennedy 1996; Newell 2004). Delaware's coastal lagoons, known locally as Inland Bays, have been experiencing the impacts of sustained nutrient input and sediment erosion from several decades of development within the watershed (Chaillou et al. 1994). The cumulative effects of these pollutants have degraded water quality and reduced the diversity and abundance of submerged aquatic vegetation (SAV), fishes, and invertebrates (Scotto et al. 1983; Chaillou et al. 1994). According to a 1993 assessment, more than 75% of the area in the Inland Bays failed the Chesapeake Bay Program's SAV restoration goals, which are a combination of measures that integrate nutrient, chlorophyll, and water clarity parameters (Chaillou et al. 1994). The conditions were the worst in the canal systems on which many of the homeowners in the Inland Bays watershed reside at least part-time. Chemical contaminant levels exceeded the US Environmental Protection Agency's guidelines in 91% of the area of dead-end canals, and 57% of their area had dissolved oxygen concentrations less than the state standard of 5 mg/L (Chaillou et al. 1994).

Oyster populations in the Inland Bays were largely wiped out by MSX disease in the 1950s, and there have been no recent population assessments (Scotto et al. 1983). Subsequently, restoring oyster populations for their ecological and commercial contribution to the health and viability of coastal estuaries is a common priority and activity among community-based estuary programs (Brumbaugh et al. 2000). Oysters provide ecological services by filtering sediments and algae from the water column, increasing water clarity, and potentially removing nutrients such as nitrogen and phosphorous from eutrophic waters. The filtering activity of oysters also facilitates pelagic-benthic coupling by converting phytoplankton in the water column into biodeposits available to benthic organisms (Newell 2004). Oyster reefs are the primary source of hard-bottom habitat in the predominately soft-bottomed estuaries of the Mid-Atlantic. The complex three-dimensional structure of their reefs provides a habitat for fish and other invertebrates (Kennedy 1996).

The use of community volunteers to help rear oysters for restoration has become common practice throughout the Mid-Atlantic region (Luckenbach et al. 1999; Brumbaugh et al. 2000; Goldsborough and Merritt 2001). The Delaware Center for the Inland Bays (CIB) initiated its program, referred to as 'oyster gardening,' in the summer of 2003 with the help of the Delaware Sea Grant Marine Advisory Program. By placing oysters in floating cages in the Inland Bays' canal systems, growers intend on using the oysters to improve local water quality and clarity, along with providing broodstock to help restore populations to the estuary. Oyster aquaculture can provide many of the same services as oyster reefs (Harding and Mann 1998; Kilpatrick 2002). O'Beirn et al. (2004) examined the

macrofaunal communities inhabiting a raft aquaculture site on the Eastern Shore of Virginia and found a total of 45 species after 10 months of colonization.

This paper describes some of the habitat changes brought about to local ecosystems experiencing small-scale oyster restoration programs by incorporating findings from a 2006 examination of the habitat value of 'rack and bag' oyster aquaculture compared to a created oyster reef (Part I) with ongoing research in the Inland Bays involving the habitat value of floating oyster gardens (Part II). For in-depth analysis and discussion of Part I, please refer to Erbland and Ozbay (2008).

Materials and methods

Part I

The objective of the 2006 study was to examine how macro-epifaunal species abundance and biomass compared in oyster aquaculture cages versus an adjacent created oyster reef.

Study sites

The Indian River Bay is one of the three Inland Bays of southern Delaware and is approximately 3.2 km wide by 9.7 km long, with a surface area of 38 km^2. The bottom is composed of sand and mud, the mean water depth is 1.7 m, and the tidal amplitude is 1.3 m (Scotto et al. 1983; Smullen 1992). The Indian River Bay is classified as highly to very highly enriched under the Chesapeake Bay Program classification scheme (Scotto et al. 1983). The site for this study was in the CIBs James Farm Ecological Preserve near Ocean View, Delaware (Fig. 1), and was selected because it is host to a 5-year-old, created oyster reef, located approximately 4.3 km to the ocean inlet in a relatively well flushed cove (Erbland and Ozbay 2008).

Sampling design

A two (habitat type) by three (month) factorial design with four replicates for each habitat type (rack and bag cages and reef) in each month was used (Erbland and Ozbay 2008). Setup began and all oysters for aquaculture cages were brought to the site in April of 2006. Twelve 'modified rack and bag' oyster cage systems were used in this study. Each vinyl-coated, 25-mm wire-mesh cage measured 61 × 61 × 61 cm and contained four internal divisions, with each of the upper three occupied by a single 61 × 61 × 10-cm plastic, 5-mm mesh bag. Twelve cages were placed subtidally (average depth 1.2 m) in a single line along the western edge of the reef and spaced 3 m apart. The sub-tidal oyster reef consisted of a 0.1-hectare (30.5 × 30.5-m) base of surf clam (*Spisula solidissima*) shell with clusters of living *C. virginica* and *C. virginica* articulated shells. Twelve sampling baskets, constructed from the bottom 20 cm of a 20-l bucket, were deployed on the reef. Each basket was drilled with 12 holes (40-mm diameter) to allow water and faunal exchange. Oyster clusters of 7–9 cm were collected directly from the reef and used to fill baskets with 2 l measured by displacement. The baskets were then placed in cavities dug into the reef and surrounded by the displaced shell and oysters to lie even with the reef surface. Baskets were spaced 3 m apart in a 3 × 4 grid.

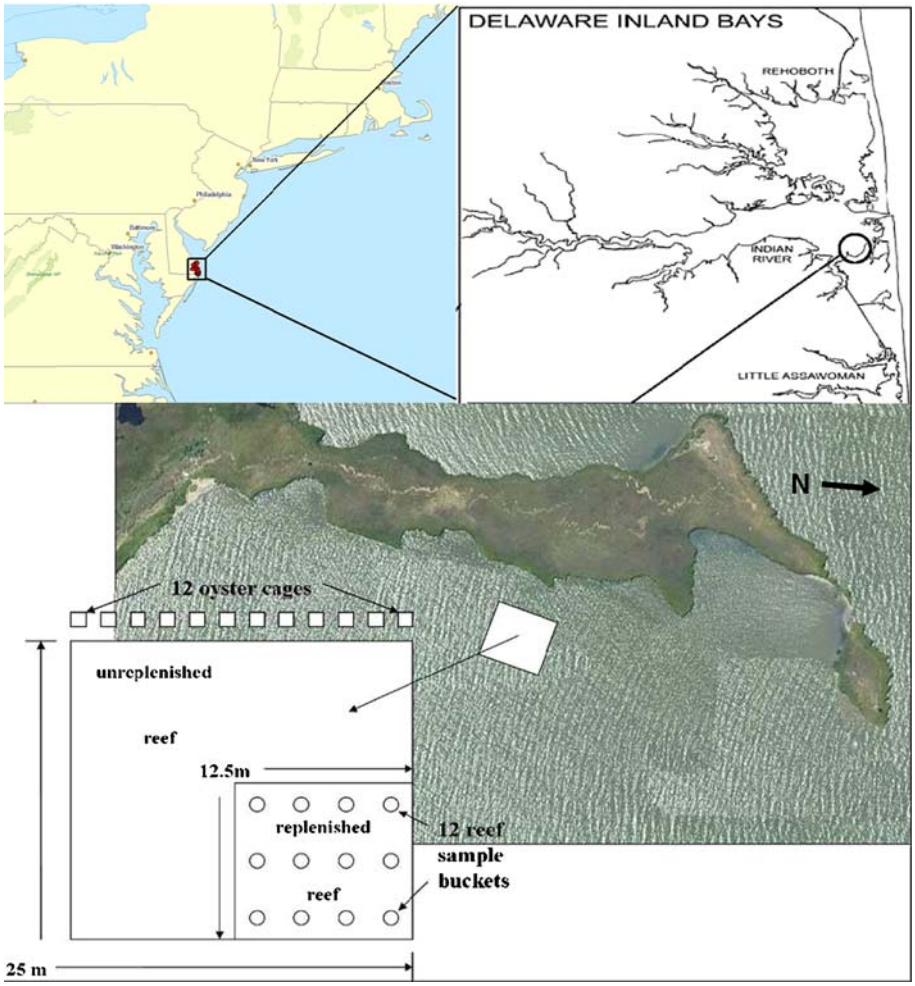

Fig. 1 Location of oyster reef and aquaculture gear at three spatial scales, and layout of the 2006 experiment. Modified from Erbland and Ozbay (2008) (Part I)

Three ecological measures (species richness, evenness, and diversity) were used to compare the macro-epifaunal communities in the two habitats. Cultured oysters consisted of mostly 12-month-old spat with a few 2- and 3-year-old adults. Oyster spat were of the Northeast-Haskins Resistant Strain and were spawned in the spring of 2005 at the Rutgers University Cape Shores Hatchery near Cape May, New Jersey. Oysters were evenly distributed between cages. Sampling occurred on August 10, September 6, and October 3, 2006 (Erbland and Ozbay 2008).

Rack and bag cages were cleaned approximately every 2 weeks (immediately after a sampling event) to remove sediments and algae that, if allowed to accumulate, would have dramatically reduced water flow, especially with this on-bottom type of gear, and would have likely caused significant oyster mortality, which is clearly not a goal of a restoration program, regardless of habitat value (John Ewart, personal communication).

Water quality, oyster data, and motile macro-epifauna

Temperature, salinity, and dissolved oxygen were measured 1 m above the reef during each site visit using a YSI multi-probe (YSI Inc., Yellow Springs, Ohio). Samples were taken within 3 h of low tide during the afternoon. All macro-epifaunal sampling occurred during spring low tide. The oyster reef was sampled by retrieving every third basket starting from a random point. The selected baskets were quickly covered and then enveloped by a 3-mm mesh lift-net before being lifted from the water and carried to a boat. Baskets and netting were placed on a tarp and all motile macro-epifauna were removed from baskets, oyster clusters, and netting and preserved in 70% ethanol. Baskets and oyster clusters were returned to preserve the reef structure. All collected organisms were identified to species according to Pollock (1998), sorted, and enumerated before being dried and weighed. The cages were sampled by envelopment with a 3-mm mesh lift net that had been placed below every third cage, from a random starting point, 2 weeks prior to sampling. Gear and netting was lifted aboard a boat and processed immediately. Oyster bags were removed from the gear and emptied into a plastic bin. All motile macro-epifauna were preserved in 70% ethanol. Cages, bags, and oysters were returned to the water (Erbland and Ozbay 2008).

Data analysis

Three ecological measures (species richness, evenness, and diversity) were used to compare the macro-epifauna between rack and bag cages and the created reef. Species richness, species evenness, and species diversity were calculated using Primer 5.2.4 (Clarke and Warwick 1994). Abundance and biomass for the most abundant shared species were compared in two-way analysis of variance (ANOVA) between habitat and month, performed using JMP 5.1.2 (1989–2004 SAS Institute Inc.).

Part II

Our study aims for 2007 were to evaluate the habitat value of floating oyster aquaculture or 'gardens' by examining the motile macro-epifauna found within them. The development of species assemblage over time was monitored by sampling floats left in the water for 1, 2, and 3 months without being cleaned or otherwise touched by the oyster gardeners.

Study sites

Three areas within Delaware's Inland Bays (Fenwick Island, Rehoboth, and South Bethany) were examined in this study. It was important to include oyster gardeners in each bay area, since a range of environmental quality and growing conditions is represented and covers the entire geographic extent of this restoration program. Each study site consists of a floating cage tied to a dock located at the residences of oyster gardeners living on canals in the Inland Bays watershed. Constructed out of poly-vinyl chloride (PVC) pipe and vinyl-coated, 14-gauge 25-mm wire mesh, each float held two wire baskets measuring 46 × 46 × 23 cm. Sites were chosen randomly from a pool of volunteer oyster gardeners that were willing to participate in the study.

Sampling design

Our floating cage study occurred over the course of 4 months, July through October, 2007. There were three replicate cages of three fouling periods (1, 2, and 3 months) in each of three study areas for a total of 27 study cages. Oysters were of mixed year classes of the 'wild type,' unlike the disease-resistant strain used in Part I, and were obtained as spat on shell from the 2004, 2005, and 2006 cohorts from the Horn Point Laboratory, University of Maryland Center for Environmental Science, Cambridge, Maryland. All oysters at the study sites were already growing in floating cages in the canals since their initial stocking in 2004, 2005, or 2006. A preliminary cleaning of the cages took place in July, during which all previous fouling organisms were removed by washing with a freshwater hose and scrubbing with a wire brush. At this time, water quality data were taken and the total number of oysters (live and dead) was recorded for each of the two baskets in each of the floating cages. Proceeding being cleaned, the cages were not cleaned again or otherwise touched until that site's designated macro-epifaunal sampling. Samplings occurred at approximately 1-month intervals for the next 3 months. Floating cages were not cleaned more frequently due to their position up in the water column, placing the oysters approximately 20–40 cm below the surface, where a level of fouling detrimental to oyster growth was not anticipated. This proved to be in error, but allowed for an assessment of 3 months of summertime fouling on oyster survival and species assemblages. Water quality data and water samples for chlorophyll-*a* and nutrient testing were also collected each month. Each sampling event took 3 days to complete.

Water quality, oyster data, and motile macro-epifauna

Water quality parameters temperature, salinity, pH, and dissolved oxygen were measured using a YSI multi-probe (YSI Inc., Yellow Springs, Ohio). Turbidity was measured using a Secchi disk with a 20-cm diameter. All water samples were collected with 250-ml bottles from an area directly beside the floating cage so as to minimize the disturbance of fauna within the baskets. All water samples were labeled with the site name and time of collection, and kept cool in a Styrofoam cooler with ice packs.

Specimens were collected from the oyster baskets by using a net with a 3-mm mesh size supported by a square PVC frame 24 in wide. This was achieved by placing the net under each basket as it was lifted out of the larger floating cage with a boat hook. With the net enveloping the basket, the oysters were washed thoroughly with a freshwater hose and jostled several times to ensure that all animals were collected. The macro-epifaunal contents of the baskets were carefully picked by hand from the net and preserved in 70% isopropanol solution prior to being identified and counted back at the field station. The proportion of live and dead oysters was recorded and a subsample of oysters was randomly selected and their lengths measured to the nearest 0.1 mm. Fifteen percent of the live oysters and 15% of the dead oysters were measured in each basket. A minimum of ten oysters was measured when 15% of the oysters in a basket would be less than ten individuals.

Data analysis

Species richness, evenness, and diversity were used to compare the macro-epifauna in floating cages and were evaluated with two-way ANOVA by bay area and month along

with water quality variables and oyster survival using MiniTab 15.1.1.0 (MiniTab Inc., State College, Pennsylvania).

Results

Part I

Through the course of the study at the James Farm, temperatures ranged from 12.3 to 24.5°C, salinities ranged from 27.0 to 31.2 ppt, and dissolved oxygen ranged from 7.6 to 12.6 g/ml. The total abundance of all organisms was significantly greater ($P < 0.01$) in the oyster cages (959 individuals/m^2) than on the reef (414 individuals/m^2; Fig. 2). Biomass on the reef was much higher in August than in September or October, represented mostly by *Panopeus herbstii*. There were highly significant ($P < 0.01$) interactions between habitat and month for both of these measures (Table 1).

A total of 18 macro-epifaunal species were collected in this study; eight were found only in the cage habitat, six of which were significant (Table 2). The skilletfish (*Gobiesox strumosus*), while found only on the reef, was not sufficiently abundant to achieve statistical significance (Erbland and Ozbay 2008).

In total, species richness was significantly greater ($P < 0.01$) in the aquaculture cages ($d = 9.92$) than on the created reef ($d = 4.33$), but it was not significantly different ($P > 0.05$) across months (Fig. 3). Habitat and month differences in species evenness values were both highly significant ($P < 0.01$), with the cages ($J' = 0.48$) having a less even distribution of species than the reef ($J' = 0.65$). Species diversity (Table 1) was not significantly ($P > 0.05$) different between the created reef and the rack and bag cages, but there was a highly significant ($P < 0.01$) month effect with diversity increasing through time (Erbland and Ozbay 2008).

Part II

The temperature ranged from 23.3 to 30.3°C, and salinity ranged from 28.2 to 33.1 ppt from July to October 2007 at study sites in the Inland Bays canals. Dissolved oxygen levels

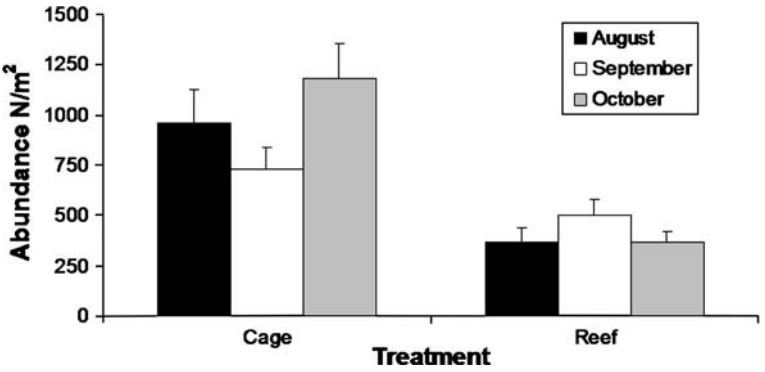

Fig. 2 Mean total abundance (*N*) of macro-epifauna by month for each habitat type (±1 SD; Erbland and Ozbay 2008; Part I)

Table 1 Significance levels of two-way ANOVAs between habitat and month for community-level measurements comparing a 'rack and bag' culture system with a created reef in Delaware's Inland Bays, USA (Erbland and Ozbay 2008)

	Habitat	Month	Interaction
Total			
Abundance	**		**
Biomass			**
Species richness	**		
Species evenness	**	**	
Species diversity		**	

Blank not significant

* $P < 0.05$; ** $P < 0.01$

Table 2 Significance levels of two-way ANOVAs for individual species abundance and biomass for a 'rack and bag' culture system and a created reef in Delaware's Inland Bays, USA (Erbland and Ozbay 2008)

Species	Abundance			Biomass		
	Habitat	Month	Interaction	Habitat	Month	Interaction
Ampharetidae	**	**	**	*		
Anguilla rostrata						
Arbacia punctulata						
Archosargus probatocephalus	**			*		
Callinectes sapidus	**	**	**	**	*	*
Chaetodon ocelatus					*	
Gobiesox strumosus						
Gobisoma bosc	*	*			**	
Hypsoblennius hentzi					*	
Ilyanassa obsoleta				NM	NM	NM
Lutjanus griseus	*			*		
Mycteroperca microlepis	**			*		
Nereididae	*	**	**	**	**	**
Opsanus tau						
Palaemonetes vulgaris		*		*	**	*
Panopeus herbstii	**	*		*	**	**
Tautoga onitis						
Urosalpinx cinera	*			NM	NM	NM

NM not measured, *blank* not significant

* $P < 0.05$; ** $P < 0.01$

were found to be highest at sites nearer the bay and lowest in the dead-end canals with a range from 2.3 to 9.6 mg/L (Fig. 4).

Species found in the floating cages were grass shrimp (*Palaemonetes* spp.), mummichog (*Fundulus heteroclitus*), naked goby (*Gobiosoma bosc*), rainwater killifish (*Lucania parva*), striped blenny (*Chasmodes bosquianus*), oyster toadfish (*Opsanus tau*), American eel (*Anguilla rostrata*), inland silverside (*Menidia beryllina*), clam worm (*Neanthes succinea*),

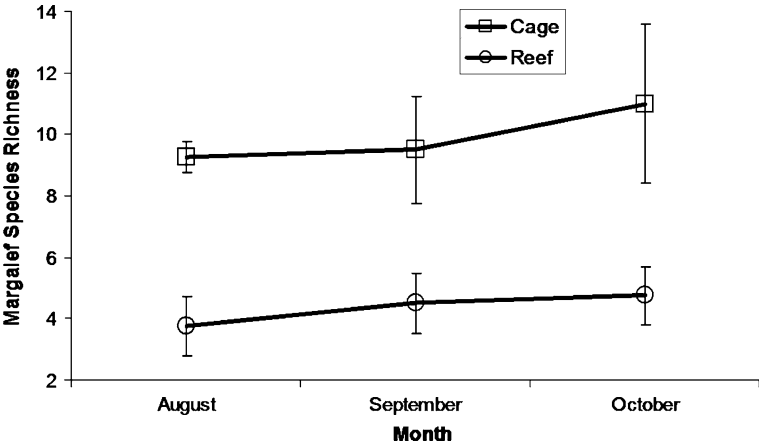

Fig. 3 Mean species richness values of macro-epifauna by month for each habitat type (±1 SD; Erbland and Ozbay 2008; Part I)

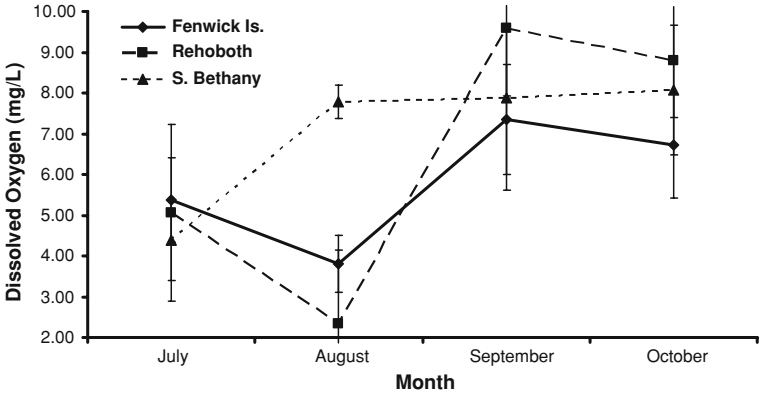

Fig. 4 Mean dissolved oxygen levels (mg/L ± 1 SD) by bay area within Delaware's Inland Bays over the 2007 study period (Part II)

black-fingered mud crab (*Panopeus herbstii*), white-fingered mud crab (*Rhithropanopeus harrisii*), blue crab (*Callinectes sapidus*), Asian shore crab (*Hemigrapsus sanguineus*), and scud (Amphipoda).

Thirteen species were detected in each bay area over the course of the study, although species assemblage varied. A two-way ANOVA revealed no significant differences in species richness, evenness, or diversity by bay area or by month ($P > 0.05$). The total abundance, however, varied by area, with Fenwick Island having the most abundant macro-epifauna samples consistently over the study period (50.5% of all specimens), with Rehoboth Bay (31.0%) and South Bethany (18.5%) having lower levels of abundance, respectively. *Palaemonetes* spp. was by far the most abundant species collected in each area and represented 77.1% of the total abundance for all bay areas.

Dissolved oxygen levels were significantly higher ($P < 0.01$) during September and October than in July and August across all bay areas (Fig. 4). No differences were detected in any other water quality parameters measured by bay area or by month.

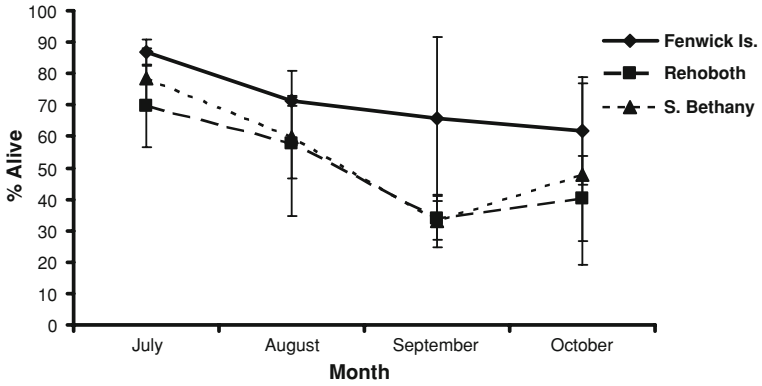

Fig. 5 Percentage of live oysters at study sites in three bay areas within Delaware's Inland Bays over the course of the 2007 study period (Part II)

The percent survival of oysters varied by bay area and by month and ranged from 87 to 33% (Fig. 5). Fenwick Island oysters had significantly more oysters alive between August and October (66.3%) than those in either Rehoboth (44.2%) or South Bethany (47.2%; $P < 0.05$). Although oysters experienced moderate to heavy mortality over the course of the study period, new growth was observed on some of the surviving individuals at some sites.

Discussion

The results of these studies show that the methods of oyster aquaculture employed at these sites support ecologically and economically important macro-epifauna, even at a very small scale. In the Indian River Bay, there is an extremely small natural oyster population consisting of a few scattered individuals and no evidence of any 'natural' reefs to use as a reference (Delaware Inland Bays Estuary Program 1993; John Ewart, personal communication). The intent of this created reef was to test the viability of the James Farm location as a restoration site. The oysters placed here, in conjunction with the modified rack and bag cage system, produced a healthy crop of oysters and supported many beneficial and desirable species. The habitat value of created reefs and aquaculture systems would be amplified if these habitats occurred in a network of patches interspersed with other favorable habitats, such as seagrass beds (Peterson et al. 2003). Oyster aquaculture methods similar to the types discussed here may provide connectivity in an otherwise fragmented habitat by serving as refuges and forage areas for transient species moving through an estuary and further enhancing the benefits of surrounding habitats (Harding and Mann 1998; Breitburg 1999).

In Part I, species richness was significantly greater in the aquaculture cages than on the created reef and remained stable across months. This suggests that most species able to colonize the rack and bag cages did so soon after the experimental setup and were not significantly displaced or succeeded by other fauna. Species diversity did increase over time in both the created reef and the rack and bag cages, perhaps due to progressing colonization or seasonal changes in habitat suitability. The most profound difference between the rack and bag system and the created reef is the number of species that were

found only in the rack and bag cages. Of the 17 species found in the cages, only eight of these were also found on the created reef. The reef structure, although 5 years old, may not have provided adequate three-dimensional relief for the species found only in cages. Juveniles of four 'reef-oriented' fishes (gag grouper, grey snapper, sheepshead, and tautog) were unique to the cages, which may have provided superior foraging opportunities for these transients than the relatively low profile, convoluted reef surface. Blue crabs were also found only in the cages and were composed of molting adults and hard-shelled juveniles. Mud crabs and naked gobies were the most abundant species throughout the study and were in similar abundance in the cages and on the reef. Grass shrimp and oyster drills were more abundant in the cages and were especially prolific in a few of the October replicates. Grass shrimp (*Palaemonetes* spp.) are known to be an important forage species for many commercial and recreational fishes and have been used as indicators of estuarine health (Leight et al. 2005). Differences in the efficiency of gear needed to sample two very different habitat types cannot be overlooked here. However, efforts were made (dropping a net through the water column over each reef basket) to ameliorate these discrepancies.

The results from Part II provide further insight into the dynamics of the estuarine ecology of Delaware's Inland Bays. The number of species found in each bay was the same; however, species' assemblages varied. Additionally, the species found in the floats in the canal systems in 2007 (Part II) differed dramatically from that found at the James Farm site in 2006 (Part I). Of the species found only in the aquaculture cages at the James Farm site, none were found in the floating cages in the canals. The fishes attracted to the cage systems at the James Farm site may not have been present in the canals due, in part, to the lower average dissolved oxygen levels in the canals. Blue crabs, particularly juveniles, were commonly found in floating oyster gardens (Part II), as in the rack and bag system (Part I). Use of aquaculture gear by blue crabs, a commercially and recreationally important species, the populations of which are known to be in peril in the Mid-Atlantic area (Messick and Casey 2004), may constitute a significant refuge habitat in the Inland Bays estuary. Although common on the created reef, no oyster drills were collected in any of the oyster floats in the canals in any bay area. Perhaps a lack of connectivity between the Inland Bays' canals and any offshore oyster reefs (or even the James Farm reef) prohibited the movement of this non-pelagic spawning species into the canals. Changes in species composition may pertain to seasonality or colonization time and may be further confounded by unequal colonization rates between bay areas. The close proximity of the James Farm to the Indian River inlet and the Atlantic Ocean may well explain the source of some species. Nevertheless, species which associate with natural oyster reefs were found among oysters in the floating cages (Part II), specifically, black-fingered mud crab, white-fingered mud crab, oyster toadfish, naked goby, and striped blenny. These three 'resident' fishes require oyster shells for spawning substrate (Breitburg 1999; Harding and Mann 2000) and would very likely be enhanced by the oyster-growing operations described here, especially considering the extremely limited oyster shell remaining in the Inland Bays. Higher total species abundance in Fenwick Island than in Rehoboth and South Bethany may be explained primarily by their proximity to the inlets from the Atlantic Ocean in Ocean City, Maryland, and Indian River, Delaware, respectively. The canals in the South Bethany area are the furthest from either inlet and are connected to the Indian River inlet to the north ($\sim$13 km) by a narrow, shallow canal and to the Ocean City inlet ($\sim$21 km) to the south by a stretch of marshland, and two shallow bays (Little and Big Assawoman Bays) inhibiting strong tidal exchange and making tidal migration of fishes and other species difficult, along with reducing the potential for larval recruitment. Fenwick Island also experiences the most tidal flushing of the three bays (John Ewart, personal communication).

Further data from Part II reveals a higher percent of oysters alive at Fenwick Island than either Rehoboth or South Bethany. Oyster mortality seen across bay areas over the course of the study period may be explained by several factors. Periods of low dissolved oxygen occurred in the canals during the summer months and could have caused stress to the oysters and affected their survival. Interestingly, dissolved oxygen levels were similar in each bay over time, with an apparent increase during September and October (Fig. 4). Despite the ecological effects evident at this scale, there were no noticeable improvements on the measured water quality parameters either at the James Farm site or in any of the canals attributable to oyster filtration. A significant increase in oxygen levels, due to cooler fall water temperatures and much less frequent phytoplankton blooms (University of Delaware Citizen Monitoring Program [UDCMP] 2008) suggests that there are major seasonal dynamics that likely influence the habitat value of the aquaculture systems discussed here that may out-weigh those of colonization time. The results and observations from Parts I and II make it apparent that much care is needed in the form of regular cleaning of sediments and algae for oysters to survive and grow well in these degraded environments. In Part II, the oyster floats were cleaned monthly in a systematic fashion to allow for the study of fouling time on habitat value. Unfortunately, this could not prevent sediments from accumulating on the oysters and likely negatively affected their survival. If volunteer oyster gardeners would have cleaned their floats according to their own schedules however, it would have been impossible to examine how cleaning frequency affected habitat value. Developing standardized guidelines to optimize oyster growth without reducing habitat value is critical to our understanding of this restoration program.

When properly maintained, the oysters on the reef, in rack and bag cages, and in floating cages could serve as broodstock in the estuary enhancing natural recruitment that is currently so limited in the Inland Bays. Oysters ultimately harvested from the system would take with them excess nutrients from the bay incorporated in their tissues (Shumway et al. 2003). Using a variety of aquaculture techniques to create a patchwork of habitats throughout the estuary may be the most effective way to restore ecosystem functionality to the Inland Bays. This information will undoubtedly help decision makers and the general public formulate opinions and policies in the future. Using oysters to improve habitat and local water quality may provide localized benefits even in estuaries with environmental conditions similar to those of Delaware's Inland Bays. Oyster aquaculture can provide additional or alternative habitat for native macro-epifauna, even at small scales, without additional types of habitat modifications long before larger oyster restoration goals are realized. The fate and structure of oyster aquaculture for restoration or for commercial purposes in Delaware and other Mid-Atlantic states in the USA relies on evolving our understanding of the ecological costs and services that these efforts bestow upon estuarine ecosystems.

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