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Can't Go Wrong With Eastern Oysters (*Crassostrea virginica*): Restoring the Delaware Inland Bays' Biodiversity

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Crassostrea virginica is notably known for its ability to create complex habitats known as oyster reefs [1]. Oyster reefs provide the primary source of hard bottom habitat along the eastern seaboard of the United States, yet natural reefs are absent from the Delaware Inland Bays [2,3]. Oysters form reefs through a positive feed-back loop in which the shell matrix formed by resident oysters provides new substrate for the continual recruitment, settlement, and survival of successive generations [4]. Shellfish beds trap and incorporate shells, sediment, algae, and other floating particles which provide a framework of material for tube-builders, bacteria, microalgae, invertebrates, other benthic species to live within [5]. A variety of fauna utilize these structures for refuge and resource acquisition [6-9]. Large oyster reefs are analogs to coral reefs, forests, salt marshes, and other habitats that perform critical ecosystem services [10].

In Delaware Bay, Taylor and Bushek [11] describe a relatively rapid development of a diverse ecological community on constructed intertidal oyster reefs (Figure 1) similar to the natural sub-tidal oyster community studied by Maurer and Watling [12]. Oyster reefs increase species richness when compared to adjacent oyster-free areas, and may serve as essential habitat for numerous species of fish and invertebrates [13-16]. However, these restoration efforts have been impeded by substrate and recruitment limitations along with many other detrimental factors in their environment including water quality, land use, habitat alteration, diseases. Overfishing, habitat degradation, diseases have decimated oyster populations and there is a growing need for large scale restoration and enhancement in our local estuaries.

Enhancing oyster population abundance in the Delaware Inland Bays is an extremely difficult task. Due to extremely low population counts, natural recruitment of *C. virginica* is rare in these waters. Additionally, historic accounts of oysters in the Delaware Inland Bays are controversial, as very limited documentation exists [17]. In order to optimize ecosystem rehabilitation efforts, basic knowledge is needed before any large scale restoration efforts are put underway [18]. It is important to realize oysters grown in aquaculture gear are creating habitat for a variety of species before they are planted for restoration in the bays [17]. Several demersal species such as blennies, gobies, and skilletfish, utilize oyster shell as spawning substrate [19]. When oyster restoration efforts are attempted, it is unclear how restoring oysters in various habitats influences community structure [20]. Murray et al. [21] suggested investigating structure forming biota is valuable because bioengineered habitats such as oyster reefs are diverse and vulnerable to impacts. Restoration efforts with native Eastern Oyster (*Crassostrea virginica*) in the Delaware Inland Bays (Figure 2a) have been limited and challenging but progress is being made.

Figure 1: Clusters of oysters function together to form an oyster reef.

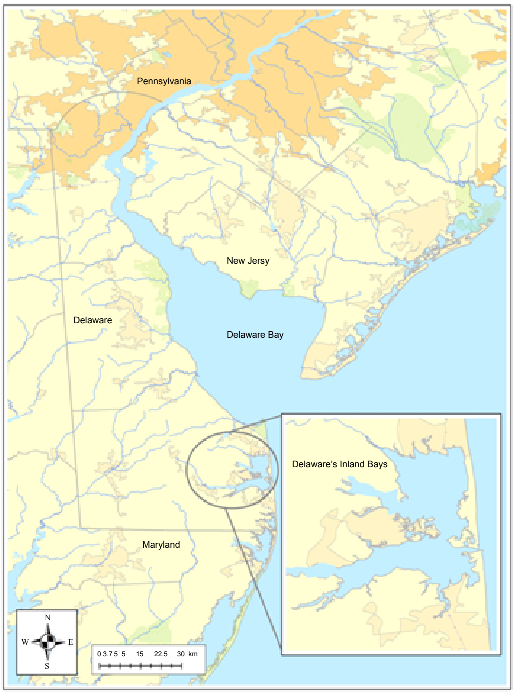

Figure 2a: Delaware Inland Bays.

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To facilitate oyster population expansion, The Delaware Center for the Inland Bays with help from the Delaware Sea Grant Marine Advisory Program, started Delaware's oyster gardening program in 2003. In 2005, staff and students from Delaware State University joined this program focusing on research efforts and program development and implementation. According to Brumbaugh et al. [22] oyster aquaculture through community based restoration programs can be an effective small scale restoration technique. Measuring biodiversity in and around the equipment is a holistic means to evaluate the impact of culture operations on the ecosystem (Figure 2b). Unlike some finfish farming, rearing shellfish in high densities in shallow water can have positive effects on the environment and may increase biodiversity.

To date, Delaware's oyster gardening program has logistically provided the resources (i.e. oysters and gear) for a series of research projects to assess the overall success of the oyster restoration, habitat value, and water quality of the bays. Initiated in 2005, these research projects progressed from first utilizing cages and artificial reefs, to current operations utilizing Taylor floats, and then stocking oysters into

Oyster Gear	**Taylor Floats**	**Taylor Floats**	**Rip-raps**
2006	**2007**	**2008**	**2010-2011**
Taxa			
Ampharetidae	*Palaemonetes pugio*	*Palaemonetes spp. (P. vulgaris, P. pugio, P. intermedius)*	*Fundulus heteroclitus*
Anguilla rostrata	*Fundulus heteroclitus*	*Chrysaora quiquecirrha*	*Palaemonetes pugio*
Arbacia punctulata	*Gobiosoma bosc*	*Fundulus heteroclitus*	*Lucancia parva*
Archosargus probatocephalus	*Lucania parva*	*Gobiosoma bosc*	*Cyprinodon variegatus*
Callinectes sapidus	*Chasmodes bosquianus*	*Lucania parva*	*Palaemonetes intermedius*
Chatedon capistratus	*Opsanus tau*	*Chasmodes bosquianus*	*Gobiosoma bosci*
Gobiesox strumosus	*Anguilla rostrata*	*Opsanus tau*	*Callinectes sapidus*
Gobisoma bosc	*Menidia beryllina*	*Anguilla rostrata*	*Fundulus luciae*
Hypsoblennius hentzi	*Neanthes succinea*	Xanthid crabs (*Panopeus herbstii*, *Eurypanopeus depressus*, *Neopanopeus sayi*, *Rhithropanopeus harisii*)	*Fundulus confluentus*
Ilyanassa obsoleta	*Chrysaora quinquecirrha*	*Callinectes sapidus*	*Fundulus majalis*
Lutjanus griseus	*Panopeus herbstii*	*Gobiesox strumosus*	
Mycteroperca microlepis	*Rhithropanopeus harisii*	*Apeltes quadracus*	
Nereididae	*Callinectes sapidus*	*Lagodon rhomboides*	
Opsanus tao	*Hemigrapsus sanguineus*	*Menidia menidia*	
Palaemonetes vulgaris	*Gammarus* spp	*Paralichthys dentatus*	
Panopeus herbstii		*Neanthes succinea*	
Tautoga onitis		*Cynoscion nebulosus*	
Urosalpinx cinerea		*Eucinostomus argenteus*	
		Syngnathus fuscus	
		Archosargus probatocephalus	
		Nassarius vibex	
		Hippolyte sp.	
		Orthopristis chyrsoptera	
		Anchoa mitchelli	
		Alpheus heterochelis	
		Seriola zonata	
		Cyprinodon variegatus	
		Centropristis striata	
		Stylochus ellipticus	
		Diadumene leucolena	
		Haliplanella luciae	
		Bryozoan spp.	
		Cliona sp.	
		Botryllus schlosseri	
		Balanus eburneus	
		Halichondria bowerbanki	
		Hydroides dianthus	
		Geukensia demissa	
		Crepidula fornicata	
		Molgula manhattensis	
		Gammarid amphipods	
		Probopyrus pandalicola	
		Sabellaria vulgaris	
		Enteromorpha sp.	
		Ceramium sp.	
		Gracilaria sp.	
		Polysiphonia sp.	
		Agardhiella sp.	
		Fucus sp.	
		Ectocarpus sp.	
		Chaetomorpha sp.	

Table 1: List of species observed during 2006-2011 study period in and around oyster aquaculture equipment during oyster gardening program in Delaware Inland Bays [2, 4, 24].

shoreline rip-raps (Table 1). One of the main focuses of all these projects has been to monitor species diversity and abundance in and around the cages, floats, and rip-rap crevices. Studies conducted around submerged aquaculture gear in 2006, found 18 species showing significantly greater abundance and richness in and around the oyster cages (Figure 3a) than in adjacent low-profile oyster shell reefs and natural shorelines [2]. In 2007, Marenghi and Ozbay [3] found 15 species around the Taylor floats vs. the eutrophied, turbid, soft-bottom lagoon (including 3 species that require oyster shells for spawning substrate). In 2008, 57 taxa of fishes and invertebrates and 8 species of macro algae were collected from floats (Figure 3b), greatly contributing to the diversity of the native ecological community [3]. Many of these species have commercial or recreational importance and are habitat-limited in the Inland Bays estuary due to direct and indirect loss of tidal wetlands, oyster reefs, and seagrass beds, which are particularly important as juvenile feeding and staging areas. Furthermore, newly settled juvenile oysters have been found for the first time within floating oyster gear in man-made, residential canal systems. Oysters in small abundances (<200 oysters per float) increase species diversity in aquaculture gear located in stagnant waters of dead end lagoons [23] and provides justification for future large scale efforts in the Delaware Inland Bays. The most recent study, utilizing rip-raps as potential hard substrates for oyster stocking (Figure 3c), resulted in less species diversity than natural shorelines. Difficulty of capturing species in and around the rip-rap crevices was a major problem, and most likely the resulting catch did not fully represent the community living within the rip-rap crevices. However, species distribution overall was more even for the rip-raps stocked with oysters as compared to rip-raps without oysters or the natural marsh shorelines (Figure 3d and 3e), and

Figure 2b: Impact of culture operations on the ecosystem

Figure 3c: Rip-raps stocked with oysters

Figure 3a: Oyster cages

Figure 3d: Planting oysters in rip-rap crevices

Figure 3b: Taylor floats

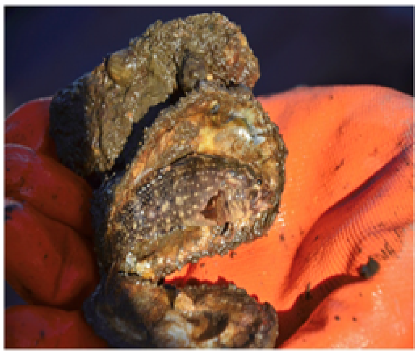

Figure 3e: Blenny utilizing a dead oyster as habitat

over 10 species were recorded or observed in and around the crevices in rip-raps with oysters [24]. The most abundant species from all study sites (81% of total catch), the mummichog, *Fundulus heteroclitus*, was found significantly largest at the rip-rap with oyster shoreline, possibly because it is feeding on smaller prey within the small creviced oyster stocked communities [24].

In Virginia, 45 species of macro-fauna were recorded inhabiting one commercial oyster farm that used floating equipment [25]. In a study in Rhode Island, species richness was significantly greater in submerged aquaculture equipment than in a nearby seagrass bed or an un-vegetated sand flat, especially for fishes and invertebrates in their early life stages, demonstrating the equipment may benefit some species more than others [26]. In the study by White et al. [27], rip-rap contained higher species diversity and higher mean species richness, when compared to two other shoreline habitats with log jams and mud banks in the Kansas River. Modified shorelines have the most drastic effect on fish densities when the shoreline has been extensively modified from the supra-tidal down to the sub-tidal zone [28], thus creating a deep-water zone adjacent to the shoreline. Results from Toft et al. [28] suggest that both shoreline substrate type and slope of the shoreline are the most important factors affecting fish densities. Near shore marsh habitat consistently had greater abundance, richness, and biomass of fish than beach or open habitats in Massachusetts estuaries [29].

These studies are critical to our understanding on the complex ecological interactions that occur and will allow farmers, managers, and regulators to fully appreciate the important ecological services oysters provide. Measurable effects like these coupled with continuing community involvement makes oyster gardening a vital component of the oyster restoration effort in Delaware. Eastern oysters are part of the solutions in our journey to restore and mitigate the habitat that has been long lost in Delaware waters and needs long term care and attention to persist. Since 2005 we have been assessing the role of live oysters in providing habitat, community metrics of resident fishes and decapod crustaceans using various aquaculture techniques and equipment that confirm our claim that indeed oysters form habitat and increase species diversity in Delaware waters.

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