Citizen Science and Technology Support Reintroduction of the Eastern Oyster (*Crassostrea virginica* Gmelin) in an Urban Estuary

Beth Ravit[1*], Magda Usarek-Witek[2], Meredith Comi[3]

[1] Center for Urban Environmental Sustainability (CUES)
Department of Environmental Sciences
School of Environmental & Biological Sciences
Rutgers University
14 College Farm Road
New Brunswick, NJ 08901
P: 848-932-5752
E: ravit@envsci.rutgers.edu

[2] New Jersey Department of Environmental Protection
Division of Land Use
P.O. Box 420
Mail Code 501-02A
Trenton, NJ 08625

[3]Oyster Restoration Program Director
NY/NJ Baykeeper
52 W. Front St.
Keyport, NJ 07735

*Corresponding Author: Beth Ravit, PhD.

ABSTRACT
The advent of 21st Century digital data collection technologies and inexpensive online software expands opportunities to integrate volunteer support of scientific data collection. The 4,144 km^2 Hudson-Raritan Estuary encompasses New York/New Jersey Harbor, one of the most urbanized estuaries in the world. Reintroduction of the Eastern Oyster (*Crassostrea virginica*) could contribute water quality benefits, potentially reducing turbidity and nitrogen loadings. Recruitment of citizen scientist volunteers, using hand-held GPS devices, allowed researchers to collect data, map, and initially evaluate over 30 miles of shoreline to assess site-specific potential for oyster reintroduction. This rapid and inexpensive data collection further refined previously generated maps based on a limited number of physio-chemical parameters. Trained and supervised volunteers increased the spatial scale of the survey. Utilizing free and/or easily accessible software enhanced public dissemination of the scientific data.

Key Words: Citizen Science, urban estuary, species reintroduction, Eastern oyster, GIS mapping

INTRODUCTION

Since initiation of the Audubon Christmas Bird Count in 1900, citizen scientists have been engaged in data collection. However, recent innovations in digital technology are increasing opportunities to include the public in scientific data collection. There are a number of different reasons to encourage the inclusion of non-scientists in research initiatives. Scientists may interact with the public for the purpose of increasing environmental/ecological knowledge while enhancing the stewardship of a natural resource (Lundmark 2003; Bonney et al., 2009), as well as to acquire specific scientific data (Lepczyk 2005; Delaney et al., 2008; Ingwell & Preisser 2010; Gallo & Waitt 2011).

Questions associated with the engagement of citizen scientists and the data they collect include concerns about data quality assurance/quality control and overall reliability of the data collected (Foster-Smith & Evans 2003; Newman et al. 2003; Galloway et al., 2006; Kremen et al., 2011; Riesch & Potter 2014). In spite of these concerns, a number of scientists have noted multiple benefits associated with data collection by citizen scientist volunteers, especially when research must address large spatial scales (Bonney et al., 2009). With adequate training, these benefits can now be augmented through the expanding use of digital equipment/smart phones (Cohn 2008; Silverton 2009).

The Hudson-Raritan Estuary (HRE) encompasses NY/NJ Harbor, one of the most urbanized estuary systems in the world. Habitat degradation in urban estuaries has resulted in the extinction of once ubiquitous fauna (Jackson 2001); in the case of the HRE, extinction losses include the Eastern Oyster (*Crassostrea virginica* Gmelin), historically an integral member of this estuarine community (MacKenzie 1992; McCay 1998). However, passage of U.S. environmental laws and regulations over the last five decades has resulted in water quality improvements which may once again allow native species to survive. Reintroduction of the oyster could contribute additional water quality benefits including reductions in turbidity and the system's high nitrogen loadings (Coen et al. 2007; Grabowski et al. 2012).

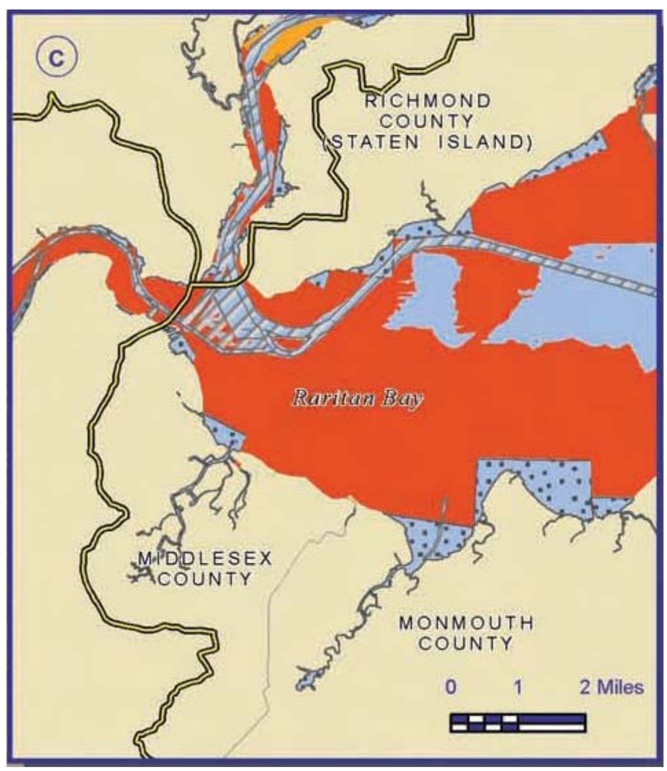

Figure 1. Map showing potential oyster restoration locations identified in the draft Hudson-Raritan Estuary Comprehensive Restoration Plan. ***Map reproduced from the draft HRE Comprehensive Restoration Plan (2009).***

By correlating a species' presence/absence with specific environmental or habitat characteristics, populations can be reintroduced at sites whose attributes closely match sites where existing populations remain (Barnes et al. 2007; Pollack et al. 2012). A Draft Comprehensive Restoration Plan (CRP 2009) developed for the HRE modeled four physio-chemical parameters critical for juvenile oyster survival (salinity, dissolved oxygen, turbidity, bathymetry). This model resulted in the production of a map (Fig. 1) suggesting that multiple locations within the estuary could potentially support successful oyster reintroduction.

However, our previous research within this mapped area suggested that successful survival and long-term fitness of reintroduced oysters would be very site-specific (Ravit et al. 2012; Ravit et al. 2014). In an estuary such as the HRE, where once native oysters are now considered to be 'ecologically extinct', larval densities are thought to be extremely low, and historic food webs and nutrient loadings are anthropogenically altered, commonly employed mapping/modeling approach may have limited value in determining locations with a high potential for reintroduction success.

Our research objective was to evaluate whether the CRP (2009) target of 200-acres of reintroduced oyster reef was a feasible goal given existing habitat conditions in Raritan Bay. We determined that additional data describing site-specific habitat attributes were needed. Our goal was to more precisely identify locations where existing conditions might be likely to support oyster reintroduction success, while also identifying those locations where the chances of oyster survival might be low.

However, given the size of the HRE (4,144 km^2/1,600 mi^2) and the absence of system-wide ongoing scientific monitoring programs, obtaining site-specific data is not easily accomplished. We decided to focus our data collection efforts on Raritan Bay. This portion of the HRE was the original site of hundreds of acres of oyster reef known as the Great Beds of Raritan Bay (McCay 1998), and our research oysters previously placed in Raritan Bay appeared to be healthy and capable of successful reproduction (Ravit et al. 2014). We also decided to try to engage 'citizen scientist' volunteers to expand the spatial scale of our data collection efforts.

METHODS

NGO Volunteer Recruitment

Non-governmental organization (NGO) project partner NY/NJ Baykeeper posted a request for volunteers on the organization's website and 40 individuals responded. The scientific expertise of these volunteers varied greatly, from environmental professionals employed by Monmouth County, NJ Parks Department to inexperienced high school students. Out of the initial 40 individuals who responded to the request for volunteers, 18 attended a required training session and subsequently participated in the data collection.

To give volunteers a basic understanding of the project's scientific objectives and data collection techniques, all volunteers were required to attend a formal three hour training session prior to field work. Environmental benefits attributed to the presence of the Eastern Oyster, the animal's life cycle and physiology were described. Volunteers were shown pictures of the various biota whose presence/absence data were being collected. These photos were laminated for volunteer reference during field work.

Participants were also trained use a drop down screen and to input quantitative data into Magellan Arc hand-held GPS devices.

Field Data Collection

We preloaded the GPS devices with a drop down menu, which contained twenty-three specific environmental variables (Table 1) that described various habitat characteristics. These attributes were selected because they might positively or negatively affect successful oyster reintroduction. Three-member teams (a Rutgers scientist or Baykeeper oyster program staff member, plus two volunteers) collected data at sampling locations covering approximately 30 miles of the Raritan Bay NY and NJ shoreline. Sampling sites were located approximately 100 meters apart, ending southeastward at Sandy Hook, NJ and northwestward at Crescent Beach Park, located on the southern shore of Staten Island.

At each sampling location water column and substrate data were collected (Fig. 2) using hand-held GPS units during a time period between two hours before to two hours after mean low tide. Water quality measurements (temperature, salinity, TSS, oxygen) were obtained in water ~1 m deep, approximately 30 cm below the water surface, using hand-held probes (YSI, model #55). Benthic samples were then collected using clam rakes. Shoreline observations were made at the location which was at a direct right angle to the water column sampling point and digital photos were taken of the shoreline opposite the data collection points. Using a touch keypad, a box was checked for all variables observed. Specific water quality data numerical parameters were entered using the device's touch keypad. The data were uploaded, stored in the hand-held units, and subsequently downloaded at the Rutgers Center for Remote Sensing and Spatial Analysis (CRSSA), where data analysis and mapping was completed.

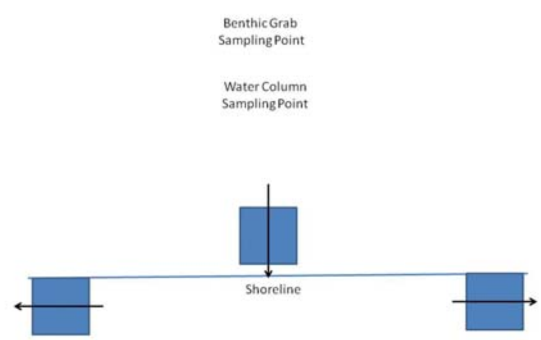

Figure 2. Schematic illustrating sample collection.

Map Generation

A Rutgers Center for Urban Environmental Sustainability (CUES) summer intern integrated the coordinate points and habitat attribute data collected by the volunteers into a GIS layer (*potential restoration locations*). The GPS coordinates were imported into ArcGIS as a shapefile with attribute tables. The attribute table derived from the GPS data was then exported to Microsoft Excel (2007), and the attributes were integrated into an Oyster Reintroduction Index Score (ORIS) for each location sampled.

Each habitat attribute sampled was given a positive or negative value (Table 1) between -5 and +5, with the exception of low dissolved oxygen. Because death results for sessile oysters when dissolved oxygen remains below 4 mg L^{-1} over an extended time period, a reading below this concentration was given a value of -10. Values were summed for each sample collection point to derive the overall ORIS Index Score. Locations were ranked to determine low and high scoring sites based on the criterion selected. The ORIS results were then integrated into the attribute table of *potential restoration locations* layer using ArcGIS. The results were displayed in a traditional two dimensional format, as well as an online interactive digital format (a link to an interactive version of the map can be found at http://cues.rutgers.edu/benthic/index.html.

Table 1. Oyster Reintroduction Score parameters and weight given to each in calculating the overall Oyster Reintroduction Index Score (ORIS).

Factor	Rank	Criteria	Score	Reason Selected
Bulkhead	Negative	Presence	-1	Non-natural
Oyster Drill	Negative	Presence	-1	Potential predator
Armored	Negative	Presence	-2	Potential attractive nuisance
Roadway	Negative	Presence	-3	Runoff potential toxic effects
Soft clam Live	Negative	Presence	-4	Existing species
Substrate Silt	Negative	Presence	-4	Potential to smother oysters
Ulva mats	Negative	Presence	-4	Potential to smother oysters
Water Salinity	Negative	Below 10	-4	Too fresh
Hard clam	Negative	Presence	-5	Existing species
High Energy	Negative	Presence	-5	Unstable conditions for accretion
Substrate Soupy Mud	Negative	Presence	-5	Potential to smother oysters
Dissolved oxygen	Negative	Below 4	-10	Summer conditions
Blue Mussel Live	Positive	Presence	1	Indication of food & water quality
Oyster Dead	Positive	Presence	1	Substrate
Rock	Positive	Presence	1	Substrate
Sand Beach	Positive	Presence	1	Natural shoreline
Gravel	Positive	Presence	2	Potential substrate
Eel Grass	Positive	Present at shore	3	Good water quality
Spartina	Positive	Presence	4	Natural, lower energy
Water Salinity	Positive	Above 10	4	
Dissolved oxygen	Positive	Above 4	5	Summer conditions
Firm Hard Sand	Positive	Presence	5	
Live Oysters	Positive	Presence	5	Supportive conditions for survival
Oyster spat	Positive	Presence	5	Food & Water Quality supportive of oysters
Dock	Neutral	Presence		
Mussel Bed	Neutral	Present at shore		
Phragmities	Neutral			Shoreline
Razor clam Live	Neutral			
Red Seaweed	Neutral			
Riprap	Neutral	Presence		May be positive (substrate) or negative
Shell Hash	Neutral	Presence		High Energy
Water Temperature	Neutral			Summer sampling time period

The online interactive map was created using the ArcGIS Online platform provided by Environmental Systems Research Institute (ESRI). The finalized *potential restoration locations* layer was converted into a KML file using the ArcGIS conversion toolbox, and the ranked sample locations in the KML file uploaded into the ArcGIS online interface. The field photos were linked to each sampled location through simple html coding. Each individual layer in the online interactive map was selected and isolated from the ArcGIS layer and converted to the KML file format so it could be uploaded onto the website. The basemap is provided through ArcGIS Online and the digital images were created in Photoshop using the volunteer's field photos. Potential viewers are able to select a sampled location and view all scientific data associated with that location, as well as the adjacent shoreline photos. The map provides a unique way to illustrate possible oyster reintroduction locations with high or low chances of success, while giving the general public access to scientific data from specific locations on Raritan Bayshore.

The printed version of *oyster restoration locations* is composed of the edited attribute data known as the *potential restoration locations* GIS layer combined with data available from the New Jersey Department of Environmental Protection (NJDEP) and New Jersey Department of Transportation (NJDOT). The bathymetry map originated from the division of water supply and geosciences department within NJDEP, under a series of bathymetric digital elevation grids. The base maps that include municipalities and roadways came from NJDEP and NJDOT. All the data integrated within the printed map is projected under the NAD 1983 State Plane New Jersey 2900 Feet coordinate system. All GIS layers in the completed figure were individually exported for ArcGIS as a .PNG file and edited in Photoshop. Once the layers were stylistically edited they were superimposed on top of each other to create the final map figure.

RESULTS

The map generated based on the ORIS valuations, shows the overall ranking for each sampling location (Fig. 3). Employing a NOAA bathymetry map (Fig. 4), the ORIS valuations were overlaid to calculate subtidal acreage within a depth range of 3–10 ft. (~1–3m) adjacent to locations where the ORIS was highest. Based upon the environmental parameters sampled, over 1,000 subtidal acres in New Jersey waters could be considered for future oyster reintroduction evaluation. Based on the attributes sampled, the northern Raritan Bayshore adjacent to Staten Island does not appear to provide significant oyster restoration acreage opportunities.

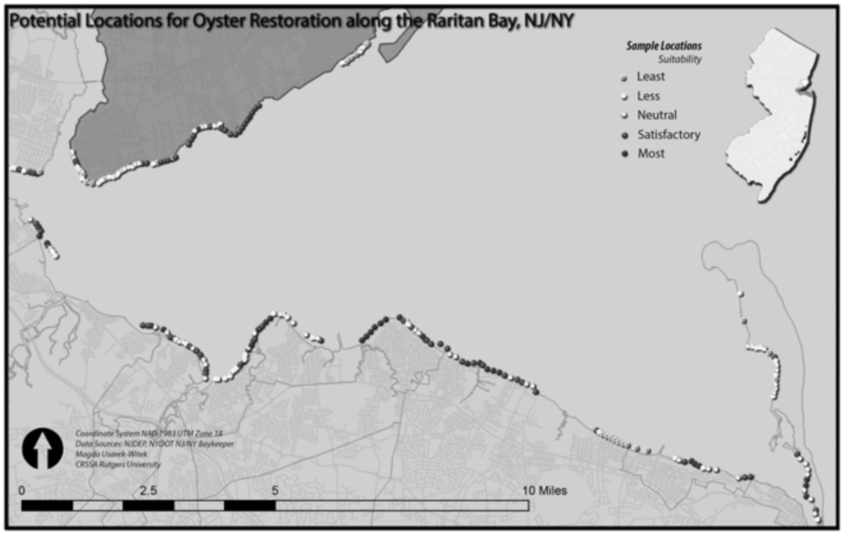

Figure 3. Oyster Reintroduction Index Score (ORIS) derived for locations sampled on the NJ and NY Raritan Bay shore.

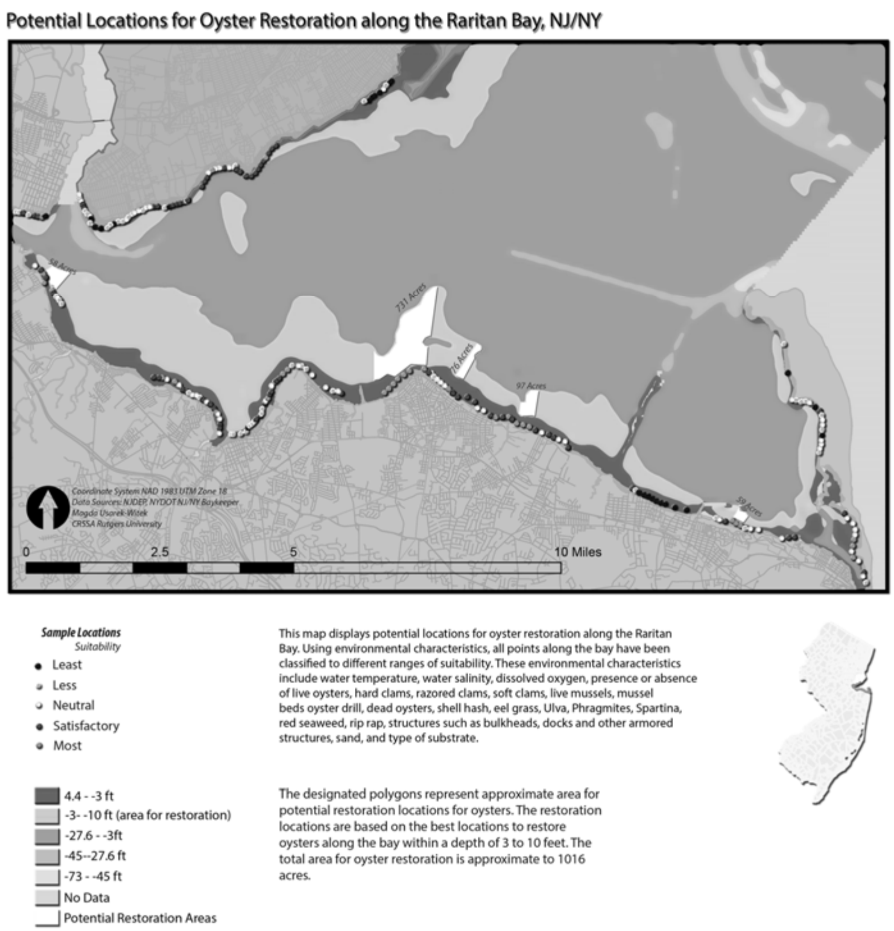

Figure 4. Oyster Reintroduction Index Scores (ORIS) overlaid on NOAA Bathymetry map indicating location of 3 to 10 ft. Mean Low Water (MLW) depths. Purple coloration indicates subtidal areas adjacent to high ORIS locations.

DISCUSSION

Recruiting citizen volunteers and a student summer intern allowed research scientists and NGO restoration practioners to complete an initial evaluation of habitat characteristics over 30 miles of Raritan Bayshore to estimate site-specific suitability for oyster reintroduction. An evaluation at this spatial scale could not have been completed within a similar time frame (twelve weeks) or at a nominal cost without the participation of the citizen scientist volunteers. Data consistency and quality were maintained by creating integrated teams that consisted of both scientists and non-scientists who had completed the formal training related to our data collection methods and objectives.

The maps generated are a first attempt to focus attention toward locations that may have a greater chance of supporting long-term oyster reintroduction success and to eliminate sites that appear to be unsuitable for oyster reintroduction at this time. A publically available interactive map allows oyster restoration practioners (professionals, regulators, and NGOs) to view photographs documenting the shoreline conditions and to view all data collected at a specific location. We emphasize that these maps are a starting point only, and further scientific vetting is required before any of these higher scoring locations could be considered appropriate for long-term oyster reintroduction sites. We also note that the data collection occurred prior to SuperStorm Sandy, and the variables evaluated may have changed as a result of this extreme storm event.

CONCLUSIONS

Citizen scientists have been participating in scientific data collection for over a century. However, with the advent of 21st Century technologies such as digital data collection, and online software becoming common place, the opportunities to integrate volunteer participation in scientific data collection are expanding. Including well trained and appropriately supervised volunteers in scientific data collection can greatly increase the efficiency and spatial scale of data collection, while minimizing costs. Engaging students knowledgeable in computer mapping and geomatics, while utilizing free and/or easily accessible software can increase dissemination of scientific data to inform decision making by restoration practioners and to enhance public knowledge.

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