<u>FINAL REPORT TO THE HUDSON RIVER FOUNDATION</u>

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Principal Investigator(s): Porter Hoagland and Di Jin

Title: A Framework for Valuing the Ecosystem Services of Shellfish Restoration in the NY/NJ Harbor Estuary

Grantee Institution: Woods Hole Oceanographic Institution

Matching Funds: $49,893

Reporting Period: April 1, 2015 to October 30, 2017.

Accomplishments:
Our research project has been directed at developing a framework for characterizing the net economic values arising from flows of ecosystem goods and services (ESs) associated especially with the restoration of shellfish beds and oyster reefs in the Hudson River, the Hudson-Raritan Estuary, and the NY/NJ Harbor and Estuary (the greater "Hudson Ecosystem").

During Years 1 and 2, we compiled extant values (including non-market values) of the array of ESs that might be provided by shellfish beds and oyster reefs, and we have developed a preliminary model of oyster reef restoration, including factors affecting shellfish productivity.

We have also undertaken work in three areas that extends the research that was originally proposed to HRF. These areas comprise a literature search and review of ecosystem service values for the Hudson Ecosystem, the development of a model of oyster reef restoration, and the assessment of cultural ecosystem services associated with estuarine education programs. Further, we have developed estimates of ES "endpoints" based upon values reported for the broader Mid-Atlantic region.

Specifically, our research team realized the following accomplishments:

- Surveying relevant valuation approaches, studies, and estimates for the ecosystem services (ESs) of the Hudson Ecosystem (Attachment 1).
- Development of estimates of ES endpoints for the Hudson Ecosystem (Attachment 1)
- Identification of the relevant ecosystem services (ESs) for oyster reefs in the Hudson Ecosystem (Attachment 1).
- Application of preliminary estimates of ES values to oyster restoration in the Hudson Ecosystem to estimate annual ES flows (Attachment 1).
- Reviewing and discussing the relevant literature on the valuation of river and estuarine non-market ecosystem services in an ***urban environment*** such as New York City (Attachment 1).
- Development of a model of oyster growth in the Hudson River (Lanoue and Hoagland 2016) as a function of relevant parameters, including salinity (Attachment 2).
- Development of an empirical model of cultural ES values (Hutcheson *et al*. 2017) arising from environmental education in the Hudson River Estuary (Attachment 3).

Name and degree candidacy of students involved in project:

- Julia Lanoue. 2016 B.S. in Environmental Science, Brown University. 2015 WHOI Summer Student Fellow. [Development of theoretical models of oyster growth.]
- Kelly Heber Dunning. 2016 PhD in Natural Resources Management, Department of Urban and Environmental Planning. Massachusetts Institute of Technology. 2015 WHOI Guest Student. [Assistance in literature searches for estimates of ES values relevant to the Hudson Ecosystem.]
- Walter Hutcheson. 2017. B.A. in Biology, New York University. 2016 WHOI Summer Student Fellow. [Development of empirical models of the economic value of K-12 environmental education in Hudson River Estuary.]

Student Oral and Poster Presentations:

- Lanoue, J. 2015. Modeling oyster productivity in response to channel deepening in the Hudson River Estuary. Woods Hole, MA: Marine Policy Center, Woods Hole Oceanographic Institution (13 August). **Oral presentation.**
- Lanoue J, Hoagland P. 2016. Assessing the potential effects of channel deepening on oyster restoration in the Hudson River Estuary. *36th Milford Aquaculture Seminar*, Shelton, CT (11-13 January). **Poster presentation.**
- Lanoue J, Hoagland P. 2016. Modeling oyster *Crassostrea virginica* productivity in response to channel deepening in the Hudson River Estuary. *107th Annual National Shellfisheries Association Meeting*, Las Vegas, NV (22-26 February). **Poster presentation.**
- Lanoue J. 2016. Assessing the potential effects of channel deepening on oyster restoration in the Hudson River Estuary. Undergraduate Thesis Defense. Providence, RI: Institute at Brown for Environment and Society, Brown University (April). **Oral and poster presentations.**
- Hutcheson W, Hoagland, Jin D. 2016. Estimating the economic value of K-12 environmental education in the Hudson Estuary. Woods Hole, MA: Marine Policy Center, Woods Hole Oceanographic Institution (5 August). **Poster presentation.**
- Hutcheson W, Hoagland, Jin D. 2016. Estimating the economic value of K-12 environmental education in the Hudson River Estuary. *ASLO 2017: Mountains to the Sea (M2C)*, Honolulu (26 February – 3 March). **Poster presentation.**

Attachments:

- **ATTACHMENT 1**: Report on ecosystem service valuation and the Hudson Ecosystem
- **ATTACHMENT 2:** Development of a model of oyster growth in the Hudson River (abstract and poster)*
- **ATTACHMENT 3:** Development of an empirical model of cultural ES values arising from environmental education in the Hudson River Estuary (abstract and poster)*
- **ATTACHMENT 4:** References

* Full paper will be sent upon request. Hutcheson *et al*. (2017) is currently under review at the journal *Ecosystem Services*.

ATTACHMENT 1: Report on ecosystem service valuation and the Hudson Ecosystem

Introduction

We reviewed the published and gray literatures on ecosystem service (ES) valuation for the Hudson Ecosystem, and we present here some of the extant economic valuation estimates. A comprehensive understanding of ES values can help planners assess tradeoffs among human uses (or non-uses) that are incompatible. Here, we present value estimates without explicit consideration for how such estimates eventually would be used by planners. In practice, the separation of estimates and applications may be challenging to carry out, as many planning exercises need to consider not only the nature of dynamic linkages among ecosystems and stakeholders but also the identity of relevant gainers and losers (Johnston and Russell 2011).

For the large and important natural resource area comprising the New York-New Jersey Harbor Estuary, its tributaries, and coastal wetland environments, it is remarkable that there are very few *primary* estimates of ecosystem service values that have been developed through original valuation studies. It is plausible that analysts have been dissuaded by the industrialized characteristics of the system, which are dominated by shipping and ports, petroleum refining and storage, and the historical use and disposal of hazardous substances and heavy metals. Much of the policy attention and dialogue has been focused on the need to deepen the harbor and its channels and to sequester or remove hazardous dredge spoils from the system. The range of potential ecosystem services has been limited by the degraded condition of the region's wetlands, waters, and sediments. When compared qualitatively to the use of the Hudson for commercial purposes, the relative scales of ecosystem services may have been seen as too unimportant to require quantitative tradeoffs.

With the efforts of the New York-New Jersey Harbor Estuary Program, the Hudson River Foundation, the Billion Oyster Project, and many other interests and stakeholders, this lack of attention to the importance of the system's ecological and environmental services is now changing. Nevertheless, the lack of primary sources valuing the Hudson's ecosystem services may hinder the application of economic analysis to clarify tradeoffs among competing estuarine uses. It is therefore relevant and necessary—albeit somewhat problematic—to consider *secondary* estimates of ecosystem service values, involving transfers of benefits from other locations, times, and socio-economic contexts.

Primary Ecosystem Service Estimates

One notable primary ES valuation study for the Hudson Ecosystem is the work of Ziemba *et al*. (2014), who employ the hedonic pricing method (HPM) with data on more than 50,000 property transactions in five counties in the Hudson River valley in order to estimate the potential flood mitigation benefits of wetlands. The authors find that, although wetlands do not contribute directly to property values, they mitigate declines in the values of properties subject to flooding. For an average property, wetlands may reduce the cost of flooding in the 100-year flood zone by 15% of the property's value.

In a similar effort, concerning the broader Mid-Atlantic Region, encompassing the Hudson among other ecosystems, Narayan *et al*. (2016) found reduced coastal property damages on the order of $0.6 billion due to the presence of living shorelines during Hurricane Sandy. Across the entire US Northeast, the authors estimated an average of 10% reduction in property value losses. In Ocean County, New Jersey, using data on flooding from 2,000 historical storms dating back over a century, the authors estimated an average of a 20% reduction in property value losses.

Our own work sponsored by HRF on this grant comprises one of the first estimates undertaken anywhere of the valuation of estuarine education as a type of cultural ecosystem service. Hutcheson *et al*. (2017) developed estimates for the economic value of K-12 estuarine education at New York City's Hudson River Park. A "travel cost" approach using data compiled regularly by the Park yielded a conservative estimate of education benefits on the order of $0.2 million/yr, implying a capitalized value of about $10 million. This work supports an optimistic view of urban environmental education, through which a growing understanding of the importance of ecological systems could lead to future environmental improvements in the Hudson Ecosystem.

Secondary Ecosystem Service Estimates

There is a long record, dating back at least 30 years, of economic valuation studies focused on non-market ES endpoints in the Mid-Atlantic Region, including those for saltwater recreational fishing, beach uses, improvements in water quality, wildlife viewing (birdwatching), and the total economic values of estuaries and associated upland watersheds. Some of the most important of these studies are listed in Table A1-1. ES values from these and other studies have been compiled in various online databases (*e.g*., de Groot *et al*. 2012), including most recently the US Geological Survey's "Benefits Transfer Toolkit" (USGS 2017). In such compilations, these values tend to be reported as or recalibrated into estimates of willingness-to-pay (WTP or consumer surpluses) per person per day. Table A1-2 presents Mid-Atlantic regional average use value estimates for some marine recreational endpoints as reported in the USGS benefits transfer database.

Table A1-1: Some important ecosystem service valuation studies for the Mid-Atlantic Region

Year	Authors	Focus
1990	Bockstael et al.	Chesapeake Bay striped bass recreational demand
1991	Leeworthy & Wiley	New Jersey recreational beach use value
1994	McConnell et al.	Mid- and South Atlantic sportfishing value
2002	Johnston et al.	Peconic Estuary (Long Island, NY) resource services
2004	Lipton	Chesapeake Bay improved water quality value
2006	Costanza et al.	New Jersey value of ecosystem services and natural capital*
2010	Myers et al.	Delaware Bay recreational bird watching value
2015	Koicin et al.	Long Island Sound Basin total economic value*
2015	Walsh et al.	Chesapeake Bay adaptation to sea-level rise
2015	Moore et al.	Chesapeake Bay and watershed lakes improved water quality value
2017	Santoni et al.	Delaware tidal wetlands ecosystem services valuation

*Benefit transfers.

For purposes of coastal and ocean planning, however, it is valuable to know the spatial distributions of the underlying resources from which ecosystem services flow, the spatial patterns of human uses of the resources, and the spatial configurations of marginal ES values that arise from these human uses. With the advent of geographic information system (GIS) mapping, the spatial distributions of resources and human uses have been fairly well resolved in the Mid-Atlantic Region. Less clear are the scales and spatial distributions of the economic values associated with the region's ecosystem services.

Table A1-2: Average use values (WTP/person/day) for coastal and ocean recreation (2016 $)
Source: USGS (2017) [https://my.usgs.gov/benefit-transfer/]

	Northeast*	Southeast**
Beach Use	$36	$77
Boating (motorized)	$101	$23
Boating (non-motorized)	$18	$87
Fishing (saltwater)	$63	$118
Swimming	$28	$14
Wildlife Viewing	$63	$62

*Includes NY, NJ, DE, MD.
**Includes VA.

Location and Socio-Economic Context

A critical issue is that the value of most ecosystem goods and services depends significantly on their location (Boyd 2012). This location-specific nature is determined not only by ecosystem characteristics but also by location-specific socio-economic features (preferences, income, wealth, population densities, or other demographic elements). For example, in their analysis of property values in England, Gibbons *et al*. (2014) found that a positive price premium on property values associated with domestic gardens, green space, and areas of water were greater in metropolitan property sales than in sales of properties located outside metropolitan areas.

Benefit Transfers

Secondary estimates involve the transfer of benefits from other locations and socio-economic contexts. Two such examples from the region include the work of Costanza *et al*. (2006) and Liu *et al*. (2010) for ecosystem services in New Jersey, including coastal and estuarine services, and Koician *et al*. (2015) for the ecosystem services and natural capital of Long Island Sound and its associated upland watershed. (Notably the latter study relies significantly upon the earlier work of Johnston *et al*. (1990) concerning the valuation of resource services in the Peconic Estuary, located at the eastern end of Long Island.)

Benefit transfer efforts are an important initial step, but spatially resolved estimates of ES values sometimes show widely divergent values when compared with the results of primary data collections and analysis. Fig. A1-1, for example, reveals very different average estimates of total economic value from the benefit transfer studies cited above when compared to a recent study of the non-market value of tidal marshes in the Delaware estuary, the latter comprising mainly cultural ES values such as a wide variety of recreational activities (Santoni *et al*. 2017).

In the case of the Hudson Ecosystem, Meixler (2017) presents a recent example of benefits transfer to assess the impacts of Hurricane Sandy on the wetlands of Jamaica Bay, New York. The author examined before-and-after aerial photos of coastal landscapes, finding that beach erosion was the most damaging consequence of the storm and that only moderate flooding and sand deposition occurred. To evaluate the scale of economic losses, the author transferred the ES values compiled for New Jersey by Costanza *et al*. (2006), which are themselves a mix of primary and secondary sources. Although almost two-thirds of the storm's damages in Jamaica Bay were expected to be reversed within 5 years, Meixler estimated that up to $6.5 million in economic

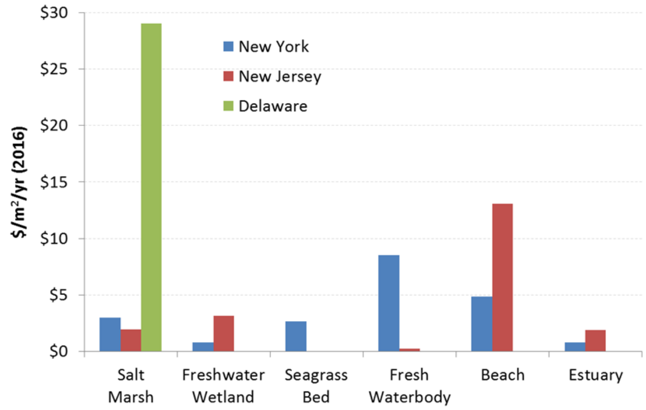

Fig. A1-1: Rudimentary representation of ecosystem service values for resource categories in the Hudson Ecosystem based upon secondary data using a benefit transfer approach. The figure depicts the wide disparity in ES values, which may depend upon location and socio-economic context. Units are 2016 dollars per square meter per year ($\$/m^2/yr$), and the heights of the bars represent median values between low and high estimates. Each resource category comprises the sum of a set of annual ES endpoints transferred from a variety of original studies or secondary sources. Sources: Koician *et al*. (2015) for New York; Costanza *et al*. (2006) for New Jersey; Santoni *et al*. (2017) for Delaware.

damages occurred as a consequence mostly of the reduced storm protection service provided by beaches. The quantification of ecosystem services in a spatial dimension also provided a way of prioritizing locations for potential gains as a consequence of restoration and enhanced protection.

Benefits of the restoration of oyster reefs

Restoration of oyster stocks, constituting one or more "reefs," contributes to the overall improvement of coastal ecosystems. A number of programs have been established to restore oysters to the Hudson Ecosystem, including the Billion Oyster Project. Education programs, including those at Hudson River Park have begun to introduce K-12 schoolchildren to oysters and other native fish (Fig A1-2). Benefits of oyster reefs restoration are realized through multiple pathways in linked social and ecological systems, and many of the beneficial effects interact with other ecological effects. This can render the accurate valuation of the ecosystem services associated with oyster restoration problematic.

Fig A1-2: Staff member from the Hudson River Park displaying a large Eastern oyster grown on a piling in the estuarine reserve that comprises a seaward extension of the park.

A small number of studies have developed quantitative estimates of the economic benefits from oyster restoration (Hicks *et al*. 2004; Kasperski and Wieland 2010; Grabowski *et al*. 2012; DePiper *et al*. 2017). Economic benefit components are summarized in the middle column of Table A1-3. Grabowski *et al.* (2012) have reported that the most valuable ecosystem service provided by oyster reefs is shoreline protection, and restoring the reefs is a good "living shoreline" type of response option to sea-level rise resulting from climate change (Fig. A1-3).

Table A1-3: The Potential Benefits of the Restoration Oyster Reefs

Ecosystem service	Benefit description	Valuation method
Provisioning	Oyster harvests	Market value
Regulating	Water quality improvements Nitrogen removal Shoreline protection Carbon sequestration	Willingness-to-pay (contingent valuation) Replacement cost; credit exchange markets Replacement cost Carbon tax; credit exchange markets
Cultural	Tourism and recreation Education	Contingent valuation and travel cost Travel cost
Supporting	Nursery habitats Biodiversity Landscape processes	Market values Contingent valuation Contingent valuation

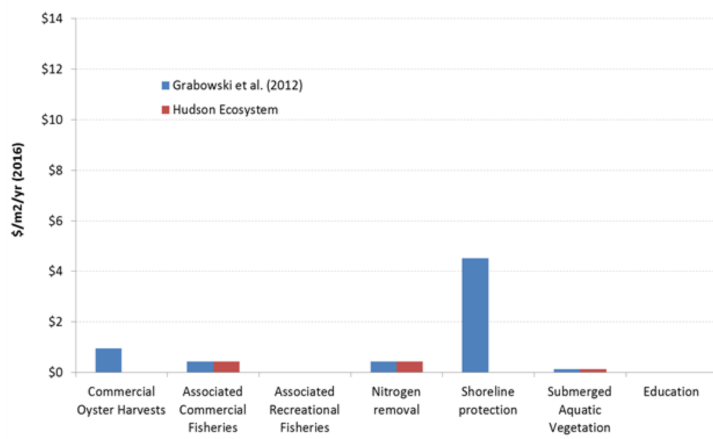

Fig. A1-3: Rudimentary representation of annual ecosystem service values for oyster reefs in the United States (Grabowski *et al.* 2012)) and in the Hudson Ecosystem based upon secondary data using a benefit transfer approach. Units are 2016 dollars per square meter per year ($\$/m^2/yr$), and the heights of the bars represent median values between low and high estimates. [Note the change in scale compared with Fig. A1-1 above.] Ecosystem services from some of the proposed restoration efforts in the Hudson may be limited as a consequence of the presence of pollutants, implying the absence of commercial or recreational shellfisheries for oysters, or the existence of shoreline protection (bulkheading) that may limit the living shoreline value in certain locations.

In the Hudson Ecosystem, however, some of the candidate oyster reef restoration sites are located in areas that potentially limit the scope of ES benefits. For example, restoration sites in the Hudson River and New York Harbor may be unavailable for commercial or recreational harvests, due to pollution in the water column or sediments (bacteria, hazardous materials, heavy metals, sediment loads). Further, shoreline protection benefits are likely to be minimal—but not completely absent—in these same areas because of the presence of extensive bulkheading or other coastal armoring. As a consequence, ES benefits may be restricted mainly to those arising from nutrient (N) assimilation, biological diversity through the provision of reef habitat, water quality improvements, or environmental education. The realization of actual ES benefits depend strongly upon environmental and socio-economic contexts, however, suggesting that recreational fishing, education, or shoreline protection benefits arising from oyster reef restoration could be significant in certain areas of the Hudson Ecosystem.

As discussed above, a common approach for estimating the total ecosystem service (ES) values in a study region involves separate estimations of: (i) the unit value ($\$/m^2/yr$) of the ecosystem and (ii) the area of the ecosystem. The total value is then the product of the unit value and the area (Costanza *et al*. 1997; de Groot *et al*. 2012). Unfortunately, this approach has its limitations in application to some types of service flows, such as oyster reef restoration in the Hudson Ecosystem, due to lack of appropriate unit values. Most ES valuation studies have been undertaken in *rural* or *suburban* settings. A simple transfer of valuation estimates from the literature to potential service flows in an *urban* setting, such as New York City, could underestimate the social value of oyster restoration efforts significantly.

Results from meta-analyses of the wetland valuation literature suggest that the prediction of a wetland's value based on previous studies is highly uncertain, and, consequently, the need for site-specific valuation remains significant (Woodward and Wui 2001; Brander *et al*. 2006). Socio-economic variables (*e.g*., income and population density) may exhibit positive effects on ES values, but often such variables are omitted from valuation analyses. Brander *et al*. (2006) find average transfer errors of 74% for wetlands, with under one-fifth of the transfers showing errors of 10% or less.

Most valuation results are incomplete, and they do not measure the full ES benefits associated with a resource. For example, the value of ecosystems to nearby real estate could be estimated through hedonic approaches, but such estimates usually do not comprise a complete set of ecosystem service benefits (Boyd 2012). Mahan *et al*. (2000) explained that their estimation of the value of urban wetlands captured only the benefits to neighboring property owners, not the aesthetic value enjoyed by commuters, visitors, or other transient beneficiaries.

In their recent study of ocean and coastal resources in Ireland, Doherty *et al*. (2014) showed that, while access to coastal recreation was valued by survey respondents, having access for visual recreation only, such as might occur through walking or jogging (*i.e*., without direct contact with the water), could provide substantial economic benefits to residents. The authors found higher willingness-to-pay (WTP) for coastal resources exhibiting good water quality and good odors (smells) than for direct recreational uses.

Living Shorelines

A major concern of coastal communities is to protect against erosion and subsequent property loss resulting from storm events and sea-level rise. Traditional shoreline protection methods which rely mostly on gray infrastructure (*e.g*., seawalls, jetties, floodgates, and rock groins) have been criticized for their negative impacts on the natural ecosystems (Gittman *et al*. 2015). As a result, coastal cities like New York and Boston and many communities along the coast are considering green infrastructure in their efforts to enhance resilience to coastal hazards (ARCADIS 2014; Popkin 2015; Ruckelshaus *et al*. 2016; Rella *et al*. 2017).

Coastal green structures include constructed wetlands, oyster reefs and barrier islands, and ecologically enhanced bulkheads and revetments. The main idea of green infrastructure is to create or maintain a "living shoreline." Given careful consideration of the site and strategic placement of components along the entire upland-to-wetland profile, these shoreline protection construction projects can provide habitat for plants and animals (Fig. A1-4). Specifically, living shorelines provide erosion control benefits; protect, restore, or enhance natural shoreline habitat; or maintain coastal processes through the strategic placement of plants, stone, sand fill, and other structural organic materials (*e.g*., coir fiber logs, oyster reefs, *etc*.).

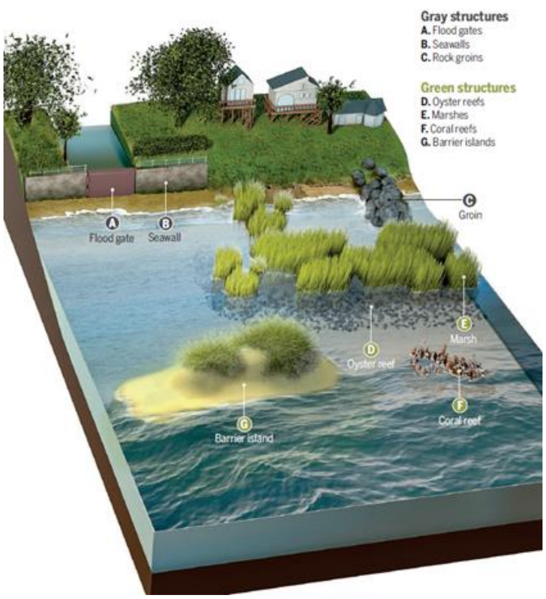

Fig. A1-4: Gray and green infrastructure for coastal protection: uniting gray and green structures could create layered, hybrid defenses that provide both ecological and economic benefits (Popkin 2015).

According to Popkin (2015), shorelines made of marsh grasses and oyster reefs may work better than concrete armor to protect against the hazards of rising seas. Indeed, a recent study by Gittman *et al*. (2014) reports that marshes—both with and without sills—protected estuarine shorelines from erosion better than bulkheads during Hurricane Irene (a Category 1 typhoon). The authors found that 76% of bulkheads surveyed had been damaged by the storm; in contrast, coastal vegetation recovered to pre-hurricane levels within a year. The study concluded that bulkheads were probably the least cost effective method for shoreline protection. Many green design concepts actually combine green and grey components, creating hybrid, layered defenses that can offer both ecological and economic benefits. The hybrid design may achieve the best payoff because of the complementary strengths and weakness of both approaches to protection (Popkin 2015).

Valuing "*urban*" green infrastructure

According to a recent review by Elmqvist (2013), the provision of ecosystem services in urban areas depends upon both the quality and quantity of urban green infrastructure. Ecosystem service values usually are not taken into account fully in urban policy-making, however. Urban green infrastructure includes parks, gardens, wetlands, rivers, lakes and ponds in cities, as well as the natural areas surrounding urban spaces (Fig. A1-5). Urban green infrastructure can contribute to improvements in the quality of life for humans in cities. Studies have documented sizeable benefits associated with urban green infrastructure (Crompton 2001 and 2005; Smith *et al*. 2002; Tajima 2003; Sherer 2003; Cho *et al*. 2008; Kolbe and Wüstemann 2015). Crompton (2005) suggests that a positive impact of 20% on property values near a passive park is a reasonable starting point for estimating the park's impact. Voicu and Been (2008) estimated the impact of community gardens on neighborhood property values in New York City. They find that gardens

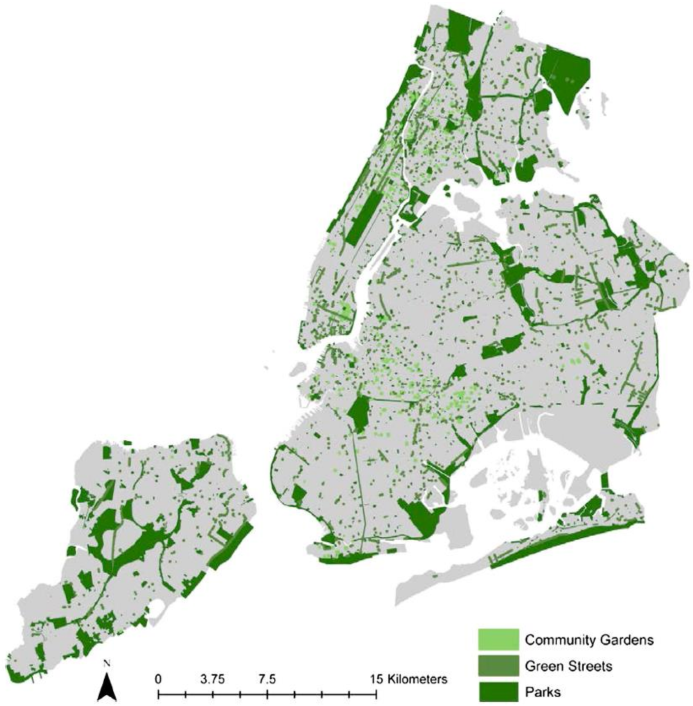

Fig. A1-5: Map of New York City green infrastructure from McPhearson et al. (2014). Note that the literature typically does not consider either estuarine or riverine space to constitute green infrastructure.

have significant positive effects, especially in the poorest neighborhoods. Higher-quality gardens lead to greater positive impacts.

Squires (2013) presented a comprehensive discussion of the interactions among urban issues, the built environment, and environmental resources. The author has argued that natural resource and environmental issues should be examined in the context of shared space and related policy priorities, including affordable housing, education, poverty, and social exclusion. Applications of the hedonic pricing method (HPM) to urban areas have found positive effects associated with the quality of local schools and their proximities to parks and negative effects associated with the incidence of crime and the presence of air pollution. *Ex ante*, we might expect that coastal or marine ecosystem services, such as those arising from oyster restoration, also could influence housing prices through multiple pathways.

Wu and Plantinga (2003) investigated how open space amenities affected the location decisions of individuals from different income groups and the spatial structures of urban development. The provision of new open space likely benefits some income groups more than others, but it also may increase the income diversity of a city. When open space is located closer to a city center, it can provide a more favorable tradeoff between access to open space amenities and the costs of commuting. One might consider a river or an estuary adjacent to a city center as open space that cannot be developed, and therefore it quite likely would generate similar types of ES benefits.

Moizeau (2015) argued that the overlapping-generation effects of education can lead to long-term impacts on different communities in a city. Education decisions are influenced by peers who favor a social ethos that either honors or discredits education. If environmental education associated with oyster restoration affects the social norms of low income communities positively, such restoration could lead to measurable long term benefits.

Residences and population densities can affect the total benefits in a region significantly. Using HPM, the total benefit is calculated as:

$$Total\ Benefits = \left[\frac{Benefit}{Property}\right] \cdot [\#\ of\ Properties]$$

And for a stated preference survey:

$$Total\ Benefits = \left[\frac{WTP}{Person}\right] \cdot [\#\ of\ Population]$$

Thus, aggregate benefits for an area are estimated by summing the relevant household measures across all households. The total benefits could be increased either by an increase in the unit benefit measure or by increasing the number of residences in the region (Freeman 1979). As a consequence, given high population densities in urban areas, the benefits associated with coastal and ocean ecosystem services, such as oyster reef restoration, are likely not fully measured or valued by transferring the results from studies in nonurban settings.

Valuing the benefits of "*metro*-nature"

Wolf *et al*. (2015) have argued that existing presentation and classification of urban ecosystem services do not capture adequately the full range of nature-based benefits and services within metropolitan environments, particularly cultural ecosystem services (*cf.*, MEAB 2003). For example, nature can contribute positively to public health (*e.g.*, psychosocial, cognitive, and physical health and well-being), and typically these health benefits are not accounted for fully. The authors propose a classification schematic that interprets a broader definition of ecosystem services, particularly cultural services, from an urban perspective (Fig. A1-6).

Fig. A1-6: Metro-nature services and benefits (Wolf *et al*. 2015).

The term "metro-nature" is used to describe the collective opportunities for human nature experiences that improve urban livability. Within the metro-nature system, "environmental fitness" provides foundational support for human health (*e.g.*, clean air and water); "wellness support" represents an urban condition (*e.g.*, parks, community gardens, trees, and green spaces) that provides supplemental benefits; "supportive spaces" and "healing places" are facilities and institutions where people conduct routine activities (*e.g.*, school or the workplace with landscape designs to improve human function); "amenity and aesthetic" describes the most widely perceived benefit of trees, parks, and greenery; and "community" indicates that metro-nature affects the wellbeing of everyone in the environment, directly and indirectly, and that community investment is necessary to achieve optimal levels of all services. Note that one of the ecosystem services provided by oyster reefs is to improve and maintain water quality, which would contribute directly to the improvement of baseline condition of metro-nature.

By analyzing potential cost savings, avoided costs, and increased incomes in the context of public health management, Wolf and Robbins (2015) estimated the value of six metro-nature benefits (*i.e*., birth weights, incidence of attention-deficit hyperactivity disorder (ADHD), school performance, occurrence of crime, incidence of cardiovascular disease, and incidence of Alzheimer's disease). The study demonstrated the importance of nature contact in urban areas over the course of the human lifespan. The authors found that metro-nature led to economic effects on the order of between $3-7 billion annually in the United States (2012 USD).

Conclusions and Recommendations

The Hudson Ecosystem's stakeholders and resource managers clearly recognize the importance of coastal and ocean ecosystem services to the estuary and the broader region. A solid foundation of ecosystem service valuation has been established already in the Mid-Atlantic region, but there are very few studies that have developed primary ES values for the Hudson. Salient regional environmental trends include rising sea levels, heightened risks of flooding and erosion, warmer oceanic and estuarine waters, ongoing degradations of coastal waters due to nitrogen and phosphorous releases, and, in the longer term, decreasing oceanic pH and carbonate levels. These trends will necessitate more attention to estimating the values of ecosystem services, in order to begin to measure the scale of potential losses and the benefits of responding to mitigate effects.

Many of the Hudson's ES endpoints, such as merchant shipping, recreational boating, pipelines and cables, and waste disposal, either are not exposed or are insensitive to the effects of climate change. Sea-level rise and increased risks due to extreme high tides and storm surges do pose significant threats to exposed seaports and human coastal developments, especially residences and community infrastructures. Other important ES endpoints appear to be much more vulnerable to climate change, including commercial and recreational fisheries, wildlife viewing, and living shorelines, especially salt marshes, seagrass beds, intertidal lands and resources, and oyster reefs. It will be important for the Hudson's communities and stakeholders to address these vulnerabilities on several fronts, and primary ES valuation studies will be critical.

Some of the Hudson's ES values will be difficult to estimate (navigation, underwater cultural resources, waste assimilation, and ocean science, among others). Consequently, relevant values must be transferred from other studies pertaining to similar ESs from other locations and times. Such "benefit transfers" can be subject to significant uncertainties, and the wide ranges of estimates from compilations of studies can render planning problematic.

A corollary to the problem of incomplete coverage is that some local studies may be relied upon extensively to estimate ES values for the region. One of the most important and influential set of studies included those that developed estimates for the Peconic Estuary System undertaken by researchers at the University of Rhode Island in the late 1990s (Johnston *et al*. 2002). These studies are still quite influential, forming one basis for recent estimates of the ES values for the Long Island Sound Basin (Kocian *et al*. 2015). ES values may arise at different locations and different points in time. Variables comprising geography (distance), environment (weather, climate, water quality, seabed features, currents, natural hazards), human uses (congestion, permanent vs. temporary occupation), or human preferences (cultural norms) can influence ES values strongly.

Many nonmarket valuation studies have focused mainly on developing WTP estimates without explicit reference to the spatial extent of the coastal or ocean areas that are being valued. In many cases, careful characterization of the relevant areas can be developed through combining information about use patterns with valuation studies. Such work is a clear priority for establishing ES values for important human uses of the coasts and oceans, such as those for recreational fishing or boating.

Little work has been undertaken on the passive use components of total economic value, even at the level of the Mid-Atlantic region. Indirect, active uses, such as waste assimilation, sometimes also are categorized as a component of passive uses, and developing estimates of ES values for C-sequestration and denitrification in near coastal waters is a clear priority. For the former, the effectiveness of sequestration across coastal and marine environments (salt marshes, intertidal zones, seabeds, ocean waters) will be important.

Further characterizations of the spatial distributions of services, human uses, and the values arising from those services and uses would be beneficial in assessing the extent of potential vulnerabilities and characterizing appropriate management responses. Primary valuation studies, such as those that have been undertaken already for the Chesapeake, Delaware, and Peconic estuaries, will yield more accurate and potentially useful estimates of the economic values at stake. Increased investments in scientific research about the spatial and temporal characteristics of ecosystem services are warranted as they will lead to improvements in ES valuation.

Importantly, several examples exist or are under development in the Mid-Atlantic Region of market-based institutions for realizing the values of ecosystem services, including auctions of allowances to fossil fueled power plants based upon a regional CO_2 cap, intrastate credit exchanges for macronutrients based upon waterbody TMDLs (total maximum daily loads), and an ITQ (individually transferable quota) program for harvests of surf clams and ocean quahogs. These institutions provide a foundation for their further expansion to the Hudson Ecosystem and to a broader array of natural resources and their associated ecosystem services. A clear priority for the region will be the design of equally innovative institutions for conserving living shorelines, and ES valuation will comprise a central element for moving such a policy forward.

ATTACHMENT 2: Development of a theoretical model of oyster growth in the Hudson River

ASSESSING THE POTENTIAL EFFECTS OF CHANNEL DEEPENING ON OYSTER RESTORATION IN THE HUDSON RIVER ESTUARY

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Oyster reefs provide essential ecosystem services for coastal environments, including water filtration, critical habitat, nutrient assimilation, storm surge protection, and opportunities for commercial or recreational harvests. In the Hudson River Estuary, located between New York City and New Jersey, restoration efforts now are being implemented to replenish Eastern oyster (*Crassostrea virginica*) populations mainly to improve water quality and to enhance regional biodiversity. Oyster growth rates are sensitive to salinity, however, and recent ship channel deepening in the lower estuary may change the salinity distribution spatially and temporally, thereby potentially shifting the optimal locations for restoration. Using both an individual post-settlement growth model and a population growth model, we simulate the growth of an oyster reef under different salinity regimes. This is done to determine the number of oysters to be planted in order for the reef to reach a carrying capacity of 330,000 oysters five years after the restoration's start date. Using insight from empirical oyster growth models, we modeled growth as a function of salinity, temperature, turbidity, flow rate, and chlorophyll at Hastings-on-Hudson, one of the potential restoration locations in the Hudson River. Our results provide further evidence for the importance of the link between oyster growth and salinity fluctuations at both individual and population scales. Because the Hasting-on-Hudson candidate restoration site is a low-salinity environment, an increase in salinity from channel deepening may increase oyster growth rates there, enhancing the site's potential for reef restoration. Increasing the salinity at Hastings-on-Hudson by 2 ppt resulted in an 80% increase in recruitment causing the reef to reach carrying capacity at much shorter time scales. This study also demonstrates how ecological modeling could be used in conjunction with restoration efforts to simulate possible environmental scenarios in order to maximize societal benefits from restoration.

Assessing the Potential Effects of Channel Deepening on Oyster Restoration in the Hudson River Estuary

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HUDSON RIVER FOUNDATION for Science & Environmental Research

Introduction

- The Hudson River Estuary (HRE), located within the New York/New Jersey area, historically maintained high population densities of the Eastern oyster, *Crassostrea virginica*
- Oyster populations in the HRE declined drastically during the late 19th and early 20th centuries due to overharvesting and poor water quality
- Recently, efforts by the Hudson River Foundation and others were undertaken to restore oyster populations, in part to improve water quality within the HRE
- One potential obstacle to oyster restoration is channel deepening (harbor dredging), which is projected to change the salinity gradient within the HRE

To understand how salinity could affect oyster restoration in the HRE, we carried out a modeling study focusing on the growth rate of a single hypothetical oyster using environmental data collected by Grizzle et al. (2012).

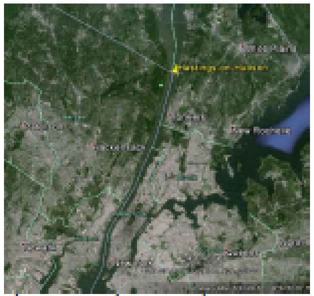


Figure 1 – Map view of study site

Methods

Study Area

- The study focuses on Hastings-on-Hudson, a small area within the HRE in Westchester County (**Figure 1**). This location was chosen because it was identified by numerous restoration reports as a site with high potential for reef restoration
- Hastings-on-Hudson is characterized by low salinity concentrations which frequently drop to zero

Data Collection

- Environmental data was collected at Hastings-on-Hudson by Grizzle et al. (2012) from May 2011 to August 2011
- Hourly measurements of salinity, temperature, turbidity, chlorophyll were recorded

Post-settlement Oyster Model

- The model is an adaptation of the oyster growth model developed by Powell et al. (1992) (**Figure 2**)
- Net production was calculated to determine oyster growth using the data from May to August 2011 in terms of mg dry weight/oyster/day

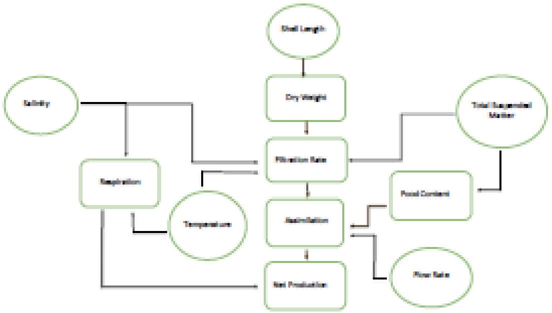
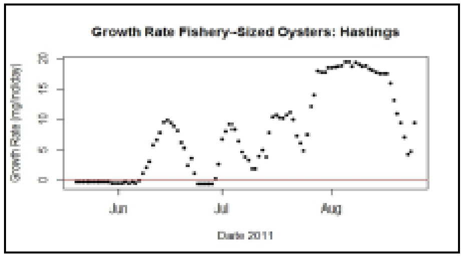
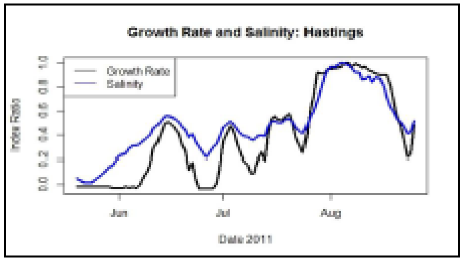


Figure 2 – Schematic of post-settlement oyster model adaptation

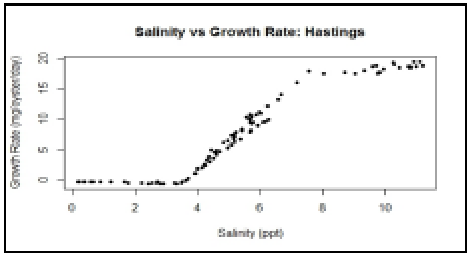
Results



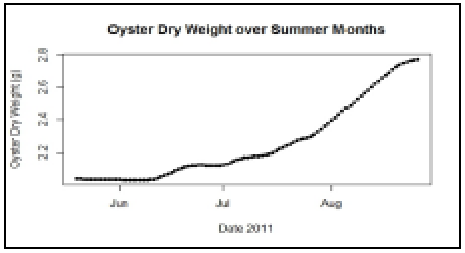
A pattern of alternating high and low growth patterns were observed, where growth would increase on two week time scales



Patterns of the environmental parameters were compared to the growth pattern seen. The oyster growth rate closely tracks the pattern seen in the salinity level.



Growth rate was plotted against salinity to determine how growth rate was changing with salinity



The growth rates were converted to changes in biomass. The simulations showed an increase of 0.7 g dry weight during the summer of 2011.

Discussion and Conclusion

- Through these simulations, it was possible to examine the relationship between oyster growth at Hastings-on-Hudson and salinity, showing that low salinity levels resulted in possible loss in biomass
- The rise and fall of the growth rates can be explained by the tidal patterns within the HRE
- Because Hastings-on-Hudson is a low salinity area, it is inferred that an increase in salinity levels due to channel dredging may increase oyster productivity in the area
- Further research would involve incorporating output from a hydrodynamic model to track changes in oyster productivity in an environment pre- and post-dredging and linking the individual growth model to a population growth model to track the growth patterns of an entire reef.

<u>ATTACHMENT 3</u>: Development of an empirical model of cultural ES values arising from environmental education in the Hudson River Estuary

THE ECONOMIC VALUE OF ENVIRONMENTAL EDUCATION AT NEW YORK'S HUDSON RIVER PARK*

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Environmental education is one type of "cultural" ecosystem service (ES). Published studies valuing the educational services of estuarine environments in urban settings are uncommon. This study estimated the economic value of K-12 estuarine education at New York City's Hudson River Park. A "travel cost" approach using data compiled regularly by the Park yielded a conservative estimate of education benefits on the order of $208,000/yr, implying a capitalized value of about $10 million. The results support an optimistic view of urban environmental education, through which a growing understanding of the importance of ecological systems could lead to future environmental improvements.

*Submitted to the journal *Ecosystem Services*.

Estimating the Economic Value of Environmental Education in the Hudson Estuary

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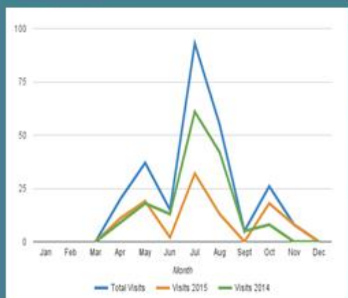
Abstract

Our project seeks to estimate the economic value of K-12 coastal or marine environmental education. Education about the environment is known as a type of "cultural" ecosystem service, but, to date, very little work has been done to evaluate such services in economic terms. Specifically, we have been compiling data on visits by schools and summer camps from 32 New York City school districts to the Hudson River Park on the lower West Side of Manhattan. The Park offers educational programs focusing on the environmental aspects of the Hudson River and Estuary, including the potential restoration of the once-extensive, native oyster reefs. In order to develop estimates of the value of education in this context, we are adapting a method from the field of environmental economics known as the "travel cost" approach, which commonly has been used to estimate the economic value of recreation in natural areas.



Total trips per month by organizations to Hudson River Park. Educational programs are offered to schools in April, May, June, September, October, and November and to camps in June, July, and August.

Hudson river park offers hands-on environmental education programs relating to the Hudson River Estuary and its ecology.

Methods

Data on school or summer camp trips for students or campers to participate in the Hudson River Park's environmental education programs were obtained from the Park's Education Department.

Budget and demographic data for school districts were obtained from New York City's Department of Education.

Income and college education data were obtained from the US Bureau of Census (2010) by zip code and assigned to the relevant school districts.

The effect of distance on the number of school or camp trips was estimated using a negative binomial regression model for count data, with demographic, income, and education level categories used as additional predictors.

Budget, income, and travel time data were used to calculate the opportunity costs of the students participating in educational programs about the Hudson Estuary.

Data

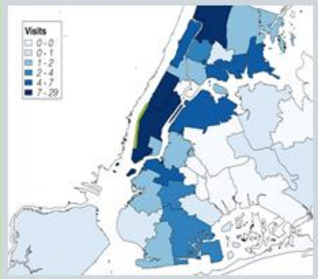
- **Visits, Organization, and Location**
  Hudson River Park Education Department
- **Income, Education Level by Zip Code**
  US Census Bureau (2010)
- **Racial Characteristics, Language Proficiency of students by school district**
  NYC Department of Education

Model

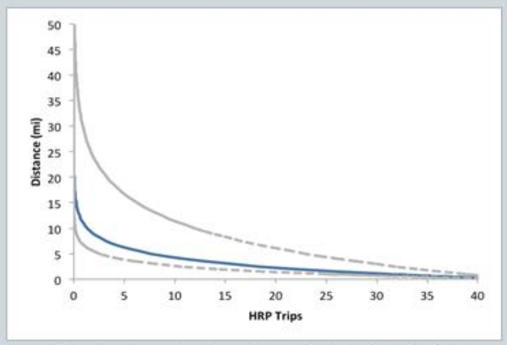
- Average trips per year for years 2014-15 by school district used as a response variable
- Distance from district center to Hudson River Park used as an effect variable
- Income, education level, and demographic characteristics of each school district used as additional effect variables to describe distance effect

Value Estimate

- Average dollars/student/hour were calculated using school budget and enrollment data from the NYC Department of Education.
- Travel time was calculated using relationship of distance to travel time of organizations visiting the park
- Average students per trip was calculated using data from Hudson River Park



Map of NYC school districts with data on visits to Hudson River Park. Hudson River Park is represented as the light green polygon on the southwest side of Manhattan.



The basis for a demand curve for environmental education showing the relationship between the distance of a school district from Hudson River Park to the number of school or camp trips. The closer a school district is to the Park, the more trips are expected from schools or camps in that district. Expected values and confidence intervals were calculated using Model V in table 1.

Results

Distance had an impact on the choices of schools or camps within each district to participate in Hudson River Park's environmental education programs. Distance HR is negatively related to trips.

Distance to an alternative site (Brooklyn Bridge Park), Income, College Education, % African American students, and % English language learning students also had an impact on participation..

Model	I	II	III	IV	V
Distance HR	-0.1167 * (0.0586)	-0.5212 *** (0.1163)	-0.48492 *** (0.10906)	-0.44029 *** (0.10815)	-0.35465 ** (0.11045)
Distance BB		0.3979 *** (0.1070)	0.41500 *** (0.10423)	0.42030 *** (0.10375)	0.40864 *** (0.10339)
Income			0.20108 * (0.09285)		
College Education				0.06371 * (0.02729)	0.13275 ** (0.04119)
Black					2.59289 . (0.07281)
ELL					11.96327 * (1.44530)

Table 1. Results of negative binomial regressions. Key: Top row=coefficient, Bottom row=std. error, p-values indicated as: '.'=.10, '*'=.05, '**'=.01, '***'=.00.

Discussion

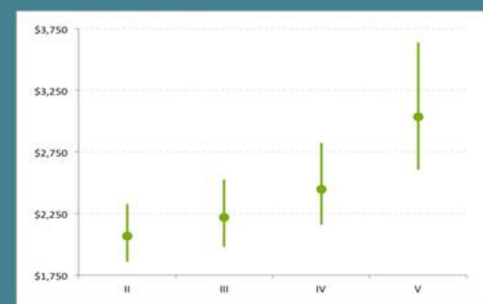
School or camp trips depend negatively on the distance of school districts from the park..

Income and College Education both had significant positive effects on the number of trips. This suggests that districts with wealthier and more educated populations may value environmental education more.

Schools or camps in districts with higher proportions of African American or English language learning students made more trips, suggesting environmental educational programs are recognized as important for minority or immigrant populations.

Using distance coefficients from each model, the welfare value of Hudson River Park's environmental education programs are estimated to range from $240k/yr to $1.1m/yr

Using a discount rate of 2%, the capitalized values of environmental education relating to the Hudson Estuary range from $12m to $54m



Estimated welfare values per visit to park programs from models II-V. Bars represent 95% confidence intervals for each model.

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