Hudson-Raritan Estuary Comprehensive Restoration Plan

Volume II

DRAFT

March 2009

the WATERS we SHARE

Hudson~Raritan Estuary
Comprehensive Restoration Plan

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US Army Corps of Engineers®

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In partnership with

New York - New Jersey Harbor Estuary Program

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- The Port Authority of New York & New Jersey
- National Oceanic and Atmospheric Administration
- U.S. Environmental Protection Agency
- U.S. Fish & Wildlife Service
- New Jersey Department of Environmental Protection Division of Fish and Wildlife
- New Jersey Department of Transportation
- New York State Department of Environmental Conservation
- New York State Department of State, Division of Coastal Resources
- New York City Mayor's Office
- New York City Department of Parks and Recreation
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List of Acronyms

CARP	Contamination Assessment and Reduction Program
CRP	Comprehensive Restoration Plan
CSO	Combined Sewer Overflow
CWA	Clean Water Act
dbh	Diameter at breast height
DDT	Dichloro-Diphenyl-Trichloroethane
DO	Dissolved oxygen
EFH	Essential Fish Habitat
FAA	Federal Aviation Administration
HAPC	Habitat Areas of Particular Concern
HEP	New York/New Jersey Harbor Estuary Program
HRE	Hudson-Raritan Estuary
HRF	Hudson River Foundation
NEPA	National Environmental Policy Act
NJDEP	New Jersey Department of Environmental Protection
NOAA	National Oceanic and Atmospheric Administration
NYCDEP	New York City Department of Environmental Protection
NYCDPR	New York City Department of Parks and Recreation
NYSDEC	New York State Department of Environmental Conservation
NYSDOS	New York State Department of State
PANYNJ	Port Authority of New York and New Jersey
PCB	Polychlorinated Biphenyl
ppt	Parts per trillion
REMAP	Regional Environmental Monitoring and Assessment Program
SAV	Submerged aquatic vegetation
TEC	Target Ecosystem Characteristics
TMDL	Total Maximum Daily Load
TSS	Total suspended solids
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service

1.0 Introduction

The Comprehensive Restoration Plan (CRP) for the Hudson-Raritan Estuary (HRE) is intended to serve as a master plan for restoration efforts within the HRE. Volume I of the CRP presented the overall plan, by defining the goal of the HRE Ecosystem Restoration Program and identifying the restoration targets. The CRP's restoration targets are in the form of Target Ecosystem Characteristics (TECs) that have been assigned measurable short- and long-term objectives (Table 1-1). Volume 1 identifies potential opportunities to achieve the TEC objectives, potential funding opportunities and partnerships for implementation and subsequent management strategies for the restoration plan. Considerations and recommendations for resolving challenges to current agency policies and guidelines that would streamline restoration efforts were also identified in Volume I of the CRP.

The purpose of Volume II of the CRP is to serve as a technical companion to Volume I that will assist restoration practitioners in planning, conducting and measuring the success of restoration projects within the HRE. This volume provides general guidance on restoration planning, as well as information specific to the TECs. For each TEC, the ecological value, current status and research needs are discussed, and guidance for conducting restoration projects and performance monitoring is provided. Volume II of the CRP is organized into the following chapters:

Chapter 1: Introduction

Chapter 2: Conducting Restoration Projects

Chapter 3: Restoring Target Ecosystem Characteristics

Table 1-1. Target Ecosystem Characteristics (TECs) in the Hudson-Raritan Estuary study area.

TEC	Target Statement
Coastal Wetlands	Create and restore coastal wetlands, at a rate exceeding the annual loss or degradation of wetlands in the HRE study area, to produce a net gain in acreage.
Islands for Waterbirds	Restore and protect roosting, nesting, and foraging habitat for long-legged wading birds on islands in the HRE study area.
Coastal and Maritime Forests	Create a linkage of forests accessible to avian migrants and dependent plant communities from Rockaway Peninsula, NY to the coasts of New York and Raritan Bays to Sandy Hook, NJ.
Oyster Reefs	Establish oyster reefs at several locations in the HRE study area.
Eelgrass Beds	One eelgrass beds in each of the eight HRE planning regions that can support eelgrass.
Shorelines and Shallows	Create or restore shoreline and shallow sites that meet a 3-zone criterion specified for an integrated site with a vegetated riparian zone, an inter tidal zone with a stable slope, and illuminated shallow water.
Habitat for Fish, Crab, and Lobsters	Create functionally related habitats in each of the eight regions of the HRE.
Tributary Connections	Reconnect freshwater streams and inland habitats to the estuary to provide a range of quality habitats to aquatic organisms.
Enclosed and Confined Waters	Upgrade the water quality in enclosed waterways and tidal creeks within the estuary to match or surpass the designated use of their receiving waters.
Sediment Contamination	Isolate or remove one or more sediment zone(s) that is contaminated until such time as all HRE sediments are considered uncontaminated based on the all related water quality standards, related fishing / shelling bans or fish consumption advisories, and any newly-promulgated sediment quality standards, criteria or protocols.
Public Access	Improve direct access to the water and create linkages to other recreational areas, as well as provide increased opportunities for fishing, boating, swimming, hiking, education, or passive recreation

2.0 Conducting Restoration Projects

Conducting successful restoration requires careful planning to ensure that (1) the project is designed to assist with achieving the goals of the overall HRE program, (2) the type of restoration is suitable for the project site, and (3) performance can be measured to track success. The following sections provide general guidance on planning and implementing restoration projects within the HRE.

2.1 Planning Considerations

Planning for ecosystem restoration within the HRE study area has the potential to pose challenges due to the vast number of municipalities, agencies, and stakeholders within the region. Competing interests of the HRE's user groups could slow the progress of achieving the TEC objectives. Linking planning efforts among stakeholders would provide increased opportunities for municipalities, planners, developers, and agencies to actually provide opportunities to meet economic, public and ecological goals within the HRE study area. For example, the development of the CRP coincides with major transitions occurring in the estuary's waterfronts. Shipping facilities are being upgraded, residential communities are expanding, and there are emerging demands for greener landscapes, increased waterfront access, and improved environmental health. The renewed focus on the waterfront provides an opportunity to promote the CRP to all segments of the public and build the long-term support that is needed to achieve significant progress. The TEC targets can be achieved through collaboration with these planners and implementing innovative restoration techniques. Residential development provides potential restoration and community involvement opportunities. Restoration opportunities also exist for areas with dedicated urbanized land uses, such as restoring habitat value to hardened shorelines.

One of the first attempts at restoration while maintaining shoreline stabilization in the HRE study area is occurring in the Harlem River, where the New York City Department of Parks and Recreation (NYCDPR) is replacing existing steel bulkheads with a structurally-complex shoreline containing gabions, various sized rip-rap boulders, native wetland plants, and a series of tide pools. This application of innovative techniques can be beneficial in working toward restoration targets, and similar techniques can be incorporated into future infrastructural plans for the HRE study area.

Many municipalities in the HRE study area have master plans or open space plans that represent communities' long-term visions for improving land use and waterfront areas. Occasionally, unrelated plans are developed for the same location with different, and sometimes conflicting, goals and visions. These plans may not correlate with the objectives of the CRP by proposing a land use where habitat could be created or proposing an inappropriate habitat given the site's physical conditions. The process of reaching out to communities and local governments to learn about their master plans should be conducted as part of due diligence in the planning process. Project proponents should seek out these plans, collaborate, and identify habitat restoration/creation areas that coincide or enhance existing plans. Next steps for the U.S. Army Corps of Engineers (USACE) HRE Feasibility Study will consider municipalities' master plans to identify potential competing land uses and to add to the menu of restoration opportunities along local waterfronts.

Table 2-1. Checklist for restoration project planning (NRC 1992).

Project Planning and Design	
1.	Has the problem requiring treatment been clearly understood and defined?
2.	Is there a consensus on the restoration program's mission?
3.	Have the goals and objectives been identified?
4.	Has the restoration been planned with adequate scope and expertise?
5.	Does the restoration management design have an annual or midcourse correction point in line with adaptive management procedures?
6.	Are the performance indicators—the measurable biological, physical, and chemical attributes—directly and appropriately linked to the objectives?
7.	Have adequate monitoring, surveillance, management, and maintenance programs been developed along with the project, so that monitoring costs and operational details are anticipated and monitoring results will be available to serve as input in improving restoration techniques used as the project matures?
8.	Has an appropriate reference system (or systems) been selected from which to extract target values of performance indicators for comparison in conducting the project evaluation?
9.	Have sufficient baseline data been collected over a suitable period of time on the project ecosystem to facilitate before-and-after treatment comparisons?
10.	Have critical project procedures been tested on a small experimental scale in part of the project area to minimize the risks of failure?
11.	Has the project been designed to make the restored ecosystem as self-sustaining as possible to minimize maintenance requirements?
12.	Has thought been given to how long monitoring will have to be continued before the project can be declared effective?
13.	Have risk and uncertainty been adequately considered in project planning?
During Restoration	
1.	Based on the monitoring results, are the anticipated intermediate objectives being achieved? If not, are appropriate steps being taken to correct the problem(s)?
2.	Do the objectives or performance indicators need to be modified? If so, what changes may be required in the monitoring program?
3.	Is the monitoring program adequate?
Post-Restoration	
1.	To what extent were project goals and objectives achieved?
2.	How similar in structure and function is the restored ecosystem to the target ecosystem?
3.	To what extent is the restored ecosystem self-sustaining, and what are the maintenance requirements?
4.	If all natural ecosystem functions were not restored, have critical ecosystem functions been restored?
5.	If all natural components of the ecosystem were not restored, have critical components been restored?
6.	How long did the project take?
7.	What lessons have been learned from this effort?
8.	Have those lessons been shared with interested parties to maximize the potential for technology transfer?
9.	What was the final cost, in net present value terms, of the restoration project?
10.	What were the ecological, economic, and social benefits realized by the project?
11.	How cost-effective was the project?
12.	Would another approach to restoration have produced desirable results at lower cost?

Other planning considerations are technical in nature, many of which will ultimately be guided by the TECs and their targets. The USACE Planning Guidance Notebook ER-1105-2-100 discusses six criteria or concepts that should influence restoration and preservation actions (USACE 2000):

- *Scarcity:* a resource with a limited range or abundance may be considered valuable or significant in a specific geographic range;
- *Representative:* a resource that is representative of a natural or undisturbed area, such as a large number of native species in a specified range;
- *Status and Trends:* trends indicate the declining or imperiled health of a resource and should also consider its potential for recovery through human intervention;
- *Connectivity:* improve connectivity or reduce fragmentation by creating suitable habitat corridors, removing barriers, and addressing patterns of fragmentation;
- *Limiting Habitat:* habitat that is essential for important species or critical to a species' recovery and survival may be considered limiting and warrant protection; and
- *Biodiversity:* efforts that improve or increase biodiversity should be considered.

These concepts can be applied for individual restoration projects, but may yield the greatest utility when applied in a larger context (e.g., estuary-wide). A generic checklist of project planning and implementation considerations may be helpful in prioritizing actions and improving chances of success (Table 2-1 [NRC 1992]).

2.2 Regulatory Constraints

As part of project planning, project proponents should recognize that various Federal, state and local environmental regulations influence land use decisions through resource protection, land use control, and pollution control (Table 2-2). The purpose of the CRP is not to supersede local regulatory authority, but to provide guidance on future activities such as projects, policy collaboration, data collection, and economic development. Identification of and coordination with interested regulatory agencies is essential early in the planning phase of a project. Even though permit applications are generally not prepared and submitted until the project design phase, early communication with regulatory agencies can streamline the planning process. Early communication can help to guide the process by identifying potential compliance issues that can delay or even prevent projects from occurring. The USACE, state regulatory programs, local conservation commissions, county planning departments, and regional commissions should be consulted to discuss project concepts and to determine the required approvals. Environmental and land use constraints associated with projects may include:

- Federal, state, and/or local wetlands regulations;
- Federal Emergency Management Agency designated 100-year floodplain and floodways where earth fill and structures are limited;
- Threatened or endangered species subject to the Federal Endangered Species Act and/or state regulations;
- Consistency with Coastal Zone Management Act;
- Historical and/or archaeological resources or features (e.g., dams subject to the National Historic Preservation Act

Table 2-2. Pertinent Federal resource, land use, and pollution control statues that should be reviewed when planning a restoration project (adapted from Kreske [1996]).

	Statute	Concern
Federal Resource and Land Use Control Statutes	Airport and Airway Development Act of 1970	Airport development impacts on communities
	Archeological Resources Protection Act of 1979	Prehistoric artifacts including skeletal remains
	Coastal Zone Management Act of 1972	Control of projects in coastal zone
	Department of Transportation Act of 1966 (section 4(f) and Federal –Aid Highway Act of 1968 (section 18(a))	Use of land for highways (especially parks and other reserves)
	Endangered Species Act of 1973	Protection of endangered/threatened plant and animal species
	Farmlands Protection Policy Act of 1981	Conversion of farmlands
	Federal Land Policy Management Act of 1976	Multiple use of Department of Interior public lands
	Fish and Wildlife Coordination Act of 1953	Fish and wildlife conservation, interagency coordination
	Forest and Rangeland Renewable Resources and Planning Act of 1974	Comprehensive planning for USFS forests and rangelands
	Magnuson-Stevens Fishery Conservation and Management Act Amendments of 1990	Management of marine fisheries and mammals
	Marine Mammal Protection Act of 1972	Marine mammal protection
	Marine Protection Research, and Sanctuaries Act of 1972	Marine sanctuaries
	Multiple-Use Sustained-Yield Act of 1960	Multiple use management of national forests
	National Environmental Policy Act of 1969	Environmentally informed decisions, public involvement
	National Forest Management Act of 1976	Directs forest planning
	National Historic Preservation Act of 1966	Preservation of prehistoric sites/structures
	Outer Continental Shelf Lands Act of 1953	Offshore oil development
	Wild and Scenic Rivers Act of 1968	Balances river development with permanent protection of the nation's free-flowing rivers
	Wilderness Act of 1964	Management of wilderness areas
Federal Pollution Control Statutes	Clean Air Act Amendments of 1970	Air pollution
	Comprehensive Environmental Response, Compensation, and Liability Act of 1980	Protection from and clean-up of hazardous waste
	Federal Environmental Pesticide Control Act of 1972	Pesticide pollution
	Federal Insecticide, Fungicide and Rodenticide Act of 1974	Pesticide pollution
	Federal Water Pollution Control Act Amendment of 1972(Clear Water Act)	Water pollution including filling wetlands
	Marine Protection, Research, and Sanctuaries Act of 1972 (Ocean Dumping Act)	Ocean dumping of wastes/ dredged material
	Noise Control Act of 1972	Noise pollution
	Resource Conservation and Recovery Act of 1976	Hazardous and non-hazardous waste management
	Rivers and Harbors Act of 1899	Deposition of refuse (Section 13) in navigable waters
	Toxic Substances Control Act of 1976	Chemical substances control

or state regulations promulgated by State Historic Preservation Offices (or Tribal Historic Preservation Offices on Native American lands);

- Contaminated sediments and hazardous waste;
- Other site features (e.g., buildings, utilities, walls, and bridges) that will potentially affect restoration work activities; and
- Off-site constraints upstream of a project area that may affect success of the project, such as bridges (e.g., footing scour potential), and buried utility lines.

Proposed environmental restoration projects can encounter public resistance resulting from perceived threats (e.g., existing land/water uses, jobs, etc.) or from misunderstanding the project's scope (Kreske 1996). Although public involvement may not be a required component of every restoration project, the benefits of early disclosure will likely be substantial. Public involvement provides an opportunity for consensus building, where issues are identified early and steps can be taken to resolve them so that project momentum continues. Taking adequate measures to publicly disclose the project's goals and proposed actions, through public meetings or publications, will identify communities' desires and help focus efforts on those issues requiring resolution. In turn, this will help eliminate unnecessary investigations and build support, saving time and money. The level of public involvement and effective methods of reaching the public vary by location and depend on the type of project proposed, emphasizing the need to know a region's constituent groups and key stakeholders. Constructive feedback on a project should be integrated into the proposed project components so that the public sees their contribution and the role they played in shaping the project.

The USACE's Feasibility Phase will utilize the CRP to develop an environmentally and economically sustainable ecosystem restoration program. The development of this program will include fulfilling the National Environmental Policy Act (NEPA) requirement for all recommended actions through the preparation of a Programmatic Environmental Impact Statement (PEIS) with the expectation that regulatory agencies may be able to simplify the approval process for restoration actions within the HRE study area.

2.3 Siting Considerations

Site selection is a critical step in the restoration process that can have long-term implications on the project's success and quality of ecosystem services provided. It is important to weigh the benefits associated with site size, adjacent land uses, and community needs and preferences.

It is best to consider restoration sites with a suitably large "critical mass" of area to maximize the value of the restored habitat, maximize the economies of scale, and protect against deleterious effects of adjacent land uses (NRC 1992). Many of the TECs would return more and higher quality ecosystem services with larger parcels of restored habitat, such as coastal forests, wetlands, and when improving upstream access in coastal streams (e.g., select streams that provide the most upstream access once a barrier is removed). For linear habitats along the shoreline, such as eelgrass and maritime forests, several areas can be created/restored and linked together over time. Smaller-sized projects tend to provide commensurately fewer ecosystem services, but can be extremely valuable for creating very scarce habitats, meeting special

needs, or meeting the goal of a diverse system. They are also useful for educational and outreach purposes because they are often easily accessible and located within areas communities would like to reclaim, thereby increasing stakeholder support for the overall program. Large- and small-sized restoration projects should be pursued and constructed, resulting in a mix of ecologically and educationally beneficial projects. Additionally, because the HRE study area is densely developed and intensely used, any parcel of available land, regardless of size, should be investigated for its suitability as a restoration site.

The goal of the CRP is to develop a mosaic of habitats that provides society with renewed and increased benefits from the estuary. This mosaic of habitats would provide multiple ecological benefits and ecosystem services. Therefore, wherever possible restoration projects should be sited adjacent to existing complementary habitats or be designed to incorporate several TECs or habitat types into one project. For instance, many species of shellfish could be restored in addition to oysters, mudflats and wetlands provide habitat for benthic invertebrates as well as fish and bird species, maritime dunes are essential for the stability of maritime forests, and grasslands are a complementary, though ecologically rare, habitat type in the estuary. Creating large plots of heterogeneous habitat complexes provide a measure of resilience and sustainability, even enabling systems to recover from catastrophic events (Pastorok et al. 1997). Knowledge of species distributions, migratory routes for animals, and dispersal patterns for plant species are important considerations when determining the spatial scale and location of the habitat (NRC 1992). However, it may be difficult to identify available land adjacent to existing habitats or outside of industrial and commercial influences in the HRE study area.

In many cases, restoration projects in the HRE study area will be implemented opportunistically in response to available funding, community concerns, and the presence of project proponents. Restoration should strive to establish valuable habitats that provide increased ecosystem services and ecological benefits to the HRE study area in accordance with the system-wide philosophy of the plan. Each project sponsor should consider whether their proposed action (1) meets the identified TECs; (2) could include additional TECs to their project plans; (3) considers upstream and downstream consequences of project implementation; and (4) considers how the project might integrate with other local projects to provide an even greater benefit. To be successful, opportunistic restoration requires understanding many large-scale processes, including the structural components (i.e., habitats) necessary to improve biological, chemical, and hydrological functions. It is also important to recognize the physical and biological context within which restoration is occurring and integrate individual actions to fulfill a collective vision for the landscape (NRC 1992). The CRP provides the framework to guide opportunistic restoration projects to maximize the system-wide benefits by working towards achieving the objectives of the TECs.

Finding a balance between the ecological needs of the habitat and human needs and behaviors will be a major challenge to siting projects. The HRE study area contains many locations where permitted land uses, such as Combined Sewer Overflows (CSOs), landfills, port terminals, and hardened shorelines are necessary to society and the economy and cannot be removed. In some cases, projects may be sited in areas where stakeholders can directly influence major causes of ecological disturbance, to minimize or eliminate the disturbance (NRC 1992). Sensitive habitats should not be planned for areas prone to disturbance. Populous areas may also not be appropriate for restoring sensitive habitats because the costs associated with restricting access and safeguarding against vandalism and disturbance from feral or domesticated animals can be prohibitive (NRC 1992). Additionally, restricting access to popular recreational locations can cause community resentment

toward future restoration activities. Instead, restoration projects sited in populous areas should be designed to incorporate recreational uses, providing natural settings and enabling residents to gain a greater appreciation for the services habitats provide.

2.4 Setting Site-specific Goals

It is important to determine the goals and objectives of a restoration project at the outset to make project success easier to gauge and more likely to achieve. Clear goals and objectives assist in communicating restoration plans to potential funding sources, agency partners, and the general public (Pastorok et al. 1997). Project goals should be consistent with the goal of the CRP and, where possible, should incorporate elements of the TEC target statements and planning region-specific guidance.

Project goals are general statements about the desired outcome and typically refer to the ecosystem attributes to be restored, such as habitat type, water quality, plant communities, public access opportunities, or fish and wildlife resources. Goal statements provide a general framework for the project, such as to "restore the native plant community and limit the presence of invasive species," "develop recreational facilities to increase public access", "restore naturally sloping intertidal shorelines with a vegetated upland," or "restore historic alewife runs to XYZ stream." Project objectives are more precise, and may include the specific characteristics, quantitative statements, and tangible benefits of the habitat quality, water quality, or plant and animal communities to be restored. For example, if the goal was to restore shoreline habitat, an objective might be to create subtidal habitat complexes to benefit juvenile fish or to create a 100-ft wide native vegetated buffer along the shoreline.

Developing and prioritizing specific objectives at the project out-set has been shown to lead to project success (Yozzo and Sexton 1996, NRC 1992). However, many factors play a role in determining the scope of a restoration project, thereby affecting the level of detail that can be specified. The size and complexity of the project are typically influenced by surrounding land uses, the size of the existing or degraded habitat, and the budget. Having prior knowledge about a site can greatly improve the planning and goal-setting phase. When available, existing site data should be reviewed to determine past use, level of degradation, existing species complexes, and major impairments that should be addressed through restoration. It may also be helpful to apply this knowledge and site-specific understanding to determine what influences the broader regional landscape may have on the project (e.g., nutrient/sediment inputs, species distributions; Yozzo and Sexton 1996). Because of the constraints surrounding restoration projects, care should be taken when establishing study objectives to maximize project benefits, paying particular attention to functional tradeoffs. For instance, designing a project to maximize the output of one particular function or TEC (e.g., habitat for estuarine-dependent fish) may involve a trade-off where other functions are not adequately incorporated into the design (e.g., bird/wildlife habitat, shoreline stabilization).

In addition to project goals and objectives, project-specific performance indicators and success criteria should be developed to measure project success. Performance indicators are quantitative, measurable characteristics used to determine if a project will meet pre-determined success criteria and generally evaluate changes in structure (e.g., plant distribution,

organic matter, bathymetry, etc.) and communities utilizing an area (e.g., benthic invertebrates, finfish, wildlife, etc.). Performance indicators can be developed during the life of the project, such as target species height and basal area in a maritime forest, the number of colonial waterbirds nesting on an island, the presence of target fish and crustacean species at a subtidal reef, or the range in daily low dissolved oxygen concentrations in an enclosed basin. Performance indicators should be biologically relevant so they provide insight into the system's structure and function, and be relatively sensitive to environmental stressors so they can be used as a proxy for environmental health. They should also have some intrinsic value from a social perspective. From a planning perspective, it is helpful to establish performance indicators consistent with successful regional restoration monitoring programs. Doing so can provide some assurance that the performance indicators are project-appropriate and allows for comparisons of baseline/post-restoration results with other successful projects (Yozzo and Sexton 1996).

Success criteria, which are used to evaluate performance indicators, are targeted outputs that should be developed and agreed upon by the technical study team (i.e., project's proponents, outside experts, consultants, etc). For example, if the goal of a project is to restore native wetland plants, the success criteria might be the number of acres of marsh that should be re-colonized by cordgrass (Spartina spp.) at 3, 5, and 10 years post-restoration. The failure of a project to meet these acreage targets should trigger re-evaluation and perhaps implementation of corrective measures at the site (i.e., adaptive management; Pastorok et al. 1997, Weinstein et al. 1997). This re-evaluation should also consider if the location of the restoration action was appropriate (e.g., tidal regime, land use, etc.).

Ultimately, projects should be designed to produce tangible and measurable outputs, with realistic and attainable goals, objectives, and success criteria. Programs should be flexible to allow for changing conditions, perceptions, or new information to be incorporated into the project. Incorporating flexibility with active project management ensures that the appropriate combination of physical action and modifications to project goals/criteria are employed to achieve success (Yozzo and Sexton 1996).

2.5 Monitoring Programs

Establishing a self-maintaining system requires continuous information during the planning, construction, and post-construction phases, which is gained by monitoring (Yozzo and Sexton 1996). Developing a monitoring program reduces the uncertainty associated with establishing habitats that mimic natural systems. Monitoring plans should be project-specific, focusing on meeting the goals and objectives and evaluating the variables most critical to restoration success. Monitoring of natural "reference" areas in addition to the restoration site is imperative to the monitoring process and in both designing and adaptively managing the site. Reference sites situated within the local geographic area (or "reference domain") can provide a model for the relative acreage and juxtaposition of each habitat type. Monitoring data from the reference and restored sites can be used to determine how similar the sites are to performing ecological services and how successful the restoration project has been, ultimately improving long-term success and efficiency. Since the HRE is highly urbanized, Baldwin (2004) suggests that "*Reference areas, ecological benchmarks, should be chosen within the urbanized system where species have succeeded despite urban constraints. Because the vegetation communities in existing urban wetlands are adapted to an urban environment restoring vegetation similar to that found in other urban wetlands provides a more realistic goal than attempting to create vegetation similar to that of undisturbed wetlands.*"

Conducting baseline monitoring of restoration and reference sites is critical so that baseline conditions can be evaluated against post-construction conditions. Performance indicators, which are used to evaluate the goals, vary seasonally, in frequency, and in the length of time to become established, and these considerations should be incorporated into project-specific monitoring plans. Post-construction monitoring should cover a time period appropriate to evaluate project goals and continue until the system is self-sustaining, whether it is less than or longer than five years (Simenstad and Thom 1996, Neckles and Dionne 1999).

The benefits of careful, comprehensive post-construction monitoring cannot be over-emphasized. Despite this, restoration projects are not always adequately monitored, especially post-construction, often due to cost or other factors (i.e., USACE projects adaptive management period proposal is 5 years). To defray costs, many programs in the HRE study area rely on volunteers, such as the NY/NJ Baykeeper, the NYC Audubon Society, and other non-governmental entities for supplemental monitoring data or for collecting a majority of the monitoring data. Volunteer-based monitoring programs are a low-cost alternative and can gather valuable, high-quality data if properly trained and supervised (Leslie et al. 2004). Directly involving volunteers in the restoration process has added benefits by promoting public awareness and enthusiasm for habitats in the HRE study area and encouraging the public to take ownership of the program. In the absence of long-term comprehensive monitoring, project proponents will be unable to demonstrate that restored/created ecosystems have provided the desired functions, or will lack necessary feedback to determine whether adjustments should be implemented to optimize outputs and achieve success.

Another important outcome of project-specific monitoring is to track progress toward the TEC targets and to supplement existing ecological data collected in the HRE study area. Restoration practitioners should be responsible for reporting monitoring results to the managing body of the CRP. At a minimum, the mapped project location, acreage, TECs included in the project, cost (estimated or actual), and project status should be reported when major milestones are reached. For larger projects, it would also be helpful for restoration practitioners to report lessons learned, project constraints, species lists, roles of stakeholders, and ways adaptive management was implemented to improve future projects. Not only does this provide a record of success to encourage future investments, it enables the overall CRP to be better managed by identifying TECs that need attention more than others.

3.0 Restoring Target Ecosystem Characteristics

The purpose of the CRP is to promote restoration that will contribute to achieving the TEC objectives in the HRE study area. The TECs are measurable objectives for meeting the critical habitat and societal needs of the HRE study area. The TECs represent an initial, decisive environmental agenda for the estuary as well as a long-term strategy that can evolve with changing environmental conditions and human needs. The following sections describe the current status, present the targets, and identify opportunities for restoration of the TECs in the HRE study area.

3.1 Habitats

Five of the TECs represent habitat types that were historically abundant, but have either been eliminated or significantly reduced in size in the HRE study area. These habitats are essential to the ecology of the HRE, and the purpose of these TECs is to restore acreage of these valuable habitats in the HRE study area. The following sections describe the TEC habitats and their short- and long-term objectives, presents potential restoration opportunities within the HRE study area, current status and research needs, and suggested monitoring parameters.

3.1.1 Coastal Wetlands

Coastal wetlands, defined as tidally influenced wetlands connected to the open waters, historically represented a significant habitat complex in the HRE study area. They are among the most productive ecosystems on Earth, with measured production rates exceeding those of tropical rain forests and freshwater wetlands (Good et al. 1982).

Coastal wetlands are characterized by a distinctive vegetation community. Smooth cordgrass (*Spartina alterniflora*) dominates intertidal salt marsh communities in the HRE study area. This species generally occurs between mean high water (MHW) and mean sea level and may vary in growth form (i.e., tall, medium, and short), depending on tidal flooding frequency and duration. Above MHW (high marsh) the floral composition of salt marshes increases in diversity, with several plant species typically present, including saltmeadow hay (*S. patens*) and salt grass (*Distichlis spicata*). The structure and function of many coastal wetlands in the HRE study area have been altered in recent decades by the proliferation of an aggressive European genotype of common reed (*Phragmites australis*) that forms monoculture stands. There is considerable interest in restoring coastal wetlands in the estuary by removing common reed and re-establishing native salt marsh vegetation (e.g., *Spartina* spp.).

It is understood that there are some differing opinions regarding the value of *Phragmites* and other non-native species. However, the intent of the CRP is not to enter that debate, but rather to restore, to the extent practicable and feasible, indigenous species. Decisions regarding the appropriateness of invasive versus other native species will be made at the site specific level, not as a part of the programmatic plan. The management of invasive species to maintain diversity is an important responsibility of the Federal government and other agencies and organizations. Executive Order 133112 requires the National Invasive Species Council to produce a National Management Plan for Invasive Species every two years, and this plan serves as the blueprint for all Federal action on invasive species. The Plan was written in association with eight working groups, the Invasive Species Advisory Committee, and input obtained from the public at public hearings held across the country.

Salt marsh vegetation is very effective at stabilizing shorelines and protecting coastal areas from erosion during storms. By trapping sediment, coastal wetlands retain important sediment-bound nutrients in the estuary instead of allowing these nutrients to be carried to sea (Seneca and Broome 1992). Sediment retention in coastal wetlands is important for chemical detoxification, nutrient retention and recycling, and decomposition processes (Seneca and Broome 1992). The ability of coastal wetlands to retain high levels of nitrogen has important implications for eutrophication and nitrogen-loading to the HRE study area. Coastal wetlands with widths as small as several hundred feet (a few hundred meters) can be nutrient-rich and highly productive because of their sediment trapping abilities (Teal and Howes 2000).

Coastal wetlands provide valuable habitat for a variety of organisms. Juvenile fish and crustaceans gain refuge from predators and benefit from abundant prey resources in salt marshes. Wading birds, such as egrets and herons, prey upon resident fishes and invertebrates in salt marshes. Migratory waterfowl use salt marshes as stopovers during their winter and summer migrations. A variety of mammals use salt marshes for foraging, breeding, and refuge. Northern diamondback terrapins (*Malaclemys terrapin terrapin*), forage and breed in salt marshes.

Coastal wetlands can be important recreation areas and can offer numerous educational opportunities. Examples of human recreational uses in coastal wetlands of the HRE include bird watching, fishing, boating, and hiking. Ecological studies and educational programs in the HRE include participation by school children, college students, and graduate research students. The aesthetic qualities of coastal wetlands are valued by many who choose to reside in or visit the coastal zone.

Historically, coastal wetlands represented a significant habitat complex in the HRE study area. However, a large portion of the coastal wetland habitat in the HRE study area has been degraded or destroyed by human activities. The most devastating losses have occurred since World War II and before the implementation of the Clean Water Act (CWA) when large expanses of wetlands were filled, drained or diked (Bone 1997).

In the last 30 years, cumulative wetland losses have slowed due to the implementation of protective legislation and mitigation. Yet, acres of wetlands still disappear and are degraded annually in the HRE study area. Many factors have been suggested as possible contributors to current wetland habitat loss: sea level rise; alterations in the estuary's sediment budget; erosion due to changes in wave energy; effects of contaminants; changes in hydrologic connectivity; or excessive consumption of marsh grasses by waterfowl (Steinberg et al. 2004). Other threats arise through changes in soil chemistry and moisture (e.g., during droughts), such as soil oxidation, soil acidification, and metal toxicity which can cause sudden losses of acres of wetlands. Stressed wetlands may be more susceptible to fungal pathogens and elevated salinities (Lindstedt and Swenson 2006). Wetland loss is complex and is likely a function of many factors, each of which varies in intensity and exposure among regions of the HRE study area.

These wetland functions are not expected to have estuary-wide effects (e.g., water quality improvements throughout the estuary). Instead, individual coastal wetland projects should evaluate the merit of creating subsets of the following seven functions within the vicinity of the project site, paying particular attention to the ecological and societal needs of the region: 1. nutrient and carbon retention; 2. plant community support; 3. sediment accretion and stabilization; 4. habitat for estuarine nekton (i.e., fish and macrocrustaceans); 5. habitat for wetland birds; 6. habitat for other marsh-dependent organisms (e.g., small mammals, diamondback terrapins, terrestrial invertebrates); and 7. scenery and recreation (Bain et al. 2007).

Restoration and creation of wetlands should not be the only method by which this habitat complex is preserved. The scientific and regulatory communities should also be encouraged to identify ways to conserve existing wetlands in the HRE study area.

TEC Guidance

Coastal wetland restoration and creation projects should attempt to create high-quality and sustainable systems that closely mimic native communities. Oftentimes, degraded wetlands represent the greatest potential for enhancing ecological function in an area and may represent the most cost-effective opportunities. Although non-native plants (e.g., common reed, *Phragmites australis*) provide some ecological functions and fulfill some species habitat requirements, projects should strive to establish native plant communities, recognizing that maintaining these assemblages will likely require intervention and a commitment to periodic maintenance.

Implementation of a preferred restoration activity will be subject to review and approval by the appropriate regulatory agencies. Proper planning and obtaining early project support by regulatory agencies at the outset of planning process will aid in identifying and resolving any physical, regulatory, and institutional constraints (i.e., standard contaminant sampling).

Suggested Monitoring Parameters

Coastal wetland monitoring protocols should be tailored to individual project goals and incorporate some degree of site-specificity (Niedowski 2000). To gauge success, restoration goals, objectives, performance indicators and success criteria should be clearly stated and regularly re-evaluated under an adaptive management framework. A well-designed monitoring program will allow practitioners to detect deviation from projected results months, years, or decades following construction. For example, yearly monitoring of a restored salt marsh might reveal encroachment by *Phragmites australis* or other invasive plant species. Hydrologic monitoring may reveal deficiencies in the design of a culvert or water control structure, which may result in insufficient drainage. Manual harvesting or chemical control may be periodically required to control the spread of invasive plants. The specific design features of a culvert or water control structure may require enhancement or modification during successive years to optimize tidal flow patterns

Suggested parameters to be monitored at salt marsh restoration and reference sites include:

- *Surface topography and elevation*
- *Tidal creek cross-sections, sinuosity and density (i.e., number and order of channels per unit of area)*
- *Water table depth*
- *Surface water level changes*
- *Surface and groundwater quality*
- *Soil organic matter and water content*
- *Sediment accretion rates*
- *Plant species distribution and cover*
- *Benthic invertebrate communities*
- *Utilization of the marsh by finfish and crustaceans*
- *Utilization of the marsh by wildlife*
- *Storm surge and flood hazard*

A post-construction monitoring program should include components similar (or identical) to those measured during baseline site assessments. An additional component to consider monitoring is the public use of a restored or newly created coastal

wetland (e.g., paddlers, birders, anglers, educational groups), which assesses the intrinsic and recreational value of coastal wetland projects.

3.1.2 Waterbirds

Waterbirds function as important predators in estuarine systems, are indicators of ecosystem integrity, and are intrinsically valuable to the public (Bain et al. 2007). Aquatic birds (or "waterbirds") include a variety of birds adapted to life in and around coastal habitats. Waterbird groups include seabirds (e.g., pelicans, cormorants, gulls and terns), shorebirds, (e.g., plovers and sandpipers), waterfowl (e.g., ducks, geese), and long-legged wading birds (e.g., herons, egrets, and ibis). Within the HRE study area, a particular subset of waterbirds, the long-legged wading birds, are the focus of this TEC. Nine species of egrets, ibises and herons are collectively known as the "Harbor Herons," and this assemblage has been monitored annually in the HRE by New York City Audubon and its agency and institutional partners for over two decades (Bernick 2007).

As top predators in coastal wetlands, waterbirds consume fish and crustaceans within coastal wetlands and other littoral areas, thereby playing an important role in energy transfer and controlling population dynamics in these communities. Waterbirds in their natural setting are sought after by members of the birding community, members of which are often active supporters of ecological restoration initiatives, especially in urban locales. In addition to the important ecological role and the viewing opportunities waterbirds offer, they also function as indicators of ecological health. Through bioaccumulation of contaminants in the food web, bird reproduction can be impaired, leading to diminished or extirpated populations.

The Harbor Herons have experienced a dramatic comeback since the 1960s, when populations were nearly extirpated by centuries of hunting, pollution, and habitat loss. With improved water and habitat quality, herons began populating the uninhabited islands of the Arthur Kill, Kill Van Kull, East River, and Jamaica Bay during the late 1970s (Steinberg et al. 2004). Ten islands in the HRE study area currently function as nesting rookeries for resident and transient waterbirds. Some islands occur in open water, like those in Lower New York Bay, while others are close to land, like those in the East River, or surrounded by intertidal marshes, such as the islands in Jamaica Bay. In each situation the islands are isolated, vegetated by trees and shrubs essential for nesting, yet located within close proximity to foraging sites (typically intertidal wetlands). Even islands that appear far removed from feeding grounds may provide valuable habitat in an urban setting. Several waterbird species in the HRE study area have been documented to fly approximately 12 miles (20 km) to reach foraging areas (Nagy 2005). Because these species are highly mobile, they can utilize alternative nesting sites when nesting habitat degrades on some islands.

Species such as black-crowned night heron (*Nycticorax nycticorax*), yellow-crowned night heron (*Nyctanassa violacea*), glossy ibis (*Plegadis falcinellus*), snowy egret (*Egretta thula*), and great egret (*Casmerodius albus*) are the most abundant and of primary concern in the HRE study area. At their peak, waterbird nesting in the estuary constituted nearly 25% of the entire New York, New Jersey, and Connecticut populations (Steinberg et al. 2004, Kerlinger 2004). However, recently productive nesting habitats, including islands in the Arthur Kill and Kill Van Kull, have been virtually abandoned by waterbirds within the past several years, and breeding populations may now be declining once again.

TEC Guidance

Several factors influence the use of islands by nesting waterbirds, including habitat changes and increased disturbance. Many of the estuary's shorelines are subject to strong currents and erosive wave action, which can reduce foraging habitat. Further losses to foraging habitat have occurred through recent oil spills, persistent contamination, remnant debris, encroaching development, and invasive non-native species (Yozzo et al. 2001).

Increased disturbance on the islands has caused declines in suitable nesting material or habitat and decreased the number of suitable nesting areas in the HRE study area. Potentially critical disturbances to waterbird nesting habitat and suggested methods for mitigating the disturbances include:

- *Invasive vines and shrubs* - During the 2007 Audubon survey, egrets and herons were observed nesting on the invasive multiflora rose shrubs (*Rosa multiflora*) and an invasive vine, kudzu (*Pueraria montana*; Bernick 2007). This is a concern because waterbirds can become tangled in the invasive vines and as invasive vines spread, they can replace more desirable native tree species. Invasive species removal programs and programs to plant native tree species suitable for nesting can be conducted to ameliorate the impact. These programs should be targeted on islands that are currently used by waterbirds as the native trees will require several years of growth to provide suitable nesting habitat.
- *Asian long-horned beetle* - The recent discovery of an Asian long-horned beetle (*Anoplophora glabripennis*) infestation on Pralls Island in March 2007, led resource managers from NYSDEC, NYCDPR, U.S. Department of Agriculture, and New York State's Department of Agriculture and Markets to remove 3,000 potential host trees on that island (Bernick 2007). Heavy infestations of this non-native, invasive species of beetle kill important hardwood trees, like gray birches and red maples. Adult beetles burrow into the trees to lay eggs, and larvae later develop and feed deep within the tree. Deforestation is one of the few known management tools for controlling this species once an infestation occurs. However, the deforestation of Pralls Island also presents a restoration opportunity for creating a coastal community of native hardwood trees (see Coastal and Maritime Forests TEC).
- *Double-crested cormorants* - Population increases of the double-crested cormorant (*Phalacrocorax auritus*) may be negatively affecting waders. Cormorants, which also nest in trees, tend to foul (i.e., excessive waste accumulation) and sometimes kill suitable nesting trees. However, there is not yet sufficient information to determine whether increases in the double-crested cormorant population in any way relate to observed numbers of waterbirds in the HRE study area.
- *Contamination* - Some of the islands in the HRE study area may contain contaminated soils, surface waters, and biota, from oil spills or historic industrial or medical uses. Sediment contamination can have sub-lethal behavioral effects on birds, and contaminants biomagnified through consumption of fish and invertebrates may lead to reproductive anomalies in avifauna. Relatively little data is available regarding potential effects of contaminants on waterbirds in the HRE study area. This is an important avenue for future research, prior to implementation of restoration actions pertaining to waterbirds and their habitats.
- *Predators* - Evidence of egg predation, particularly by raccoons, has been observed on several of the islands, but because there are no local natural resource agencies conducting predator monitoring on the islands, little is known about mammalian predator populations. To maximize the success of waterbird restoration projects, it might

be beneficial to initiate a predator-monitoring program as part of an active pre- or post-restoration management regime. Predator control methods could be considered on islands with known impacts on colonial waterbirds both to prepare the sites for restoration and, if necessary, to periodically maintain these predator levels. Although there is no formal predator eradication program, the NYSDEC will remove predators in response to calls.

- *Human disturbance* - Abandonment of islands may also occur due to human disturbance, which is a growing concern due to the increased demand for public green spaces (Nagy 2005). Increased human presence on islands can disrupt the nesting behavior of the waterbirds and leave eggs vulnerable to predation. It may be beneficial to educate the public about the nesting waterbirds and the risks associated with human disturbance by placing interpretive signs along island trails. Conducting volunteer-based habitat restoration or invasive species removal programs also promotes an increased awareness of the waterbirds. For islands where public access will be permitted, restricting access to the colonies during the nesting season may be necessary.

Although the factors contributing to the abandonment or colonization of an island are complex, this behavior emphasizes the need for diverse and scattered island habitat. Changes in habitat availability or suitability can affect local population levels through failed nesting attempts or abandonment. If many of the existing threats to waterbirds continue, they may cause further population declines in breeding pairs in the HRE study area. Therefore, restoring optimal rookery habitat on existing islands and creating additional foraging habitat (in the form of intertidal wetlands) can provide estuary-wide benefits to thousands of waterbirds.

Data Needs

Future baseline studies should evaluate the specific attributes of each island in terms of soils/substrate, vegetation cover, predators, and human disturbance (including contamination of soils and biota). In the face of potentially significant increases in sea level rise within the HRE study area in coming years, island habitats should be restored with long-term sustainability in mind; this may entail raising the elevations of low-lying areas with clean fill (e.g., dredged sand from ongoing channel maintenance projects) prior to the restoration of native vegetation communities.

In order to gain a better understanding of the spatial relationships between existing nesting areas and available foraging habitat, it is recommended that radio-telemetry and banding studies be conducted on groups of several birds from each of the active colonies to determine where they are feeding and the direction/distance they travel. This should be implemented as a baseline monitoring component at existing rookeries, and incorporated into a long-term monitoring program at restored islands, following re-colonization by waders.

An important baseline data component will be to identify the presence of contaminated soils or biota on the islands, evaluate body burdens for the populations, and determine the effect of contaminants on behavior and reproductive health of waterbird populations. Beyond the initial baseline characterization, it will be important to monitor contaminants in soils and biota at restored sites on a long-term basis (years to decades) to be able to evaluate this factor on the integrity of waterbird populations in the HRE study area, relative to improvements in nesting/foraging habitat.

Suggested Monitoring Parameters

Waterbird site monitoring protocols should be tailored to individual project goals and incorporate some degree of site-specificity (Niedowski 2000). To gauge success, restoration goals, objectives, performance indicators and success criteria should be clearly stated and regularly re-evaluated under an adaptive management framework. A well-designed monitoring program will allow project managers to detect deviation from projected results months, years, or decades following construction. For example, yearly monitoring of a restored rookery/nesting site might reveal encroachment by common reed (*Phragmites australis*), tree-of-heaven (*Ailanthus altissima*), sumacs (*Rhus* spp.), or other invasive or undesirable plant species. Manual harvesting or chemical control may be periodically required to control the spread of invasive plants. The specific design features of an island-nesting site may require enhancement or modification during successive years to ensure integrity in the face of storms and/or erosion from vessel wakes.

Within the HRE study area, a considerable body of knowledge exists on the numbers of breeding pairs for individual wader populations. However, additional information is needed on the specific environmental attributes of islands and other areas that currently serve or may have historically served as nesting sites. Collection of this information should precede any large-scale implementation of restoration projects intended to benefit waders and/or shorebirds in the HRE study area. Suggested parameters to be monitored at restored waterbird rookery/nesting sites include:

- *Surface topography, elevation, and shoreline erosion*
- *Surface water quality*
- *Soil organic matter and contaminant concentrations in soils and biota*
- *Plant species distribution and cover, especially influx of invasive species*
- *Colonization or re-colonization of the site by target waterbird species, as well as by non-target waterbirds, such as cormorants*
- *Quantifying nesting/fledgling success*
- *Determination of material used in nest construction at active rookeries*
- *Movements of target species between rookeries and foraging sites*
- *Utilization of the site by other wildlife, especially predators on eggs and chicks*
- *Utilization/disturbance of the site by humans*

Ideally, a waterbird restoration site should be monitored until it appears mature and self-sustaining, and is being used in successive years by a sub-population(s) of the target species.

3.1.3 Coastal and Maritime Forests

The Coastal and Maritime Forests TEC addresses ecologically rare and unusual systems that have become vulnerable to extirpation, within the HRE study area and globally. These plant communities are important ecological corridors, providing habitat and food resources to support many wildlife species.

Maritime plant communities are dynamic systems that occur across a range of fringe seacoast habitats in narrow, discontinuous bands (NBS 1995). These forests, often described as “strand forests”, are influenced by strong salt spray, high winds, unstable substrates (e.g., dune deposition/shifting), and have characteristically stunted and contorted trees with

"salt-pruned" branches (NBS 1995, Yozzo et al. 2003, Edinger et al. 2002). The relative influence of physical stressors like salt spray or sandy soils limits canopy height and shapes species composition in maritime forests (NBS 1995). High surface soil temperatures, sandy soils with low nutrients, an unpredictable supply of freshwater and periodic seawater inundation also make these lands formidable to most plant species (Bain et al. 2007, NBS 1995, Yozzo et al. 2003). Some maritime species have evolved adaptations to protect against salt spray, such as completing their entire life cycle between major storms, growing in a low-profile form to avoid the spray, or growing beneath protective canopies of more salt-tolerant species (Bain et al. 2007).

Maritime communities are perpetually shifting complexes that interchange in response to the dynamics of the substrate. Beach and dune habitats are the most dynamic of the maritime vegetative communities, being modified by winds and waves and stabilized by vegetation. When the dunes are altered, this changes the inland shrub and forested lands, bringing them closer to shore, pushing them further inland or even periodically eliminating them. Herbaceous and shrub layers thrive on the outskirts of the forest and in bog areas, behind the dune and swale communities. Both evergreen and deciduous trees, such as American holly (*Ilex opaca*), oaks (*Quercus* spp.), sassafras (*Sassafras albidum*), shadbush (*Amelanchier canadensis*), black tupelo (*Nyssa sylvatica*), beech (*Fagus grandifolia*), red cedar (*Juniperus virginiana*), northern bayberry (*Myrica pensylvanica*), and beach plum (*Prunus maritima*), commonly dominate the forest community. The species composition can depend upon how connected these communities are to nearby forests on the coastal plain (Bain et al. 2007).

Coastal forests are non-maritime communities found within the coastal plain, but are not exposed to the same intensity of salt spray, wind, and substrate shifting as maritime communities. Because of this, trees are of normal stature and not contorted or "salt-pruned", despite the minor salt spray from severe storms like hurricanes. Coastal forests occur on dry, well-drained, low-nutrient soils, do not have dense, viney undergrowth, and have low species diversity typically dominated by one or two tree species. These communities include oak, hickory (*Carya* spp.), beech, holly, red maple (*Acer rubrum*), and pitch pine (*Pinus rigida*) forests (Edinger et al. 2002).

Barrens (i.e., pine barrens) occur on shallow, low-nutrient soils, comprised of stunted or dwarfed trees. These communities occur on stabilized dunes, glacial till, outwash plains, and rocky soils and include species such as pitch pine, scrub oak (*Quercus ilicifolia*), post oak (*Quercus stellata*), and blueberry (*Vaccinium corymbosum*) and huckleberry (*Gaylussacia baccata*) shrubs. Pine-dominated forests blend with pine-oak forests as soil composition changes, but species composition generally stays the same, with only abundance changing (Olsvig et al. 1998). Parts of Long Island, mostly outside of the HRE study area, have remnant pine barrens that are similar to the New Jersey Pinelands. However, these forests are highly disturbed and cover a much smaller area than those of New Jersey (Olsvig et al. 1998).

Most coastal and maritime forests in the HRE study area have been degraded or eliminated by timber harvest and development. Recent encroaching development has increasingly impacted and fragmented these communities. Although there have been few attempts to restore these forests, many species in these habitat types are opportunistic and can rapidly colonize protected areas, making restoration of these forest communities in the HRE study area potentially feasible (Yozzo et al. 2003).

TEC Guidance

These forest communities provide many functions including:

- Corridor for wildlife. When close to or connected to a mainland, maritime forests can provide wildlife species with dispersal corridors to access coastal habitats and can be areas of high species diversity (Yozzo et al. 2003, NBS 1995).
- Food source. Many of the maritime tree species are fruit-bearing and have co-evolutionary relationships with avian migrants, such as robins, towhees, and warblers, providing an important food source for their fall migration (Bain et al. 2007).
- Stormwater reclamation. Forests of approximately 20 acres can provide some stormwater reclamation services by minimizing runoff into waterbodies and recharging the groundwater.
- Shoreline/land stabilization. Shoreline and dune vegetation reduces erosion and protects these areas from wave energy. These forests are fringe habitats, adapted to harsh and dynamic conditions that can occur in coastal or maritime zones and survive in regions where other plant species may not.
- Nesting habitat. The diamondback terrapin (*Malaclemys terrapin*) and many shorebirds (e.g., plovers [subfamily: Charadriinae]) use sandy soils inland from dunes for nesting habitat. The maritime forests can provide secondary nesting habitat for bird species.
- Refuge from predators. The specific physical characteristics of some of these forest types can make these habitats relatively isolated from others, affording refuge from predation.
- Habitat for rare, threatened, and endangered species. Although these species are not restricted to coastal and maritime forests, these areas provide much needed feeding and breeding habitat.
- Seed source. Because maritime forests lie directly along the Atlantic Flyway, they are visited by many birds and act as a nucleus, dispersing seeds from the berries over a wide northward and southward distribution (Bain et al. 2007).
- Cover for migratory staging. Herons and egrets do not nest in these habitats, but will stage in them during post-breeding dispersal.
- Aesthetic value. Forests can provide scenic views along the coastline and offer hiking and wildlife-viewing opportunities.
- Protection from climate change. Establishing habitat along the shoreline can provide the buffer needed to protect developed areas from sea-level rise. Trees provide shading and do not radiate heat like paved surfaces. Trees also support cleaner air, which is a goal of the PlaNYC 2030 initiative.

Several areas of the HRE could be appropriate for creating these forest habitats. For instance, brownfields could be a potential restoration opportunity, where clean fill material could be placed over a degraded site to make it suitable. The clean material chosen for these sites should be appropriate for the development of the desired plant community as well as economical. Topography may need to be altered to create opportunities for a diverse tree community. Wherever possible, plantings should be native to the HRE study area, and care should be taken to ensure plantings do not carry invasive species (e.g., Asian longhorned beetle). Coastal and Maritime Forests are being restored on closed landfills, like a coastal oak forest that has been restored along with freshwater and tidal wetlands within the boundaries of Fresh Kills. Closed landfills are

occasionally appropriate locations for maritime grasslands, which are regionally rare and vulnerable to extinction throughout their range. Ultimately, whatever upland site is chosen, the substrate, salt-influence, and water table would influence the forest community, making it difficult to entirely engineer sites for these forest communities. Currently there is no estuary-wide soils data set that can be used to identify potential areas for siting these forest communities, and this represents an important data need.

In addition to these siting and planning considerations, there are several other management and regulatory considerations to restoring these forest types within an urban estuary like the HRE. For instance, several of these forest types are adapted to and maintained by periodic fires. However, prescribed burnings are not permitted within city limits for safety reasons and pollution control. It may be possible to gain regulatory and public acceptance for managing fire-dependent systems, but in the interim, cutting/mowing plants, clearing the under-story, planting burnt seeds, or using a combination of these methods may successfully sustain these forests.

Another regulatory consideration is the potential proximity of these forest types to major airports in the HRE study area. The Federal Aviation Administration (FAA) has been concerned with land use decisions that affect bird populations within a five-mile radius of any airport. The FAA is concerned with increasing the amount of habitat that would attract birds (i.e., fruiting trees and shrubs) near airports. Bird strikes by planes are common and can cause significant and costly engine and equipment damage. These concerns are often addressed through cooperative interagency policies, like Wildlife Hazard Management Plans, that detail preventative measures to reduce wildlife attractants, minimize hazards, and identify responsible parties. Several wildlife biologists working in and around the HRE study area believe that the presence of maritime forests near airports could reduce the local presence of geese, ducks, and gulls, potentially reducing the number of bird strikes near airports. State and city agencies have been collaborating with airports in the HRE study area and with the FAA to minimize wildlife risks to aviation and human safety and protect habitats adjacent to airports.

Some habitat tradeoff issues may arise when planning coastal and maritime forest restoration. These forest communities should not replace wetlands or grasslands, which are also critical habitats that should be preserved and restored.

Suggested Monitoring Parameters

Within the HRE study area, little information exists for coastal and maritime forests, and additional information is needed on the specific environmental attributes (e.g., soil criteria, required minimum acreages). Collection of this information should precede any large-scale implementation of forest restoration projects in the HRE study area. A post-construction monitoring program should include components similar (or identical) to those measured during baseline site assessments. Suggested sampling parameters for both restoration and reference sites include:

- *Presence/absence of plant species*
- *Percent cover*
- *Soil texture, organic matter, and water content*
- *Water table depth*

- *Wildlife observations*
- *Site conditions assessment*
- *Public Use*
- *Storm surge and flood hazard*

Although qualitative, photography can be a useful addition to a monitoring program. Photographs at fixed stations and sampling quadrats should be a routine part of all monitoring in communities in which the amount of tree and shrub cover versus open habitat (e.g., grassland) is critical. Where possible, aerial photos could be obtained from states or flown annually to provide a holistic view of changes in ground cover and patchiness. Periodic topographic surveys may also be appropriate for maritime forest communities, to document shifting substrates and their influence on community composition.

3.1.4 Oyster Reefs

Oyster reefs provide spatially-complex substrate and benthic structure that is important for many estuarine organisms. A well-developed reef will typically consist of intricately layered formations of live oysters on the exterior and layers of old oyster shell forming the base and reef interior. Deep crevices created by the oyster shell provide refuge for numerous species of small aquatic organisms. Whether these small organisms are sedentary or mobile, each functions as a critical player in the lower trophic levels. Oyster reefs are also feeding, breeding, and nursery grounds for finfish and large crustaceans, where multi-species congregations occur (Harding and Mann 1999). Included in this diverse assemblage are many important commercial and recreational species such as striped bass (*Morone saxatilis*), bluefish (*Pomatomus saltatrix*), and weakfish (*Cynoscion regalis*). Oyster reefs provide attachment sites for the eggs of many small fishes, such as gobies and blennies, as well as the oyster toadfish (*Opsanus tau*). Juvenile and adult oysters are important prey for gastropods, whelks, sea stars, crabs, and boring sponges. Intertidal oyster reefs provide rich feeding grounds for many shorebird species.

Oysters are valuable organisms that can actually promote the growth and viability of other habitats. By filtering particulate material from the water column, oysters form an important link between the pelagic (i.e., open water) and benthic food webs. Through water clarity improvements, oysters can enhance other subtidal habitats like eelgrass by increasing the amount of light that can penetrate the water (Cerco and Noel 2007). In some geographic areas, oyster reefs may develop substantial vertical relief off the sea floor, altering patterns of current flow and possibly creating or expanding shallow water habitat by trapping sediments. Oyster reefs can encourage the growth and expansion of salt marshes located inshore of the reefs by functioning as natural breakwaters (Coen and Luckenbach 2000).

In addition to providing many ecosystem functions, oyster reefs have been an important cultural and economic resource in the HRE study area. Historical accounts from Colonial times document abundant oyster populations in the estuary (MacKenzie 1992). Large expanses of oysters in upper Raritan Bay stretched a mile in diameter and were referred to as the "Great Beds" (MacKenzie 1992). Populations also existed in the Hudson River and tributaries of Staten Island, although the upstream extent to which they occurred is uncertain (MacKenzie 1992). Through oyster seeding and culturing practices, the oyster fishing industry in the estuary thrived in the mid to late 19th century and was estimated to cover approximately 200,000 acres (810 km2; Kennish 2002, Bain et al. 2007). However, by the early 20th Century, poor water quality conditions and incidence of human-transferable diseases, such as typhoid and intestinal illnesses, resulted in declining

harvest and by 1925, the oyster industry in the estuary was abandoned (MacKenzie 1992). The loss of historic oyster beds permanently altered the structure and function of the estuary's benthic ecosystem. This loss eliminated a significant habitat resource for estuarine fish and invertebrate species that rely on spatially-complex submerged structures.

There are potential indirect economic values associated with oyster reef restoration efforts, including environmental education and stewardship opportunities and localized improvements to recreational fishing. Oysters are filter feeders and can significantly contribute to localized water quality improvements. However, this benefit is commonly exaggerated and should not be extrapolated to producing estuary-wide effects in the HRE study area (Pomeroy et al. 2006, Cerco and Noel 2007). Oyster restoration can and should be used in conjunction with other methods of reducing nutrient inputs to improve estuary-wide water quality (Cerco and Noel 2007).

Today, no known oyster reefs exist in the HRE study area. However, scattered live oysters can be found in certain areas, indicating the presence of isolated populations or a larval transport source that originates outside the study area. Oyster restoration programs, such as the NY/NJ Baykeeper's Oyster Restoration Program oyster gardening and seeding program have become increasingly popular through enthusiastic grassroots participation. Research initiatives, such as the Hackensack Meadowlands Oyster Habitat Development Study, established through partnerships with Rutgers University, NY/NJ Baykeeper, Hackensack Riverkeeper and NJ Meadowlands Commission, are investigating oyster viability within portions of the HRE study area (Von-Weis 2007). The Oyster Reefs TEC addresses important biological and physical contributions to the estuary, and emphasizes the unique role oysters have played in the culture and history of the HRE.

TEC Guidance

Although much of the HRE study area meets the water quality and depth requirements for oyster reproduction and growth, the lack of hard substrate may be a major factor limiting oyster populations. The primary means of restoring oyster populations is to provide additional hard substrate for larvae to settle upon. This is typically accomplished through the creation of artificial reefs made of oyster shell, shells of other shellfish species, or man-made structures such as dredged material capped with shell, concrete rubble, or reef balls. Larval oysters are planktonic (i.e., drift using water currents) for the first few weeks of their life and are dispersed by water currents. The larvae settle on hard substrates where they remain for the rest of their life. Reefs made of shell or other material may initially provide the same or greater habitat quality as living oyster reefs. Invertebrate and vertebrate species rapidly colonize the reef structures and attract other organisms creating an entire community (Meyer and Townsend 2000). However, reefs with sustaining populations of living oysters, whether natural or artificially created, are believed to provide high quality habitat because oysters cement their shells creating deeper interstitial spaces, generate their own substrate, and provide a continual food source for organisms (Rodney and Paynter 2006).

Restoration may not be possible in places that historically contained reefs because the estuary's hydrodynamics have been altered by shoreline hardening, bathymetry changes, and the addition of in-water structures, such as piers. Reefs must be situated in areas with sufficient tidal flow to transport food particles to oysters, to reduce or eliminate episodic hypoxia (i.e.,

low dissolved oxygen), and to gently scour fine particles that may foul a reef bed in calmer waters. Optimal hydrodynamics are also critical for the re-circulation of oyster larvae, ensuring settlement on the restored reefs.

Consideration of optimal depths for constructing reefs will be an important siting factor. In prehistoric and colonial times, most oyster beds in the HRE study area occurred at depths of 2-16 feet (MacKenzie 1997). American oysters in the northeastern U.S. are limited to subtidal habitats because of shallower habitats freeze in the winter (Dame et al. 1984). Assuming a desired vertical relief of at least three feet, and having three or more feet of water above the reef (at Mean Low Water) to protect from wave action and ice shear, locations for restored reefs in the HRE study area will likely need to be seaward of the six foot depth contour.

Historical salinity patterns in the HRE study area have changed, and this may have implications for siting of oyster restoration projects. Because of changes in freshwater inputs to the estuary, some historically freshwater areas that did not have recorded evidence of oysters may now be able to support them. The interaction between salinity and incidence of oyster diseases must also be considered in a restoration plan. The notable diseases that affect oysters are Dermo, caused by *Perkinsus marinus*, and MSX, caused by *Haplosporidium nelsoni*. While not harmful to humans, these diseases have seriously reduced oyster harvests in Chesapeake Bay and other mid-Atlantic estuaries. In general, the greatest incidence of disease occurs in high-salinity waters, greater than 15 ppt.

Siting areas for oyster reef construction may present some trade-off issues in the HRE study area. For instance, the most suitable areas for oyster reefs may already support other shellfish species (e.g., hard clams, *Mercenaria mercenaria*). Oyster reef restoration projects can be placed in areas near existing shellfish populations, but should not affect other shellfish species. Another potential issue with constructing an artificial oyster reef through the addition of hard-surface substrate is replacing existing soft bottom habitat and modifying the composition of the surrounding community. However, reefs are thought to benefit the benthic community, where the proximity of hard and soft-bottom substrates increases the diversity of substrate, changes water velocities and flow, and improves the diversity and abundance of prey items (Grabowski et al. 2005).

Another trade-off issue concerns areas with existing commercially fished shellfish populations. According to the New Jersey Department of Environmental Protection (NJDEP), shellfishing in New Jersey is a $700 million per year industry and could be jeopardized by potential public health concerns resulting from illegal oyster harvest in closed waters.

During the TEC Workshop, state regulatory agencies recommend conducting pilot projects, not large-scale projects, due to habitat trade-off issues and public health concerns. These pilot projects and their associated monitoring programs will help to determine whether the creation of larger reefs may be possible and will help to increase the likelihood for success of future restoration efforts. Pilot oyster reef restoration projects should be conducted at appropriate locations as determined by detailed feasibility investigations, preferably within waters open to shellfish harvesting, within existing enforcement areas in closed waters, or within carefully selected areas with optimal water quality that are closed to harvesting.

Additionally, the NYSDEC has requested that restoration practitioners and project sponsors consider the following when preparing an oyster restoration proposal in New York waters:

- Pilot scale projects provide the benefit of community involvement
- Proposals for large-scale projects need to discuss habitat exchange issues
- Risk management strategies should be discussed
- Shells should be from New York. Out-of-State shells may require treatment prior to use in New York waters.
- Spat should only be from New York and northern states because of disease concerns.
- Protection of Waters and Coastal Zone Consistency permits will be required for oyster restoration projects
- Suggest coordination with the Food and Drug Administration (FDA) and the Interstate Shellfish Sanitation Conference.

Although the NJDEP has not provided a formal set of guidelines to be followed when planning oyster restoration projects in New Jersey waters, they do not recommend restoration projects for commercially harvested shellfish in prohibited or special restricted waters (i.e. closed to shellfishing). Because they are concerned with illegal harvest of oysters and associated health risks, the NJDEP and NYSDEC recommend considering the restoration of shellfish species that have no commercial value in these waters. Presently efforts are being made to coordinate oyster reef restoration activities within the existing states' permitting framework. While the goals of the regulations are quite defensible (i.e., avoiding public harm with respect to navigation or the environment, protecting public health, etc.), alternative mechanisms for achieving them are being considered.

Because the success of oyster reef restoration has not been demonstrated in the HRE study area, and oysters can be considered an "attractive nuisance" for illegal harvest, it may be prudent to consider restoring shellfish species other than oysters that provide similar ecosystem services, such as hard clams, softshell clams, blue musses and ribbed mussels. Although the ecological benefits of these species are not as substantial as those of oyster reefs, the risks associated with restoration may make these projects more attractive.

- Hard clams (*Mercenaria mercenaria*) – Also known as Northern quahogs, are the most widely distributed commercial clam in the United States, and are abundant in the Raritan and Sandy Hook bays (Stanley and Dewitt 1983). Hard clams obtain food particles by vertically extending a siphon up to the sediment-water interface, and therefore may not be as efficient in filtering the overlying water column as oysters or mussels, both of which grow in very dense aggregations on the seafloor or as epiphytes on submerged hard structures. While hard clam beds may provide some degree of structural heterogeneity in comparison to bare sand flat or mud flat, most of the biomass is located below the sediment-water interface; the three-dimensional structural attributes of oyster or mussel beds that provide critical habitat are not present in clam beds. Besides being a harvested species, another drawback to creating additional hard clam beds is that the Quahog Parasite Unknown (QPX), a single-celled microscopic parasite causing disease and occasionally death of hard clams, may parasitize them.
- Softshell clams (*Mya arenaria*) – Also known as steamers or long-neck, are common in intertidal and shallow water. This species can be pollution-tolerant, but because it is commercially and recreationally harvested, numerous beds have been closed due to high bacteria counts. Reportedly low population levels may be indirectly related to habitat losses of marsh, eelgrass, and littoral habitat in the estuary. Similar to hardshell clams, softshell clams are not as efficient as oysters in filtering the water, and they provide limited structural habitat (Yozzo et al. 2004).
- Blue mussels (*Mytilus edulis*) – Blue mussels are common in both intertidal and shallow subtidal areas throughout

the HRE, typically attached to rocks, and shells, pilings, and other hard substrates. Unlike clams, which are buried in sand, mussels filter the overlying water column directly through their open valves within which lays a siphon, and gills. Thus, mussels are capable of filtration at any point at which they occur in the water column not just at the sediment-water interface. When submerged within shallow subtidal or flooded intertidal areas, blue mussel beds may provide structurally complex refuge or foraging areas for small finfish and motile invertebrates such as mud crabs, grass shrimp and sand shrimp (Yozzo et al. 2004).

- Ribbed mussels (*Geukensia demissa*) – Ribbed mussels are a characteristic shellfish species in salt marshes. In certain areas of the HRE, such as Jamaica Bay, ribbed mussels exhibit a "clumped' growth form, typically along creekbank edges of salt marshes. When inundated by high tides, these submerged mussel aggregations may provide forage and refuge habitat for small fish and motile invertebrates including killifish, gobies, sand shrimp, grass shrimp, juvenile lobsters, and mud crabs. In other areas, individual ribbed mussels may be widely dispersed across the intertidal marsh surface, partially buried in the mud. A very common marsh-resident fish, the mummichog, has evolved a spawning strategy which involves the deposition of eggs in empty mussel shells located in the upper intertidal zone, or high marsh (Able 1984, Taylor and DiMichele 1983, Yozzo et al 1994).

  The proposed construction of ribbed mussel beds was highlighted as a potential means of improving water quality conditions in the PlaNYC 2030. Under this scenario, a $20m^3$ mussel bed to be created in Hendrix Creek is hypothesized to be capable of filtering the entire daily effluent load from the 26th Ward wastewater treatment plant. Ribbed mussels are not commercially or recreationally harvested in the HRE and therefore, restoration of this species, for local water quality improvement and other ecological benefits, poses little safety risk to humans.

Data Needs

A critical piece of information that can help to guide restoration efforts in the HRE study area is an understanding of the hydrodynamics that will determine larval transport and settlement. Settling larvae require a suitable hard substrate for survival. Strategic placement of reefs will be necessary to form sustainable oyster beds. The HRF recently funded a study where researchers at the State University of New York Stony Brook are researching the viability, growth, reproduction of oysters at several sites in the HRE. Larval retention times are a driver for presence of oyster populations because high velocities will carry spat/larvae out to sea. For this reason, the researchers are also preparing a map of retention times and water quality (salinity, DO) to predict optimal locations for oyster restoration.

Suggested Monitoring Parameters

Suggested parameters to be monitored at restored reefs include:

- *Water quality, with emphasis on total suspended solids/turbidity*
- *Hydrodynamic/wave energy characteristics in the vicinity of restored oyster reef*
- *Sediment deposition*
- *Oyster Spat Settlement, Growth, Fecundity, Mortality and Incidence of Disease*
- *Benthic and epiphytic invertebrate communities*
- *Utilization of Constructed Reefs by Fish and Invertebrate Communities*

3.1.5 Eelgrass Beds

Eelgrass (*Zostera marina*), is one of the few plants that occurs almost exclusively in subtidal waters with marine salinities, utilizing the water column for vertical support (Fonseca 1992). The Eelgrass Beds TEC represents a habitat that is vertically and horizontally complex, attracting dense and diverse communities of macroinvertebrates, shellfish, and fishes, as well as providing critical nursery habitat for important fishery species like bay scallop (*Argopecten irradians*), summer flounder (*Paralichthys dentatus*), Winter flounder (*Pseudopleuronectes americanus*), tautog (*Tautoga onitis*), weakfish (*Cynoscion regalis*) and blue crab (*Callinectes sapidus*; Fonseca 1992, Yozzo et al. 2003). Although few organisms feed directly on living eelgrass, their beds support all trophic levels and provide many ecosystem services to the estuary.

Eelgrasses are widely distributed in marine waters, ranging as far north as the Arctic Circle on both coasts of the United States (Fonseca 1992). Along the Atlantic coast, eelgrass beds occur from the Canadian Maritime Provinces south to the Albemarle-Pamlico Sound in North Carolina. In the HRE study area, eelgrass beds were historically abundant along the Raritan Bay shore in north-central New Jersey (Bain et al. 2007). A wide-ranging infestation of the marine slime mold (*Labryinthula zosterae*) along with declining water quality in many coastal areas, virtually eliminated eelgrass from the HRE and other Atlantic coast estuaries during the 1930s (Bain et al. 2007).

Eelgrass can grow rapidly, producing large quantities of organic matter (Fonseca 1992). This primary production supports a complex food web that cycles nutrients between sediments and surface waters (Fonseca 1992). In sheltered regions, eelgrass patches spread to form large beds that are highly dynamic, yet persistent communities (Fonseca 1992). Movement of organisms and water in and around the beds transports organic matter to adjacent habitats, helping to enrich the estuary (Fonseca 1992).

Eelgrass beds also provide physical benefits to the ecosystem. Wave and current energy is dissipated through the beds, reducing erosion and sediment resuspension, and preserving sediment-dwelling bacteria and fungi (Bain et al. 2007, Fonseca 1992). Enhanced sediment stability increases the accumulation of organic and inorganic materials (Fonseca 1992). Eelgrass plants produce oxygen and can filter nutrients and contaminants, improving the surrounding water quality (Bain et al. 2007). The improved conditions surrounding eelgrass beds enhance their self-sustainability by providing stable sediment and optimal water quality for eelgrass bed expansion.

Eelgrass beds are very sensitive to sedimentation and turbidity. The rapid addition of a few centimeters of sediment can completely bury eelgrass. Even small reductions in water clarity can degrade eelgrass bed quality and curtail growth rates (Fonseca 1992). For these reasons, eelgrasses are typically found in coarser substrates with moderate water velocities ($\leq$ 1 meter/second), where water movement gently clears accumulating sediments but does not increase turbidity (Bain et al. 2007). Although most of the HRE study area is thought to be too turbid to sustain eelgrass beds, small patches of eelgrass persist in the Shrewsbury-Navesink Rivers (Bain et al. 2007).

TEC Guidance

Seagrass restoration is an international science, with many U.S. researchers and agencies developing successful seagrass restoration programs, throughout the mid-Atlantic and southeastern states and in the Pacific Northwest and parts of southern California. The techniques, successes, and lessons learned from decades of implementation are well-documented and should serve as guidelines for restoration in the HRE study area (Fonseca et al. 1998, Thom 1990, Pickerell et al. 2005). Pilot eelgrass restoration projects and their associated monitoring will help to determine whether the creation of larger eelgrass beds may be possible and will help to increase the likelihood for success of future restoration efforts.

Eelgrass restoration programs typically have varying degrees of success and, occasionally, unexpected outcomes. Eelgrass growth and recruitment seems to be dependent upon a balance between wave action and ambient water quality conditions. Additionally, it may not be possible to use known locations of historic eelgrass beds as a site criteria because vessel traffic, bathymetry, shoreline conditions, and freshwater inputs have likely changed in the last 40 or more years. Eelgrass may have also existed in deeper waters, but was less visible and may not have been documented in historic records. For these reasons, it is important to select pilot project sites that span a range of conditions within the known habitat requirements for eelgrass, which can often be accomplished within a relatively small area. Within several meters of a shoreline, the variation in depth, light penetration, wave tolerance, and sediment texture (e.g., grain size, silt/clay) can be considerable. This natural variation will help determine the most suitable conditions and refine criteria for larger-scale restoration programs in that water body.

Design considerations of particular importance for eelgrass beds include transplant spacing, light attenuation, and patterns of current flow in the vicinity of the transplant site. Careful attention must be paid to the spacing of individual planting units in order to achieve success. An appropriate current regime is critical for eelgrass transplant success. If current velocities are too high in the vicinity of the transplant site, transplant success will be poor due to loss of transplant units, and coalescence may never occur. Conversely, in low-energy areas, developing beds may be subject to poor water quality and suffocation by fine sediments, epiphytes (i.e., plants growing on plants) and drifting macroalgae. Depth and water clarity exert the primary controls over eelgrass zonation and the degree of colonization by epiphytes.

A variety of planting and seeding techniques should be employed during the pilot projects to determine the most effective methods. These include planting individuals taken from healthy donor beds or seedlings reared under laboratory conditions. Planting should occur during the period when the eelgrass plants are dormant, which generally occurs from mid-September to November when water temperatures in the HRE are at or less than 22°C. Although less commonly employed than transplant techniques, eelgrass can be propagated in estuarine waters by direct application of seeds. In Chesapeake Bay, eelgrass seeds have simply been broadcast by hand off small motorboats (Orth et al. 1994). "Seed buoys" have been used successfully to broadcast eelgrass seeds in New York waters of Long Island Sound and in the south shore bays of Long Island (Pickerell et al. 2005). The effort and costs associated with these techniques varies, as can the level of success. Where applicable, experimentation with seeding/planting unit density and donor sites for transplants should be conducted. This can increase the efficiency and success of larger scale initiatives.

Several abiotic and biotic factors could adversely affect eelgrass seed propagation and shoot development, resulting in failure of experimental beds to survive. These include eutrophication, macroalgal blooms, bioturbation, water quality

degradation, increased turbidity, and wave energy. Many of these factors are interconnected. For instance, eutrophication decreases water quality and clarity by increasing the frequency and magnitude of algal and phytoplankton blooms, which increases light attenuation. Lacking sufficient light, eelgrass bed productivity and spatial coverage decreases. Under sustained or chronic low light conditions, eelgrass will eventually die off altogether.

Grazing represents a potential problem for planting eelgrass in Jamaica Bay. Ducks and geese may eat the newly planted shoots and leaves in restored eelgrass beds. It may be necessary to deploy exclusion nets and cages to protect the new transplants from direct grazing by waterfowl and other animals, including green crabs (*Carcinus maenus*) and hermit crabs (*Pagurus pollicaris*) which are known to prey on new eelgrass shoots and seeds, respectively.

Should the HRE study area prove unsuitable for large-scale eelgrass restoration, planting a polyhaline (i.e., brackish-water) species of submerged aquatic vegetation (SAV), widgeongrass (*Ruppia maritima*) is a potential alternative. Widgeongrass is more adapted to warmer climates than eelgrass and has a less restricted range of physical habitat requirements, including salinity and temperature. Because widgeongrass is more tolerant, it is a pioneer species, and can quickly become established. The ecological functions associated with widgeongrass have not been as extensively studied as those associated with eelgrass, and widgeongrass may provide fewer ecological benefits as compared to eelgrass.

There may be some user group conflicts or habitat tradeoffs associated with eelgrass restoration. Recreational boaters and fishermen can be resistant to eelgrass restoration, as the long, slender leaves can become entangled in outboard motor propellers. The boat propellers themselves can cause substantial damage to eelgrass beds, leaving behind telltale "prop scars," which may persist for months, or years (Zieman 1976). There may also be conflicts to eelgrass restoration in nearshore waters where coastal development is occurring. Public resistance could be curbed through a public outreach campaign focused on the benefits of restoring eelgrass within the HRE study area. Additionally, eelgrass restoration should not occur in areas where shellfishing occurs, particularly in or adjacent to hard clam and/or scallop beds.

The future of eelgrass restoration in the HRE study area may be advanced through the implementation of the following near-term actions.

- Managers need to be involved in the research/restoration process so they better understand and support eelgrass research and monitoring.
- The importance of post-restoration monitoring and sharing/implementing lessons learned should be emphasized. Monitoring will refine the suitability criteria and improve subsequent restoration programs.
- It is necessary to develop a restoration plan for eelgrass that shifts away from opportunistic restoration and moves toward developing a strategic plan that focuses on restoration in suitable locations throughout the estuary. This plan should set achievable targets. It may be beneficial to use structural versus functional targets when evaluating restoration success.
- Proponents for eelgrass restoration among the agencies and environmental groups should be identified.

Data Needs

Pilot projects will provide critical information to assist with the implementation of the Eelgrass TEC. Detailed studies on habitat preference will help to select locations for more expansive restoration projects. Estuary-wide substrate and sediment grain size data sets would be useful to help select sites for large-scale restoration efforts. It must be emphasized that many interacting factors drive a site's suitability, and the GIS analysis provided in CRP Volume I is not able to capture these dynamic processes at this scale.

Suggested Monitoring Parameters

Monitoring of eelgrass transplant or seeding projects focuses on quantitatively estimating the degree of planting success. A secondary objective of an eelgrass-monitoring program is to ascertain the recovery of ecosystem function and community structure that has been achieved. This typically involves collecting data on water quality/nutrients within the beds, colonization of the bed by epiphytic and benthic organisms, and use of the bed by fishery species (Thayer et al. 1975, Homziak et al. 1982, Smith et al 1989; Fonseca et al. 1990).

Suggested parameters to be monitored at restored eelgrass beds and reference sites include:

- *Water quality, with emphasis on TSS/turbidity*
- *Hydrodynamic/wave energy characteristics in the vicinity of the eelgrass pilot beds, pre- and post-restoration*
- *Sediment characterization (e.g., organic content, grain size, toxicity, accretion rates)*
- *Transplant survival, aerial coverage, and number of shoots*
- *Epiphyte community composition and biomass*
- *Benthic invertebrate communities*
- *Fish communities*
- *Incidence of disease*

3.2 Habitat Complexes

Two of the TECs focus on ensuring the connectivity of different habitat types to provide habitat complexes for species that require more than one habitat during their life cycle. These habitat complexes are important for organisms that move between habitats to forage or spawn. Loss of the connectivity of these habitats decreases their overall value. The following sections describe these habitat complexes, the objectives for the TECs, potential restoration opportunities within the HRE study area, data needs and monitoring parameters for each TEC.

3.2.1 Shorelines and Shallows

The Shorelines and Shallows TEC addresses important physical, chemical, and biological services to the nearshore habitats of estuaries by creating natural sloping shorelines with three contiguous habitat types. These habitat types generally are comprised of (1) littoral zones that remain inundated with shallow water, (2) intertidal areas that are regularly submerged during high tides, and (3) riparian zones that are important transitional habitats between land and water. This TEC targets habitats of four meters or less mean low water, based upon the U.S. Environmental Protection Agency's (USEPA) working definition of shallow waters, where "critical functions such as biological productivity and ecological balance must be reconciled with human activities" (Reilly et al. 1996).

Littoral zones typically support high densities of organisms and high species diversity, particularly when vegetated. Because of the high densities of invertebrates, slower current velocities, and available refuge, littoral zones support resident populations of small fish and crustaceans and provide critical nursery habitat areas for transient species. Larger fish tend to remain in deeper water habitat, on the outskirts of littoral areas, feeding on macroinvertebrates and small fishes that may be carried outward by tidal currents (Findlay et al. 2006).

Intertidal areas represent a dynamic transition zone between fully aquatic and terrestrial shoreline habitats. Some plants and animals have evolved adaptations to life in intertidal environments that are alternately flooded and drained twice daily. Although diversity of intertidal areas is reduced in comparison to most shallow subtidal habitats, characteristic species assemblages persist in the intertidal zone. During high tides, mobile aquatic species move into flooded intertidal areas to feed or avoid predators, and retreat during low tides. During falling tides, shorebirds and terrestrial predators move onto the exposed mud or sand flats to feed on worms, mollusks, buried crabs, and fish trapped in shallow intertidal pools.

In the HRE study area, many natural shorelines have been replaced with bulkheads, revetments, and dock/pier infrastructure. These shoreline structures have eliminated transitional intertidal and littoral areas. Hardened shorelines amplify wave energy, which can increase erosion and deepen nearshore waters, affecting water quality/clarity and habitat availability. Pier construction can reduce channel width, reduce current velocities, and increase sedimentation. These structures may directly and indirectly impact growth, survival, and recruitment of fish and other estuarine macrofauna (Able and Duffy-Anderson 2006). Increased sedimentation reduces available water column habitat and buries existing, natural hard substrates. Shading impacts of shoreline structures on aquatic flora and fauna are increasingly being recognized in aquatic resource assessments, and recent research conducted within the HRE study area has documented fewer species, lower abundances, and fewer feeding opportunities underneath large over-water structures in comparison to open water, pile fields, or edge habitat (Able and Duffy-Anderson 2006).

TEC Guidance

Shoreline restoration can occur in any of the planning regions of the HRE study area, and would be especially desirable where creating longer, continuous natural shorelines with more expansive upland buffers is possible. Projects within the Lower Hudson River, Upper Bay, and Harlem River/East River/Long Island Sound planning regions of the HRE study area should be targeted for restoration because these areas have the highest percentage of hardened shoreline. Although many options exist when considering shoreline and shallow-water restoration, creating gradually sloping shorelines with upland and littoral habitat should take precedence in the HRE study area, particularly in planning regions dominated by hardened shorelines.

In most cases, a Shorelines and Shallows restoration opportunity should include areas that have both hardened shorelines and adjacent undeveloped or vegetated uplands, but not necessarily the presence/absence of intertidal or littoral habitats. Removing hardened shorelines should be the focus of this TEC and will not be possible if there is nearshore development. However, intertidal and littoral habitat can be created during restoration projects and should not be viewed as pre-requisites for site-suitability.

In working waterfronts with an abundance of permanent, hardened shorelines, installation of habitat enhancement features such as modular artificial reef structures would improve aquatic habitat in areas that were previously derelict or suffering from impaired habitat quality. Many attributes that determine habitat quality along shorelines are interrelated and include:

- Water depth,
- Bottom topography,
- Substrates/sediment type,
- Current velocity,
- Sedimentation rates,
- Light regime,
- Wave energy regime, and
- Surface area, volume and texture of in-water structures.

New waterfront features or reconstructed shorelines should be planned to minimize sediment accumulation and scour, thereby retaining original bottom topography and water depths. It is also possible to improve existing facilities by installing site-appropriate structures, such as underwater baffles or training walls to redirect flows and maintain desirable depths and exposed substrates. Increasing the height of piers above water and decreasing their width may provide more light to shaded waters (Able and Duffy-Anderson 2006). Light-transmitting pier designs made of fiberglass or comparable materials or conventional piers retrofitted with glass "windows" are under development and may be a viable design option in the future (Shaefer and Lundin 1999). Physical complexity can be increased by modifying or adding structural elements, such as texturized bulkheads, fluted or terraced pilings, and individual reef elements, like reef balls or stacked hollow cubes along a shoreline. These structural elements can provide general habitat enhancement or target individual species by varying the size of crevices and structural materials (e.g., filling hollow areas with oyster shell, and/or creating structures with OysterKrete – biologically enhanced material to stimulate oyster growth).

Habitat tradeoff issues will likely arise through the implementation of the Shorelines and Shallows TEC. Under the current regulatory climate, creating shallow water habitat in deep waters is often viewed as a habitat loss. However, demonstrating success through pilot projects would reduce the perceived risk incurred from losing deep-water habitat. Therefore, pilot projects, such as bulkhead removal or adding habitat value to bulkhead or pier restoration projects, are recommended in the near term. Throughout the HRE study area, many waterfront development projects are being planned and designed to provide increased waterfront access to residents. Many of these are large-scale projects, incorporating several types of access points (e.g., fishing piers, kayak/boat launches) and views along miles of shoreline. These projects provide exceptional opportunities to create intertidal, natural sloping shorelines, to demonstrate shoreline softening and enhancement techniques, and to garner public support for restoration within the HRE study area.

Established design criteria should serve as guidelines when implementing shoreline and shallow water restoration in the HRE. To provide adequate stormwater protection, the upland buffer zone should be a minimum of 100 ft from the shoreline, although it is recognized that this may not be possible in the most urban regions of the HRE study area, like the Harlem River, East River, and Western Long Island Sound, Lower Hudson River, and Upper Bay planning regions. Where possible, larger, more complex vegetated buffer zones or wetland areas could be restored to provide additional ecological benefits. Because the estuary is a turbid environment, the illuminated littoral zone would be less than four meters in depth, but even

shallow water areas below the depth at which light penetrates can provide important shellfish, invertebrate, and nursery habitat. Other design criteria, such as upland vegetative cover or shoreline gradients, are site-specific and should be determined on a project-by-project basis.

The size of shoreline restoration projects will typically be determined by land use, land ownership, and the proximity of navigation infrastructure, such as navigation channels, wharfs, and piers. Larger projects can provide additional ecological benefits, through greater numbers of potential habitats, improved biodiversity, and higher species recruitment. Although no minimum acreage limits are specified for this TEC, projects should be designed to maximize ecological benefit for the area restored. Smaller projects would likely incur maintenance or monitoring costs that may be cost-prohibitive in relation to project size.

Linking aquatic and terrestrial habitats creates opportunities to restore additional habitats on available upland and aquatic areas. Available terrestrial areas could be considered for construction of maritime forests, wetland communities, or other upland habitat types. In the core of the HRE, where shorelines are predominantly hardened, shoreline restoration opportunities exist along islands. Some of these islands are inhabited almost solely by wading birds and could be further restored by implementing restoration techniques in the Waterbirds TEC. Many physical and chemical characteristics that make an area desirable for sloping shorelines and shallow water habitat are also appropriate for establishing aquatic vegetation or reefs.

Suggested Monitoring Parameters

Baseline monitoring of shorelines and shallow water areas slated for restoration provides detailed information about the conditions of the site and may assist in the selection and prioritization of measures to best restore an area's habitat quality and ecological function. Monitoring may include topographic surveys, characterization of sediments (including contamination issues), nearshore hydrodynamic surveys, assessment of subtidal, intertidal and upland vegetation communities, benthic and epiphytic (e.g., organisms living on plants) community surveys, nearshore fish/macrocrustacean surveys, and use of nearshore areas by birds and other wildlife.

Suggested parameters to be monitored at restored shorelines and reference sites (if available) include:

- *Changes in nearshore bottom contours and intertidal/upland topography resulting from both natural depositional/erosional processes, and the implementation of restoration activities, pre- and post-restoration*
- *Nearshore water quality, with emphasis on TSS/turbidity*
- *Hydrodynamic/wave energy characteristics along the shoreline, pre- and post-restoration, as a means of gauging the benefits of shoreline re-contouring, re-vegetation and removal of in-water and over-water structures and/or debris*
- *Storm surge or flood hazard within the floodplain*
- *Sediment characterization (e.g., total organic carbon, grain size, toxicity)*
- *Benthic and epiphytic invertebrate communities*

- *Fish communities*
- *Use of shorelines and shallows by the human community*

3.2.2 Habitat for Fish, Crabs, and Lobsters

This TEC ensures that suites of habitats will be created to benefit many life stages for a range of resident, transient, and migratory species (Bain et al. 2007). It calls for the restoration or development of a mosaic of diverse, quality habitats intermixed throughout the estuary for sustaining fish, crab, and lobster populations. Many important estuarine and marine species are in low or declining abundance throughout the HRE study area, and the relationships among these habitats are important for target species to complete their life history. This provision (i.e., suites of habitats) focuses on the spatial arrangement of and relationships among habitats to include areas like oyster reefs, eelgrass beds, and tidal marshes, which are components of other TECs, as well as non-TEC habitats like soft-bottom, unvegetated shallows or sponge and amphipod beds (Bain et al. 2007).

Fish and crustacean populations are a gauge of an estuary's condition in terms of water quality and ecosystem function (Steinberg et al. 2004). Low abundances may indicate a lack of suitable habitat. Many recreational or commercial fishery species are also ecologically important as predators and benthic (i.e., sea floor) feeders that cycle carbon and nutrients to other trophic levels in the estuary (Bain et al. 2007). Each species has specific habitat needs, especially during spawning or early development, which often requires specific substrates or structural elements. For instance, vegetated or structurally complex areas provide refuge from predators, whereas broad, sandy flats may be ideal foraging areas (Bain et al. 2007).

Over 100 species of fish, crab, and lobster rely on habitats of the HRE study area for at least some portion of their life history (USFWS 1997). However, these populations are threatened by localized poor water quality, sediment contamination, absence of littoral structure, blockages to migratory routes, and overfishing. Many habitat impairments are exacerbated by the lack of intertidal and littoral habitat, a result of historic bulkheading and shoreline filling. American eels (*Anguilla rostrata*) have declined steadily in the estuary since the early 1990s; this may be due to a gradual reduction of habitat quality and overfishing (Steinberg et al. 2004). Blue crabs in the HRE study area exhibit high annual variation, which may indicate irregular recruitment patterns (Steinberg et al. 2004). The Atlantic stock of striped bass has fully recovered from overfishing in the 1980s (Mayo et al. 2006), but striped bass in the HRE study area are still threatened by contamination and poor habitat quality. Increased abundance of the southern New England stock of American lobster has been met with increased harvest (Mayo et al. 2006). Other stocks, like summer and winter flounder, are not as abundant due to overfishing and show variable catch rates in the HRE study area, attributed to degradation of subtidal areas and/or fishing pressure on the adult population (Mayo et al. 2006, Steinburg et al. 2004). The most effective way to sustain or increase fish populations in the HRE may be to restore and/or create mosaics of critical habitats to provide what habitat was historically lost, such as intertidal wetlands, eelgrass beds, and oyster reefs among others.

Ten target species were identified in the TEC Report, representing select demersal or benthic fish and large crustaceans (Bain et al. 2007). These species and the habitats that are critical to their life stages are provided in CRP Volume I, Table 3-5, Section 3.2.2. The target species are either abundant or economically important, and all are well-studied. Targeting habitat restoration for these species should also benefit other species in the HRE study area.

TEC Guidance

The use of a habitat varies by aquatic species based on physical and biological requirements, and the role habitats fulfill in species' life stages can differ depending on their position in the landscape (e.g., an oyster reef would be used differently if adjacent to a large sand flat as opposed to amphipod mats). Eighteen specific habitat sets consisting of two or more functionally related habitats were identified in the TEC Report, with suggestions for scale of and spacing among habitats (Bain et al. 2007). Using this list for guidance and not as a comprehensive compilation, habitat sets should be chosen for restoration based on the target species' requirements and regional goals for that species.

The distance between habitats, the size of habitats, and the time it takes for recruitment of species should be considered when planning restoration projects. Habitat size and many of the relationships among habitats will be determined based on site-specific, existing conditions of the habitats. These include habitat quality, presence of contamination, and habitat tradeoff issues (Bain et al. 2007). Recruitment to recently restored or new habitats is generally species-specific and depends on the life history, population size, mobility, and habitat needs of the species. However, certain site-specific characteristics, such as hydrodynamics and water quality, can also restrict the number of individuals and species able to use a habitat. Restoration projects should consider the various life history attributes and specific habitat requirements of the target species when developing project goals and monitoring criteria.

Habitat arrangements can be particularly important in tidal systems. In estuaries, the need for adjacent habitats is more apparent because constantly changing water levels can determine habitat availability. Tidal fluctuations should be considered when designing habitat sets under this TEC; some species move among intertidal and subtidal habitats as determined by predation pressure or availability of prey resources. Several recommended habitat sets consist of intertidal areas because these are typically productive habitats, providing physical structure and trophic resources and benefiting the species and life stages able to exploit them.

Each restoration project should take into consideration the habitat types that target species rely on and incorporate these habitats into the design. Sometimes, intact and derelict shoreline structures can serve as habitat for species that rely on structure for feeding and/or protection from water flow, such as tautog and black sea bass. These areas can also concentrate fish and are often highly sought after by fishermen. However, because of the potential hazards to individual and navigational safety, it may be necessary to remove derelict structures before pieces are dislodged or break off.

While restoring habitat for other TECs, a useful method for achieving the targets of the Fish, Crabs, and Lobsters TEC could be considering what complementary habitats can be restored nearby. Adjacency among habitats would encourage the use of multiple habitats by species, ultimately making other TEC habitats more successful by facilitating recruitment and species use. Also, new TECs should be built near existing, complementary habitats if possible (e.g., building oyster reefs near tidal creeks). Developing restoration projects by first evaluating landscape characteristics and issues will ultimately lead to more successful and sustainable habitats. Some habitats, when in proximity, can enhance each other by attenuating wave energy or mediating nutrient loadings (e.g., oysters reefs and eelgrass, oyster reefs and salt marshes; Coen and Luckenbach 2000).

Essential Fish Habitat (EFH) should be considered when identifying sites for habitat restoration. Recognized by the Magnuson-Stevens Fishery Conservation and Management Act of 1996, EFH in U.S. waters is designated by regional Fishery Management Councils and is defined as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." EFH designations are intended to protect life stage-specific habitat complexes for Federally managed species, such as, flatfishes, skates, and mackerels, and are managed in various jurisdictions by NOAA's Fishery Service, regional Fishery Management Councils, and state natural resource agencies. Habitat Areas of Particular Concern (HAPC) are discrete subsets of EFH that provide extremely important ecological functions or are especially vulnerable to degradation.

Approaching this TEC from an EFH or HAPC perspective may be effective as it would provide guidelines for which habitats, or assemblages of habitats, to restore. Moreover, proposals benefiting EFH or HAPC may initially have more support from governing agencies. Because this approach may exclude important habitats not designated as EFH or HAPC, any habitat that can be considered essential to a target species' life stage, whether or not it is designated as such, should be considered for restoration under this TEC.

Suggested Monitoring Parameters

Baseline monitoring of estuarine habitat complexes slated for restoration provides detailed information about the conditions of the site and may assist in the selection and prioritization of measures to best restore an area's habitat quality and ecological function. Monitoring may include topographic/bathymetric surveys, characterization of sediments (including contamination issues), hydrodynamic surveys, assessment of existing subtidal, and intertidal vegetation communities, benthic and epiphytic community surveys, target fish/macrocrustacean surveys, and use of estuarine habitats or habitat complexes by birds and other wildlife.

Suggested parameters to be monitored at restored estuarine habitat complexes and reference sites include:

- *Changes in shallow-water bottom contours and intertidal topography resulting from both natural depositional/ erosional processes, and the implementation of restoration activities, pre- and post-restoration*
- *Water quality, with emphasis on TSS/turbidity*
- *Hydrodynamic/wave energy characteristics in the vicinity of the desired habitat complex, pre- and post-restoration, as a means of gauging the benefits of bathymetric re-contouring, planting submerged or emergent vegetation, and creation of hard substrate, such as oyster reefs*
- *Sediment characterization (e.g., total organic carbon, grain size, toxicity)*
- *Benthic and epiphytic invertebrate communities*
- *Fish communities*
- *Parameters for individual habitats restored within these complexes (i.e., eelgrass, coastal wetlands, etc.)*

3.3 Environmental Support Structures

Two of the TECs focus on repairing the environmental degradation associated with infrastructure that restricts the flow of water. The HRE study area contains many dams that serve to store water for a variety of functions, such as drinking water reservoirs or recreational ponds. Other structures that are common in the HRE study area were designed to allow the passage of water, such as culverts under bridges and roadways. These structures can restrict the movement of fish and

can change the natural circulation or drainage routes and can result in environmental degradation. The following sections describe the environmental issues associated with these support structures, the objectives for the TECs, and potential restoration opportunities within the HRE study area.

3.3.1 Tributary Connections

The purpose of this TEC is to reconnect streams to the estuary to provide a range of quality habitats to aquatic organisms. This TEC focuses on restoring connections between and corridors within streams, including but not limited to restoration of natural stream channels, adjacent freshwater wetlands, riparian uplands, and tributary connections through barrier removal or fish passage construction.

Tidally-influenced streams and creeks provide thruways for fish to access habitats across a gradient of abiotic factors (i.e., salinity, depth, temperature, dissolved oxygen, sediment type). Many migratory or highly mobile fish species require access to these upstream areas to spawn because eggs or larvae have specific life history requirements that are very different from juvenile or adult life stages. In addition to benefiting native migratory species, like American shad (*Alosa sapidissima*), alewife (*A. pseudoharengus*), blueback herring (*A. aestivalis*), striped bass (*Morone saxatilis*), and American eel (*Anguilla rostrata*), re-establishing tributary connections may also benefit resident fish and invertebrate populations by providing greater access to feeding, spawning, and refuge habitats. Several freshwater mussel species may also benefit from improved fish passage, as they are dependent upon fish movement to complete their life history (Peckarsky et al. 1990).

Barriers, which can loosely be defined as "filters" that restrict passage, can be man-made or natural, "habitat" barriers. Man-made barriers to fish passage are often the easiest to define, such as dams, tide gates, and road culverts. The characteristics that make a barrier impassable can be specific to a species or group of species. For example, low-height dams or structural barriers may be impassable to certain species which lack the ability to ascend gradients (e.g., alosids); however, strong-swimming species (e.g., salmonids) may be capable of ascending the barrier to reach upstream habitats. Eels have the ability to wriggle up dam faces, ascending barriers that are completely impassible to other fish species.

Low dams were typically built in the HRE study area to support early American industry and agriculture (Bain et al. 2007). Today, many of these small dams are currently inoperative or no longer needed. However, some dams provide local communities with water supply, recreation, utilities, or have aesthetic/historic value (Bain et al. 2007). Dams are typically impassable by fish due to the height difference between the downstream water and the upstream water. In the HRE study area, at least 92 impoundments exist, many on major waterways like the Navesink, Passaic, and Hackensack rivers. Reconnecting estuary-tributary pathways can be accomplished by removing derelict or unnecessary barriers, modifying barriers to promote fish passage (e.g., breaching, notching), or constructing fish passage structures (e.g., fish ladders, bypass channels). Possible candidate dams for retro-fitting with passage structures include those that currently provide a water-supply or safety function, or small, historic dams that may be regarded as important historical or cultural resources.

The most common fish passage structures are steeppass, denil, and pool-and-weir fishways. Typically constructed of concrete, wood, or aluminum, these structures generally consist of a series of gradually inclined steps with resting pools

located at regular intervals. These provide fish with a means of migration that simulates natural stream conditions. If engineered properly with regard to the swimming ability of the target species, fish ladders/fishways represent a viable option for restoring connectivity. In a few special cases, mechanized fish lifts or elevators have been installed to actively transport fish up and over dams for access to upstream spawning areas. It is unlikely that this type of technology would be required to restore fish passage at known barriers in the HRE study area. However, stocking of adults and juveniles as a means of supplementing dwindling stocks or to reintroduce fish in systems in which they have been completely extirpated, may be worthy of consideration. Recently, alewife have been introduced in the lower Bronx River by NYCDPR's Natural Resources Group, along with installation of fish passage structures at several barriers, in an attempt to reinstate the former historic run.

Whether partially or completely closed, tide gates are barriers to all upstream fish migration. Partially opened gates can create high velocities. Even when fully opened, tide gates can be a barrier because they might not open far enough or frequently enough to allow fish passage. The control schedule of existing tide gates can be modified so that gates remain completely open during upstream fish runs and during downstream juvenile migrations. New, self-regulating tide gates can be installed in place of conventional gates. These allow normal amplitude tides to enter and exit, but are designed to close in the event of atypical storm tides, preventing flooding of homes, roads, and other infrastructure.

Culverts under roads or rail beds can represent migration barriers due to an excess drop at the culvert outlet, high velocity or turbulence within the culvert barrel, inadequate water depths within the culvert barrel, or debris/sediment accumulation at the culvert inlet or within the barrel. Recent awareness of the problem culverts pose to fish passage and stream degradation has prompted the installation of culvert bridges or arched pipes with flat bottoms, although these are not commonly found in the HRE study area (Gibbons et al. 2005). Other "habitat" barriers relate to physical qualities or the condition of the water that may deter certain fish from entering the area. These barriers can be due to certain conditions of salinity, water temperature, water velocity, water depth, or dissolved oxygen; or interactions of these parameters, outside of the suitable range for a species or group of species.

Natural barriers to fish passage can be rock ledges, beaver dams, debris dams, or sedimented channels. Where natural falls exist, upstream reaches have historically been separated from downstream communities/species and may have developed distinct populations that could be harmed through the "introduction" of downstream populations. While some natural barriers can be made passable, it is recommended that natural falls not be made passable to protect upstream populations.

Barriers also affect in-stream and riparian habitat, creating a need to improve tributaries on a system-level. For instance, a dam removal project may alter in-stream habitat and riparian zones adjacent to where the water was previously impounded. Habitat restoration should be inclusive of in-stream habitat requirements and riparian habitat quality for all biota. In-stream habitat features, including logs, boulders, root-wads, gravel bars, riffles, and pools, provide diverse physical and biological conditions and typically represent areas of high species diversity. Riparian habitat stabilizes streams, protects against runoff, controls stream temperatures, and provides nutrient inputs that nourish and sustain benthic communities.

Restoring in-stream habitat upstream or downstream of a barrier and riparian habitat, such as forested floodplains and freshwater wetlands, could fulfill this target. Where possible, projects should attempt to include multiple components (i.e., in-stream habitat, riparian habitat, barrier removal) to increase the number of functional benefits and the ecological

contribution of the tributary to the estuary. Although projects with multiple components are encouraged, small projects that aim to restore even one component also provide substantial benefits and should be conducted.

Stream length and riparian acreage restored could be appropriate metrics for the TEC goal statement. For restoring habitat under this TEC, the following guidelines should be followed:

- Habitat restoration should focus on riparian habitat that is or once was connected to the estuary.
- Tributaries with higher stream orders that are proximal to an estuary body should be targeted for restoration. These can be freshwater areas with no tidal influence.
- Projects with fish passage components should focus on impediments, which when removed make several miles of stream passable.

TEC Guidance

The sequence with which restoration of multiple components on a tributary are undertaken is an important planning consideration for this TEC. When a project contains a barrier removal component, the impediment should be removed before restoration of the other downstream or upstream components occurs. Shoreline stabilization and native species plantings are often necessary in these projects to reduce erosion and minimize invasive species colonization. Additionally, on tributaries with multiple impediments, the most downstream impediment should be made passable and monitored to confirm usage rates before additional fish passage projects on that tributary are planned.

Although there are several components to this TEC, improving fish passage to restore migratory fish runs in the HRE study area should still be a priority. When planning a fish passage project, whether it entails an impediment removal or fish ladder construction, restoration practitioners should also plan to restore or enhance other components of the tributary, as is suggested by this TEC. Restoring habitat upstream of a barrier should be considered if the tributary is biologically connected to the estuary (e.g., via a fish ladder), otherwise the benefits of the enhanced upstream habitat would not be accessible to estuarine organisms. Additionally, fish passage projects should focus on tributaries with historic fish runs of herrings or American eels or locations where these species are found congregating below a barrier.

A habitat tradeoff issue may occur with beavers and with the recreational and ecological value of slow moving water. Beaver dams are a natural stream barrier, forming impoundments, and may become a factor affecting fish passage restoration in the HRE study area. The first beaver siting in New York City in almost 200 years occurred during 2007 in the Bronx River. Beaver populations throughout New York State have been increasing, and it is likely that beaver dams in the HRE study area will become more common. Although beaver dams may preclude upstream passage of small fish, these natural barriers provide ecological benefits (e.g., wetland creation) and are not recommended for removal unless they present economic or safety hazards.

A thorough evaluation of the upstream environment should be conducted to determine the impacts of barrier removal. The slow-moving water found upstream of impoundments, whether natural or man-made, typically supports different fish communities and shoreline vegetation and can be highly valued. If these impounded waters provide recreational

sport fishing opportunities to nearby residents, it may be extremely difficult to gain support for a barrier removal project. Additionally, the shoreline vegetation may include regulated wetland communities that could be impacted by a barrier removal. In scenarios like these, it is important to gain public support during preliminary planning stages.

Data Needs

With so many potential components (e.g., in-stream habitat, riparian habitat, barrier removal), projects initiated under this TEC can be extremely complex, incorporating engineering, design, and construction aspects, and addressing economic and political concerns. Reconnaissance surveys and evaluations of baseline conditions in the vicinity of planned tributary re-connection projects are essential components of the restoration planning process. These are conducted to: 1) determine the feasibility of a site prior to in-depth restoration planning and 2) develop success criteria for individual projects. For example, initial monitoring of a tributary stream for removal or breaching of a low-head dam might reveal the presence of vulnerable infrastructure (e.g., bridges, road abutments, utilities) that may require removal, relocation, or shoreline reinforcement prior to project implementation. Baseline Information needs associated with a planned tributary re-connection project include:

- Land ownership
- Bridges/utilities possibly affected
- Barrier ownership
- Community interest/willingness
- Presence of cultural resources (often the dam itself)
- Hydraulics, stream channel morphology
- Sediment load/transport
- Presence of contaminated sediments behind a barrier
- Biological impacts (e.g., presence of mussels beds downstream, or spread of invasive species via barrier removal)
- Water quality upstream and downstream of the barrier
- Fish consumption advisories (opening tributaries to migratory fish from polluted downstream areas of the harbor may result in stricter consumption advisories)
- Presence of historic fish runs
- Current fish presence below the barrier, and size/age class distribution of target species, if present
- Identification of non-target species likely to be affected by barrier removal, upstream and downstream
- Project longevity (fish ladder construction requires long-term considerations for maintenance and logistic support)

It is especially important to determine the amount, type, and contaminant level of sediment behind dams during reconnaissance surveys. Large volumes of sediment upstream of a dam could make a dam removal project cost-prohibitive, and finding alternative uses or disposal sites for sediment can be difficult, especially if the material is contaminated. The type of sediment can also affect removal costs, requiring the use of large machinery and monitoring sediment removal/re-suspension to adhere to state and Federal regulations. Occasionally clean sediments can be used to stabilize/re-grade shorelines, saving on transport and disposal costs. The greatest concern over dam removal projects is the presence of contaminated sediments. This is due, in part, to a negative perception brought about by events associated with a very early dam removal project on the Upper Hudson River – the Fort Edwards Dam, located 54 miles north of Albany, NY. Project proponents failed to conduct pre-removal sediment characterization studies upstream of the dam, and when the dam was

removed in 1973, several tons of PCB-laden sediments were released downstream. This resulted in the temporary closure of the Hudson River for fishing and the declaration of a portion of the upper Hudson downstream of Fort Edward as a Federal Superfund site. To prevent repeating these damaging events, it is imperative to investigate historic and current upstream land uses during reconnaissance surveys to determine if hazardous materials or byproducts were introduced into the tributary. Sediment testing should also be conducted to quantify the type and extent of contamination.

Suggested Monitoring Parameters

During the post-construction monitoring phase, resources should be carefully allocated to allow for an adequate duration and scope of assessment. In areas where connectivity has been restored, responses of migratory fish populations, such as the number of fish annually migrating upstream or the number of young fish found in reconnected waters, should be evaluated to provide an additional metric of success (Bain et al. 2007). Performance of the TEC should be measured as the number of habitat types reconnected and the number of reconnections to estuarine open waters made in the HRE study area (Bain et al. 2007).

Techniques for monitoring fish at dam removal sites or fish passage structures may include conventional visual identification and counts, or presence/absence surveys conducted both upstream and downstream of the former barrier. Techniques might either include a variety of active or passive net gears or electro-fishing, either from a boat in deeper waters or backpack shocker for shallower areas.

As an alternative, or supplement to conventional sampling techniques, the advent of high-resolution video or hydroacoustic imaging technology (e.g., DIDSON) offers the ability to provide consistent, long-term monitoring of fish passage at dam breaches or through fishways. Juvenile and adult migrants can be captured and tagged with Passive Integrated Transponders (PIT tags). Successive passage of the individuals through the former barrier (or at upstream or downstream locations) can be ascertained by installing a scanning device along a bottle neck in the passageway or by recapture and analysis using a hand-held scanning device. Traditional mark-and-recapture techniques (e.g., fin clipping, marking, internal anchor tags) may also be applied to estimate the efficacy of tributary re-connection efforts in restoring migratory pathways.

In addition to monitoring of the target species or communities, an additional set of environmental parameters should be monitored in association with tributary connection projects involving the removal of an obstruction or impediment to migration. These include:

- *Documentation of the formation of shoals downstream of a former impediment.*
- *Channel scour/bank erosion (may be temporary or persistent).*
- *Changes in particle size distribution within downstream areas.*
- *Lowering of groundwater levels in the vicinity of a former impediment.*
- *Integrity of wetlands and other shallow aquatic habitats upstream of former impediments.*
- *Sedimentation/turbidity effects on downstream gravel bars, mussel beds, SAV, wetlands, etc. following tributary re-connection.*

- *Changes in stream benthic invertebrate communities in response to altered hydrodynamics and substrate type.*
- *Changes in flooding potential, particularly to nearby properties*

3.3.2 Enclosed and Confined Waters

The Enclosed and Confined Waters TEC focuses on poorly flushed, enclosed, constricted, and over-dredged subtidal areas of the HRE study area that exhibit periodic or continuous poor water quality. Examples of enclosed and confined water bodies occurring in the HRE study area include tidal creeks, enclosed basins, and bathymetric depressions with poor circulation. These water bodies are often characterized by a host of degraded conditions, including contaminated sediments, hypoxic/anoxic water masses, noxious odors, hardened shorelines, accumulation of fine sediments, and little or no vegetated buffers, creating low quality habitat that is of limited use for foraging, nursery, or refuge by estuarine organisms.

Dead-end tidal creeks are remnant natural tidal drainage features that have been cut off from their headwaters and partially filled. Historically, many tidal creeks were present throughout the HRE study area, as drainage features associated with intertidal wetlands. As the estuary became increasingly populated and developed, these water bodies were successively straightened and/or diverted through culverts, or filled throughout their length. The lower sections of these creeks, near the confluence with the estuary, were sometimes dredged for fill material or to provide navigation access for neighborhood industries and recreational vessels. This created narrow, linear channels with hardened shorelines and single outlets (Bain et al. 2007). These confined waterways often exhibit impaired tidal flow, have limited flushing, and are dredged to depths greater than the surrounding estuary, promoting poor water circulation and stratification (Yozzo et al. 2001, Bain et al. 2007). A variation of these dead-end tidal creeks are the head-end of basins and bays that can also have poor water quality due to poor circulation combined with land use, CSO inputs, and marinas.

Man-made bathymetric depressions are deep holes that were created by removing sediment for on-land construction (i.e., borrow pits). Some natural depressions exist in the HRE study area (e.g., Lower Bay) that do not have poor circulation and offer quality benthic habitat. However, artificial depressions are characterized by impaired water circulation, fine organic sediments, and vertically stratified temperature and dissolved oxygen concentrations that can be as low as 4°C and 0-1 milligrams/liter, respectively, in the deepest pits of Jamaica Bay (Vittor & Associates 2005). These bathymetric depressions may also contain debris, such as derelict vessels/vehicles, construction materials, and pilings.

Enclosed and confined waters in the HRE study area often have extremely poor water quality due to years of unregulated dumping and discharge (Yozzo et al. 2001). Because these basins have been cut off from their historic creeks and there is limited tidal flushing from the estuary, major inputs to enclosed and confined waters often include stormwater runoff coupled with human and industrial wastes from CSOs, vessels, and shoreline facilities (Bain et al. 2007). The combination of poor circulation and high rates of organic matter decomposition leads to periodic or chronic hypoxic or anoxic conditions (Yozzo et al. 2001). Confined waters typically exhibit low species diversity and abundance, are dominated by a few opportunistic species. In the most extreme cases, extensive mats of sulfur bacteria and blooms of dinoflagellates, cyanobacteria and macroalgae may develop in enclosed and confined basins (Yozzo et al. 2001, Bain et al. 2007). Because these areas mix slowly with adjacent waterways, they tend to retain and concentrate materials and contaminants from runoff, groundwater, and sewage outfalls, often resulting in considerable sediment degradation (Bain et al. 2007).

TEC Guidance

The Clean Water Act requires that all states are responsible for establishing and meeting appropriate uses for surface waters within their jurisdiction. These 'designated uses' of surface waters consider the public use and value of the water body based on water quality criteria for parameters of concern (i.e., pathogens, contaminants, dissolved oxygen). The water quality criteria specify safe limits for the 'best use' of that water body (e.g., fishing, recreation, navigation, etc.). The State of New Jersey designates four classes and New York State designates five classes for surface water use in estuaries. Best uses are classified for larger water bodies, where smaller tributaries and basins are often not designated separately from their receiving waters. When smaller tributaries or basins are designated, their receiving waters may have a higher use class than the basin because of circulation issues in the confined waterway.

The designated use classifications are evaluated through statewide water quality assessment programs, as required by Section 303(d) of the CWA. The list of water bodies not attaining their designated use are placed on the state's Impaired Water Body List (i.e., Section 303(d) List). For impaired water bodies, states typically consider developing a Total Maximum Daily Load (TMDL) program or other strategy to reduce source inputs, thereby returning the water body to its designated use. For New York State, TMDL programs are not required to be created for some water bodies, such as those where the impairment is the result of historic conditions rather than a pollutant that could be controlled via a TMDL program.

Unfortunately, not all water bodies are monitored by these water quality assessment programs, especially smaller water bodies like confined basins. Thus, there are water bodies in the HRE study area that do not meet their use classifications but are not included on the 303(d) List. Moreover, the assessment programs are restricted to traditional parameters and long-term monitoring locations and may not consider water quality issues related to deep bathymetric depressions with poor circulation. It may be beneficial to increase the scope of statewide water quality monitoring to include small confined basins or deep bathymetric depressions not currently monitored under existing programs.

Each confined basin, degraded tidal creek, or bathymetric depression with poor circulation will likely have different sets of impairments, requiring the development of site-specific actions to restore the water, sediment, and habitat quality. Site modifications to improve water and habitat quality of enclosed basins, tidal creeks, and bathymetric depressions with poor circulation include:

Shoreline softening. Many confined waterways are hardened by bulkheading; these features may be converted to naturally vegetated shorelines. By creating wetlands or upland forested habitat along estuarine shorelines, the volume of sediments and nutrients entering the watershed as runoff from roads and other impervious surfaces may be reduced through interception and sequestration. Softened shorelines also provide feeding and refuge areas for biota and can improve microclimatic conditions by shading surface waters. Along with shoreline modifications, it may be beneficial to stabilize the bottom of basins having CSO inputs. In basins with large CSOs, solids accumulate down-gradient of the discharge outlet, resulting in extremely soft and flocculent substrates. During heavy rain events, this material is scoured and solids are washed into receiving waters, potentially degrading water quality.

Debris removal. Debris can collect along the shoreline of enclosed basins, smothering shoreline vegetation and shallow subtidal habitats. Although shoreline debris can provide some protection against erosion, in most cases shoreline debris should be removed so that shoreline vegetation and soft-bottom benthic habitat can become established. The NYSDEC and NJDEP are local sponsors for a USACE program to control floatables in the HRE study area by removing potential sources of drift, such as abandoned piers, wharfs, derelict vessels, and debris. To date, a total of 21 reaches within New Jersey (16 reaches) and New York (5) have been cleared of debris, and six reaches are continuing to be cleared.

Dredging contaminated sediments. Because there is limited flushing in many of the confined basins, they tend to become depositional areas, concentrating contaminants. Although there are some current sources of contamination, persistent, legacy chemicals from several decades to a century ago present the largest threat that continue to contaminate the HRE study area when overlying sediments are disturbed. Output from the CARP model suggests sediment removal as the optimal restoration measure for severe contamination.

Combined sewer overflow (CSO) treatment or abatement. Hundreds of CSOs are located throughout the HRE study area and are a chronic contributor to poor water quality conditions. Many of these CSOs are located at dead ends of enclosed basins and tidal creeks. The New York City CSO abatement program includes provisions for installing large, underground storage facilities to hold wastewater overflows, then subsequently pumping the wastewater back to the treatment plant. These in-line storage tanks improve dissolved oxygen concentrations and reduce hydrogen sulfide (H2S) emissions because the solids settle in the bottom of the tank and do not enter the receiving water body. Other components of the CSO abatement program include sewer cleaning, in-stream aeration, floatables booms/skimmer boats, and structural improvements to achieve use attainment standards of receiving waters, such as wet weather optimization and regulator improvements (Gibbons and Yuhas 2005). NJDEP's Division of Water Quality also has a CSO abatement program who's mission is to upgrade or reduce the current number of CSOs.

Restoring water circulation patterns. Existing water circulation patterns can be altered to improve water quality in selected areas. Re-contouring deep basins promotes circulation and de-stratification of the water column (Yozzo et al. 2001). It can be difficult and costly to improve water circulation in dead-end basins. However, one of the more effective methods is to redirect flow from the receiving water to the end of the upstream basin, creating continuous circulation through the basin. This method is cost-effective when under/over-ground piping from the receiving waters to the end of the basin is already in place (e.g., Gowanus Canal). Although frequently promoted as a means of improving local hydrodynamics, removing breakwaters or accumulated sediments at the mouths of dead-end waterways typically does not dramatically improve flushing or reduce sedimentation in these basins. Re-contouring entrance channel sediments may not necessarily work as a stand-alone measure, and should be combined with other restoration measures to achieve measurable increases in flushing.

Additionally, alterations to the watersheds of tidal creeks have resulted in measurable impacts to receiving water bodies. For instance, in Jamaica Bay freshwater inputs from the tidal creeks historically resulted in a distinct salinity gradient from the mouth of the bay to its periphery. Currently, the lack of continuous freshwater inputs from the creeks and the redirection of freshwater flow through municipal wastewater outfalls to the middle of the bay have negatively impacted water circulation and resulted in a highly saline water body. Because almost no freshwater currently enters the bay at the shorelines or through the tidal creeks, it may be limiting habitat for species needing less saline water or a gradient between saltwater and

freshwater (e.g., oysters, juvenile fish). Thus, there may be an opportunity to restore salinity gradients to surface waters within water bodies like Jamaica Bay, creating more suitable habitat and benefiting estuarine species.

Suggested Monitoring Parameters

Baseline monitoring of confined waterways provides detailed information about the conditions of the waterway and assists in the selection and prioritization of measures to best restore an area's water quality and ecological function. Monitoring may include bathymetric surveys, characterizing local contaminant inputs, hydrodynamic surveys, calculation of tidal prisms (e.g., change in water volume covering an area between high and low tides), sediment characterization (e.g., Sediment Profile Imaging [SPI] cameras), dissolved oxygen/temperature profiles, benthic community surveys, and possibly fish surveys.

Suggested parameters to be monitored at restoration and reference sites include:

- *Changes in estuarine bottom contours resulting from both natural depositional/erosional processes, and the implementation of restoration activities, pre- and post-restoration.*
- *Water quality, with emphasis on identification of the distribution of hypoxia/anoxia in space and time.*
- *Hydrodynamic characteristics of the waterway, pre- and post-restoration, as a means of gauging the benefits of remedial dredging, bathymetric re-contouring, and removal of structures such as breakwaters, berms, derelict vessels, etc.*
- *Sediment characterization (e.g., total organic carbon [TOC], grain size, contamination, toxicity).*
- *Benthic invertebrate communities*
- *Fish communities*
- *Use of enclosed and confined basins by the public*

3.4 Contamination Issues

Centuries of urbanization have resulted in extensive contamination issues throughout the HRE study area. One of the TECs focuses on contamination issues by establishing objectives to remove or isolate contamination and to restore conditions to prevent the future accumulation of contaminants. The following sections describe these contamination issues, the objectives for the TECs, and potential restoration opportunities within the HRE study area.

3.4.1 Sediment Contamination

Sediment quality characteristics are critical to the estuarine ecosystem, to the success of other TECs, to human health and safety, and to the port's economic viability (Bain et al. 2007). Many areas within the HRE exhibit sediment contamination to varying degrees, brought about by historical industrial discharges, municipal point and non-point source pollution, and inputs from the upper reaches of the Hudson River Estuary (upstream of the HRE Study area). An important goal of Federal and state (NY and NJ) natural resource agencies, and estuary management programs (i.e., The NY/NJ Harbor Estuary Program [HEP]) has been to undertake efforts to reduce the degree of contamination within sediments of the HRE. By reducing contaminant concentrations in the sediment, the potential for bioaccumulation of contaminants in estuarine organisms and

the spread of contamination to relatively clean areas may also be reduced (Bain et al. 2007). Specifically, there are several HEP work groups associated with sediment contamination in the HRE: 1) Regional Sediment Management; 2) Contaminant Assessment and Reduction Program and 3) Toxics. The Regional Sediment Management Work Group will be the group to focus on this TEC in the future.

Sediments of the HRE study area are a long-term repository of contaminants including PCBs, dioxins, mercury, pesticides such as DDT, and polycyclic aromatic hydrocarbons (PAHs). Although production and uses of many of these chemicals have been banned in the U.S. for many decades, they have persisted in the benthic environment and within aquatic organisms Bain et al. 2007).

PCBs are a class of organic compounds used in the electrical industry as insulating fluids and oils for industrial transformers and capacitors, and are characterized by high chemical stability, low flammability and high resistance to biological degradation (Nadeau and Davis 1976). They are poorly soluble in water and highly soluble in fats. PCBs were manufactured in the U.S. from 1929 – 1977 by Monsanto and sold under the trade name Aroclor™. Although first identified as an environmental hazard in 1966, PCBS were not widely recognized as an environmental and human health hazard until the mid-1970s. The primary source of PCB contamination in the HRE, as well as the entire tidal Hudson River from Troy to New York Harbor, was the removal of the Fort Edward Dam in 1973.

Dioxins and furans are chlorinated organic compounds that can be found in the environment due to natural combustion (e.g., forest fires), but also through waste incineration, fuel combustion, and as a manufacturing by-product. Dioxins were a by-product of a widely used defoliant in the 1960s (i.e., Agent Orange), and large amounts of dioxins were released into the lower Passaic River, which have subsequently spread throughout the HRE, with highest concentrations close to the lower Passaic source, followed by Newark Bay and portions of the Hackensack River, Arthur Kill, and Kill Van Kull. DDT, one of the first and best-known organic pesticides, was used to control insect-vector diseases and as an agricultural insecticide. PAHs are primarily created through the incomplete incineration of organic fuels, and are therefore tightly linked to energy production. PAHs can enter the environment through point sources (e.g., oil spills), and non-point sources (e.g., atmospheric deposition and overland runoff).

A variety of heavy metals may be present in HRE sediments. Some metals such as lead, are widely distributed throughout the HRE study area, as a result of atmospheric deposition and other non-point source inputs. Others, such as cadmium, mercury, chromium and copper may occur in very high concentrations in specific geographic areas, as a result of direct point-source inputs. Mercury is a naturally occurring heavy metal, and is a neurotoxin that can enter the environment through atmospheric deposition as a by-product of coal combustion and the improper disposal of industrial or household products containing mercury.

A more recent concern in the HRE study area is "emerging" or newly-recognized contaminants such as fluorinated alkyl substances, used in "non-stick" coatings; poly-brominated-diphenyl-ethers (PBDEs), used in developing fire retardant materials); and pharmaceutical substances, (including anti-depressants, birth-control drugs, and caffeine). The latter group of chemicals enter the estuary primarily via treated wastewater. These compounds and their metabolites are not completely removed through current wastewater treatment technologies and have the potential to accumulate in sediments and

organisms. There is still considerable uncertainty regarding the potential and actual risks of these contaminants and their fate in the environment (Strandberg et al. 2001, Kolpin et al. 2002).

Currently, every planning region of the HRE study area has exhibited some degree of sediment degradation due to contamination. The Regional Environmental Monitoring and Assessment Program (REMAP) conducted by the USEPA in 1993-1994 and again in 1998, found that pervasive contamination across chemical groups in the HRE study area had declined (Adams and Benyi 2003). Areas that exhibit persistent degraded sediment quality include the Newark Bay basin, the Arthur Kill, and parts of Upper New York Bay (Steinberg et al. 2004). Many locations within the HRE study area have been evaluated for contaminant concentrations, but the extent of contamination throughout the estuary has never been evaluated in a comprehensive fashion. Additionally, because most of these chemicals originated from a combination of point and non-point sources, managing and curtailing inputs has been difficult (USACE 2004).

Sediment-bound contaminants are chemically charged molecules, allowing them to adhere to the silty sediments of the estuary and persist in fat cells of living tissue. Through absorption, respiration, and ingestion of water and food, benthic organisms can uptake non-essential chemicals as easily as essential chemicals, making them particularly prone to bioaccumulation of sediment-borne contaminants (Rand 1995). Bioaccumulation is an environmental concern both because of the contaminant's effects on the organism and on higher trophic levels, like fish, birds, and humans (i.e., biomagnification; Rand 1995).

Because species bioaccumulate and biotransform chemicals differently, contaminants may have different effects on species as they pass throughout the food web (Rand 1995). In some cases, high concentrations of single contaminants can be as lethal as low concentrations of a mixture of contaminants. Most effects are sub-lethal, in that the effects may manifest themselves singly or as a combination of behavioral (e.g., swimming, feeding, predator-prey interactions), physiological (e.g., growth, reproduction, development), biochemical (e.g., enzymatic, ion levels), or histological (e.g., immune system, genetic, carcinogenic) modifications (Bain et al. 2007).

Contamination can greatly reduce the intrinsic biological and recreational value of the HRE study area through fish consumption advisories, human health and ecological risks, and economic impacts through restrictions of commercially harvested species. Sediment contamination also affects navigation and commerce within the HRE study area, valued at an estimated $25 billion annually and directly or indirectly supporting approximately 229,000 jobs (USACE 2008). Contaminated sediments can increase the cost of maintaining navigation channels by as much as four to five times due to the added cost of transporting and processing the material for disposal or reuse (USACE 2008). Alternatively, clean sediments can be used in habitat restoration projects, upland construction and development, for remediation at the Historic Area Remediation Site ([HARS] a past ocean disposal site for dredged material and refuse located in the NY Bight, outside of the HRE study area), or for habitat creation, enhancement, or restoration (Yozzo et al. 2004, USACE 2008). Sediment classified as Non-HARS suitable material would be placed upland for beneficial use through solidification/stabilization for the remediation of brownfield sites.

HEP's 2008 Regional Sediment Management (RSM) Plan provides a coordinated framework for activities related to sediment quality, contaminated sediment quantity, and dredged material management, and supports the restoration objectives of this TEC (HEP 2008). The RSM Plan recommended eight objectives, four of which pertain to sediment quality:

1. Ensure new sediments are clean
2. Ensure new sediments entering the HRE remain clean
3. Reduce direct exposure
4. Reduce transport of contaminants to other areas

A potentially valuable tool in managing sediment quality may be the categorization of sediments of the HRE study area based on their potential to impair the estuary. The following classification was proposed in the RSM Plan. These proposed sediment categories are:

- Clean sediments that support unrestricted beneficial uses.
- Sediments that do not pose an immediate threat, because they are either deeply buried or do not pose a threat to ecological health. These have few beneficial uses, but are suitable for placement at the HARS.
- Sediments that significantly impact ecological health and all levels of human use. These have few beneficial uses and are not suitable for placement at the HARS.
- Sediments that are an ongoing source of contamination and require decontamination (including solidification/ stabilization) before being used beneficially.

The proposed classification system would allow managers to prioritize remedial activities, targeting areas that have the greatest potential to cause harm. The last category of sediments is important because these areas can act as sources of contamination to other areas within the watershed. Contaminated particles can become resuspended due to disturbance, tidal currents, or flow and deposited in other areas, contaminating clean or recently restored sites. This is also an economic concern because contaminated sediments can be transported to navigation channels, thereby increasing the costs of material disposal.

There are several existing datasets that can be used to evaluate existing conditions and project future patterns in sediment contamination in the HRE study area. These are:

CARP Model - The Contaminant Assessment and Remediation Program (CARP) offers valuable information on existing contaminant levels and predictions of future conditions based on changes in contaminant loadings and movement of contaminants through the estuary. The CARP models can simulate the effect of known continuing contaminant inputs (i.e., atmospheric, sewage treatment plants, CSOs, stormwater, tributaries, runoff, in-place sediments, and ocean) and the effect of implementing specific load reductions on concentrations in water, sediment, and biota. The CARP models also address the fate and transport of particular contaminants based on changes to contaminant inputs on an estuary-wide basis. The model does not account for influences of unknown sources of contamination such as un-permitted discharges of pollutants and unreported spills. A potential limitation of the CARP models is that they only provide estimates of contamination for surface sediments, potentially limiting their application throughout the HRE.

USEPA Regional Environmental Monitoring and Assessment Program (REMAP) - Under this geographically broad sampling program, sediments were collected throughout the HRE study area and the NY Bight Apex during 1993 and 1994 and again

during 1998, forming the basis for the evaluation of sediment quality in the region (Adams and Benyi 2003). In the REMAP data have been used as a foundation for current analyses in the region, such as the Health of the Harbor report (Steinberg et al. 2004).

Site-Specific Sediment Data - These data can be compiled from Superfund sites (e.g., Passaic, Hackensack, Newark Bay, Gowanus, etc.) and from other site-specific investigations and programs, such as brownfields sites and remediated (capped) landfills located adjacent to coastal habitats.

USACE/USEPA Evaluation of Dredged Material Proposed for Ocean Disposal ("Green Book") - When channel deepening or maintenance dredging projects are conducted in the HRE study area, composite samples of dredged material are tested to determine its suitability for placement at the HARS (USACE 2008). Recent dredging activity in the HRE has focused on the Arthur Kill, Kill Van Kull and Newark Bay waterways; however, dredged material characterization data will potentially be available Harbor-wide throughout the duration of the HRE Program.

Literature on Sediment Toxicity - Sediment toxicity tests can be applied to all contaminants of concern, can provide data on cause-effect relationships, and are amenable to field verification. However, most toxicity testing measures acute lethality of contaminated sediments, which is useful in identifying "hot spots," but cannot be extrapolated to moderately contaminated areas (Rand 1995). Literature on site-specific sediment toxicity or general findings could be applied to regions of the HRE study area.

Navigation Dredging Bathymetric Surveys - Pre- and post-dredging bathymetric surveys may yield valuable information on potential contaminant sources and sinks, as determined by subaqueous geomorphology, bathymetry, and sediment characteristics.

Data Needs

Several data needs have been identified for the HRE. Focused studies to address these data needs/gaps will assist resource managers in developing a better understanding of sediment contamination within the HRE, increase confidence of modeling outputs, and more accurately identify restoration opportunities.

- Bathymetry (historical and current) An important consideration when assessing the extent of contaminated sediments is whether a known contaminated area functions as a source of contamination to other areas within the watershed. Identification of depositional and erosional zones would provide such insight on sources (and sinks) of contamination.
- Hydrodynamic data - Additional hydrodynamic data collection may be required to better understand sediment transport and deposition within Newark Bay and the Hudson River. Because it would require substantial effort to identify sources and sinks throughout the HRE study area, a simpler, although cruder, approach would be to determine the overall flux of contaminants (i.e., the volume of contamination entering and leaving) from each Planning Region of the HRE. However, this approach would not provide sufficient information to determine the effects of contaminant transport on a particular restoration opportunity.
- Ambient conditions in the HRE study area - Many physical, chemical and biotic properties of the aquatic environment

control contaminant fate and transport (CRP Volume 1, Table 3-7, Section 3.4.1). While the CARP has evaluated many environmental parameters, additional parameters and information will strengthen model predictions and increase site-specific forecasting of contaminant retention and mobility.

- Storm event records - Severe storm events represent an important mechanism for mobilizing deep layers of contaminated sediments, through scour and resuspension. For any potential restoration project, it would be beneficial to look at the worst event prior to implementation. The CARP has forecasted scenarios to include severe events, but on a limited spatial scale. Future development of the CARP models could result in an enhanced understanding of the effect of severe storms on sediment/contaminant distribution.
- Point and non-point sources (historical and current) - Legacy contaminants are a major source of contamination in the HRE study area, and areas may be identified using historical information. Ongoing contamination inputs from runoff, stormwater, and head-of-tide are particularly important sources to monitor. The CARP has acknowledged the need to conduct additional research and data collection of contaminant loading from stormwater & CSOs to increase the confidence in the model projections.
- List areas under active remedial investigation by USEPA, NJDEP, or NYSDEC - A number of historically contaminated sites within the HRE are currently undergoing investigation for remediation under Federal, state or local authorities, or through partnerships among authorities/agencies. It would be beneficial to compile a comprehensive, up-to-date inventory of sites and associated data that have been completed, are underway, or are planned within the HRE study area.
- Evaluate impact of sediment contamination on biota - The CARP models have evaluated bioaccumulation in benthic organisms and age-dependent bioaccumulation in white perch and striped bass, but additional data collection is needed to better reconcile differences among field and laboratory results (HydroQual 2007). Additional data collection was recommended by HydroQual to determine how varying levels of sediment contamination affect bioaccumulation and to determine factors causing sediment-related toxicity.

Suggested Monitoring Parameters

Baseline monitoring of contaminated sites provides detailed information about the sediment type/texture, bathymetry, and the nature/extent of contamination. Baseline assessments assist in the selection and prioritization of measures to best remediate sediment quality and restore ecological function. Monitoring may include bathymetric surveys, identifying characterization of local contaminant inputs, hydrodynamic surveys, sediment characterization (e.g., Sediment Profile Imaging [SPI] cameras), measurement of contaminant concentrations, benthic community surveys, and bioassay/ bioaccumulation studies.

Suggested parameters to be monitored at remediation and reference sites include:

- *Changes in estuarine bottom contours resulting from both natural depositional/erosional processes, and the implementation of restoration activities, pre- and post-restoration.*
- *Hydrodynamic characteristics of the waterway, pre- and post-restoration, as a means of gauging the feasibility and the benefits of remedial dredging, bathymetric re-contouring, and capping with clean sand.*
- *Sediment characterization (e.g., contamination, TOC, grain size, toxicity).*

- *Benthic invertebrate communities.*
- *Bioassay/Bioaccumulation.*

3.5 Societal Values

An important component of this ecological restoration plan is to recognize that people are a part of this ecosystem, and the plan should incorporate features that will benefit the public. One TEC was designed to promote access to natural areas for the public. The following section describes the public access TEC and its objectives, and presents potential restoration opportunities within the HRE study area

3.5.1 Public Access

According to the Public Trust Doctrine, public trust lands, waters, and living resources in a state are held by the state in trust for the benefit of all of the people. The doctrine establishes the right of the public to enjoy these resources for a wide variety of recognized public uses (NYSDOS 2008). Public access to the estuary means providing residents of the HRE study area with accessible routes to natural areas, enabling them to enjoy local scenic, natural, cultural, historic, and recreational resources (Bain et al. 2007). Contact with nature can afford numerous public benefits in the form of educational experiences, relaxation, and improved quality of life (Bain et al. 2007). Public access areas include:

1. Direct access (e.g., boat launching, swimming, recreational fishing),
2. Indirect access (e.g., waterfront promenade),
3. Vistas (e.g., scenic overlook), and
4. Upland access routes (e.g., pedestrian route, bike path; Bain et al. 2007).

Throughout the HRE's history, there has been a conflict of interest concerning the use of the waterfront. Differing views among government, local communities, and private industries were rarely able to reach a consensus when deciding between urban or natural uses, or some combination thereof, for the waterfront. Often, attempts to create parkland during the 19th century were rejected as being inconsistent with the economic goals and commercial opportunities for the city. By the mid-20th century, views had changed and the focus became urban renewal (Bone 1997).

Since then, water quality improvements have been matched by a reanimation of recreational activities along the waterfront and within water bodies of the estuary (Bone 1997). A reconnection with the estuary has accompanied these activities, resulting in increased popularity and momentum of community-led environmental programs and restoration efforts. Through environmental improvements and increased community participation in the HRE study area, there as been an increased demand for recreational and outdoor educational opportunities at parks and natural areas.

TEC Guidance

Understanding how residents of the HRE are served at existing recreational areas is vital to satisfying the public's desires for green spaces and waterfront access. The number of visitors, number of amenities, or the quality of surrounding habitat can be used to measure access quality, but this information does not exist for many areas of the HRE. Therefore, municipalities

and local non-government entities that are more intimately connected with the needs and desires of their constituents may be the best suited to undertake the majority of access creation and upgrade projects.

Access should be appropriate for the local community and designed to include complementary activities and signage in multiple languages. People stay longer and visit a public area more frequently when it offers multiple amenities. To promote the use of access points, it would be appropriate to include design elements such as seasonal programming, restrooms, restaurants, fishing piers, and floating docks for transient boaters. Businesses along the waterfront or adjacent to a habitat complex should be encouraged to participate in the creation or enhancement of access points. These businesses can benefit by offering seasonal outdoor services. Increasing public access for residents and tourists can help meet the growing demand for recreational opportunities and can provide economic benefits on local and regional scales (Bain et al. 2007).

Community access to waterways in the HRE is improving despite the isolation of many areas from the shoreline by highways and industrial infrastructure. Direct access points may be more challenging to construct and potentially have more public resistance in an urbanized setting. However, promoting a direct connection between communities and the water engages the public in the surrounding environment, strengthening the sense of stewardship and ownership in an area. These access points will also afford more opportunities for active recreation in the HRE.

Where possible, public access targets should be coupled with habitat restoration activities, incorporating access points and the public into each project's design. New waterfront public amenities are an opportunity to connect the public to the estuary and provide an opportunity to tell the CRP's story through signage and interpretive programs. At these sites, the public can experience the improved habitats directly through enhanced angling and recreational opportunities. Areas with natural, intertidal shorelines could be targeted for public access because these are aesthetically pleasing, offer areas for respite during low tide, and can provide additional components like intertidal pools that are both educational and increase nearshore habitat complexity. Many subtidal habitat restoration projects also benefit fish communities, such as oyster reefs or artificial reef habitat, and can provide recreational fishing opportunities near piers or further offshore for boaters. Habitat restoration and enhancement is dependent upon its perceived benefit (i.e., value) to constituents. Therefore, projects that engage the public and areas that provide recreational opportunities in the HRE will likely gain greater political and economic support.

Areas with demonstrated community interest and existing stewardship components may be appropriate places to target public access sites. Communities and environmental organizations can often be involved in the planning, design, and post-construction phases of restoration projects. Monitoring programs can be supported by volunteer organizations, providing public outreach and educational opportunities. Placing interpretive signs along trails and pathways also offers educational opportunities and enhances the public perception of and stewardship for the environment. Interpretive signage can call out important habitats and inhabitants of an eco-region along a trail or waterway. More formal environmental education programming can be incorporated into restoration projects, though these are typically seasonal and require staffing.

The Public Access TEC may encounter more land use trade-offs than other TECs. Industrial or commercial land uses can be considered conflicting if they create safety issues for direct access or lack aesthetic quality. Access will be limited around airports, port terminals and other secure areas. Although industrial activity and public access co-exist in the Hackensack Meadowlands, Newtown Creek, and the Bronx River, active ports and maritime industries may take precedence over creating

new public access points. Through strategic partnerships, vacant lots and brownfields could be restored to offer access opportunities. Similarly, all natural areas, except for environmentally sensitive areas (e.g., nesting habitat), should be viewed as opportunities to create public access. Providing access to other areas and habitats creates scenic destinations and peaceful retreats from urban life.

Data needs

A comprehensive plan for public access TEC will require additional information from the municipalities in the HRE study area. As a part of their Feasibility Investigation, the USACE will work with HEP's Public Access Work Group to gather local planning documents to identify planned and existing access points. This information will be used to create an HRE-wide data set of pubic access locations that include site-specific information, including access type, ownership, acreage, amenities, number of annual visitors, and overall quality rating. This information will build upon the Metropolitan Waterfront Alliance database for the existing 436 public access points currently identified.

Monitoring

The initial baseline for this TEC can be measured as the number of residents that have some form of access within a short walk or public transit trip, or the number of residents that do not meet these specifications. This metric could be applied throughout the period of implementation of projects contributing to the TEC goals, as a means of gauging the increase in public access brought about by the completion of new projects.

One advantage of public access projects is that the results are relatively tangible; increased public use of a site is easily quantified. Beyond simple visitor counts, the specific aspects of public visitation/access can be assessed by polling, or interviewing random or targeted subsamples of the visitor population. For example, anglers using public fishing piers or other publicly accessible fishing locations can be interviewed using standardized, well-established protocols (Malvestuto 1983). This could be paired with efforts to gather data on finfish populations associated with restored or enhanced sub-aquatic habitat features in the vicinity of fishing piers, such as the reef ball field recently constructed in the lower Hudson River off of Manhattan. Kayakers/canoeists can be intercepted at designated launch sites and queried about their experience on the water. Paddler surveys could include queries on length of trips, frequency of trips, other locations visited, average distance traveled to launch sites, amount of money spent per trip, and suggestions to improve launch facilities. Similarly, birders, photographers, or those strolling or cycling along a waterfront promenade may be asked to participate in a survey documenting aspects of their recreational experience, including distance traveled, frequency/duration of visitation, use of public transportation, and costs of equipment/travel to the access site.

References

Able, K.W. 1984. Variation in spawning site selection of the mummichog, Fundulus heteroclitus. Copeia 1984. 522-525.

Able, K. W., and J. T. Duffy-Anderson. 2006. Impacts of piers on juvenile fishes in the Lower Hudson River. Pages 428-440 in Levinton, J. S., and J. R. Waldman, editors. The Hudson River Estuary. Cambridge University Press, Cambridge, New York.

Adams, D., and S. Benyi. 2003. Sediment quality of the NY/NJ Harbor system : A 5-year revisit. U.S. Environmental Protection Agency. Final Report. EPA/902-R-03-2003.

Bain, M., J. Lodge, D.J. Suszkowski, D. Botkin, A. Brash, C. Craft, R. Diaz, k. Farley, Y. Gelb, J.S. Levinton, W. Matuszeski, F. Steimle and P. Wilber. 2007. Target Ecosystem Characteristics for the Hudson Raritan Estuary: Technical Guidance for Developing a Comprehensive Ecosystem Restoration Plan. A report to the Port Authority of NY/NJ. Hudson River Foundation, New York, NY. 106 pp.

Baldwin, A.H. 2004. Restoring complex vegetation in the urban settings: The case of tidal freshwater marshes. Urban Ecosystems 7:125-137

Bernick, A.J. 2007. New York City Audubon's Harbor Herons Project: 2007 Nesting Survey. Prepared for the New York City Audubon. New York, NY.

Bone, K. (Editor). 1997. The New York Waterfront: Evolution and building culture of the Port and Harbor. Monacelli Press, Inc., New York.

Cerco, C. F., and M. R. Noel. 2007. Can oyster restoration reverse cultural eutrophication in Chesapeake Bay? Estuaries and Coasts 30(2): 331-343.

Coen, L. D., and M. W. Luckenbach. 2000. Developing success criteria and goals for evaluating oyster reef restoration: Ecological function or resource exploitation? Ecological Engineering 15(3-4):323-343.

Edinger, G.J., D.J. Evans, S. Gebauer, T.G. Howard, D.M. Hunt, and A.M. Olivero (editors). 2002. Ecological communities of New York State. Second edition. A revised and expanded edition of Carol Reschke's Ecological Communities of New York State. (Draft for review). New York Natural Heritage Program, New York Department of Environmental Conservation, Albany, NY.

Findlay, S., C. Wigand, and W. C. Nieder. 2006. Submersed macrophyte distribution and function in the tidal freshwater Hudson River. Pages 230-241 in Levinton, J. S., and J. R. Waldman, editors. The Hudson River Estuary. Cambridge University Press, Cambridge, New York.

Fonseca, M. S. 1992. Restoring seagrass systems in the United States. Pages 79-110 in G. W. Thayer, editor. Restoring the nation's marine environment. Maryland Sea Grant College, College Park, Maryland.

Fonseca, M.S., W.J. Kenworthy, and G.W. Thayer. 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. NOAA Coastal Ocean Program Decision Analysis Series No. 12. NOAA Coastal Ocean Office, Silver Spring, MD.

Fonseca, M.S., W.J. Kenworthy, D.R. Colby, K.A. Rittmaster, and G.W. Thayer. 1990. Comparisons of fauna among natural and transplanted eelgrass Zostera marina meadows: criteria for mitigation. Marine Ecology Progress Series 65:251-264.

Gibbons, S., and C. Yuhas. 2005. Combined Sewer Overflows: What's happening in New York City. The Tidal Exchange. Autumn 2005. NY/NJ Harbor Estuary Program.

Good, R.E., N.F. Good, and B.R. Frasco. 1982. A review of primary production and decomposition dynamics of the belowground marsh component. pp. 139-157 in: V.S. Kennedy, Ed., Estuarine Comparisons. Academic Press, NY.

Grabowski, J.H., A.R. Hughes, D.L. Kimbro, and M.A. Dolan. 2005. How habitat setting influences restored oyster reef communities. Ecology 86(7):1926-1935.

Harding, J. M., and R. Mann. 1999. Fish species richness in relation to restored oyster reefs, Piankatank River, Virginia. Bulletin of Marine Science 65(1): 289-300.

Homziak, J., M.S. Fonseca, and W.J. Kenworthy. 1982. Macrobenthic community structure in a transplanted eelgrass meadow. Marine Ecology Progress Series 9:211-21.

HydroQual. 2007. A model for the evaluation and management of contaminants of concern in water, sediment, and biota in the NY/NJ Estuary: Contaminant Fate and Transport and Bioaccumulation Sub-models. Contamination Assessment and Reduction Program.

Kennish, M. J. 2002. Environmental threats and environmental future of estuaries. Environmental Conservation 29(1): 78-107.

Kerlinger, P. 2004. New York City Audubon Society's Harbor Herons Project: 2004 Nesting Survey. New York, NY: New York City Audubon Society.

Kolpin, D.W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B. Barger, and H.T. Buxton. 2002. Pharmaceuticals, hormones and other organic waste and contaminants in U.S. streams in 1999-2000: a national reconnaissance. Environmental Science and Technology 36:1202-1211.

Kreske, D.L. 1996. Environmental Impact Statements: A practical guide for agencies, citizens, and consultants. John Wiley & Sons, Inc., New York, NY.

Leslie, L.L., C.E. Velez, and S.A. Bonar. 2004. Utilizing volunteers on fisheries projects: benefits, challenges, and management techniques. Fisheries 29(10): 10-14.

Lindstedt, D. M., and E. M. Swenson. 2006. The case of the dying marsh grass. Louisiana Department of Natural Resources. In partial fulfillment of DNR Interagency Agreement No. 2512-05-12.

MacKenzie, C. L. 1992. The Fisheries of Raritan Bay. Rutgers University Press, New Brunswick, NJ.

Malvestuto, S.P. 1983. Sampling the recreational fishery. pp. 397-420 in: Nielson, LA, D.L. Johnson, and S.S. Lampton, eds. Fisheries Techniques. American Fisheries Society, Bethesda, MD.

Mayo, R., F. Serchuk, and E. Holmes. 2006. Status of fishery resources off the Northeastern United States. NOAA's National Marine Fisheries Service Northeast Fisheries Science Center. http://www.nefsc.noaa.gov/sos/

Meyer, D.L., and E.C. Townsend. 2000. Faunal utilization of created intertidal Eastern Oyster (*Crassostrea virginica*) reefs in the southeastern United States. Estuaries 23(1): 34-45.

Nagy, C. 2005. New York City Audubon Society's 2005 Harbor Herons Monitoring Program. New York City Audubon Society. New York, NY.

National Biological Service (NBS). 1995. Ecology of maritime forests of the southern Atlantic coast: A community profile. U.S. Department of the Interior, Biological Report 30.

National Research Council (NRC). 1992. Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. National Academy Press, Washington, DC.

Neckles, H. and M. Dionne. 1999. Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine. A GPAC Workshop, June 2-3, 1999. Wells National Estuarine Research Reserve, Wells, ME.

New York/New Jersey Harbor Estuary Program (HEP). 2008. Regional Sediment Management Plan. pp. 33.

Niedowski, N. L. 2000. New York State Salt Marsh Restoration and Monitoring Guidelines. A report prepared for the New York State Department of State, Division of Coastal Resources and New York State Department of Environmental Conservation.

Olsvig, L.S., J.F. Cryan, and R.H. Whittaker. 1998. Vegetational gradients of the pine plains and barrens of Long Island, New York. pp. 265-282 in: R.T.T. Forman, ed. Pine Barrens: Ecosystem and landscape. Rutgers University Press, New Brunswick, NJ.

Orth, R.J., M. Luckenbach, and K.A. Moore. 1994. Seed dispersal in a marine macrophyte: implications for colonization and restoration. Ecology 75:1927-39.

Pastorok, R.A., A. MacDonald, J.R. Sampson, P. Wilber, D.J. Yozzo, and J.P. Titre. 1997. An ecological decision framework for environmental restoration projects. Ecological Engineering 9:89-107.

Peckarsky, B.L., P.R. Fraissinet, M.A. Penton, and D.J. Conklin, Jr. 1990. Freshwater macroinvertebrates of Northeastern North America. Cornell University Press. Ithaca, NY.

Pickerell, C.H., S. Schott, and S. Wyllie-Echeverria. 2005. Buoy deployed seeding: Demonstration of a new eelgrass (*Zostera marina* L.) planting method. Ecological Engineering 25:127-136.

Pomeroy, L. R., C. F. D'Elia, and L. C. Schaffner. 2006. Limits to top-down control of phytoplankton by oysters in Chesapeake Bay. Marine Ecology Progress Series 325: 301-309.

Rand, G. M. 1995. The Fundamentals of Aquatic Toxicology. Taylor and Francis, New York, NY.

Reilly, F.J., R.J. Spagnolo, and E. Ambrogio. 1996. Marine and estuarine shallow water science and management. Estuaries 19(2A):165-168.

Rodney, W.S., and K.T. Paynter. 2006. Comparisons of macrofaunal assemblages on restored and non-restored oyster reefs in mesohaline regions of Chesapeake Bay in Maryland. Journal of Experimental Marine Biology and Ecology 335(1): 39-51.

Seneca, E. D., and S. W. Broome. 1992. Restoring tidal marshes in North Carolina and France. Pages 53-78 in G. W. Thayer, editor. Restoring the nation's marine environment. Maryland Sea Grant College, College Park, Maryland.

Shaefer, D. and J. Lundin. 1999. Design and Construction of Docks to Minimize Seagrass Impacts. US Army Corps of Engineers WRP Technical Note VN–RS–3.1 June 1999. Available at http://el.erdc.usace.army.mil/elpubs/pdf/vnrs3-1.pdf

Simenstad, C.A., W.G. Hood, R.M. Thom, D.A. Levy, D.L. Bottom. 2000. Landscape structure and scale constraints on restoring estuarine wetlands for Pacific coast juvenile fishes. Pages 597-630 in M. P. Weinstein and D. A. Kreeger, editors. Concepts and controversies in tidal marsh ecology. Kluwer Academic Publishers, Dordrecht, Netherlands.

Simenstad, C.A., and R.M. Thom. 1996. Assessing functional equivalency of habitat and food web support in a restored

estuarine wetland. Ecological Applications 6:38-56.

Smith, I., M.S. Fonseca, J.A. Rivera, and K.A. Rittmaster. 1989. Habitat value of natural versus recently transplanted eelgrass, Zostera marina, for the bay scallop, Argopecten irradians. Fishery Bulletin 87:189-96.

Stanley, J.G., and R. DeWitt. 1983. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Mid-Atlantic) – Hard Clam. U.S. Fish & Wildlife Service Biological Report 82 (11.41). U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg MS. Technical Report EL-82-4.

Steinberg, N., D.J. Suszkowski, L. Clark, and J. Way. 2004. Health of the Harbor: The first comprehensive look at the state of the NY/NJ Harbor Estuary. A report to the NY/NJ Harbor Estuary Program. Hudson River Foundation, New York, NY. 82pp.

Strandberg, B. N.G. Dodder, I. Basu, and R.A. Hites. 2001. Concentrations and spatial variations of polybrominated dephenyl ethers and other organohalogen compounds in Great Lakes air. Environmental Science and Technology 35: 1078-1083.

Taylor, M.H. and L. DiMichele. 1983. Spawning site utilization in a Delaware population of *Fundulus heteroclitus* (Pisces: Cyprinodontidae). Copeia 1983:719-725.

Teal, J. M., and B. L. Howes. 2000. Salt marsh values: retrospection from the end of the century. Pages 9-19 in M. P. Weinstein and D. A. Kreeger, editors. Concepts and controversies in tidal marsh ecology. Kluwer Academic Publishers, Dordrecht, Netherlands.

Thayer, G.W., S.M. Adams, and M.W. LaCroix. (1975). Structural and functional aspects of a recently established Zostera marina community. pp. 518-540 in: L.E. Cronin (Ed.) Estuarine Research. Academic Press, New York.

Thom, R.M. 1990. A review of eelgrass (*Zostera marina* L.) transplanting projects in the Pacific Northwest. The Northwest Environmental Journal 6:121-37.

U.S. Army Corps of Engineers (USACE). 2000. Planning Guidance Notebook. Department of the Army. U.S. Army Corps of Engineers. ER 105-2-100.

U.S. Army Corps of Engineers (USACE). 2004. Hudson-Raritan Estuary Environmental Restoration Feasibility Study: Estimated contaminated sediment replacements volumes in the New York & New Jersey Harbor. Draft. Interim Report. US Army Corps of Engineers, New York District, New York, NY.

U.S. Army Corps of Engineers (USACE). 2008. Dredged Material Management Plan for the Port of New York and New Jersey- 2008 Update Department of the Army. U.S. Army Corps of Engineers.

U.S. Fish and Wildlife Service (USFWS). 1997. Significant Habitats and Habitat Complexes of the New York Bight Watershed. Coastal Ecosystem Program.

Vos-Wein, N. 2007. Pearls in the Meadowlands? Hackensack Tidelines. Summer 2007, Volume X, Issue 3.

Vittor & Associates. 2005. Norton Basin/Little Bay technical summary report: 2000-2003 baseline surveys. Prepared for New York District, U.S. Army Corps of Engineers, New York, NY. Barry A. Vittor & Associates, Inc, Lake Katrine, NY.

Weinstein, M.P., J.H. Balletto, J.M. Teal, and D.F. Ludwig. 1997. Success criteria and adaptive management for a large-scale wetland restoration project. Wetlands Ecology and Management 4:111-127.

Yozzo, D.J., J.E. Davis, and P.T. Cagney. 2003. Coastal Engineering for Environmental Enhancement. Chapter V - 7: in: L.

Vincent and Z. Demirbilek, (eds.), Coastal Engineering Manual, EM-1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C.

Yozzo, D.J., K.I. Hester, and D.E. Smith. 1994. Abundance and spawning site utilization of *Fundulus heteroclitus* at the Virginia Coast Reserve. The Virginia Journal of Science 45:187-197.

Yozzo, D.J., J.M. Rhoads, P. Wilber, W. Nuckols, L. Hollen, and R. Will. 2001. Beneficial uses of dredged material for habitat creation, enhancement, and restoration in NY/NJ Harbor. US Army Corps of Engineers. New York District, New York, NY

Yozzo, D., and J. Sexton. 1996. Planning and evaluating restoration of aquatic habitats from an ecological perspective. IWR Report 96-EL-4. Prepared for the U.S. Army Corps of Engineers, Waterways Experiment Station, MS and Institute for Water Resources, VA.

Yozzo, D.J., P. Wilber, R.J. Will. 2004. Beneficial use of dredged material for habitat creation, enhancement, and restoration in New York—New Jersey Harbor. Journal of Environmental Management 73:39-52.

Zieman, J.C. 1976. The Ecological Effects of Physical Damage from Motor Boats on Turtle Grass Beds in Southern Florida. Aquatic Botany 2:127-139.