Target Ecosystem Characteristics for the Hudson Raritan Estuary:

Technical Guidance for Developing a Comprehensive Ecosystem Restoration Plan

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Executive Summary

The Hudson-Raritan Estuary (HRE) environmental restoration program was authorized by the U.S. Congress in 1999, and developed as an effort of an array of agencies and organizations to enhance port facilities, the regional economy, and the New York/ New Jersey Harbor environment. However, progress has been slowed by the lack of an ecosystem-scale restoration approach, a program goal, clear objectives, a method for selecting specific projects, and the capability to report progress. Therefore, the HRE program asked an interdisciplinary expert team to develop an ecosystem context for restoration, a system scale plan to frame specific projects, measurable objectives, and a means to track program performance. This report presents a holistic plan based on scientific knowledge and designed to guide the HRE agencies and organizations identifying site-specific projects and making a detailed restoration agenda. This report also describes and justifies an approach to ecosystem restoration, includes public interests, synthesizes information from agency programs and scientists, and establishes a framework for relevance and public information.

The HRE restoration plan was designed by a scientific team (10 members) supplemented by periodic consultation with implementing agency representatives. Team deliberations defined the properties of the restoration problem, the approach, a program goal, and specific measurable objectives. Additional experts were sometimes used to develop justification and documentation for specific plan elements, and a large expert workshop was conducted early in the project to generate initial restoration ideas. The approach and program goal were broadly defined, and the key plan elements, measurable objectives, followed from them.

Four principles were adopted in defining a feasible approach to HRE restoration: the ecosystem is human dominated, it has been irreversibly changed, it is dynamic and will change further, and environmental enhancements can be made by the application of science and technology. In addition, public benefits were determined to be critical for enhancing both the natural and human components of the ecosystem. A goal was developed to direct the HRE restoration effort to ecosystem elements or habitats that promote human and natural benefits.

Measurable objectives for HRE restoration were termed target ecosystem characteristics (TEC). A TEC is a specific ecosystem property or feature related to the ecosystem restoration goal and having societal and management value. A TEC statement provides the quantity of an ecosystem attribute in a region by a specific time. A workshop with scientific experts and agency representatives was held to develop candidate ecosystem targets for restoration planning. The resulting list (23) and a synthesis of past agency and organization documents yielded 97 objectives and target items. The project scientific team worked through the long list of candidate TECs and selected 11 for the agenda presented here.

Titles for these are:

1. Oysters and oyster reefs
2. Eelgrass beds
3. Coastal wetlands
4. Shorelines and shallows
5. Habitat for fish, crabs, and lobsters
6. Enclosed and confined waters
7. Sediment quality
8. Tributary connections
9. Waterbirds
10. Maritime forest
11. Public access

Each target has near term (2012) and long term (2050) statements followed by documentation including background, technical merit, policy and management relevance, implementation information, and performance measures.

The approach to restoration used in this work links human and environment benefits of the HRE by seeking ecosystem properties or habitats that promotes human and natural benefits. The approach is consistent with the HRE restoration vision of the management agencies: a "functioning ecosystem and a strong vibrant port providing benefits to everyone". It is also consistent with renaturing restoration concept in use in other human dominated ecosystems.

TECs were designed to have ecological benefits and provide the public more opportunity to experience, enjoy, and learn about the estuary environment. The public access target is directly relevant to people. Major habitat features such as the shoreline and shallows target provide highly visible sites that can be visited, appreciated as a complex combination of conditions, and experienced as a contrast to the built shorelines. While both natural and public gains were the aim, the 11 TECs differed substantially from one another in scope and justification. TECs were developed with some of the following outcomes in mind: replicating restoration projects and sites; reversing loss rates; developing unique ecosystem attributes; eliminating problems; and meeting fixed criteria. Initial restoration efforts were often seen as testing the concept, innovating, and providing a dispersed small benefit, while long term specification were intended to achieve the promise of each TEC.

The approach used for restoration planning, combined with quantitative ecosystem target statements, succeeded in forming a clear and powerful argument for HRE restoration. A product of both natural and human considerations, it is an agenda that will need to be reconsidered and revised through time. Recommendations are reported on next steps, maintaining scientific input and assistance, promoting a shared responsibility for restoration, and reporting on progress. Restoration actions and projects should proceed in confidence that progress on the targets will improve the HRE. This project team expects that the ecosystem restoration agenda meets implementing agency needs, acts as a "blueprint" to improve the Hudson-Raritan Estuary (environment, and sets a stage for new restoration targets based on advancements in science and public understanding.

1. Introduction

Background

The natural features of the Hudson-Raritan Estuary (HRE), including its bottom topography, shorelines and adjacent wetlands, have been dramatically altered to accommodate the demands and changing needs of the region. More than 80% of the harbor's tidal wetlands have been filled, shorelines have been stretched seaward, a vast network of channels (over 250 miles of federal channels) and berthing areas has been excavated to enhance navigation, and countless tons of industrial waste and human sewage have been discharged into the estuary over the years, with large amounts of toxic chemicals becoming lodged in bottom sediments and posing continuing threats to public health and the environment. While many plant and animal species have adapted, and even flourished within this changing environment, other species like the oyster have suffered declines and near obliteration.

Despite these abuses, the overall condition of the estuary has improved dramatically: contaminants in sediments have decreased to levels one-tenth of those observed 30 years ago; levels of contaminants in fish have dropped significantly; losses of wetlands and near-shore habitats have slowed considerably; dissolved oxygen levels in the harbor have greatly improved; and sewage-related pathogenic contamination has been notably reduced. Much of this improvement can be directly traced to one major piece of federal legislation -- the Clean Water Act, enacted in 1972 – which provided massive funding for sewage treatment plants and instituted a strict permit program to curb the flow of toxic chemicals into the estuary.

Even with these improvements, significant environmental challenges remain, particularly those related to the legacy of pollution and the restoration of bottom, shoreline and wetland habitats that have been altered or lost. Recognizing the importance of restoring the estuary, the U.S. Congress authorized the Corps of Engineers to undertake the Hudson-Raritan Estuary Environmental Restoration Study (HRE Study) in 1999.

In 2004, fifteen separate governmental and non-governmental organizations met as a "Harbor Roundtable " to discuss the linkages between efforts to enhance the economy of region through port deepening and efforts being developed to protect and restore the estuary's valuable ecological resources. The Harbor Roundtable found that while environmental restoration has strong stakeholder support, projects and programs are drastically under funded and are progressing very slowly toward fruition. The reasons include the following:

- A comprehensive plan has yet to be finalized that has a unifying restoration goal;
- Individual restoration projects that are now being developed lack the justification of how they contribute to the overall goal;

- The planning process needs greater transparency and more effective stakeholder involvement;
- Many habitat types are not being considered for restoration;
- A scientific basis for restoration is sorely needed;
- The Corps' HRE Plan should have seamless integration with other programs, particularly the NY/NJ Harbor Estuary Program (HEP); and
- The eventual HRE restoration plan needs to be truly comprehensive and include consideration of restoration opportunities outside Corps authority.

While these concerns were voiced specifically about the HRE Study, many of these same issues are endemic to other large restoration projects throughout the country. The root problem is that ecosystem restoration is a relatively new and extremely complicated enterprise. Consequently, innovative planning mechanisms must be established to set realistic goals, incorporate appropriate scientific information, obtain stakeholder and multi-agency advice, and be capable of dealing with large uncertainties.

As a first step in addressing some of these obstacles, the Hudson River Foundation, in partnership with Cornell University, sponsored a technical workshop on October 25-26, 2005 to develop "Target Ecosystem Characteristics," (TECs) which are intended to provide the science basis for future restoration (Bain, et al. 2006). The workshop included a multidisciplinary group of 17 regional and national scientific experts, along with several government agency representatives who are currently engaged in restoration activities in the estuary.

The objective of the October workshop was to "brainstorm" as many TECs as possible and to provide technical justification for each. Over 20 TECs were advanced over the 2-day event. In developing the TECs, the workshop participants reached several general conclusions that will be important in guiding future work. The group acknowledged that full ecosystem restoration is not possible in an intensely human dominated setting like the HRE, but they noted that meaningful rehabilitation was indeed possible. They agreed that the overarching goal should be the restoration, rehabilitation and enhancement of an overall mosaic of habitat types.

The workshop demonstrated that it is possible to develop realistic restoration goals for the HRE and that scientifically credible design criterion can be established to guide restoration efforts for a wide range of estuarine habitats. The obvious next step was to select an appropriate suite of TECs, provide further scientific justification, and define technical specifications for each TEC such that individual projects could be developed. This report presents the work accomplished in taking that next step, and is designed to be a "blueprint" for the Corps of Engineers to use in preparing its more detailed Comprehensive Restoration Plan (CRP). Besides addressing the scientific concerns (noted above) during the preparation of this report, the authors have attempted to make the planning process more transparent and relevant to stakeholders, provided a coherent approach to restoration, considered a wider range of restoration options than previously considered, and worked to integrate this effort with other programs. Since work began on this project, the Policy Committee of the HEP has endorsed the planning efforts in connection with the Corps' HRE Study authorities and will view the eventual CRP as a the unified planning document for restoring the estuary.

Study Authority

The HRE Study was authorized by the U.S. Congress in a resolution of the Committee on Transportation and Infrastructure in April, 1999. The resolution provides the Corps of Engineers' with broad authority to evaluate comprehensive ecosystem restoration opportunities within the HRE. As part of this study, the NY District of the Corps of Engineers and the project's local sponsor, the Port Authority of New York/New Jersey (PANY/NJ), are supporting the development of a Comprehensive Restoration Plan (CRP). The Hudson River Foundation (HRF), in partnership with Cornell University and other scientists was selected to develop the scientific basis for restoring the estuary.

Study Area Description

The term, *Hudson-Raritan Estuary* is synonymous *with New York/ New Jersey Harbor Estuary*. The HRE study area (Figure 1) extends from the Sandy Hook-Rockaway Transect in the south to the Tappan Zee Bridge in the north. It includes the tidally influenced sections of the rivers flowing into the system including the Hackensack, Passaic, Raritan, Shrewsbury, Navesink, Harlem, and East Rivers. The study area includes the western portion of the Long Island Sound extending east to Greenwich Cove, Connecticut on the north shore of Long Island Sound and Matinecock Point, Long Island, New York on the south shore.

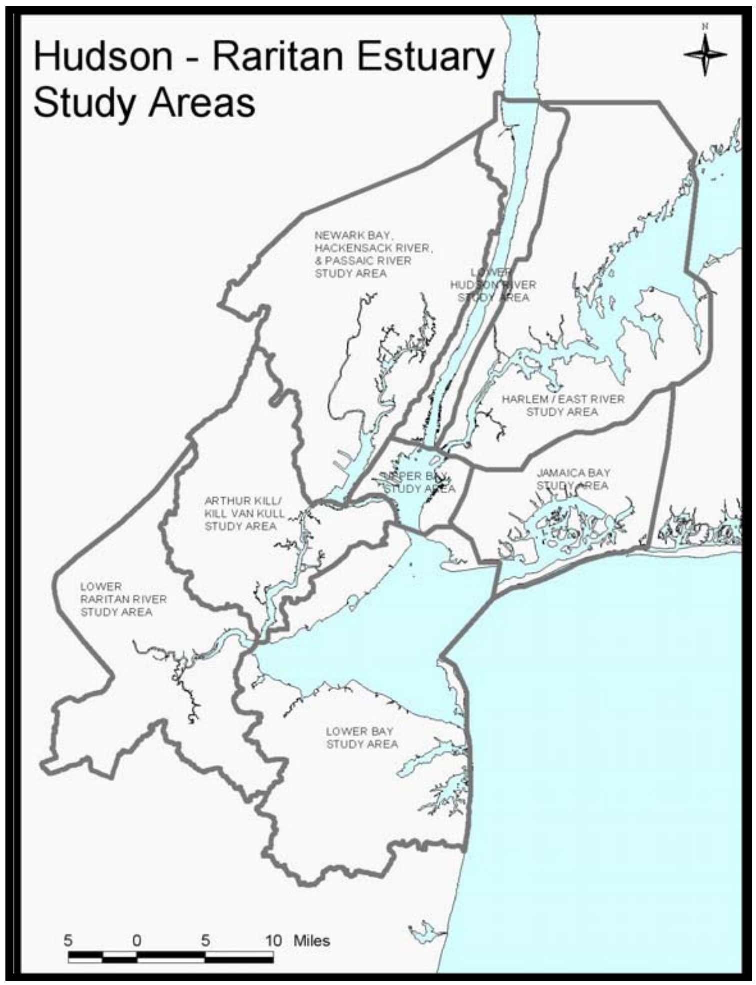

Figure 1. USACE derived study area boundaries

Major watershed divisions partition the study into eight areas:

1. Lower Raritan River Study Area,
2. Arthur Kill/Kill Van Kull Study Area,
3. Lower Bay Study Area,
4. Lower Hudson River Study Area,

5. Upper Bay Study Area,
6. Jamaica Bay Study Area,
7. Harlem River, East River, & Western Long Island Sound Study Area,
8. Newark Bay, Hackensack River, & Passaic River Study Area,

The waterways of the estuary cover approximately 500 km^2 (Adams et al. 1998) with a morphology produced by glaciers during the last ice age, and subsequently flooding by rising sea levels. The resulting islands, rivers, channels, and bays form a complex waterway with strong tidal currents and water ranging from freshwater to marine. The HRE generally meets quality standards for dissolved oxygen, but sediment contamination and bacterial levels impede safe seafood consumption. Habitats have been dramatically altered during the development of the urban center: for example, about 80% of coastal wetlands have been lost, Manhattan Island has been enlarged by 25%, and 25% of Newark Bay has been filled while average depth increased by 50% (Steinberg et al. 2004). Nevertheless, public interest and use of the waterways and surrounding environment is rising.

The metropolitan area in and around the HRE is one of the largest on earth, housing nearly 19 million people (US Census Bureau 2005). The city population is 8.2 million in a 1,200 km^2 area of which 414 km^2 is water (New York City 2006). Aside from being a major natural feature of the metropolitan area, the estuary is enormously important to the city, region, and a large part of the United States. The HRE is the largest port on the east coast and the largest petrochemical port in the U.S. Shipping and seaport activities directly and indirectly employ more than 230,000 people, generate $14 billion annually in wages and taxes, and serves about 35% of the US population (Slezak 2006). By necessity or desire, the estuary marks many prominent aspects of the metropolitan life and it has been a key factor in the emergence of New York as a cultural center in the world.

Alternative Approaches to Ecosystem Restoration

The term *restoration* is most commonly defined as returning something to a former state or condition but some variation in meaning exists. Restoration has also been used to mean the recovery of health, reputation, strength, and physical appearance. Repairing damage and undoing alteration is also termed restoration. Therefore, variation in the intent of restoration is possible and reflected in the aims and logic of different efforts to restore the environment. The concept of restoration can be applied to ecosystem scale management, and the selection of a fundamental approach sets the direction of a restoration project. Four approaches to ecosystem restoration are generally followed as described below:

1. The traditional approach to large-scale restoration planning in North America is **returning the original condition** of a site or ecosystem. Environmental restoration was defined by the National Research Council (1992) as returning an ecosystem to its former, undisturbed state with the original functions and structure. The past condition is assumed to be more pristine, authentic, or natural than current conditions. Therefore, a baseline time is used to guide

restoration design. Pre-European settlement is often considered the baseline time period in North America and ecosystem conditions are approximated or estimated for the 15th Century. Often, historical reconstructions of conditions may be used to estimate the original condition. While returning to the original condition fits the basic notion of restoration, the approach can be questioned for its reliance on an assumed superior past state, definition of a true natural condition, discounting of past human impacts, and relevance to prevailing environmental settings.

2. The protection and **restoration of ecological integrity, health, or stability** underlies many government and conservation programs in North America, and elements of this environmental management approach appear directly or suggestively in many laws and policy statements. This environmental management approach underlies many government and conservation programs in North America, and elements of this approach appear directly or suggestively in many laws and policy statements. Restoration of ecosystem integrity or health strives to return proper ecosystem structure (taxonomic composition, physical properties) and function (processes and activity rates). Indices and measures are commonly used to detect structural and functional impairment, and restoration can be employed to remedy the condition. The orientation to health marks this restoration approach as analogous to revitalization. This approach can be debated on the mechanism assumed to maintain ecosystem health, reliance on a stable state, and indirect measures of progress and success.

3. An evolutionary basis for restoration supports the approach termed **"rewilding**". The goal is reestablishing the original evolutionary setting so that natural selection guides the future state of the system. This may appear to be the same approach as returning the original condition but the motivation and logic are different. Rather than recreating the past, the purpose is to restart the evolutionary process under prior evolutionary conditions. The complex interactions among species and their environment is too much to design in detail, so reestablishing the major elements of the past is assumed to restart the processes that led to the original fauna and flora that characterized the ecosystem. Skeptics of the *rewilding* approach challenge the ambiguity of choosing a point in a process, feasibility of creating the proper complex set of interacting factors, and the viability of a genetic and selection processes following an anticipated course over time. This approach also separates humans from the evolutionary process despite humans being a product of evolutionary processes.

4. A fourth approach to restoration can be thought of as designing ecosystems for nature and people. Developing natural properties in the context of society and increasing ecosystem benefits to people has been termed ***renaturing*** in Europe. Key assumptions are that known environmental losses can be repaired and modified ecosystem attributes can benefit nature and culture. Under this approach, culture and nature are combined as equal elements of the ecosystem. Societal interests and practical constraints bear heavily on which natural characteristics are promoted and created. The *renaturing* approach has been

criticized as a pursuit of an artificial environment, fake nature, and promoting the illusion of a natural reality.

All ecosystem-scale restoration projects will purposefully or unintentionally adopt an approach to restoration. Returning original conditions, revitalizing, *rewilding*, and *renaturing* are most likely to be used, and some combination is possible.

Large-scale ecosystem restoration projects have emerged in the last decade throughout the United States and around the world. Well known cases from North America include the Everglades, Mississippi River, Missouri River, Grand Canyon and Sacramento-San Joaquin Delta. Ecosystem-scale restoration efforts are attractive because they promise the solution to complex problems, act as symbols of decisive action to the involved public; bring together many governments and private institutions, employ a systems approach that connects diverse issues, and utilize many sources of financing for a common purpose. However, the record of accomplishments for these projects remains to be established and causes of success and failure are not yet fully known. There is a pressing need to identify better ways to plan large-scale restoration activities. Restoration planning must address the fundamental approach to restoration being used, the methods for selecting goals and objectives, and the process for monitoring success and reporting progress.

The U.S. Congress assigned the National Research Council to conduct independent reviews of most of the ecosystem-scale restoration projects with substantial federal funding. Review findings have regularly assessed the projects as dissatisfactory. For example, the Upper Mississippi River-Illinois Waterway environmental plan was found (National Research Council 2001) inadequate to support decision-making because it lacked ecosystem scale understanding and information synthesis. Similar failings were identified in a review of the Missouri River recovery plan (National Research Council 2002): not encompassing of the ecosystem, poor consideration of needs and interests communities and organizations, and no context for site-specific actions. Essential needs identified from these and other project reviews include: (1) use of an interdisciplinary expert team to input an ecosystem perspective in planning; (2) a system scale planning scope to frame site-specific practices and projects; (3) measurable objectives with starting baseline conditions; (4) a way to quantify program resource needs; and (5) an accounting method to track program performance. Overall, clear but holistic planning based on scientific knowledge appears to be the primary challenge today for establishing ecosystem-scale restoration projects.

2. Methods

General Approach

This effort to design a restoration agenda for the HRE builds on past restoration planning by government agencies, private organizations, and consortia of both. It has attempted to address as many of the concerns as possible raised by the regional Harbor Roundtable and the National Research Council. Agencies involved in restoration in the HRE have developed site-specific plans and implemented several projects, but a unified and comprehensive agenda is still lacking. This study sought to use technical and scientific expertise to identify the broad and fundamental elements of an overall restoration program. Specifying restoration projects and locations was not desired because that level of implementation rests heavily on site constraints, public engagement, financing details, and other local factors. Instead, the authors have aimed to provide guidance on the range and scope of projects that should be part of an overall restoration program, and to set measurable objectives that would define program progress and performance tracking once projects are formulated.

A small group of scientists was convened to interactively define the restoration program elements and was supplemented by periodic consultation with implementing agency representatives and an outreach liaison. Through a series of deliberations, the team defined the approach, the fundamental properties of the restoration problem, a program goal, and specific measurable objectives. Additional experts were sometimes used to develop justification and documentation for specific program elements, and a large expert workshop was conducted early in the project.

Developing Target Ecosystem Characteristics

Measurable objectives have been called endpoints, characteristics, indicators, targets, and conditions in restoration programs. The term *Target Ecosystem Characteristic* (TEC) is suggested for use as the broadest planning element that is measurable. A TEC is a specific ecosystem property or feature that is related to ecosystem restoration goal and of societal and management value.

Specificity in defining target ecosystem characteristics is important to communicate precise restoration objectives and assess program progress. Target definitions also need to be grounded in biological, physical, or chemical environmental attributes. There should be a numerical expression of quantity with specified units of measure. Finally, specifications should address spatial scope (e. g., geographic boundaries) and a time frame. Thus, a target ecosystem characteristic should state:

The quantity of an ecosystem attribute in a region by a specific time

The elements of a target definition would then be:

[quantity] [attribute] [space] [time]

The specifications for precise terminology follow recommendations (Haug et al. 1984a) for implementing a common language in impact assessment. A standard format or grammar for communicating environmental planning information would facilitate the comparisons among management cases, progress through time, and decision-maker understanding (Haug et al. 1984b).

TECs were developed with a defined process that seeks broad input of many disciplines and perspectives, and allows review by independent scientists and management specialists. A workshop with scientific experts and agency representatives was conducted (25-26 October 2005) to develop candidate ecosystem targets for restoration planning in connection with HRE. (Bain, et al., 2006) The workshop was organized into small groups corresponding to major zones of the HRE: riparian, littoral, pelagic, and benthic. It succeeded in developing many (23, Table 1) and varied ecosystem targets.

After the fall 2005 workshop, a variety of past restoration and management plans were reviewed. The material was from the New York/New Jersey Harbor Estuary Program, the Hudson River Estuary Management Program (New York State Department of Environmental Conservation), and the HRE Study (led by the US Army Corps of Engineers). Objectives and goals in the reports were assembled into a comprehensive list and categorized by restoration topic or theme. When added to the 23 workshop produced candidate TECs, the total number of potential TECs totaled 97.

Outreach Summary

The development of this report included an extensive outreach effort to involve the full range of interested parties as the content evolved. This is quite challenging with a subject as complex and as controversial as the environmental restoration of Hudson Raritan Estuary. One of the most difficult elements was timing the involvement of key players in government, academic and environmental groups. While all of these groups want to be sure the overall effort is well conceived and covers the important issues, they also have limited time and therefore needed to have something concrete to react to. Taking into account these conditions, we developed a multi-part strategy to reach out and engage as broad a range of interest groups as possible.

In order to assure engagement in the development of the TEC report and the CRP to follow, early in the process the Hudson River Foundation established and chaired, with the support of the US Army Corps of Engineers, a CRP Work Group. This group has convened several times in the past year, primarily to review progress and to comment on the substance of the TEC's as they were formulated by the science team. The CRP Work Group is comprised of representatives of New York State, New York City and New Jersey state government agencies, the New York/ New Jersey Harbor Estuary Program (HEP), the NY/NJ Port Authority, the major environmental advocacy and conservation groups in the region and the relevant federal agencies. The CRP Work Group will play a continuing role as the CRP development process moves forward in coming months.

Other advantages were derived from the ongoing participation of the HEP, a Federal-state partnership with established committees and work groups which were called upon for advice and comment. In particular, at the urging of the their Management Committee, the HEP Policy Committee agreed early on to accept the Comprehensive Restoration Plan (CRP) supported by this study as the official HEP Habitat Restoration Plan. Throughout the process, the HEP Habitat Work Group has been available with ideas and comments that have improved the scope and content of the report and helped to facilitate consensus.

With the intention of securing the involvement of an even wider range of potentially interested groups and individuals, in October of 2006, as the number and scope of the TEC's began to take shape, the Foundation e-mailed several hundred people from a list supplied by HEP. They were asked to react to the list of TEC's in terms of both content and coverage, and to provide any other comments on the study approach. A number of responses were received.

When a full draft of the TEC document was ready, a series of meetings were held to present the findings and to give an opportunity to provide comments. In all cases, the TEC approach as a framework for crafting a comprehensive restoration plan and the establishment of measurable, achievable goals to "re-nature" the HRE were endorsed. The participants have also committed to continuing this partnership as the TEC work transitions into the development of the CRP.

3. Results

Restoration Approach and Goal

Of the four approaches to ecosystem restoration reviewed here, this effort's orientation is most consistent with *renaturing* because of the explicit linking of human and environment benefits. It was determined that both environmental and cultural considerations are essential for designing restoration in the HRE after considering comments from the experts workshop, interaction with agencies, and team discussions.

The project team recognized that the human setting of the New York City metropolitan region constrains potential future states of the ecosystem. Consideration of the constraints yielded four fundamentals that define the context and scope of feasible restoration objectives. First, the ecosystem is human dominated and will remain a human shaped landscape. Second, the ecosystem has been irreversibly changed in almost all its properties. Third, the ecosystem is dynamic and will change further in time. Finally, science and technology can make clear and valuable enhancements. Building on these fundamentals, a goal was developed for restoration in the sense of enhancement of the ecosystem for its wild and human inhabitants. It is:

> ***To develop a mosaic of habitats that provides society with new and increased benefits from the estuary environment***

A "mosaic of habitats" concept recognizes that more kinds and numbers of biophysical elements would enhance the ecosystem by supporting greater biodiversity, diversifying ecosystem functions, promote resilience and persistence of flora and fauna, reversing habitat losses and degradations, and increasing public exposure to the aquatic environment. Increasing societal benefits means expanding opportunities for public enjoyment, enhancing public knowledge, cultivating public interest, and building enduring public support for a clean and healthy estuary ecosystem. The element of the goal – *benefits from the estuary environments* – implies that aquatic life and biological processes add value to people and the quality of life in the metropolitan region.

The Recommended Target Ecosystem Characteristics (TECs)

The project team worked through the long list of candidate TECs, finding tremendous duplication and overlap. An initial screening by the team reduced the number of unique TECs by a factor of three. After further discussion and refinement, the team selected 11 TECs (Table 3), and began work to develop technical justifications for each. Criteria used to reduce the long candidate list included technical merit, management relevance, and feasibility. The final list of targets was limited to the number judged to be manageable and diverse for guiding a restoration program to establish a *mosaic of habitats that provide society with new and increased benefits from the estuary environment.*

The objectives of each of the 11 TECs differed substantially from one another. For example, TECs were developed with some of the following outcomes in mind: replicating restoration projects and sites; reversing loss rates; developing unique ecosystem attributes; eliminating problems; and meeting fixed criteria. The team found in the process of developing justifying and quantifying TECs, that a distinction was necessary between an initial restoration target and a long-term target. This distinction differed among the TECs, but initial restoration efforts were often seen as testing the concept, innovating, and providing a dispersed small benefit.

Once documented and justified, the final targets were reviewed by independent scientists and agency managers, and final adjustments made using the review comments. Our primary final product is a documented list of ecosystem targets that emerge from diverse thinking, careful selection, and independent review.
Full descriptions of each TEC are given in the following report chapter and include sections on technical merit, policy and management relevance, necessary implementation information, and measure of performance.

Table 1. Ecosystem characteristics for restoration developed in the experts workshop with descriptions and classifications by topic.

Target ecosystem characteristic	Description of attribute or restoration actions	Topic
Benthic nursery habitats	Increase the quantity and quality of benthic habitats supporting fish and invertebrate nursery functions	Habitat
Key bird habitats	Improve nesting sites, foraging areas, resting areas, and water dependent bird species	Habitat
Natural tributary geomorphology	Improve and restore natural channel conditions for aquatic life support	Habitat
Shallow subtidal habitats	Enhance mosaic of shallow water habitats for benthic animals, fish, and birds	Habitat
Shallow shoreline waters	Increase self-maintaining, shallow, illuminated, oxygenated waters along walled shorelines	Habitat
Productive pelagic waters for young fish rearing	Promote stable water masses with high plankton concentrations supporting larval and young fish production	Habitat
Wetland areas	Add riparian forests, maritime forests, freshwater wetlands, and salt marshes	Margins
Shore zone management	Implement and strengthen nature reserves, monitoring and adaptive management, conservation institutions, scientific investigation, citizen involvement	Margins
Stable shoreline areas	Enhance and increase shoreline and riparian buffers	Margins
Natural shoreline areas	Remove human material to allow natural vegetation and shoreline landform	Margins
Quality enclosed and confined waters	Enhance quality of poorly flushed, enclosed waters with local pollutant sources and sediment contamination	Hydraulics
Productive borrow pits	Increase productivity, oxygen levels, and water circulation	Hydraulics
Free flowing channels	Remove obstacles to water flow by structures and debris in constrained channels	Hydraulics

Table 1 (continued)

Target ecosystem characteristic	Description of attribute or restoration actions	Topic
Hydrologic connectivity	Remove or modify constrained channels and connections between open waters	Hydraulics
Anadramous fish populations	Provide habitats and improve populations of sturgeon, river herring, shad, striped bass, and other migratory species	Biota
Controlled invasive species	Manage invasive species to promote native species and ecosystem function	Biota
High benthic productivity supporting fish and shellfish	Increase biomass production of benthic organisms (infauna, epifauna, megafauna)	Biota
Functioning oyster reefs	Develop oyster reefs large enough for locally detectable water quality effects	Biota
Accessible shoreline wetlands	Provide public access to water front areas and wetlands for nature exposure	Recreation
Recreational boating zones	Create small craft and non-motorized boat access points, information kiosks, and public waterfront areas	Recreation
Water contact recreation	Reduce human health threats due to contaminated sediments, disease-causing microorganisms, toxic materials, pathogens, and other health risks	Recreation
Contained storm water runoff	Reduce sources of untreated storm water and sewer system outflows	Water quality
Minimal hypoxic waters	Improve water quality with local actions such as water circulation, untreated discharges, and local pollutant sources	Water quality

Table 2. Summary of objectives obtained through a review of HRE planning efforts.

Topic	Representative objective aims	Number	Sources[β]
Habitat	Benthic nursery habitats, biodiversity resources, habitat health, key bird habitats, open space, pelagic fish rearing waters, shallow shoreline waters, tidal wetlands	18	1, 2, 3, 5, 6, 7
Margins	Shoreline access, brownfields, conservation of tributaries, shore zone management, streams and tributaries, waterfront revitalization, wetland areas, scenic values of the shoreline	15	2, 3, 4, 7
Hydraulics	Flowing channels, connectivity, productive borrow pits, enclosed and confined waters, estuary water supply	5	2, 7
Biota	Anadramous fish populations, controlled invasive species, benthic productivity, signature fisheries, biological indicators	13	1, 2, 3, 4, 6, 7
Recreation	Interpretive facilities, fishing and swimming, floatables impacts, pathogens, bathing and shellfishing, recreational boating zones, river scenery	11	1, 2, 6, 7
Water quality	Untreated storm water, sewer system outflows, erosion and pollutants, eutrophication, remediate contaminants, hypoxic waters, non-point source pollution, nutrients and organic enrichment, PCB contamination, spills management	15	1, 2, 7
Public	Conservation and stewardship, education, funding for monitoring, port function, public access, public awareness, public Involvement, clean sediment	15	1, 2, 4, 6
Solid waste	Abandoned boats, derelict structures, dredged materials, sediment, floatable debris	5	1, 3

β. Sources:

1. New York - New Jersey Harbor Estuary Program. 1996
2. Hudson River Estuary Program. 1996
3. Hudson River Estuary Program. 2002
4. Hudson River Estuary Program. 2005a, 2005b
5. Rhoads et al. 2001
6. Harbor Estuary Program Policy Committee. 2004
7. Bain M., D. Suszkowski, J. Lodge, and L. Xu. 2006

Table 3. Brief description of target ecosystem characteristics (TEC) to be achieved by 2012 and 2050 in the Hudson-Raritan Estuary ecosystem. Areas are the eight divisions of the ecosystem in Figure 1.

Characteristic	2012 target	2050 Target	Description
Oyster reefs	500 acres total across 10 to 20 sites	5,000 acres of established oyster reefs	Initial target is to demonstrate sustainable and growing reefs with long-term area a balance of competing interests.
Eelgrass beds	Establish one bed per area.	Establish three beds in each area able to support seagrasses.	Initial target is for testing viability of seagrass in each area, and the long term goal is multiple bed sites in each area.
Coastal wetlands	One new wetland site per area providing 5 or more functions for a total of 1200 acres	Continue the pace of wetland restoration for a total ecosystem gain of 32,000 acres	Reverse loss of wetlands and their functions: nutrient retention, plant community support, shoreline erosion control, recreation and aesthetics, fish habitat, and bird habitat
Shorelines and shallows	Two sites developed in part of ecosystem	Develop all possible sites in deficient parts of system	Sites with specified riparian zones, shallow sloping shores and shallow waters
Habitat for Fish, crab, and lobster	One set of 2-habitat complexes in each area	Four sets of 2-habitat complexes in each region	Target taxa use multiple habitats through life cycle. Creating sets of habitats in a location will support more species.
Enclosed and confined waters	Upgrade designated water quality classes to match receiving waters at one site per area.	Upgrade all water quality classes in all enclosed waters to match receiving waters	The status of many enclosed and confined waters is lower than the larger receiving waters. Equalizing the status of waters will improve ecosystem water quality by enhancement of degraded sites.

Table 3 - continued next page

Table 3. (continued)

Characteristic	2012 target	2050 Target	Description
Sediment quality	Isolate or remove one contaminated sediment zone of at least 25 acres	Continue removing or isolating contaminated zones until all HRE sediments are considered uncontaminated.	HRE sediments are repositories of many toxic chemicals the effects of contaminated sediments on ecological function and human use are significant.
Tributary connections	Annually remove one fish barrier to at least three habitats.	Continue reconnecting inland and coastal habitats at a rate of one per year.	Eliminate access barriers to aquatic life able to use ponds, lakes, wetlands, streams, and rivers.
Islands for waterbirds	Enhance one island in each of the four island groups	Enhance all islands in ecosystem	Enhance islands without human uses with vegetation, soils, and nesting sites.
Maritime forest	Establish one new forest stand of at least 50 acres	Develop a total of 500 acres of forest at sites along the coastline	Coastal barriers islands have unique vegetation and forests used by migratory species, especially birds.
Public access	One site improvement per area by upgrade from visual to indirect access or indirect to direct access.	Waterways accessible to all residents within a 30 minute walk or public transit trip.	Public access to the waterways and their shorelines enhances the cultural, historical, and restoration perspective of the public. Classes of access vary in the ability to detect and experience the HRE.

4. Target Ecosystem Characteristic Statements

I. OYSTERS AND OYSTER REEFS

Target Ecosystem Characteristic

500 acres of new oyster reef habitat distributed among 10 to 20 distinct sites

This initial target for the Hudson-Raritan Estuary should be achieved with self-sustained and naturally expanding reefs by 2012.

5,000 acres of established oyster reef habitat

This long-term target should be achieved by 2050 and remain indefinitely in the estuary system.

Background

Restoration of the Eastern oyster (C*rassostrea virginica*) and its reef habitat to the Hudson-Raritan Estuary (HRE) is important from a cultural and historical perspective as well as an ecological basis. Oysters have been a prominent part of the HRE for thousands of years, but have undergone major declines from prolonged fishing pressure, recent disease, habitat degradation and loss, and likely other stresses in the last 100 years.

Oysters from the Hudson-Raritan Estuary were highly desired by the Dutch and English colonists and heavily harvested by the 1600s (Kurlansky 2006). In the 1880s, Lockwood (1883) estimated that there were about 220,000 acres of oyster reefs in the estuary but many of these were transplanted and cultured. Significant harvest of oysters from the estuary ended by the 1950s with harvest of oyster seed in Haverstraw Bay. Current regional commercial sources are limited to Long Island Sound, Peconic Bay, and some other New Jersey coastal waters (Stanley and Sellers 1986). While oysters persisted in the HRE for about 400 years after European colonization and intense human harvest and impact, this formerly prominent element of the ecosystem has lost its ecologic and economic rolls in the HRE.

The oyster's contribution to overall estuary functions is special. It creates and maintains a complex biogenic benthic habitat: the oyster reef also acts as a keystone species and ecosystem engineer whose loss from the HRE can be associated with significant change in biological (e.g., trophic structure and bioenergy flow) and physical (e. g., biogeochemical cycling and geomorphology) processes. As early as 1880, Möbius described how organisms inhabiting oyster reefs interact in a positive way and shape their physical environment (Dame 1996). Oyster reefs are known to promote the presence of other benthic suspension feeders and fishes which could be as important as oysters for clearing suspended particles from the water column (reviewed in Luckenbach et al. 1999). Finally, oyster reefs attract fishes that are a forage base for higher level predators, such as birds and game fish.

Target Justification

Technical Merit

The initial target configuration of a minimum of 500 acres of new oyster reefs at 10 to 20 sites was set to demonstrate that oyster restoration is viable in the current Hudson-Raritan estuary. The minimum size for a reef should be about 12 acres. Criteria for an established self-sustaining oyster bed include natural processes of enlargement and development of new colonies. Evaluation of initial oyster bed survival and expansion would establish the viability of this restoration strategy. The long-term target of 5,000 acres of sustained oyster reefs in the estuary is a small portion of the estimated mid-late 19th oyster bed coverage (Lockwood 1883), but should be sufficient to make significant contributions to ecosystem processes. Larger coverage might adversely impact other habitat types, and could provide a source of harvested oysters that would not meet public health standards. Finally, there is uncertainty in interpreting the historical extent of oyster reefs.

Policy and Management Relevance

Attempts are underway along the US Atlantic and Gulf of Mexico coasts to conserve and reverse the decline in oysters and their reefs (Luckenbach et al. 1999). The restoration of damaged or depleted oyster populations for ecological or socioeconomic reasons has been a dominant theme at most estuarine habitat restoration workshops and conferences: e.g., Luckenbach et al. (1999), NOAA (2002), and the biennial International Conferences on Shellfish Restorations. A 2005 workshop brought together governmental and non-governmental organizations to explore the feasibility of oyster restoration in the Hudson-Raritan Estuary (NY/NJ Baykeeper 2005a). The New York and New Jersey Baykeeper (NY/NJ Baykeeper 2005b) has recently initiated activities that show that oysters can be restored in southern Raritan Bay and the Navesink River, NJ. These efforts demonstrate broad interest and agency investment in HRE oyster restoration.

Necessary Implementation Information

Successful restoration of the Eastern oyster and fully functioning oyster reefs in the Hudson-Raritan Estuary requires a carefully designed effort that considers oyster biology and the hydrogeophysical characteristics of the present estuary ecosystem. Targets for specific estuary study areas were not set because current information is insufficient to determine where oyster beds can be re-established. The initial

Table 1-1. A summary of key environmental requirements for the Eastern oyster, based upon Shumway (1996), others, and estimated by section authors as noted.

Parameter	Description
Habitat and Setting	
Depth	0.6-5.0 m in this area (MacKenzie 1997)
Suspended particles	Larvae prefer food particles of between 20-30 µm and adults can effectively use particles >3µm , but particle composition is important; suspended sediments at about the 0.5 g/L + concentration can kill eggs and larvae (Kennedy 1991); larvae and adults can vary their ingestion rate to respond to particle volume concentrations between 2 and 100 x 10^5 um^3/ml (Kennedy et al.,1996)
Temperature	Larvae: optimum ~20.0-32.5 C (Calabrese and Davies 1970); adults: 2.0-36.0 C
Salinity	Larvae: 10-27.5 (17.5 optimum in LIS; Calabrese and Davis 1970); adults: 5 to 40 ppt.
Dissolved oxygen	20-100% saturation; larvae avoid hypoxia by swimming to surface but adults can survive several days at <1.0 mg/l (Kennedy 1991)
pH	Larvae prefer between 6.75-8.75 (Calabrese and Davis 1970)
Substrate	Exposed and clean oyster, other shell, or hard surface
Circulation	No ideal rates found, but enough to provide food and remove wastes and to keep larvae in the vicinity of the parent reef (Lenihan 1999)
Retention and sources	Spatially and temporally interlinked larval source and set opportunities for reef persistence and expansion
Sediment stability	Hard enough so that oyster growth rate can overcome any submersion
Sediment deposition	Neutral sediment balance on reef
Toxic chemicals	Concentrations below health and reproductive impairment (see Kennedy 1991; Kennedy et al. 1996)
Disease and parasites	MSX and DERMO (to a lesser extent) mortality rates can be partially controlled by focusing on lower salinity (~<12 ppt) and temperature (~< 20 C) areas and the use of MSX resistant oyster larvae/seed stock (S. Ford, Haskins Shellfish Lab., Bivalve NJ; pers. comm., 2005)

Table 1-1 (continued)

Parameter	Description
Population Properties	
Critical oyster densities	A minimum number of oyster per hectare for successful reproduction and to overcome competition with sessile benthos are known to be important but current research and data do not support a specific value.
Connectivity among reefs	Larval dynamics considered across spatially interlinked reef clusters or complexes to sustain estuary scale recruitment success.
Temporal Factors[1]	
Seeding process	3-5 years/site
Reef establishment	3-10 years/site
Reef structure	> 0.3 m of elevated habitat within 10 years/site
Recruitment detection	Within 5 years
Reef area expansion	Within 5 years

1. Values estimated by section authors from experience because biological information is not presently available.

restoration will need to evaluate the distribution of suitable conditions against a set of key oyster population and habitat requirements: 1) physicochemical conditions, 2) minimum viable bed densities, 3) circulation and current patterns, and 4) establishment time (Brumbaugh et al. 2006). Table 1-1 reviews key parameters to site and design oyster beds.

Measures of Performance

Two sets of measures are needed to assess restoration performance. The first set considers oyster population biology:

1. Proportional survival of planted juvenile oysters to maturity with a goal of greater than 25% survival after the first year.
2. Periodic recruitment of uncultured oyster spat to shell or developing reefs with a goal of successful recruitment at least once every two years.

The second set is aimed at detecting estuary habitat and ecosystem benefits of having oyster reefs:

1. Enhanced populations and distributions of reef habitat dependent or associated fish and invertebrates
2. Development or enhancement of other ecological services expected of the restoration effort, e.g., erosion control, suspended particle reduction, mobile fish and bird use of reefs.
3. Increased public awareness of the role of oysters in a healthy estuary

The ability to document these five measures will strongly support successful development of oyster reefs in the estuary.

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II. EELGRASS BEDS

Target Ecosystem Characteristic

One test bed of eelgrass in each of the eight Hudson-Raritan Estuary study areas

This initial target for the Hudson-Raritan Estuary should be achieved by 2012. Based on the success of the test beds, the long-term goal is to have self-sustained and naturally expanding eelgrass, *Zostera marina*, beds.

3 eelgrass beds established in each of the study areas capable of supporting seagrasses

This long-term target should be achieved by 2050 and remain indefinitely in the estuary system. In study areas where restoration efforts for eelgrass fail, a research plan should be developed to identify controlling factors for success.

Background

Beds of eelgrass (*Zostera marina*) were undoubtedly a prominent part of the Hudson-Raritan Estuary (HRE) seascape for thousands of years but have suffered major declines, initially from habitat degradation or destruction, beginning in the 17th century as shallows were filled. During the 1920s and 1930s, a wide band of eelgrass was distributed along the New Jersey shore from Cliffwood to Highlands (MacKenzie and Stehlik 1988). As a result of a wasting disease (Muehlstein et al. 1991), the eelgrass mostly disappeared from Raritan Bay as well as elsewhere along the Atlantic Coast. The eelgrass has never recovered substantially in the Bay since the 1930s, presumably because it has become too turbid. Small variably persistent patches are known in areas such as the Shrewsbury-Navisink Rivers, NJ, which may be a source of restoration propagules.

Eelgrass is a valuable plant. Its physical structure traps sediment and helps stabilize the coastal zone and it provides cover for juvenile fishes such as flounders, tautog, and mummichogs. In addition, birds such as geese and ducks consume eelgrass as a principal food source. Where it flourishes, eelgrass serves important ecological functions such as providing a nursery for fish and shellfish, especially blue crabs and juvenile bay scallops, and reducing erosion and turbidity. It supports a special ecological community with enhanced biodiversity (Levinton 1977), especially small mollusks, that changed when eelgrass beds disappeared (Franz 1982). Table 1 summarizes many of the important functions provided by eelgrass.

Eelgrass, like the oyster, is a keystone species and ecosystem engineer whose loss from the HRE can be associated with significant change in biological (e.g., trophic structure and bioenergy flow) and physical processes (e. g., biogeochemical cycling and sediment stability). Eelgrass is able to create and maintain a complex biogenic benthic habitat with a characteristic faunal composition.

Table 2-1. A summary of key ecosystem functions and values to human society of eelgrass, based upon Short et al. (2000).

Function	Value
Canopy structure	Habitat, refuge, nursery, settlement, support of fisheries
Primary production	Food for herbivores, support of fisheries and wildlife
Epibenthic and benthic production	Support of food web and fisheries
Cover	Protection from predations for many species
Nutrient and contaminant filtration	Improved water quality, support of fisheries
Nutrient regeneration	Support of primary production and fisheries
Sediment filtration and trapping	Improved water quality, support of fisheries
Epiphyte and epifaunal substratum	Support of secondary production and fisheries
Oxygen production	Improved water quality, support of fisheries
Organic production and export	Support of estuarine, offshore food webs, and fisheries
Organic matter accumulation	Support of food webs
Wave and current dampening	Dampen erosion/resuspension, increase sedimentation
Seed and vegetative expansion	Self-maintenance of habitat, support of wildlife
Self-sustaining ecosystem	Recreation, education, landscape level biodiversity

Target Justification

Technical Merit

The initial objective is to evaluate each of the eight study areas for the ability to support sustainable eelgrass beds (Figure 2-1).

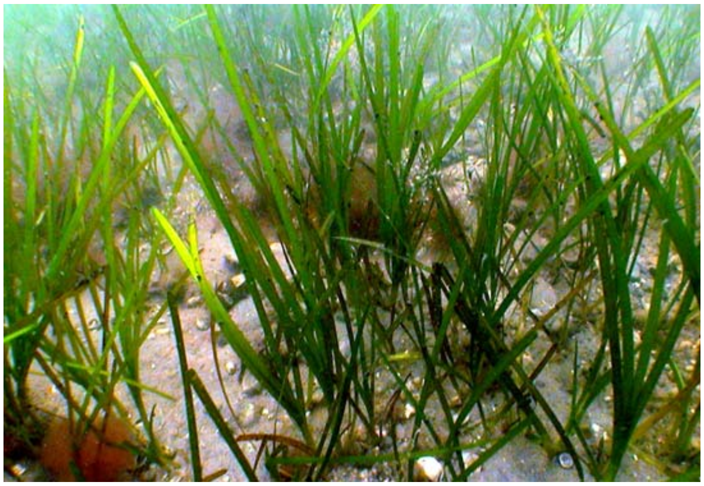

Figure 2-1. Beds of eelgrass (*Zostera marina*)

Within the eight study areas, potential seagrass project locations include but are not limited to:

- Arthur Kill/Kill Van Kull
- Jamaica Bay
- Harlem River, East River & Western Long Island Sound
- City Island
- Lower Hudson River, especially the Jersey Flats area
- Lower Raritan River
- Newark Bay, lower Hackensack River & Passaic River
- Raritan-Lower Bay
- Upper (Gravesend) Bay
- Sandy Hook Bay (this is where some of the last beds occurred the Highlands-Atlantic Highlands area –see above - and includes the bay side of Sandy Hook that once supported eelgrass beds, e.g., in Spermaceti Cove)

These test studies will provide proof-of-concept that eelgrass restoration is viable given the current water quality conditions within the Hudson-Raritan Estuary.

Established, self-sustaining and expanding eelgrass beds is the long-term target. Initial evaluation of eelgrass survival and expansion will determine support for continuation of this restoration strategy, and the feasibility for attaining the long-term target of three eelgrass beds established in each of the study areas capable of supporting seagrasses.

Eelgrass growth is strongly limited by the reduction of light penetration through the water column (Dennison and Alberte 1982). In selecting target locations for establishment of eelgrass beds, basic consideration needs to be given to known environmental preferences (Table 2-2). There is also evidence that selection of genetically diverse shoots for transplantation improves bed establishment (Revsch et al. 2005).

Table 2-2. A summary of key environmental preferences of eelgrass (*Z. marina*) summarized from Kemp et al. (2004) and Moore (In Press) and references within.

Parameter	Value
Water Movement	Minimum velocities (cm s^{-1}) 3–16 Maximum velocities (cm s^{-1}) 50–180
Hydrodynamics of erosion and accretion	Regime that is closely balanced between the forces
Wave Tolerance,	<2 m Height for growth and meadow formation
Depth transmission	Subtidal, typically to 2 m, but limited by light Minimum required light through water column is >22% of light
Light	Minimum requirement >15% light at leaf Water column light attenuation <1.5 K_d m^{-1}
Total Suspended Solids	<15 mg l^{-1}
Plankton Chlorophyll a Levels	<15 ug l^{-1}
Dissolved Inorganic Nitrogen	<0.15 mg l^{-1}
Dissolved Inorganic Phosphorus	<0.01 mg l^{-1}
Dissolved Oxygen	>2 mg l^{-1} at the bottom
Sediments	Grain size, 0.4–72 % silts and clays Organic matter, 0.4–16 %
Pore water Sulfide	Healthy plants, <1 mM Reduced growth, >1 mM Death, >2 mM
Temperature	Range about 5 - 30^{o}C, with an optimum growth and germination range of 10 - 15^{o}C
Desiccation resistance	Intolerant of desiccation
Salinity	Avoids brackish water, optimum salinity range 10 – 39 psu, may be tolerant down to 5 psu

Policy and Management Relevance

Attempts are underway along the US Atlantic coast to understand why eelgrass beds have not reestablished on their own, and to restore eelgrass beds in appropriate areas

(Fonseca et al. 1985, Fredette et al. 1985, Short et al. 2000). The restoration of eelgrass started soon after the decimation associated with wasting disease (Dexter 1950), as it became very apparent that key ecosystem services were lost with its disappearance. Since the 1930s, eelgrasses have at times rebounded and declined along the east coast for a variety of reasons (Orth and Moore 1983), but they have not consistently returned on their own.

Necessary Implementation Information

Targets for estuary zones were not set because current information does not indicate where in the ecosystem eelgrass beds can be re-established. The initial efforts focus on feasibility of restoration and understanding of water and sediment quality needed for successful restoration. Successful restoration of the eelgrass beds in the Hudson-Raritan Estuary will require a carefully designed effort. Following general guidance provided by Short et al. (2000) these criteria are proposed for assessing eelgrass restoration efforts:

- Select sites for restoration and if present identify existing natural eelgrass beds as reference sites.
- Determine time frame of assessment.
- Choose measurable representatives of functions and values (candidate indicators) to quantitatively judge the restoration.
- Measure candidate indicators at study sites.
- Rank the candidate indicators in their ability assess restoration success.
- Select a subset of candidate indicators to be qualifying indicators.

Measures of Performance

Two sets of measures are needed to assess restoration performance. The first set considers eelgrass biology:

1. Proportional survival of planted and transplanted seedlings to maturity.
2. Persistence and lateral expansion of beds through time via rhizomal growth.
3. Periodic recruitment or expansion of beds via seed set.

The second set is aimed at detecting estuary habitat benefits of eelgrass beds:

4. Populations and distributions of fish and invertebrates within eelgrass habitat compared to unvegetated bottom.
5. Development or enhancement of other ecological services, e.g., erosion control, suspended particle reduction, mobile fish and bird use of beds.
6. Increased public awareness of the role of eelgrass in a healthy estuary and a public tolerance of windrows of dead eelgrass blades on beaches.

The ability to document these six measures will support additional development of eelgrass beds in the estuary.

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III. COASTAL WETLANDS

Target Ecosystem Characteristic

One new coastal wetland that provides five or more primary functions in each of 8 study areas for a total increase in the Hudson-Raritan Estuary (HRE) of 1200 acres.

The minimum size of a wetland unit is not specified in order to allow feasibly-sized projects across the (HRE) study areas. Wetlands must be coastal, i.e., have a direct connection to the open waters of the HRE. The initial 1200 acre target should be achieved with self-sustaining wetlands by 2012.

Continue after 2012 to create 800 acres of coastal wetland per year for the 38 year period ending in 2050 for a total HRE gain of 32,000 acres.

This long-term target would increase coastal wetland acreage at approximately double the rate of loss in recent times. That is, assuming continued losses of 400 acres per year, the restoration will result in a net gain of 400 acres per year. The further assumption is that continued loss will mainly be due to sea level rise and coastal erosion rather than legal or illegal filling and dredging. Filling and dredging should cease because creation of replacement wetlands, whether as mitigation or not, is expensive and may not achieve reasonable or comparable levels of ecosystem function.

Background

Wetlands are defined under the U.S. Clean Water Act as "…areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions." In practiced, wetlands are identified and their boundaries delineated by examination of hydrologic, soil, and vegetation characteristics defined in the U.S. Army Corps of Engineers Wetland Delineation Manual [cite 1989]. Wetlands include marshes, wet meadows, swamps, bogs, and other habitats that have saturated soils within a certain distance of the surface for a minimum number of days during the growing season.

Our target is coastal marshes and other wetlands directly connected with the open waters of the 8 HRE study areas. These wetlands include the well-studied tidal salt marshes typically dominated by cordgrasses (*Spartina* spp.) in areas below Mean High Water that are flooded regularly, and areas just above MHW that are flooded irregularly. They also include regularly and irregularly-flooded lower-salinity brackish marshes and freshwater tidal marshes between Mean Low Water (MLW) and just above MHW, dominated by common reed (*Phragmites australis*), cattails (*Typha* spp.), cordgrasses, swamp rose mallow (*Hibiscus moscheutos*), bulrushes (*Scirpus* spp.), sedges (*Carex* spp.), purple loosestrife (*Lythrum salicaria*), dwarf spikerush (*Eleocharis parvula*), and other vascular plants; shrubby borders of saline marshes near MHW with high tide bush (*Iva []*), groundsel tree (*Baccharis halimifolia*), switchgrass (*Panicum virgatum*), common reed, etc.; supratidal meadows and pools from about MHW to 1 meter vertically above MHW and supporting various plants; intertidal and supratidal tree or shrub dominated swamps in fresh or slightly brackish water and supporting various plants; and other wetland types between Mean Sea Level and MHW (Kiviat and Stevens 2001, Kiviat et al. 2005 [other cits]).

Subtidal (below Mean Low Water) shallows (see *Shorelines and Shallows* TEC) and the upland areas adjoining coastal wetlands are not included in this profile. These environments, however, provide critical buffer zones that help protect coastal wetlands from natural and anthropogenic stresses as well as providing components of the habitat mosaics that many estuarine and terrestrial animals require.

The HRE had an estimated total salt marsh area of 85,000 acres in the 1880s (Will and Schneider 2005). Almost 80% have been lost at an average rate of 400 acres per year. We do not specify threshold size of created wetlands in order to accommodate available wetland creation sites in different HRE study areas. The interim goal area of 1,200 acres of created wetlands at eight sites results in an average wetland size of about 150 acres. This is approximately the average size of wetlands listed under the Harbor Estuary Program as high priority restoration sites. Hence the total area prescription appears realistic for the HRE.

The acreage target must constitute newly created wetlands rather than wetlands that are simply "restored" by changing the vegetation. The goal is to have more wetland area rather than a change in the type of wetland. For this purpose, created wetlands include the re-establishment of wetland on non-wetland soils where former wetlands were filled or drained, as well as new wetlands on pre-existing upland soils. In the latter case, the existing ecosystem must be assessed for its own ecological functions and biodiversity before the decision to convert it to wetland. In practice, the restoration of wetlands from non-wetland soil that represents formerly filled or drained wetland is the preferred method. Brownfields (former industrial or transportation sites), which are often on old wetland fill, offer opportunities for creation of wetlands and associated buffer zones.

Wetland functions as varied as sediment retention and bird habitat are as important as wetland acreage. Functions are complex and dependent on each other. Seven functions of coastal wetlands that are priorities in the HRE are identified in Table 3-1. The TEC specifies that new wetlands must demonstrate at least five of the seven functions. All sites should demonstrate two of the functions: plant community support and sediment stabilization. In addition, proposals for wetland creation should analyze the merits of creating particular functions in the regional context of existing wetlands and their functions. Proposals that will establish a viable population of a state-listed S1 or S2 plant species, or an endangered, threatened, or special concern animal species, may demonstrate only four of the seven functions. An applicant may propose to substitute one other function for one of the functions not listed in Table 3-1 with the burden of proving general and site-specific appropriateness.

Table 3-1. Selected ecological functions of coastal wetlands that can be achieved in created wetlands in the Hudson-Raritan Estuary.

Function	Description
Nutrient and carbon retention	Storage of nitrogen, phosphorus, and carbon in plants and sediments. Low water velocities, vegetation, and plant debris promote inorganic and organic sediment deposition; herbaceous or woody vegetation takes up nutrients. Wetland soils support nitrogen fixation, nitrogen mineralization, and denitrification.
Plant community support	Low water velocities and low wave stress, position in or just above the intertidal zone, high soil organic matter content, adequate nutrients, and periodic water movement. (Varied conditions support diverse flora and vegetation. Although organic soils support greater plant biomass and production, sandy soils may support rare plants not found on organic soils.)
Sediment accretion and stabilization	Rooted vegetation and woody debris (stumps and logs) anchor sediments during storms or from boat wakes. Increasingly important as sea level rises. Upland buffer zones with seminatural soil and vegetation protect wetlands from high-energy runoff.
Habitat for estuarine fishes	Shallow wetlands for spawning and nursery areas with tidal creeks that have water velocities and depths suitable for fish movement. Includes small creeks and pools that allow fish access to marsh surface. Live and dead vegetation for refuge from predators. Proximity to open waters and absence of low oxygen or high temperature.
Habitat for wetland birds (especially breeding habitat for bitterns, northern harrier, rails, willet, marsh wren, sedge wren, seaside sparrow, saltmarsh sharp-tailed sparrow)	Extensive stands of emergent vegetation providing perch and nest substrate above higher high tides and refuge from predators, humans, and storms. Proximity to creeks, pools, or mudflats for foraging. Nearby woody vegetation provides additional shelter and nest sites for certain bird species. Tall robust vegetation (e.g., smooth cordgrass, cattails, common reed) provide habitat for certain birds, whereas dense short grasses and similar plants (e.g., salt meadow cordgrass, saltgrass, black rush) support other birds. In addition to breeding habitat, wetlands should also provide roosting and foraging habitats.
Habitat for at least one additional taxon or functional group of organisms selected from the following: small mammals, diamondback terrapin, terrestrial insects and spiders	To be defined by permit applicant based on information from the general literature as well as information specific to the HRE
Scenery and recreation	Natural vistas and experiences in contrast to urban environments (Adamus 1993). Trails, boardwalks, observation platforms, and landings for non-motorized boats in selected locations make wetlands accessible. Trails should not follow shorelines or creeks because these are biodiversity and ecological function hotspots. (Amenities of wetlands are often called “values” rather than functions.)

Buffer Zones

Upland buffer zones are an integral part of the wetland environment by protecting wetland functions. They provide complementary habitat for many animal species that move back and forth between wetland and upland, and they remove nutrients, sediment, and certain other pollutants from water entering the wetland. Wider buffer zones, better soil development in buffers, and greater height and biomass of buffer zone vegetation in general increase buffer function, although even narrow herbaceous buffer zones to some extent intercept nutrients in runoff and shallow groundwater and may provide habitat for small animals. Created or restored wetlands should have the maximum (width, soil, vegetation) buffer zone feasible.

Invasive Plants and Wetland Functions

Many existing wetlands in the HRE are dominated by common reed, and many created wetlands will become dominated by common reed. There is debate about the impacts of Eurasian reed on functions and values of wetlands. While considerable effort has been invested in the removal or diminution of reed stands, recent research, and observation, document considerable positive and negative impacts on functions and values. Overall, reports of negative or positive impacts have not been supported by adequate scientific data (Kiviat 2006). Because reed marshes may be both beneficial and detrimental to biodiversity and ecosystem services, decisions about reed management must be site-specific and related to the intended functions.

Target Justification

Technical Merit

Wetlands are among the most ecologically productive environments in the world. They provide human benefits such as habitats for fish, birds, and other animals, water quality improvement, flood storage, shoreline erosion protection, and visual amenity. Wetland loss and degradation occur in human-dominated landscapes through two major causes: (1) human activities that drain, dredge, dam, fill, or otherwise alter wetlands and associated ecosystems; and (2) natural processes that may be accelerated by human-caused erosion, subsidence, sea level rise, droughts, and other factors.

Coastal wetlands (marine to tidal freshwater, and supratidal) support early life stages of a large portion of the commercially and recreationally important finfish and shellfish species in marine waters. They also provide recreation opportunities for boating, hiking, bird watching and other nature study. Wetlands reduce shoreline erosion by absorbing and dissipating energy from tides, waves, and boat wakes, by stabilizing substrates, and by enhancing deposition of suspended sediments.

High primary (plant) production in many wetlands, and the tendency for much of this production to be incorporated into wetland soils as soil organic matter, means that wetlands may have a high degree of carbon sequestration (storage). Protecting carbon sequestration in wetlands contributes to global reduction of greenhouse gas emissions. Although hard data are not available, there is reason to think that common reed and certain other fast-growing, high biomass-producing invasive plants may be especially good at sequestering carbon.

Policy and Management Relevance

The history of wetland policy in the U.S. has had three eras: (1) A classical era during which destruction of wetlands was policy; (2) a modern era during which protection was policy; and (3) A postmodern era in which wetlands are not only protected but also created and restored. The Clean Water Act includes criteria for water quality, inspections, and monitoring, with regulation of the discharge of dredged and fill material into wetlands and waters of the U.S. (Section 404). Other regulation of wetland is in the National Environmental Policy Act (NEPA), Rivers and Harbors Appropriation Act, Federal Agriculture Improvement and Reform Act, Endangered Species Act (ESA), Transportation Equity Act for the 21st Century (TEA-21), Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), and North American Wetlands Conservation Act (NAWCA). State laws also protect wetlands, for example, in New York, the Freshwater Wetlands Act (Article 24 of the Environmental Conservation Law), and the Tidal Wetlands Act (Article 25). Additional policy guidance is in the *New York State Salt Marsh and Freshwater Wetland Restoration and Monitoring Guidelines* (Niedowski 2000). This TEC supports the protection of wetlands provided for in these laws, and tailors protection and creation of wetlands to the New York City region in which massive degradation and loss of wetlands have occurred.

Implementation

In general, wetland restoration projects need to include the following steps: pre-restoration biological studies, assessment of the surrounding landscape, identification of restoration functions, design of soils, hydrology, and vegetation for the restored wetland and buffer zone, methodology to achieve restoration goals under specific site conditions, detailed specifications for construction, supervision of construction, incorporation of access for educational, recreation, and research purposes as appropriate, monitoring to assess restoration outcome, dissemination of monitoring results, management to correct problems or shortfalls identified by monitoring, and long-term stewardship to maintain desired structure and function.

Re-creation of former wetland areas requires less manipulation than creation of wetlands from uplands or subtidal habitats, and has a higher likelihood of success. Therefore, former wetland sites should have higher priority than sites on acreage that never was wetlands. Such rehabilitation should involve removal of fill, plugging of ditches, removal of tidegates and berms, and modifications other than just the removal of invasive plants.

Site evaluation includes land ownership, use and availability, topography, geology, hydrology, soils, biological diversity, and regulations. Biodiversity is a paramount consideration because the presence or likely presence of rare species or important populations may preclude modification of the site. Hydrology includes the distribution and size of tidal creeks throughout and within particular habitat types, and creek sinuosity, stability and morphology. Adequate supplies of water at the appropriate time of year are crucial to sustaining a wetland system (Donald 1991). Water depths, frequency and duration of flooding, and water chemistry are the most important factors in the survival and growth of plants. Soil surveys are important because published soil maps are not accurate on a fine scale and may lack needed information.

Selection of plants should consider how to increase the genetic diversity of locally adapted plants at a restoration site. The most important factor is to ensure that the species can, in the long-term (e.g., 25-50 years), withstand the rigors of life, and reproduce. Plants must be able to survive salinity intrusion and unusually high tides (both increasing with sea level rise); being eaten by insects, fish (e.g., European carp in low-salinity wetlands), geese, other birds, and mammals (which in some areas may eventually include deer, beaver, and nutria, as well as muskrat and other native rodents); soils likely to be of compromised quality despite organic matter or other amendments; heavy metals, herbicides, and other environmental contaminants; high nutrient (nitrogen, phosphorus) levels; rapid sediment deposition or erosion; trash and detritus mats; storm waves and boat wakes; and as-yet unidentified or unnoticed threats (e.g., marsh dieback affecting *Spartina alterniflora*). Few wetland plants withstand all this, which is why the Eurasian subspecies of common reed has been so successful.

Reintroducing wildlife should be considered only after careful evaluation of factors affecting natural recolonization, the most important of which are connectivity with nearby wetlands and the vigor and size of source populations therein. Certain invertebrates, fishes, and birds are highly mobile and commonly recolonize wetlands without human assistance. Other species may need to be translocated.

Walking trails, viewing platforms and other public access elements should be evaluated as part of the project design and included where feasible (see public access TEC). Access trails should avoid the upland-wetland edge, a zone of intense ecological function and high biodiversity. Wetlands should have buffer zones that screen wildlife from noise and visual disturbance, as well as provide complementary habitat and biogeochemical functions.

Measures of Performance

The collective performance on this target will be measured as the acreage of wetland created and the levels of wetland functions. The area factor for the interim goal is 1200 acres from at least one project in each if the eight study areas. Before 2013, when work begins on the long-term goal, past and current wetlands restoration projects throughout the HRE should be evaluated for long-term ecological function. The results of this assessment should be made available for public discussion. Performance against goals must also be assessed on a project-specific basis for each of the planned ecological functions.

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IV. SHORELINES AND SHALLOWS

Target Ecosystem Characteristic

> ***Establish new shoreline and shallows sites in two of the following study areas: Lower Hudson, Upper Bay, and Harlem-East Rivers-Long Island Sound.***

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. This initial target for the HRE should be achieved by 2012. The long-term ecosystem target to be achieved by 2050 is:

> ***Restore all available shoreline and shallows sites in the following study areas: Lower Hudson, Upper Bay, and Harlem-East Rivers-Long Island Sound.***

This long-term target can be specified once a survey of available shoreline properties is completed. Our initial assessment suggests the number of sites is low and would not require more than a restoration project every few years.

Background

Shorelines and their adjacent habitats are the transition zone between aquatic and terrestrial systems. They provide important ecosystem functions when well-vegetated, resistant to erosion, and associated with shallow waters with cover and refuge. Shorelines provide rearing habitat for amphibians, reptiles, birds, mammals (especially muskrat) and many fish species and life stages. Vegetated water edge and adjacent land retain sediments and nutrients from upland runoff and provide natural waterfront settings for people. Shorelines and Shallows should be viewed as a gradient of habitats in three zones -- the riparian zone, the inter-tidal or water edge zone, and the shallow littoral zone.

There are no clear delineating criteria for the riparian zone, and Armantrout (1998) defines these habitats as terrestrial areas where the vegetation complex and microclimate conditions are products of the presence and influence of perennial or intermittent water. A healthy natural riparian zone will consist of a variety of shrubs and long-lived tree species.

The water edge is termed the inter-tidal zone in coastal ecosystems and habitats include marshes, mudflats, beaches, and coarse rocky shores.

The shallow water or littoral zone includes habitats with light penetration to the bottom. Littoral waters often have woody debris, submerged aquatic vegetation, and illuminated open bottoms.

In urbanized areas, natural shorelines are typically converted to man-made shorelines lacking a riparian zone, inter-tidal edges, and shallows. Bulkheading, dock and revetment construction are common so that deep water can be readily accessed from elevated built land. Built shores can block the movement of sediment along the water edge, and can force small fish and other mobile organisms into deep waters with predators. Hard built edges amplify the energy of waves, which in turn can scour sediments and increase erosion. Developed land and hard structure along the shore readily transfers nutrients and sediments in elevated surface runoff.

About 16% of the HRE shoreline is largely composed of solid man-made structures (Figure 4-1). These built shorelines dominate in three study areas: Lower Hudson River, Upper Harbor, and the Harlem River, East River, and Long Island Sound. Even in these extensively developed study areas, there are small sections of the shoreline with some intact shoreline habitats (Figure 4-2) and the possibility to construct more. We therefore target these three study areas for restoration actions, although shallows and shore areas may be restored in these and other study areas as part of other TEC goals.

Restoration of shorelines and shallows is defined in terms of vegetation for the riparian zone, gradual slope for the inter-tidal zone, and water depth for the shallow littoral zone. A riparian zone with tree, shrub, or well developed herbaceous plant cover will reduce runoff inputs to open waters (Karr and Schlosser 1978, Myers 1989) and provide cover and habitat for species inhabiting water edge settings. Vegetated riparian zones are often called buffer strips, and agencies such as the U.S. Department of Agriculture and the New York Department of Environmental Conservation commonly specify 100 ft. widths, or a range from 20 to 200 ft. with an average of 100 ft. (Illinois Environmental Protection Agency 2006).

The inter-tidal zone can be composed of differing material consistent with wave exposure and underlying substrate. Coarse gravel and cobble will be common on wave exposed shores and emergent vegetation at still, protected shores. Sand beaches were common in many built shorelines of the HRE. Erratic shape, complex edges, and small channels are best for supporting a diversity of species. Regardless of the shape and material dominating the inter-tidal zone, the average slope must be consistent with stability under prevailing waves and currents. Suitable slopes vary by setting and soil characteristics but range from 30% or 2-4:1 where sand and gravel dominate (Hansen 1968, Pfankuch 1975) to 10% or 10:1 at fine sediment sites and tidal wetlands (Garbisch 1977). Marsh development in the inter-tidal zone is very desirable because of the enhanced function of vegetated water edges. Exposed plant stems dissipate wave energy, and dense vegetation creates a depositional environment (Knutson 1988). The basic approach for marsh creation is to plant a shoreline area in the vicinity of the tide line with appropriate marsh grass species.

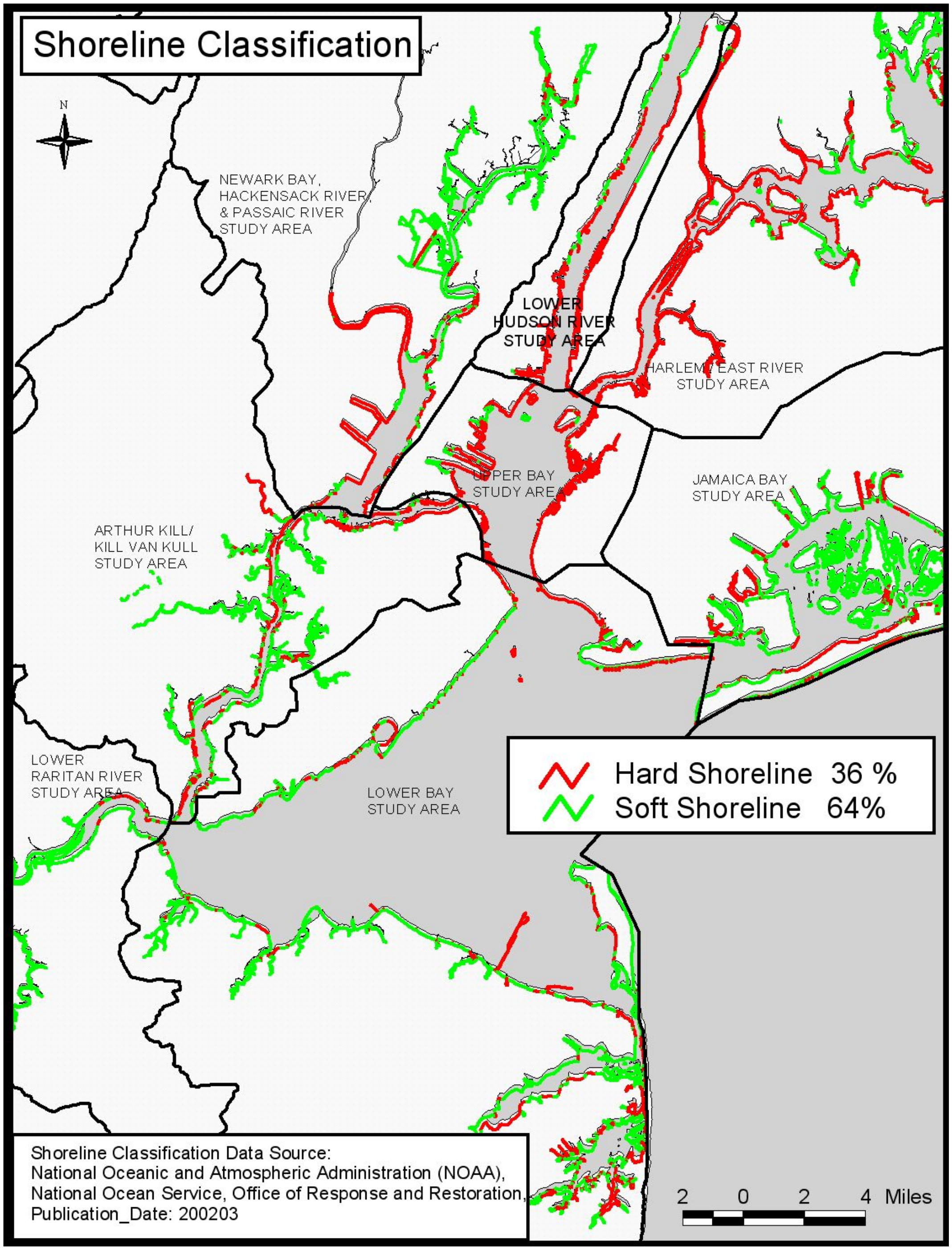

Figure 4-1. General distribution of shoreline conditions: hardened and built structures dominate the maroon and tan colored edges, and green edges vary from rock and gravel beaches to marshes and mudflats. Source: NOAA ESI Geospatial Data, 2003/03.

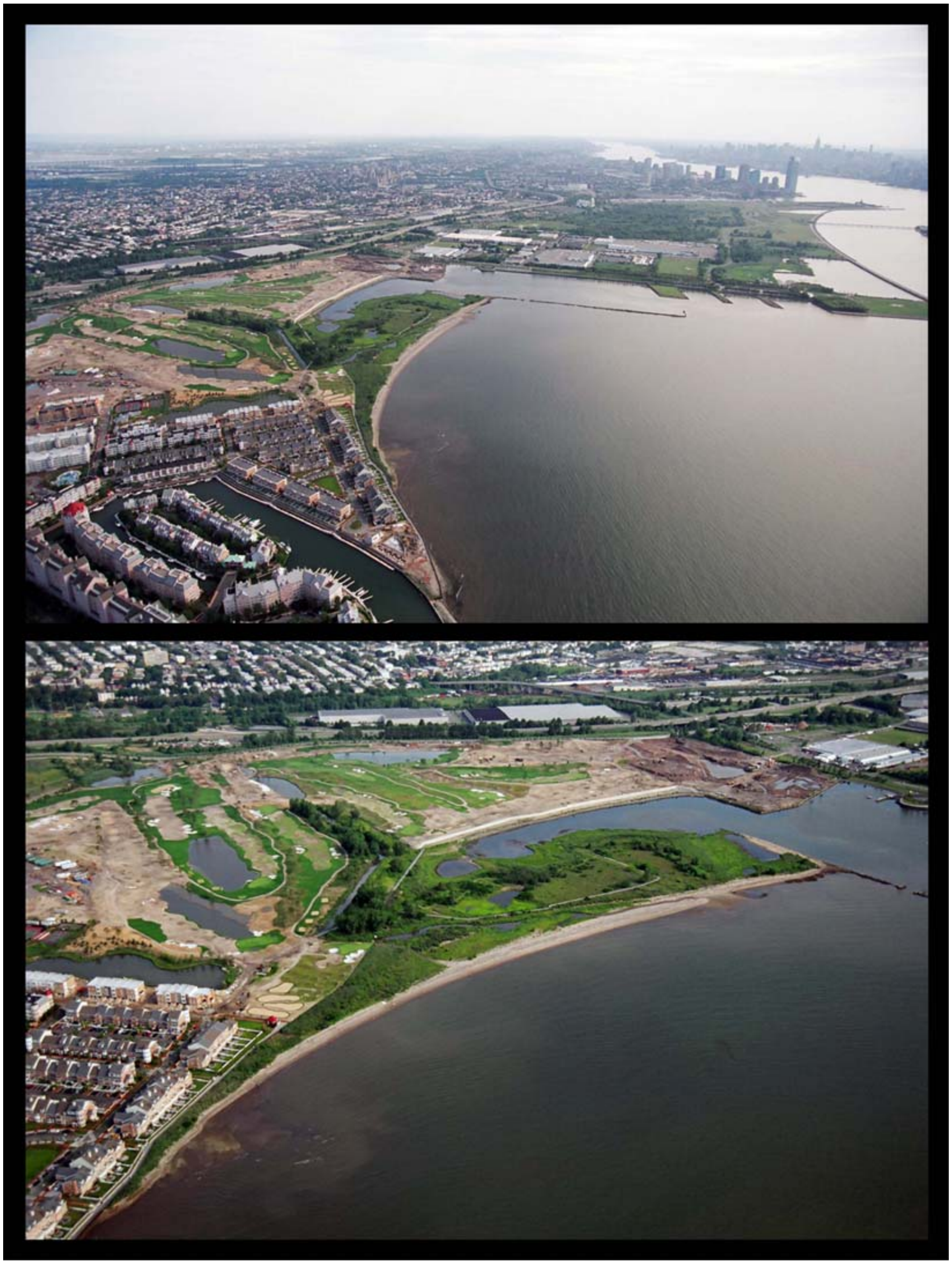

Figure 4-2. An existing shoreline and shallows site (Caven Point Beach, Jersey City) in the intensively shore developed Upper Harbor near Port Liberte (part of Liberty State Park). This site contains a vegetated riparian zone with channels and marsh, a vast mud flat extending several hundred meters out from the beach at low tide, and expansive shallow waters. Source: New York Harbor Beaches (2006).

The third component of a shoreline and shallows restoration site is the shallow littoral zone. Shallow water bottoms may be open sand, mud flats, coarse substrate shoals, or submerged vegetation. Wood and natural debris are desirable as cover for small fish and crustaceans. However, our primary specification is water depth that allows 1% of surface light to reach the substrate. This level of illumination allows plant and algae growth and is often the criteria for defining the euphotic and littoral zones. Water depth and transparency (secchi disk depth readings) determine the depth of light penetration. Scheffer (1998) and Welch (1948) estimate water depths from 1.7 to 3.0 times secchi disk readings receive 1% of surface light. We specify that 2.0 times secchi dish depth be used for the HRE since turbidity levels are fairly high compared to most inland waters referred to in Scheffer (1998) and Welch (1948). The mean secchi disk reading for HRE waters is about 5 ft. and the range from 3.2 ft. in the Hudson River to 7.2 ft. in the lower harbor (New York Department of Environmental Protection 2003). Shallow water criteria should be estimated for any proposed restoration site using typical local water transparency and mean water surface elevation (mean over tidal cycle). On average for the HRE, shallow waters would be those less than 10 ft. deep at mean water elevation.

Target Justification

Technical Merit

Ecosystem functions provided by shorelines and shallows are well established (e.g., Tockner and Stanford 2002, Tockner et al. 2002, Barwick et al. 2004) and include physical, chemical, and biological processes. Absorption of wave energy, sediment retention, and accumulation of coarse substrate are some of the prominent physical processes. Chemical processing and storage are promoted by trapping and decomposition of organic matter and the absorption and transformation of nutrients from the uplands. Shorelines provide a gradient of diverse or unique habitats that support many species using both land and water environments. In addition, shorelines are commonly associated with structured shallow waters, mud flats, marshes, sandy beaches, and coarse edges that support small and young fishes and crustaceans. Human development of shorelines replaces riparian, inter-tidal, and shallow water habitats with structures, hard surfaces and edges, and typically deepens shoreline waters. Allowing some shorelines to retain natural conditions will diversify the habitats available in the most intensively developed parts of the HRE ecosystem.

Policy and Management Relevance

Like many other coastal waterways of the Nation, the HRE has improved in water quality and public appeal in recent decades. People are again swimming, popular fisheries have rebounded, recreational boating and tourism have soared, and water accessible land has greatly escalated in value. Long neglected industrial properties and open public lands are being targeted for development, often mixed-use building including residences, restaurants, marinas, hotels, etc. An estimated 15,000 units of housing are currently in review or under construction along the Hudson River (Hopkins

2006). The new demand for development and public use of shorelines has raised concerns about sustaining these environments. Otto et al. (2004) recently published a monograph on ecological waterfront design. Their aim was to provide *"a set of planning and design principles that can be employed to .. reclaim .. river edges … in the most ecologically sound and economically viable manner possible."* A local example of growing interest is the work of New York Harbor Beaches (2006) promoting beach and unbuilt shorelines for public use and nature contact. Federal (e.g., USDA), state (New York Dept. of Environmental Conservation), and local governments have programs aimed at riparian zones, waterways buffers, green corridors, and more.

Necessary Implementation Information

The shorelines and shallows TEC is complicated because of the need to investigate and plan sites with three zones across the land-water transition. Fortunately, there are several extensive guides for restoring shoreline areas in a comprehensive manner. Implementation plans should be developed consistent with guidance in waterway corridor scale technical guides: FSIRWG (1998) and the US EPA (2006) are good examples. Riparian zone restoration practices are described for New York (NYS DEC 1992, 1993) and many others. Erosion and soil conditions need to be investigated for developing stable inter-tidal zones (methods in Chen 1975, Thorne et al. 1981). Soil bioengineering (installation of living plant material as a main structural component) practices are detailed in USDA-NRCS (1992), FSIRWG (1998), and USDA Forest Service (2002).

Measures of Performance

Performance for the shorelines and shallows TEC is straightforward: number of sites restored relative to the short and long term targets. The long term target needs to be defined from available sites. A final consideration in performance should be the maintenance of restored sites with the three primary design attributes: vegetated riparian zone, inter-tidal zone with a stable slope, and illuminated shallow waters.

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V. HABITAT FOR FISH, CRABS, AND LOBSTERS

Target Ecosystem Characteristic

> ***Complete one set of at least two functionally related habitats in each of the eight regions of the Hudson Raritan Estuary.***

This initial target for the Hudson Raritan Estuary should be achieved by 2012.

> ***Complete four sets of at least two habitats in each of the eight regions of the Hudson Raritan Estuary.***

This long-term target should be achieved by 2050 and remain indefinitely in the estuary system.

Background

Most fish, crabs, and lobsters found in the Hudson-Raritan Estuary (HRE) are there because the estuary is important or critical for at least part of their life cycle, such as providing them with a juvenile nursery (Beebe and Savidge 1988; Limberg *et al*. 2006; Morgan 2006). These species are usually part of larger east coast populations and because the HRE is a major estuary, its habitat importance to regional fishery resources transcends the HRE itself. Within the HRE, these species often use or require more than one habitat type as they progress through their life cycles or growth stages. Although our current understanding of the relative value of some of these submerged habitats is not always adequate, we do know of many functional relationships.

Typically, these species have larvae that are water column dependent, juveniles that need protective benthic or other places for nurseries, and adults that need specific feeding, spawning, or wintering grounds. Some habitat connections involve daily movement patterns of species, such as for night-time shelter and day-time feeding. The relative abundance, quality, and spatial connectivity of the diversity of habitats that are needed to enhance survival and growth can be critical to the productivity of many species within the HRE. This productivity is important to many natural resource management goals, such as those of HEP or ASMFC, and how habitats are dealt with during conflicting human activities, as often confronted by the USACE.

The conservation, rehabilitation or restoration of habitats that support fishery resources is a goal of many programs within the HRE. Everly and Boreman (1999) discuss the roles habitat and water quality play in rehabilitating many fishery resources. One approach to rehabilitation compares the historical and current extents of habitat used by selected fishery resources and then addresses those differences as expressed in absolute, relative, or landscape terms. But obtaining the data or information to make these comparisons is not always easy. For example, Everly and Boreman (1999) and Wilk *et al.* (1998) discuss the difficulties of determining habitat requirements for individual species. Such effort in Chesapeake Bay may serve as an example (Funderburk *et al.* 1991).

One practical way to proceed is to make one goal of restoring the HRE be the provision of a spatially connected mosaic of relatively healthy habitats, e.g., oyster reefs, seagrass beds, marsh fringes, intertidal flats, subtidal sandy bottom, and subtidal natural-mud-bottom habitats that closely address the functional requirements of HRE fish and decapods. This is the approach taken by this TEC.

The restoration of most of the above specific habitats are discussed in other TEC reports within this volume. Each sets phased goals for the amount of habitat that should be restored, but they do not address the spatial relationships that can be critical to the living resource species. Thus, this TEC will focus on the landscape or benthoscape aspects of those other ecosystem targets, *i.e.*, the spatial arrangement and connectivity of mostly benthic habitats using the best information or models available, *e.g.,* Minello *et al.* 1994; Minello and Rozas 2002; Zajac *et al.* 2003. In practical terms, this means focusing on habitat complexes, such as the proximity of oysters bars to salt marsh, sandy flats to oyster bars and seagrass beds, and mud flats to sandy shoals.

A preliminary listing of major HRE habitat types known to be commonly used by many fishery resource species is presented in Table 5-1; this list can probably be further broken down to the sub-habitat level, when specific habitat uses are better understood. Investigating the use of submerged habitats, especially structural habitats, by motile species in the currently turbid HRE is problematic, and is less precise than similar terrestrial efforts.

Because hundreds of fish and decapod crustacean species live in the HRE (Smith and Lake 1990), it is not practicable at this point to develop habitat relationship guidance for them all, even with the large overlaps that exist in habitat requirements. Eleven species were chosen to focus this TEC (Table 5-2); these species were chosen based on their abundance in fishery independent monitoring surveys (Conover *et al.* 1985; Wilk *et al.* 1997, 1998), their importance as fishery species or species with a special management designation, current knowledge of their habitat requirements, and the probability that their habitat needs will be somewhat congruent with other species, at some functional level. There is still much to be learned about how these and other species use these habitats, but there is a growing scientific Essential Fish Habitat (EFH) literature to begin the process.

Target Justification

Technical Merit

Fishing has been a source of food and a central commercial and recreational activity for residents of the New York metropolitan area since humans first inhabited the area (Zeisel 1988; MacKenzie 1992). Evidence suggests the Hudson-Raritan Estuary, as well as other northeast coast estuaries, have lost much of their rich former fishery productivity because of habitat degradation or loss. But fishery species abundance data for the early pristine estuary is usually only anecdotal or inferential. Most estuarine dependent fishery species, under the jurisdiction of the Atlantic States Marine Fisheries Commission, New England or Mid-Atlantic Management Councils, or NY and NJ fishery management agencies, are not currently over fished, but stock sizes are below historic levels (NEFMC 1998; ASMFC 2005). Although management efforts are mostly focused on harvest regulation, it is understand that the recruitment of healthy juveniles or adults to the regional fishery stock involves the health and productivity of their source estuaries. In addition to supporting fisheries, many fish and crustaceans found within the Hudson-Raritan Estuary are important to the ecological condition and functioning of the estuary (Strayer 2006). Predators and scavengers move carbon and nutrients from one trophic level to another and from one area to another. For example, juveniles transfer carbon and nutrient assimilated in the estuary to coastal and offshore waters. The restoration or rehabilitation of aquatic habitats into a mosaic of functionally related habitat types that address diverse fishery resource needs is clearly possible, and can be done if the functional relationships among habitats are recognized and used to focus habitat modification activities.

Policy and Management Relevance

The importance of habitat in managing fishery resources is well established in the scientific literature and the need to conserve and restore fishery resource habitats has become a national goal. The *Magnuson-Stevens Fishery Conservation and Management Act* directs the Regional Fishery Management Councils and the Secretary of Commerce to define and identify essential fish habitat (EFH) in fishery management plans (FMPs), to identify adverse effects to EFH, and to identify actions required to conserve and enhance EFH. The Acts identifies EFH as "…those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity" and those waters may include areas historically used by fish. Finally, the *Atlantic States Marine Fisheries Compact*, through the Atlantic States Marine Fisheries Commission, promotes the better utilization of the fisheries, marine, shell and anadromous, of the Atlantic seaboard by the development of a joint program for the promotion and protection of such fisheries, and by the prevention of the physical waste of the fisheries from any cause.

The habitats and their functional interrelationship, which is the focus of this TEC and other TECs, have or are being identified by Fishery Management Councils as EFH. Significant legislation calling for environmental conditions supporting fish and shellfish includes the *Clean Water Act*: "it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water."

Necessary Implementation Information

An important first step to implement this TEC is to classify existing benthic and aquatic habitats and to examine historic evidence to identify what has changed. This should be completed by 2009 in line with the *Hudson River Estuary Action Agenda 2005-2009* (NY State DEC 2005). From this evaluation, specific restoration targets can be formulated for each location, with respect to the species of interest, as well as the general spatial arrangement of habitats among the eight study areas used by USACE. The habitats that should be inventoried are partially listed in Table 5-1, and would include *Spartina*-based salt marsh, *Phragmites*-based marsh, intertidal areas by sediment type and man-made features, subtidal areas by sediment type and biogenic surface features, and water column habitats (such as the location and strength of the salt wedge and areas prone to hypoxia). Marsh, intertidal, and subtidal areas should be tied via GIS to seamless topographic/bathymetric maps. In addition to establishing historical trends for these habitats in each study area, change analysis also should focus on recent times with the goal to establish current rates of habitat loss or gain. Some work of this nature has been done recently (*e.g.*, Steinberg *et al.* 2004, Cerrato 2006), but this work needs to be expanded as much as possible and should consistently cross state boundaries in order to look at the entire HRE complex.

Essential fish habitat (EFH) of all 11 focal species has been described (summary and references) in Table 5-2. Quantifying the amount of EFH will be a challenge but is feasible. The types of habitats that constitute EFH are known in a general sense for these species, and EFH can be quantified at this general level from current and historic data sources (*e.g.*, Figure 5-1 in Steinberg *et al.* 2004).

The exact spatial arrangements and distances among habitats will be flexible by necessity. These target relationships can depend upon what we know about the habitat needs and risk factors (e.g., how much of a survivorship risk would individual EFHs 0.1, 0.5 or 1.0 km apart be?) for the fishery species targeted, if known, and their habitat use flexibility. It would also depend upon what habitats are already present, their size, shape, and quality, and spatial relationships to other nearby habitats. Another consideration will be the availability of bottom space and the opportunity and advantages of replacing existing aquatic habitats, almost all of which have some HRE ecosystem or non-fishery human use value. Additionally, the proximity of each habitat sets to other sets must acknowledge the lateral connectivity that is the focus of the Habitat Connectivity TEC. Implementation of the targets should also be viewed in the context of the other habitats discussed in other TECs and any effort to restore and maintain some semblance of relatively natural habitat diversity in certain areas. It may also depend upon if there are any physical interactions between adjacent habitat types, e.g., would an oyster reef enhance water column mixing and bring plankton or nektonic forage nearer to the bottom on down current habitats. It would be expected that each habitat set restoration/rehabilitation opportunity or site will have special characteristics that will require some judgmental evaluations and the design of restoring interrelated habitat sets may depend upon what can be done, more than what should be done. In some cases, the issue may include habitats to avoid when planning some set restoration, such as contaminated or predator rich areas, e.g., sea anemone fields.

Construction activities, such as building oyster reefs, may be used to meet the goals of the other TEC's. One path for implementing this TEC would add value by placing these newly constructed habitats at locations where they benefit from the nearby presence of habitat within the existing landscape to provide a complex that benefits fish, crab, or lobster. For example, oyster reefs constructed near salt marshes, whether those marshes exist presently or are marshes constructed to meet the goals of the wetlands TEC, are likely to benefit fish more than oyster reefs far from wetland habitats. Given the focus of the other TEC's, this path leads to an emphasis on areas between the shoreline (mainland or island) to a kilometer or so away because implementation of the other TEC's focus on this area. (Oyster reefs may be an exception if further study shows the reefs can be self-sustaining in the deeper, more saline, and predator-laden waters characteristic of areas far from shore.) An alternate path for implementing this TEC focuses on constructing habitats not directly addressed in the other TEC's (for example, building a sand flat) in order to increase local habitat diversity.

The above paths are not mutually exclusive, and careful evaluation of the opportunities and needs at specific locations may show pursuing both could benefit target species more than limiting actions to just one approach at that location. It also should be noted that a mosaic of three or more habitats can include both approaches. One example would be constructing on oyster reef near an existing salt marsh can also include building an island for birds. Another example would be constructing hard bottom near marsh that includes a tidal creek that has had barriers to fish passage removed. While both paths should be examined, the majority of the initial emphasis should be placed on adding value to the construction needed to implement the other TEC's because this approach is the most direct manner to returning key habitat mosaics to the HRE that have been lost.

The critical point of this TEC is that species depend upon more than one habitat for their survival and productivity and that once we have a aquatic habitat inventory and link species needs with that inventory, we can consider places where some habitat re-creation, restoration, or rehabilitation action can occur; a interrelated mosaic of functionally interrelated habitats should be a option in such action planning.

Measures of Performance

The measures of performance for this TEC would be the number of restored/rehabilitated habitat sets developed within each region. A second measure would the amount of suitable quality habitat included in defined sets. Because this TEC implies habitats meet common quality attributes for suitability (e.g., dissolved oxygen > 4 mg/l) some pre- and post-restoration monitoring will be needed. A monitoring program will allow testing of the underlying assumption that the abundance of demersal fish, crabs, and lobsters is limited to some extent by the amount of quality habitat in the Hudson-Raritan Estuary. The ideal performance goal of detecting an increase in populations of some target species is desirable but perhaps impractical given the many other influences on the population dynamics of these species, e.g., weather and spawning stock size management outside the HRE, as well as the logistics of attempting to get this data among the "noise" of these and other factors. However, if any means are found to do so with some level of confidence, e.g., measuring enhanced fish use of a restored habitat or habitat mosaic compared to control areas, they should be implemented.

Table 5-1. Habitat sets important to the survival and productivity of fishery resources in the HRE; the spacing information suggests the scale that these linked habitats can function best.

Habitat Sets	Functional Attributes and Spacing
Oyster reef, soft bottom, marsh fringe	Reef provides shelter for juvenile and smaller species, including forage; the soft bottom provides benthic invertebrate prey for predators using the reef for shelter; the marsh fringe is an alternate habitat for predators (e.g., blue crabs), that visit the reef to prey on small oysters, and the reef can dampen erosion forces on the marsh fringe habitat- <100m
Oysters and salt marsh	Blue crabs, and other species can diurnally, move between flooded salt marsh and oyster beds to feed and find shelter- <100m
Oysters and channels (dredged and natural)	Channels can provide the water flow to enhance healthy oyster reefs, and provide a low tide habitat for many motile organism visiting the reef to retreat, they also enhance the distribution of oyster larvae to establish new beds- <500m
Oysters and tidal creeks	Like for channels, but lower salinities can be involved which can enhance oyster spat survival- <100m
Oysters, tidal creeks, and salt marshes	These three habitats provide for close-by sheltering habitat for motile species at various tide levels- <100m
Oysters, tidal creeks and mud flats	As per above- <100m
Oysters, tidal creeks, salt marsh, and mud flats	As per the above- <100m
SAV beds, soft bottom, and marsh fringe	SAV provides the sheltering habitat structure that is important to many juvenile and adult motile species, that often find food on adjacent habitats- <100m
Salt marsh and adjoining tidal creeks	Again this set allows motile organisms to keep within a comfort range at various tide levels,- <100m
Piers and piling fields, good water flow, and soft bottom foraging grounds	The complex of baffles created by piers and piling fields have become important sheltering or orienting habitat to many fish and some invertebrates , but they function best when they have good water flow and access to near pier benthic feeding grounds- <100m

Table 5-1 (continued)

Habitat Sets	Functional Attributes and Spacing
Sponge and amphipod beds	Sponges provide micro-shelter for juvenile fish and invertebrates, as well as water filtering capacity, but their function is best when good foraging grounds, such as amphipod beds are present- <100m
Shallow intertidal zone and SAV beds	Schools of forage or juvenile fishery species often can be chased out of SAV by aggressive predators but can find shelter in nearby shallow intertidal area that does not allow these predators to easily pursue them, although other alert predators, e.g., wading birds and shore birds such as terns, can be advantaged-<100m
Peat banks and open sandy or muddy bottom, and good water flow.	Holes in peat banks harbor vulnerable juvenile lobster and American eels during daylight, but they need convenient open bottom foraging ground at night- <100m
Shallow sandy or muddy areas and channels	For some prey and predator species, channels provide a nocturnal refuge after daytime foraging on the open bottom, or a vice versa, e.g., for mysid shrimp-<500m
Marsh islands or points and good water flow near known or suspected winter flounder spawning areas	The tidal eddies at the tips of marsh islands or projecting points have been found to be favored placed for larval winter flounder who find a calmer place there to feed upon zooplankton- <100m
Clean hard bottom and active oyster reef and good water flow (overlaps Oyster TEC)	Oyster larvae are distributed by tides and for oyster restoration as habitat to reach distribution-abundance goals, clean hard substrates must be available within a few tidal cycles of dispersal for the larvae to set- <500m
SAV and shallow water habitat and clam beds	In the past extensive soft clam beds were found inshore of eelgrass beds, and these clam beds provided prey for crabs and winter flounder- <100m
Hard bottom and channels in more marine areas	This combination can allow for the development of epifauna communities, especially blue mussel beds, that can provide forage and shelter for fish and other motile fishery/forage species, as well as more water column filtering capacity- <100m

Table 5-2. Essential fish habitats and relationships for select demersal fish and motile shellfish in the Hudson-Raritan Estuary; superscript indicates principle sources of information used per species.

Focal Species	Essential Habitat	Important Habitat Mosaic
Summer flounder (*Paralichthys dentatus*) [a.] This estuarine-dependent species is a very popular sport and food fish in the polyhaline parts of the HRE during warmer months.	• Spawning occurs in on the continental shelf in the fall and winter. • Larvae enter estuaries also in the fall through winter and settle on sandy sediments. • Juveniles are usually found in estuaries and inshore waters, but move offshore in the winter with adults. • Adults are warm seasonal visitors to NY Bight coastal-estuarine waters.	Juveniles often are found along marsh fringes and up marsh creeks over muddy or shell hash bottoms in lower salinity waters, but will also use SAV beds. Older juveniles and adults are often caught on or next to structured habitats, including artificial reefs. They are opportunistic benthic and nektonic feeders, and diets tend to include more fish as they grow.
Winter flounder (*Pseudopleuronectes americanus*) [b.] This estuarine-dependent species is a very popular sport and food fish in the poly-/mesohaline parts of the HRE during cooler months.	• Spawning occurs on mud, sand or gravel sediment types within the estuary, primarily within the 10 to 32 ppt salinity zones. • Juveniles are mostly found in estuarine/coastal waters with salinities above 20 ppt and on a variety of bottom types, including SAV. • Adults occur in salinities above 15 ppt and along coastal areas on almost all bottom types.	The juveniles and adults prefer bottom temperatures within the 10-25 degree C range and will move to deeper and cooler water in the summer, and in the HRE, this is usually the lower estuary channels or beyond the estuary mouth. Post-larval diets are basically a wide variety of benthic invertebrates, including clam siphons.
Black sea bass (*Centropristis striata*) [c.] This species is a very popular sport and food fish in the polyhaline parts of the HRE during the warmer months since colonial times; in fact George Washington went fishing for "blackfish" off Sandy Hook in the 1790s.	• Spawning occurs on the continental shelf and coastal waters and larvae make it to near the mouths of estuaries before settling. • Juveniles use estuarine and coastal areas usually within some structured habitat type, such as SAV, shellfish or sponge beds. • Older juveniles and adults migrate offshore during the colder months, but during warmer months inhabit structured coastal habitats, such as mussel beds, reefs and wrecks.	Juveniles may be found associated with salt marsh fringe and channels. Although juvenile and adult black sea bass are closely associated with structured habitats, they may obtain much of their food from pelagic/nektonic (e.g., small fish and squid) sources or soft bottom habitats, e.g., crabs and bivalve mollusks.

Table 5-2. (Continued)

Focal Species	Essential Habitat	Important Habitat Mosaic
Scup (*Stenotomus chrysops*) [d.] This species is a very popular sport and food fish in the polyhaline parts of the HRE during warmer months, and Raritan-Lower Bay supported a major scup fishery until the mid-1960s.	• Spawning occurs in coastal waters during the spring-summer. • Juveniles are common in estuaries during the warmer months in salinities above ~15 ppt; they form small similar-size schools over a mix of habitat types, from mud to mussel beds. They follow the adults offshore during cooler conditions. • Older juveniles and adults are common in the estuary and coastal waters during warmer conditions and over just about every habitat type, from mud to structured habitats.	They commonly use of a variety of estuarine and coastal habitat types and have a broad dietary spectrum from benthic invertebrates to small fish that allows them to occur in many areas of the HRE. They may not be comfortable in confined waters, such as in marsh creeks, having not been generally reported there.
Tautog (*Tautoga onitis*) [e.] This semi-estuarine-dependent species is a very popular sport and food fish in the polyhaline parts of the HRE during all but the coldest months.	• Spawning occurs near the mouths of estuaries and inshore waters. • Juveniles settle in shallow estuarine waters and prefer vegetated or sheltered areas. • As tautog grow they gradually move to deeper waters but always near structured habitats, such as mussel or oyster beds, or rocky reefs or man-made structures.	Tautog in all post-larval life stages are structure oriented, and except for foraging forays on near-structure open bottom when reef food is scarce, will normally be found within or near such structures or shelter. They tend to move out of estuaries and into deeper and warmer coastal waters in the winter, or go into a semi-torpid state within a shelter or shallowly burrowed in sediments.
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Table 5-2. (Continued)

Focal Species	Essential Habitat	Important Habitat Mosaic
Oyster toadfish (*Opsanus tau*) [f.] Although this species is common in many other estuaries, an ethnic fishery for this species in the HRE area has reduced its abundance to a level to be of concern to fishery managers. It may have an ecological role in the HRE by reducing the predation on young shellfish, such as oysters, by crabs. The species is also widely used in physiological and biomedical experiments and research.	• Spawning occurs in early summer and the large eggs are laid in dens under things. Larvae stay near the den until yolk sac is absorbed. • Little has been reported on the habits of juveniles. • Adults are carnivorous ambush predators and live on the bottom in shallow water.	They are most common on sandy or muddy bottom, hiding among SAV, or under objects where they hollow out dens. Little else is known of the habitat use of this cryptic species.
Striped bass (*Morone saxitilus*) [g.] This estuarine-dependent, anadromous species is a very popular sport and sometimes food fish in the HRE- the commercial fishery closed in 1976 because of PCB contamination. There is a distinct Hudson River stock with limited distribution.	• Spawning occurs in the mesohaline Hudson River in the spring. • Juveniles occur throughout the HRE but distribution may peak at in the lower river near the salt front where many winter. • Adults can range widely and can occur from the fresh water parts of the HRE to adjacent marine coastal areas.	Juvenile bass feed in shoals areas but may move to channels to allow flood tide to move them back upstream. The bass may be more oriented to water mass than to bottom types, although they commonly use open areas, interpier areas and semi-enclosed basins. Adults are likely to be found off sandy beaches and along rocky stretches where fish prey is most available.
American eel (*Anguilla rostrata*) [h.] This catadromous species was once a very popular sport and food fish in the polyhaline parts of the HRE, but a recent decline in abundance and consumption advisories, because of high toxic organic chemical levels in its tissues, has reduced its value. Recently its glass eel stage has attracted a live export fishery to support aquaculture grow-out businesses in Europe and Asia where eels are more valued than in the US.	• Spawning occurs in the depths of the Sargasso sea. • Leptocephalus larvae move inshore and onto the continental shelf where they gradually change to the glass eel stage. • The glass eel stage moves inshore into estuaries and upstream and, when they start to show dark pigment, they are called elvers. The female elvers continue upstream to fresh water but the males may stay in the more saline parts of the estuary. • After 9-30 yrs in fresh water habitats, the mature yellow-phase females migrate downstream to become silver-phase eels and join the males for their spawning migration to the open ocean.	The complex life of this species involves a multitude of habitats, from deep ocean to the headwaters of freshwater flows within the HRE watershed. It seems to recruit randomly to estuaries and river system, so there may be no distinct local population, unlike shad or salmon. The species prefers dark conditions and shelter, and much of its life history and specific habitat uses are poorly known within the HRE. It is omnivorous and will exploit whatever potential food it can detect and get into its mouth, including carrion; this can expands its habitat use during nocturnal foraging.

Table 5-2. (Continued)

Focal Species	Essential Habitat	Important Habitat Mosaic
Horseshoe crab (*Limulus polyphemus*) [i.] This ancient, estuarine-dependent species is common in the polyhaline parts of the HRE. It was once harvested within the HRE as fertilizer, but now is valued for its blood, used for medical purposes, and for its eggs that are laid in the upper beaches in the late spring. These energy-rich eggs are food for migrating shore birds. A bait fishery for this species occurs to the south, where it is more abundant- it is used to bait eel and conch traps.	• Spawning occurs near the high tide line on polyhaline beaches in the late spring and early summer during an evening high full or new moon tides where eggs are buried. • Larvae hatch within 2-4 weeks when the next such high tide washes their nest although some eggs may not hatch for many months to a year. • The larvae and juveniles gradually disperse from their hatching beach to nearby shallow waters and shoals to feed and to burrow under the sand for protection from predators. • Adult crabs winter in deeper offshore waters and migrate inshore into estuaries as water warms. They are found on a diversity of bottom types, but because their food is more available to them in softer sediments, are more abundant there.	The horseshoe crabs dependence on having ready access to open, undisturbed sandy beaches in calmer waters with a portion of the beach at or above the mean high tide level for egg laying and larval development is its primary habitat limitation. Beach quality, e.g., slope, width, or sediment grain size, may influence spawning. As a ~200 million year old survivor, it has been able to adapt to the habitats available to it during that time. This species is thought to be fairly tolerant of heavy metal and oil contamination, but some pesticides and metals can cause larval malformations.

a. Packer *et al.* 1999
b. Periera *et al.* 1999
c. Steimle *et al.* 1999
d. Steimle *et al.* 1999
e. Steimle and Shaheen, 1999
f. Collette 2002
g. Dovel 1992; Waldman 2006
h. Morrison and Secor 2003; Waldman 2006
i. Walls *et al.* 2002; Shuster *et al.* 2003
j. MacKenzie 1992; Mercaldo-Allen and Kuropat 1994
k. Briggs 1998; Stehlik *et al.* 1998

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VI. ENCLOSED AND CONFINED WATERS

Target Ecosystem Characteristic

Upgrade the designated use of eight enclosed waterways or tidal creeks to match the designated use of their receiving waters.

Poor flushing has led these areas to become more contaminated in many cases than adjacent open waters of the estuary. The initial target to upgrade eight such areas should be achieved by 2012

Upgrade the designated use of all enclosed waterways and tidal creeks within the estuary to match or surpass the designated use of their receiving waters.

Based on experienced gained from achieving the initial target, this long-term target should be achieved by 2050 and remain indefinitely in the estuary system.

Background

Historically, over 100 tidal creeks emptied into the Hudson Raritan Estuary south of the Tappan Zee Bridge. These tidal creeks were associated with about 85,000 acres of tidal marsh and together comprised an important part of the estuarine ecosystem. Many of these creeks were filled or turned into culverts as the metropolitan area grew. Other creeks were partially filled leaving basins or canals without adjoining wetland areas. Some were dredged, often to depths three or more times greater than their ambient depth, in order to obtain fill material or to provide local navigation channels or anchorages.

As a result, many tidal creeks have become enclosed water bodies isolated from wetlands and only flushed by the tide on an irregular basis. Many also receive significant amounts of stormwater runoff, including discharges from combined sewer overflows. Due to patterns of development within the metropolitan area and past preservation efforts, many of the remaining enclosed waterways are associated with Jamaica Bay (Figure 6-1). A few others are within created land areas.

The combination of poor tidal flushing and high amounts of stormwater runoff laden with sediments, bacteria, organic carbon, and toxic contaminants has led to degraded water quality. Of particular concern are high bacteria counts (e.g., enterococcus) and low dissolved oxygen concentrations in many of these confined waters, especially when water temperatures are high. In addition, benthic habitats are commonly of poor quality. The sediments are exceptionally soft, often making it difficult to discern the interface between the sediment and the overlying water. Such sediments have few benthic animals, and those that are present likely have high concentrations of contaminants within their bodies, making them an undesirable source of food for humans or for the fish and crustaceans that feed upon them. When the dissolved oxygen concentrations are chronically low, mats of the sulfur bacterium *Beggiatoa* spp. are also likely to form.

The transformation from undisturbed creeks and streams to enclosed and confined waters also represents substantial loss of a significant habitat. Tidal creeks are many times more important to an ecosystem than implied by their area. This is why their restoration should be a priority. Marsh, seagrass, oysters and intertidal mud and sand flats serve as foraging and nursery areas for fish, crustaceans, and wading birds. Tidal creeks not only have the greatest concentration of these habitats, they also provide these habitats in close proximity to each other. This facilitates the movement of animals as they mature and their ecological needs change. These areas also nurture wetlands that can cleanse much of the runoff before it reaches the estuary, trapping sediments and contaminants that overload benthic communities and degrade subtidal habitats. Lastly, tidal creeks and enclosed basins provide the public with opportunities to directly access the shore for water-dependent recreation, making them important in shaping public perception of the value of the Hudson River Estuary.

While the natural ecological functions of tidal creeks become severely reduced as they are converted to enclosed waterways do serve a new function. They tend to retain and concentrate materials from stormwater runoff and combined sewer overflows, preventing the entry of such contaminants to the broader estuary. Many enclosed waterbodies also serve as “depositional zones” for sediment-bound contaminants from other portions of the harbor. Therefore, their restoration is complex and will achieve only localized benefits, unless restoration includes consideration of the quality of water delivered to the broader estuary.

Target Justification

Technical Merit

Both New York and New Jersey classify their waterbodies by how much they can be safely used by the public, and the states regularly report on the condition of these enclosed and confined waters. For example New York State designates five classes for “Best Use” – shellfishing (SA), bathing (SB), bathing/fishing (SC), fishing (I) and fish survival (SD) (Figure 6-1). The best use classification includes all the uses in the lower class and excludes all the uses in the higher use class. New Jersey estuarine waters have designated uses including primary and secondary contact recreation (i.e., swimmable); fish consumption, shellfish harvesting and maintenance, migration and propagation of the natural and established biota. The designated uses are assigned into three classification levels: SE 1 - Shellfish/Bathing, SE2 - Fishing and Fish Propagation and SE3 – Fishing and Fish Migration (Figure 6-1).

The designated use for many of the enclosed basins and tidal creeks is typically lower than the designated use class for the adjoining, larger waterbody. The focus of this Target Ecosystem Characteristics is therefore to upgrade the designated use of the enclosed waterways and tidal creeks to match the designated use of their receiving waters. This will require both cleanup and reconnection of the basins and creeks, and assurance that they are not delivering water that is degrading the larger receiving waterbodies.

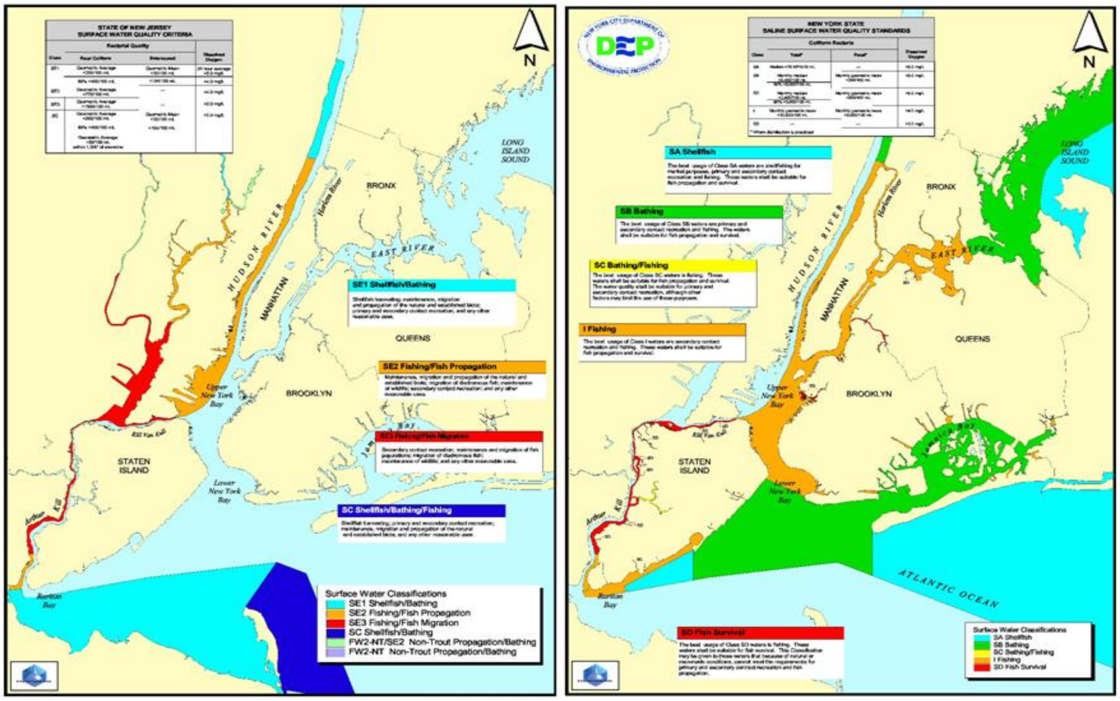

Figure 6-1 .Water Quality Classification of New York Harbor (HydroQual, 2006)

Each impaired creek and enclosed basin will likely require a different set of actions to restore water, sediment, and habitat quality. Some sets of action can be easily implemented. Others, such as those that involve combined sewer overflows, are major undertakings. Using phased goals for these areas will set the basis for integrating their restoration with other efforts in the harbor to improve water quality and reduce sediment contamination.   It will also help to set priorities for which clean-up actions should come first, while still recognizing that it is feasible to restore all the impaired tidal creeks of the estuary by 2050.

Policy and Management Relevance

Water quality in enclosed basins is tied to New York State and New Jersey water quality standards and other provisions of the Clean Water Act such as listings of impaired waters and total maximum daily load (TMDL) allocations. Enclosed basins are also included in the Use Attainability Analysis (UAAs) being conducted by the New York State Department of Conservation to evaluate the appropriateness of existing standards. In a complementary program started in 1999 NYCDEP began working on the Use and Standards Attainment (USA) project designed to address the non-attainment of water quality standards in harbor water and tributaries. The USA project will comprehensively evaluate the classification plan, designated uses and related water quality standards (McMillin 2000).

Necessary Implementation Information

Successful restoration of the enclosed basins and tidal creeks will require site-specific technical and engineering studies that determine the cause(s) of non-compliance, acceptable rates of flushing, stormwater delivery rates, and concentrations of enterococcus, dissolved oxygen, and total organic carbon. These site-specific studies may also show the need to include other environmental parameters as design goals.

Measures of Performance

The long-term measure of performance is the condition of the waterbody and whether that condition matches the designated use of the receiving water. Intermediate measures of performance, however, are useful to gauging progress and diagnosing impediments to achieving the long-term goal. Useful intermediate measures include metrics focused on water and sediment quality and metrics focused on the habitats occurring within the basins and tidal creeks.

- By basin/creek, rolling 30-day geometric means and single sample maxima for enterococcus.
- By basin, percent of observations of dissolved oxygen concentration that meet state water quality standards.
- By basin, acres of the seabottom within the enclosed basins that meet acceptable levels of sediment organic carbon (e.g., less than 5 percent organic carbon).
- Acres of water surface where the 1-percent light depth reaches the bottom or 4 meters (whichever is shallower).
- Acres of estuarine emergent marsh hydraulically connected to the basins and tidal creeks.

Information Sources

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VII. REDUCTION IN TOXIC CONTAMINANTS IN HRE SEDIMENTS

Target Ecosystem Characteristic

> ***Isolate or remove one or more sediment zone(s) totaling at least 25 acres which is contaminated based on the criteria listed below under Measures of Performance***

This interim goal should be achieved by 2012.

> ***Starting in 2014, isolate or remove one or more such areas totaling at least 25 acres every 2 years until 2050 or until such time as all HRE sediments are considered uncontaminated based on the sediment quality characteristics specified under Measures of Performance.***

Background

Sediments of the Hudson River Estuary (HRE) are a key component of the estuarine ecosystem supporting not only the ecological well-being of benthic communities, but also the recreational, commercial and industrial uses of the estuary. Due to a variety of historical and ongoing human activities, sediments throughout the estuary are contaminated with a variety of toxic chemicals including PCB, dioxin/furans, PAHs, pesticides, mercury and other metals. In much of the estuary, contaminated sediments have been linked to high levels of toxic contaminants in fish and other marine life, and have led to a number of fishing / shellfishing bans and fish consumption advisories. In addition, sediment contamination has resulted in more than three quarters of maintenance-related dredged material being characterized as unsuitable for unrestricted beneficial use or ocean placement due to excessive toxicity or bioaccumulation potential.

Because of the role of benthic habitat, clean sediments are a necessary prerequisite for achieving many other TECs including shorelines and shallows; fish, crab and lobster habitat; oyster and oyster reefs; eelgrass beds; and coastal wetlands. In simplistic terms the higher the sediment quality, the more likely there will be a healthy benthic ecosystem that supports these desired habitats.

Target Justification

Technical Merit

Harbor sediments serve as a long-term repository of many toxic chemicals listed above. Effects of contaminated sediments on ecological function and human use of the harbor are manifested in various ways including:

1. acute and chronic toxicity to benthic organisms
2. accumulation of toxic chemicals in benthic organisms and higher trophic organisms
3. limitations on the unrestricted beneficial use and disposal of dredged material from harbor shipping channels and berths
4. continuous release of toxic chemicals to the overlying water

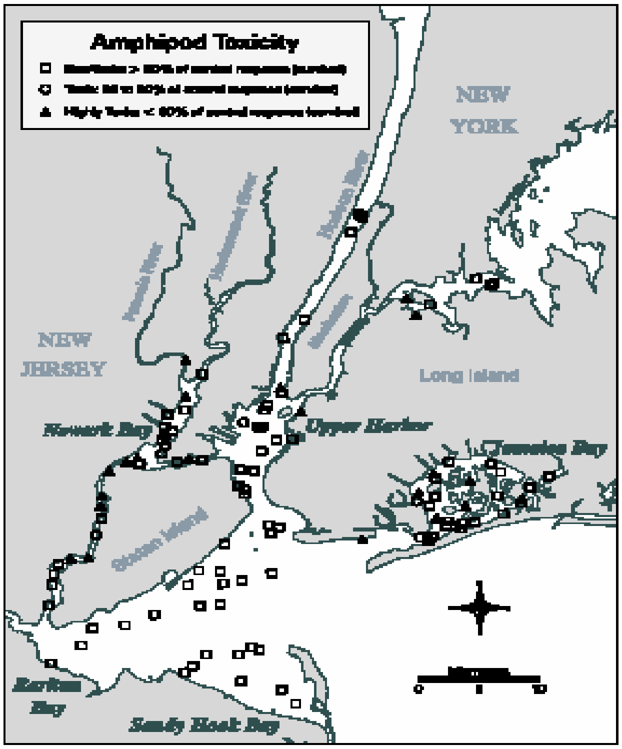

Figure 7-1. R-EMAP amphipod toxicity results (Adams and Benyi, 2003)

Several monitoring programs and special sampling studies have been conducted to characterize effects of toxic contamination in harbor sediments. For example, 10-day toxicity tests using the amphipod, *Ampelisca abdita*, were performed on surficial sediment collected throughout the harbor (Adams et al, 1998; Adams and Benyi, 2003). Results (as summarized in Figure 7-1) show that 12% of the harbor sediments were found to be acutely toxic. In addition, Rice et al. (1995) have shown in laboratory studies with HRE sediment that growth rates of a deposit feeding polychaete, *Armandia brevis*, were reduced in sediments with higher contaminant levels.

In addition, a direct relationship between contamination levels in HRE sediments and accumulation of toxic chemicals in the deposit feeding polychaete, *Armandia brevis*, and non-deposit feeding amphipod, *Rhepoxynius abronius*, has been demonstrated in laboratory bioaccumulation studies (Meador et al. 1997). These results are consistent with Contamination Assessment and Reduction Project (CARP) field-collected samples which show higher contaminant levels in worms, clams and crabs that were collected in the more contaminated areas of the harbor (HydroQual, submitted). Based on separate monitoring studies, NYS Department of Health and NJ Department of Environmental Protection currently have fishing bans and consumption advisories in place for various fish and shellfish species throughout the estuary. Dredged material testing on harbor sediments has also shown that a large percentage of the harbor has sediment that is unsuitable for disposal at the Historic Area Remediation Site (HARS) due to toxicity and bioaccumulation potential (Battelle 1996a-e). Lastly, modeling studies conducted under the CARP estimate that current releases of chemicals from contaminated sediments to the overlying water are in large part responsible for exceedances in NYS and NJ water quality standards (HydroQual, submitted).

Reductions in sediment contamination levels are therefore expected to result in a direct reduction in toxicity to benthic organisms and a reduction in bioaccumulation potential of toxic chemicals in both benthic organisms and higher trophic level species. Modeling studies conducted under CARP show that for many of the contaminants of concern the "in place" sediments are controlling the contaminant distribution in much of the estuary (HydroQual, submitted). The sediment TEC is therefore based on limiting the influence of "in place" sediment contamination through either a removal action or isolation by "capping" these sediments with cleaner sediments.

Policy and Management Relevance

Currently, 2-4 million cubic yards (MCYs) of sediment are removed from the harbor channels and shipping berths each year as part of maintenance dredging operations. Because of toxic contamination, a large fraction of this dredged material is currently considered unsuitable for aquatic capping at the HARS or for other unrestricted beneficial use projects in the harbor. Achieving the goal of clean sediments throughout the harbor is expected to provide an estimated dredged material disposal cost savings of more than a billion dollars over 40 years (USACE, 1996). In addition, cleaner sediments would result in reduced levels of toxic chemicals in fish and shellfish throughout the harbor region. This would reduce the health risks to subsistence fishers who continue to fish harbor waters despite the current fishing bans and advisories (NYS Department of Health, 1999), and would ultimately result in lifting of current fishing / shellfishing bans and advisories. In addition, a re-opening of commercial fisheries in the estuary would provide significant economic benefit to the region.

Reduction in sediment contamination levels will likely be achieved in time through source reduction, "Superfund" remedial actions in the harbor and its tributaries, and natural attenuation processes. In addition, maintenance dredging operations can help enhance the rate of contaminant reduction in HRE sediments. For example, dredging operations in contaminated areas of the harbor can be designed to reduce contaminant levels in newly exposed sediments by final adjustments of project depths. In addition, dredging of cleaner sediment, e.g., from Ambrose Channel and from pre-industrial deposits in channel deepening projects can be judiciously used as capping material to isolate highly contaminated sediments or to create cleaner sediment substrate for fish, crab and lobster habitat; oyster and oyster reefs; eelgrass beds; coastal wetlands, etc.

The TEC set out above is intended to supplement any proposed or planned Superfund actions in the estuary. Superfund remediation along with actions included in this TEC would therefore work together in reducing the overall time required to achieve uncontaminated sediments throughout the harbor.

Necessary Implementation Information

Successful implementation of the sediment TEC will require information on present distributions of toxic chemicals in the sediment, along with projections or estimates of future chemical concentrations in water, sediment and biota throughout the estuary. This information will be obtained largely from the CARP monitoring and mass balance modeling study that was recently completed for NY-NJ Harbor and adjoining waters (HydroQual, submitted). In particular, the CARP mass balance model will be extremely useful in examining the effectiveness of various implementation strategies in meeting long-term reduction goals. Additional sampling data will likely be required in and around specific project sites to identify finer-scale sediment transport behavior and current toxic contaminant distributions in sediment.

Measures of Performance

For the near term (Year 2012), the effectiveness in isolating or removing one or more contaminated sediment zones of at least 25 acres in total area will be assessed by comparing pre- and post-action contamination levels in surficial sediment. This evaluation will be based on:

1. 10-day acute toxicity testing for using the amphipod, *Ampelisca Abdita,* and following the HARS protocol.

2. 28-day bioaccumulation testing of sediments using the dredged material test organisms, *Nereis virens* and *Macoma nasuta*. Testing results will ultimately be compared to HARS matrix values PCBs or dioxins to assess performance.

3. Direct measurement of toxic contaminant concentrations in sediments. These measurements will be compared to human health or ecologically risk-based limits for toxic concentrations in sediment, as determined from New York State and New Jersey fish / shellfish advisory limits or other regulatory-based values and appropriate Biota Sediment Accumulation Factors (BSAFs) for crabs or other benthic organisms (e.g., see HydroQual, submitted)

For the longer term, isolation or removal of one or more contaminated sediment zones of at least 25 acres in total area every two years will be continued until such time that toxic contaminant levels in the HRE meet the following:

1. The sediment quality characteristics specified above
2. All related water quality standards
3. Any related fishing / shelling bans or fish consumption advisories
4. Any newly-promulgated sediment quality standards, criteria or protocols.

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USACE New York District (1996) Dredged Material Management Plan for the Port of New York and New Jersey Interim Report, September 1996, 244 pp.

VIII. TRIBUTARY CONNECTIONS

Target Ecosystem Characteristic

> ***One less barrier per year blocking the free movement of fish from estuary waters to at least three different inland habitats.***

While this TEC is related to the TEC on Enclosed and Confined Waters, the focus here is on the movement of fish species through the removal of natural or manmade barriers that prevent access to traditional upstream habitats. The initial target is to be met through 2012. The long-term target for the period 2012 through 2050 is:

> ***Continue reconnecting coastal and inland habitats at a rate of 1 project per year until all near-estuary barriers blocking inland access have been removed or made passable. Half of the new connections during this period should reach at least three new habitats.***

This long-term target should be achieved by 2050 and remain indefinitely in the estuarine system.

Background

Both resident and migratory fish move to different habitats for reproduction, rearing, feeding, refugee, and more. Therefore, reconnecting aquatic habitats would increase the environment available to fish and other aquatic species, and remove constraints on specific life stage needs. Free movement of aquatic species would also allow biotic energy transfer and full exploitation of habitats, and would increase the complexity of habitats linked to the Hudson River Estuary ecosystem. This TEC is based on fish access because barriers and passage can be analyzed using available biological criteria on fish swimming and jumping abilities. We assume that free movement of modest size fish will also allow movement of most other organisms. Barriers could be tributary dams, culverts, pipes, sand and marsh shallows, and sedimented channels.

Methods to reconnect fragmented tributary-estuary connections are barrier removal, modification of the barrier or site to promote passage, and construction of fish passage ways (fish ladders, bypass channels, etc.). We recommend using alewife (*Alosa pseudoharengus*) as the species for determining what structures act as barriers and how site modifications can allow passage. Alewife is a common anadromous fish of the HRE (Schmidt and Lake 2006) and it is in the herring family (Clupeidae) which includes many prominent migratory fishes of the ecosystem. More importantly it does not have large size, ability to overcome high water velocities or strong jumping ability, so using this fish for barrier identification and passage design will result in restoration actions that serve a large portion of the fish fauna of the estuary and connected waters.

Tributary and associated aquatic habitats to be connected to open HRE waters include ponds, lakes, wetlands, streams, and rivers. Ponds can be defined as small lentic freshwater bodies with a littoral zone (illuminated to substrate) comprising the majority of the surface area. Lakes are larger and have a larger portion as deep water. Wetlands are commonly mapped (e.g., Will and Schneider 2005) due to regulations that apply to their use. Flowing waters of streams and rivers should be classified as habitats by stream order (1st, 2nd, 3rd, etc.) from a 1:24,000 USGS topographic map (method of Strahler 1964; in Gallagher 1999a).

Our strategy of specifying that reconnections include at least three different habitats will put priority on barriers blocking access to a variety of waters. We assume for example, a dam blocking access to a river segment (confluence to confluence on 1:24,000 USGS map) with first and second order tributaries will provide more newly available habitat, and a range of habitats that can support several mobile species. Greater ecosystem benefits would be expected when a diversity of aquatic species are provided new habitats.

The HRE study regions appear to differ in the extent that dams are blocking freshwater streams, rivers, and ponds (Figure 8-1). For example, the Raritan River area has several dams while other areas like the Upper Bay have none. Figure 8-1 shows 76 dams in the HRE system but only about 30% appear to be near estuary waters where removal would provide inland habitat access. A system-wide reconnection rate of one project per year would likely exhaust all reconnection opportunities before 2050. Therefore, we do not specify reconnection project numbers by study area for this TEC.

Target Justification

Technical Merit

The watershed of the Hudson-Raritan Estuary has been extensively used by a dozen or more major migratory fish species (Waldman 2006). These include anadromous species that leave the marine environment to complete an essential phase of their life cycles in the Hudson-Raritan Estuary. Examples of important migratory species of the HRE are American shad, hickory shad, alewife, blueback herring, striped bass, Atlantic tomcod, American eel, and in the recent past, the southernmost spawning population of rainbow smelt (Rose 1993). Migratory fish require open passage along the watershed's complex network of rivers and streams (Schmidt and Lake 2006). Many of these fish once supported significant commercial fisheries in the Hudson-Raritan ecosystem (Limburg et al. 2006), but are now at historic low abundances. Finally, resident fishes are known to make movements within the system to exploit different habitats (Gowan et al. 1994) for fry dispersal, juvenile rearing, thermal refuge, and daily movements for feeding and cover. The US Fish and Wildlife Service (1997) reviews relevant species requirements for diversified habitats and access to inland waters. At present most of the required coastal habitats are blocked by dams, road culverts, bridge aprons, railroad beds, and other structures.

Policy and Management Relevance

Many barriers to fish passage such as low dams supported early American industry and agriculture. Many are no longer needed and their removal is the focus of the National Open Rivers Initiative (NOAA 2005) and National Fish Passage Program (US Fish and Wildlife Service 1999). Others that are still serviceable to local communities for water supply, recreation, and utilities but often they can be modified to restore habitat connectivity and fish passage. Other structures acting as barriers such as culverts can be modified or replaced. Restoring habitat connections is a high priority for the New York Bight portion of the Northeast Atlantic Coast (Restore America's Estuaries 2002), and some progress has been made already in the HRE watershed.

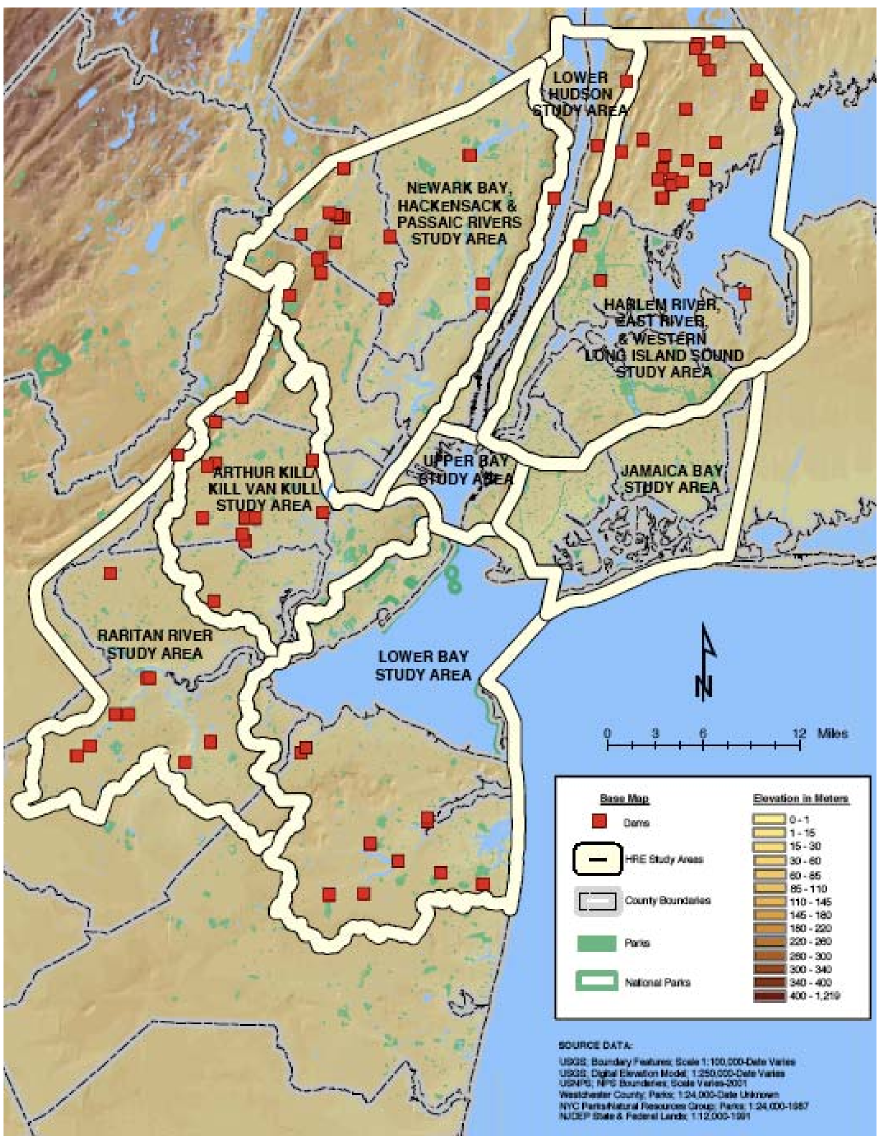

Figure 8-1. Dam Locations in the Hudson-Raritan Estuary ecosystem restoration project area by study areas. From: US Army Corps of Engineers (2005)

Necessary Implementation Information

Some barriers are the result of natural or man-induced sediment placement and can be readily removed or channeled. Others are structures, and the common way to reconnect coastal habitats is to remove all or part by breaching. Structures such as culverts, diversions, or low dams can sometimes be redesigned to provide water velocities and a gradient navigable by fish. Other common solutions include burying culverts below the waterline, redesigning approaches, changing elevations with simple pool and weir configurations, and providing a notch in the structure that provides a stream of water to allow passage (US Fish and Wildlife Service 1997). Fishways are common engineering solutions to fish passage, and they can sometimes be inexpensive to construct.

Methods to quantify the potential of a barrier to block fish movements are available in Reiser and Peacock (1985) and Gallagher (1999b). The same information can be used to mitigate barriers and design modifications allowing passage. The information can be used for a wide range of barriers: natural and small artificial structures, large dams, and even stream habitat conditions. A barrier exists if fish cannot pass the structure or location by swimming, jumping, or passing through a fish ladder or fishway. To swim over a structure, the fish must swim faster than the slowest water velocity. Fish can jump over a structure if the maximum jumping height of the fish is greater than the height of the structure and the pool of water below the structure is deep enough for the fish to reach maximum jump height.

Barriers and proposed modifications should be assessed relative to the alewife under typical seasonal flow for the movement times. The following data are needed: vertical height of structure, width of stream or passageway, breadth of water flow over structure, and the gradient at the site. The following questions should be considered when judging a barrier and proposed modifications:

- Is the maximum jumping height of the fish higher than the structure?
- Is the darting speed of the fish faster than water flow over the structure?
- Is the darting speed of the fish faster than the tail water velocity?
- Is the depth of the plunge pool *either* greater than 1.25 times the height of the barrier or more than 2.5 m deep?
- Does the plunge pool water have laminar flow within one-third the height of the structure out from the base?
- Is the gradient of the cascade steep (>45°)?
- Is the culvert level rather than on a gradient?
- Is the culvert made from a rough material?
- Is the maximum darting distance of the fish greater than the length of the culvert?

Biological data and estimation algorithms to answer these questions and other engineering criteria can be found in Reiser and Peacock (1985), Durkas (1993), Gallagher (1999b) and numerous publications by the US Fish and Wildlife Service and the US Geological Survey (http://fpdss.fws.gov/index.jsp).

Measures of Performance

The measure of performance for this TEC should be the number and types of habitats reconnected to the open waters of the HRE. Additional metrics that focus on the response of fish populations would be valuable and could include changes in the size of fish runs between years or the number of larvae or juvenile fish found in those reconnected waters.

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IX. WATERBIRDS

Target Ecosystem Characteristic

> ***Enhance at least one island within each of four island groups (Westernmost Long Island Sound, East River region, Staten Island area and Jamaica Bay) to provide roosting and nesting sites for waterbirds.***

This initial target for the Hudson-Raritan Estuary should be achieved by 2012. Based on the success of these initial island restorations, the long-term goal is:

> ***All islands in the four island groups provide roosting and nesting sites.***

This long-term target should be achieved by 2050 and remain indefinitely in the estuary system.

Background

Restoration of waterbird habitats is crucial to increase the biotic diversity of the Hudson-Raritan Estuary (HRE), and important to bringing bird watchers to natural habitats in the NY-NJ Harbor area. Waterbirds play important roles in river and adjacent terrestrial ecosystems as predators on shallow-water fish and crustacea and as prey to other vertebrate carnivores, and they are among the public's favorite wildlife for viewing. They provide a sense of nature even in the highly urbanized landscape of New York City, and have considerable educational value. Adequate populations of waterbirds help sustain ecosystem functions and provide the public ample opportunity for viewing them. Restoration efforts are all the more important because of declines in waterbird populations in the northeastern United States.

The nesting species of primary concern are Harbor Herons, which include black-crowned night herons (*Nycticorax nyticorax*), glossy ibis (*Plegadis falcinellus*), snowy egrets (*Egretta thula*), great egrets (*Casmerodius albus*), and cormorants (*Phalacrocorax* spp.). The name Harbor Heron was given to these species by New York City Audubon when they launched the Harbor Herons project in the 1980s to monitor populations and protect their habitat.

In order to provide nesting habitat for these species, restoration of island habitats is preferred (Kerlinger 1996, 1997, Rhoads et al. 2001). Islands of greatest interest are located in the area of Rikers Island, along the east Bronx, along the East River and in various other sites within NY/NJ Harbor, such as the Kill Van Kull, Arthur Kill, east of Staten Island and Jamaica Bay. Some of these islands currently support waterbird nesting and roosting, as they are undisturbed by humans and have been allowed to grow over with vegetation. Wetland and beach habitats are also important to waterbirds, especially freshwater and saltwater marshes. They are rich in small fish and crabs, and wetland creeks are ideal feeding sites for egrets and herons. Small wetland areas as well as very large sites such as the Jamaica Bay marsh and creek complex are important as sites for roosting, feeding, and nesting. Protected beaches with intermittent vegetation, especially those with broad supratidal sand flats are especially important for nesting by terns and smaller birds such as sandpipers.

Waterbirds have a large ecological impact on ecosystem function and are in turn greatly affected by their habitat setting and environmental surroundings. In migratory sites such as Jamaica Bay, visiting waterbirds such as oystercatchers, sandpipers, white ibis and curlews rely heavily on soft-sediment invertebrates (Schneider 1978), while others such as black-crowned night herons, herons, and egrets stalk fishes and crabs in shallow areas. Still other species such as double-crested cormorants, terns and gulls feed on more open water fish populations. Additionally, the islands provide vital stopover habitat for migratory birds every spring and fall. Protection of bird nesting sites inevitably has the side effect of protection of substantial areas of natural habitat from human disturbance.

Loss of nesting habitat and roosting vegetation, degradation of feeding grounds, pollution of water and contamination of prey have all contributed to reduced bird populations in the New York-New Jersey Harbor area. Abandoning direct human use of islands in the four groupings in Figure 9-1, establishment of required habitats (especially wetlands and associated woodlands and shrublands) and improvement in water quality will all combine to help restore depleted waterbird populations.

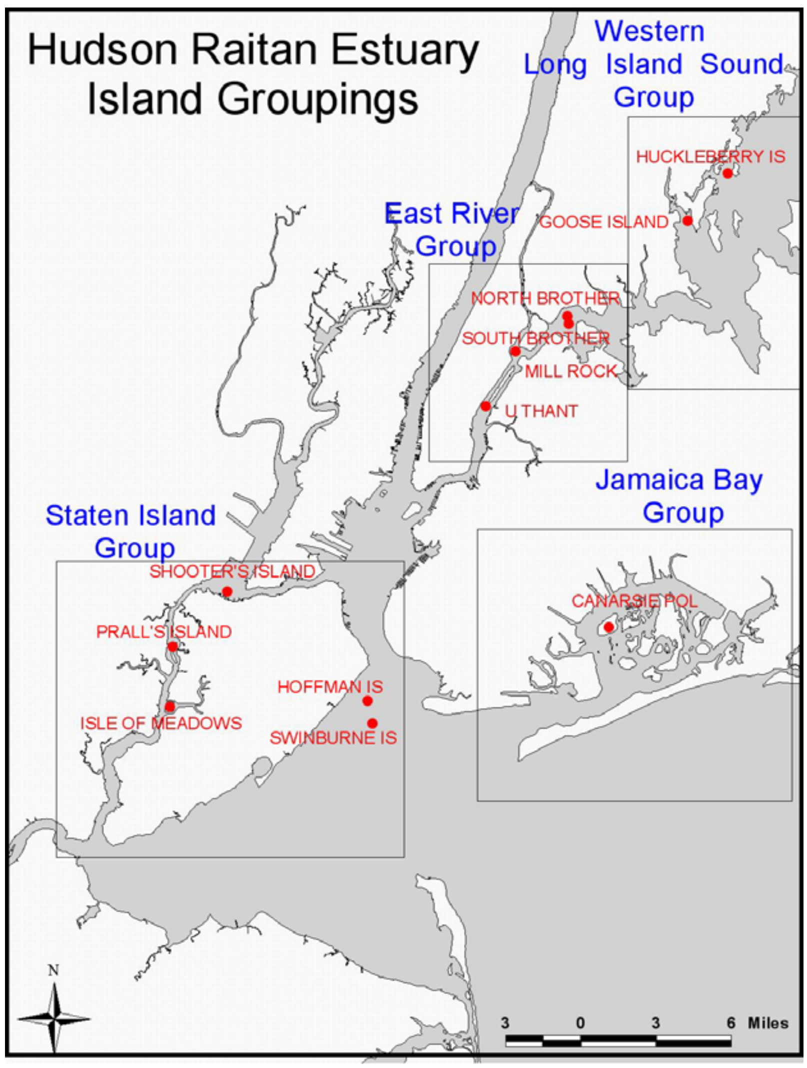

Figure 9-1. Uninhabited Island Groups in the HRE

While wetlands restoration (as discussed in a separate TEC) needs to be partially directed towards establishing suitable waterbird nesting and feeding habitat, the waterbird TEC focuses on islands in the New York Harbor region. Four groups are defined in Figure 9-1;

1- Western Long Island Sound (Huckleberry Is., Goose Is.);
2- East River (N. Brother Is., S. Brother Is., Mill Rock, U Thant Is., Roosevelt Island);
3- Staten Island (Prall's Is., Isle of Meadows, Hoffman Is., Shooters Is., Swinburne Is.); and 4- Jamaica Bay (assorted islands, Canarsie Pol).

Table 9-1. Summary of important environmental requirements for roosting and nesting waterbirds in islands

Objective	Elements
Suitable habitat	Vegetation suitable for roosting
	Substratum suitable for nesting
	Soft shoreline areas suitable for feeding on benthic invertebrates and shoreline fishes
	Suitable isolation from human disturbance to allow nesting
Population density, minimum area, spatial configuration	Critical density(s) for good quantitative and qualitative reproduction success
	Critical area and lack of disturbance to allow birds to roost, nest
	Islands near to other habitats for related functions (e.g., roosting sites near to feeding sites)
	Size of metapopulation needed for sustainability (see related Critical Density factor)
Population development	Time to establish a suitable roosting, nesting habitats:
	Development of vegetation, re-establishment of soft shores
	Protection from human disturbance
	Predator protection or removal

Parameters for waterbird roosting and nesting habitat for this TEC are listed in Table 9-1. For each island, objectives for roosting population size and nest numbers should be set, and an estimate made of the area necessary to sustain specific population density by species. The time frame over which population of nesters, roosters, and feeders will recover and increase should be short once adequate habitat is provided.

This TEC focuses on the entire functional role of the bird populations and incorporates elements of population, community, and ecosystem ecology. As the targets are met, visits by the public, including bird watching, participation in bird counts, and eco-cruises will be incorporated to optimize public support of restoration plans, while minimizing negative effects of human disturbance. In this way this TEC will be coordinated with the Public Access TEC.

Target Justification

Technical Merit

The initial target for the Hudson-Raritan Estuary allows a focused restoration of vegetation and shoreline on one island within each of the four island groups delineated above. Islands will be restored with regard to (a) vegetation, including trees and shrubs for roosting; (b) softening shorelines where possible to increase sand and mud flat habitats for feeding by shoreline foragers; (c) restoring sites for nesting and ensuring their isolation from human disturbance.

The long-term target continues restoration of island groups and includes establishing nature preserves on larger islands not currently protected for waterbirds (e.g., Roosevelt Island in the East River). By 2050, all islands should have sites restored and protected using the same approach taken in the initial target.

Policy and Management Relevance

From a policy and management standpoint, the protection and restoration of islands for waterbird sites would garner public support due to the long-standing love of birds by the public and the existence of many related non-profit organizations, such as the Audubon Society. The variety of habitats required for the waterbirds, along with the need for isolation from most human contact result in the establishment of natural areas of high value for other species, whether land or water-based, thereby supporting a number of other TEC's.

Necessary Implementation Information

The HRE system supports among the largest populations of nesting and feeding gulls in the eastern United States (see Kerlinger 1998), with over 1600 nesting pairs found in islands around Staten Island alone. However, Kerlinger (1998) noted major declines in herons and egrets in this latter area. Human disturbance and predation by great horned owls and raccoons may explain the decline, which in one case resulted in abandonment by over 200 nesting pairs of waders and gulls. Restoration therefore involves establishment of habitat protected from these animal predators and from human disturbance.

A series of bird surveys conducted by the New York City Audubon (Kerlinger 1998, 2002, 2004) provides evidence for the decline of many wader populations and identifies those islands that have lost the most pairs and those that have been affected the least (e.g., North and South Brother, Carnarsie Pol). Restoration priorities should be islands that have suitable habitat but small or nonexistent populations of birds. Species of particular concern are harbor herons; it is likely that restoration for them will tend to benefit all others.

Measures of Performance

Bird Abundance:

- Number of islands and shore areas with nests
- Number of species nesting, roosting and feeding
- Number of nests for dominant waterbird species
- Nesting and fledging success for different waterbird species
- Total population size by species

Habitat quality:

- Number of areas and size of areas with dunes, grasslands, scrub-shrub maritime forest, and other upland habitat to benefit waterbirds (and the area of each)
- Number of islands and shore areas and size of areas with vegetation suitable for roosting (and the area of each)
- Number of accessible areas and size of areas for waterbird feeding (and the area of each)
- Number of shoreline areas and size of areas suitable for debris removal and "shoreline softening"(removal of bulkheads, rip-rap, etc.) (and the area of each)
- Number of areas and size of areas with limited human access that are suitable for nesting (and the area of each)

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X. MARITIME FORESTS

Target Ecosystem Characteristic

Establish one new maritime forest of at least 50 acres

This initial target for the Hudson-Raritan Estuary should be achieved by 2012. Based on the success of this restoration, the long-term goal is :

A total of 500 acres of maritime forest distributed among at least three new sites.

This long-term target should be achieved by 2050 and remain indefinitely in the estuary system.

Background

Along Atlantic coast barrier islands a unique vegetational complex has developed in response to the ocean-dominated environment and barrier island topography. This complex of vegetation is know as Maritime Forest and has long been recognized for its unique plant communities shaped by dominating physical factors, especially storm events and salt-spray deposition (Boyce 1954; Conner et al., 2005; Forrester and Leopold, 2006).

The plant communities of these barrier islands exhibit physiognomic similarities as they are populated by species able to withstand high intensities of salt-spray deposition and respond to periodic and regular burial by unstable sands. In the more stable and protected areas of the swales and secondary dunes, woody shrubs dominate and form a maritime forest community complex. The plant species of these maritime forest communities have xeromorphic adaptations, including succulent, thick cuticles and epidermal layers; features adapted for the intense winds, salt spray, and high surface soil temperatures (Boyce, 1954). Not all plants of the dunes and swales have morphological features which may protect them against salt spray or freshwater flooding, instead some species have evolved to complete their entire life cycle between major storms or avoid salt-spray by either a low-growth form or by growing under the protective canopy of more salt-spray-tolerant species (Boyce, 1954; Tolliver et al., 1997).

An understanding of the regeneration potential within this unusual association of species is critical for its conservation as chronic herbivory by Odocoileus virginianus (white-tailed deer) may alter the long-term dynamics of this plant community.

HRE Maritime Vegetative Communities.

The dune and swale community in the Hudson Raritan Estuary area is characterized by *Ammophila breviligulata* (beach grass), *Prunus maritima* (beach plum), *Hudsonia* *tomentosa* (beach heath), and *Lathyrus japonicus* (beach pea). *Parthenocissus quinquefolia* (Virginia creeper), *Rhus radicans* (poison ivy), and *Salsola kali* (common saltwort).

Further back from the dune and swale community, and usually behind a secondary dune is the maritime forest. The forest is often viewed as having four vegetative components: the herb layer, the shrub layer, the forest layer and the lianas running through them all.

In the herbaceous layer, *Rhus radicans, Aralia nudicaulis* (wild sarsaparilla), *Gaylussacia baccata* (black huckleberry), *Parthenocissus quinquefolia,* and *Vaccinium corymbosum* contribute the majority of the coverage. Given that the herb layer is usually fairly sheltered from the salt spray, in contrast to the dune and swale community, many species have wide distributions outside of the maritime forest.

The shrub layer is usually dominated by *Vaccinium corymbosum, Amelanchier canadensis,* and *Pyrus arbutifolia, though Sambucus canadensis* (common elder), *Viburnum dentatum* (southern arrowwood), and *Rhus vernix* (poison sumac) are also regular components. The shrub layer is greatest around the margins of the forest and in boggy areas, where there is more light.

The forest is often dominated by *Ilex opaca, Sassafras albidum,* and *Amelanchier Canadensis, and Nyssa sylvatica.* In some maritime forests oak species (*Quercus sp*.) occur frequently, probably depending largely on how connected the forest is to nearby 'mainland' forests. The first four tree species are often well represented in the herb and shrub layer, and interestingly are often actually root sprouts. Reproduction in these forests is often by vegetative rather than sexual means.

One of the most intriguing and ecologically valuable facets of these forests are there co-evolutionary relationship with avian migrants. Most of the plant species of the barrier islands have large edible fruits that serve as food sources for a wide variety of bird species (i.e., catbirds, towhees, robins, yellow-rumped warblers). In particular the fruits of *Amelanchier canadensis, Vaccinium corymbosum* (highbush blueberry), *Prunus serotina* (black cherry), *Ilex opaca, Sassafras albidum, Juniperus virginiana, Nyssa sylvatica* (black gum), *Rhus* (sumac) species, and the liana *Smilax rotundifolia* (common greenbriar) are all small berries adapted for consumption and dispersal by birds.

The consumption of fruits and the subsequent dispersal of seeds by birds migrating along the barrier-island system, which is coincident with the Atlantic flyway, is an important factor favoring both northward and southward distribution of species. This is clearly true for Ilex *opaca,* whose fruits are heavily consumed by migrating birds, particularly robins. In addition, these fruits help feed the massive fall migration of millions of our neotropical migrants. Without these maritime forests and their inherent food supply, many of migrating songbirds would not have the fuel for their southern sojourn.

Target Justification

Technical Merit

The target configuration of an initial 50 acres and a long term target minimum of 500 additional acres of maritime forests is based on the already extant 264 acres at Sandy Hook, and the notion of rebuilding a chain of such sites that would connect Fire Island's maritime forests with Sandy Hook. In essence the goal is to create a linkage along the shoreline from east to west for these plant communities and the avian migrants dependent upon them.

A cursory examination of the available space and each sites proximity to the physiognomic conditions required to create a maritime forest, suggest that potential sites include Arverne area, Riis Beach, Fort Tilden, Breezy Point, perhaps some stretches along Staten Island, and perhaps additional sites on Sandy Hook. One aspect of the goal would be to create maritime forests of sufficient size that they might maintain the minimum viable populations of the basic vegetative species. We would grossly estimate this to be at least a 200+ acres site.

Policy and Management Relevance

With coastal development either in or near barrier islands along the Atlantic, the maritime forest habitat has become rare. One particular maritime holly forest plant community type occurs only on barrier islands in New York and New Jersey and has a global heritage status rank of critically imperiled (G1 as cited in Forrester and Leopold, 2006) and is especially vulnerable in New York (NYNHP 2002). Since the 1970s various groups have been looking at the Atlantic Coast's barrier islands, and noting their value as an ecological corridor and key component of the autumnal avian migration. In addition since the 1980s numerous authors (Robbins et al., 1989; DeGraaf and Rappole, 1995) have documented the plights of our neotropical migrants, and the various problems impacting their populations – especially habitat loss and fragmentation.

This TEC would address these issues, and not only re-establish a valuable ecological link through the HRE region, but also provide the means to bring more avian migrants closer to the region's residents, which in turn will hopefully build a constituency among the public for their appreciation and protection.

Necessary Implementation Information

Successful restoration of a maritime forest will require: a) locating potential sites that are close enough to the shorefront that they experience the appropriate abiotic conditions, b) are large enough to contain a minimum viable forest site, c) have soil conditions and water tables appropriate for a maritime forest, d) sufficient plant stock for re-populating such sites, and e) sufficient safeguards and protections such that they can withstand usage. On nearby Fire Island, the composition of the maritime forest (from Art, 1976) is given is Table 10-1.

A summary of environmental characteristics and key environmental requirements are given in Tables 10-2 and 10-3.

Table 10-1. Composition of the maritime forest on Fire Island (Art, 1976)

Sunken Forest, FINS
Tree Community (mean ± S.E.)

Species	Average height (m)	Density (stems/100 m²)	% of total density	Basal area (cm²/100 m²	% of total basal area	Frequency
Ilex opaca	5.1	6.2 ± 1.1	26	873 ± 141	38	76
Sassasfras albidum	4.4	30.0 ± 0.4	12	515 ± 97	23	91
Amelanchier canadensis	4.4	8.1 ± 1.3	34	435 ± 80	19	76
Nyssa sylvantica	5.3	0.8 ± 0.3	3	146 ± 66	6	26
Quercus velutina	6.1	0.1 ± *	*	113 ± 79	5	9
Q. stellata	6.6	0.1 ± 0.1	*	66 ± 46	3	6
Vaccinium corymbosum	2.9	4.0 ± 0.9	16	50 ± 11	2	65
Juniperus virginiana	4.2	0.1 ± 0.1	*	14 ± 14	1	3
Pinus rigida	6.0	*	*	13 ± 13	1	3
Prunus serotina	3.4	0.3 ± 0.1	1	11 ± 7	1	18
Rhus copallina	3.6	0.4 ± 0.2	2	10 ± 6	*	21
Pyrus arbutifolia	3.3	0.4 ± 0.1	2	4 ± 2	*	26
Rhododendron viscosum	3.1	0.4 ± 0.2	1	3 ± 2	*	15
Baccharis halimifolia	2.5	0.2 ± 0.2	1	2 ± 2	*	3
Rhus radicans	6.0	0.1 ± *	*	1 ± 1	*	6
Ilex glabra	3.0	0.1 ± 0.1	*	1 ± 1	*	3
Rhus vernix	3.9	0.1 ± 0.1	*	1 ± 1	*	3
Quercus coccinea	3.8	* ±	*	* ±	*	3
Total		24.3 ± 2.0		2259 ± 202		

* = *lt;0.1%

Table 10-2. A summary of key environmental requirements for maritime forests in the HRE Region includes:

Parameter	Description
Setting	
Coastal Setback	Potential sites must be close enough to ocean to have salt spray a major factor in vegetative community structure, but far enough back so that shrubs and trees may develop. Usually 100 yards back, but no more than 1000 yards away. This band will vary with orientation of site (i.e., SW, or West), and size of prevailing seas on nearby shore.
Substrate	Characteristically maritime forests are found on quartz/garnet/magnetite sands, those derived from glacial till. Open question how different species might survive on heavily disturbed and/or filled sites.
Salinity	At nearby Sunken Forest, the salt spray is measured in the aerosol impaction (4^{th} row below). This provides a rough indicator of intensity of salt spray needed to ensure the unique vegetative community characteristic of a maritime forest.
Population Properties	
Site size	Given species/area curves, deciding where to draw the line to include one species but not another is difficult. But using Sunken Forest data as an example, and drawing the line at maintaining a minimum viable population (>1000 indiv.) of the five dominant species, then one would need sites of at least 31 acres each. If we move the species/area demarcation lower to include the top ten species then each site would need to be 247 acres.
Temporal Factors	
Plant establishment	3-5 years/site
Forest maturity	150+ years

Table 10-3. Estimated Inputs into the Sunken Forest ecosystem g/m^2/yr

Inputs into the Sunken Forest ecosystem g/m^2/yr.				
	K	Na	Ca	Mg
Rain	0.22	4.29	0.36	0.68
Dry fallout	0.40	5.41	0.50	0.47
Bulk precipitation	0.62	9.70	0.86	1.15
Aerosol impaction	0.62	14.30	0.74	1.98
Average input (minimum + maximum/^{2})	0.73	14.15	0.98	1.91

Measures of Performance

The initial measure of performance would be to assess the success of newly planted specimens, and how the initial planting of each species fared over a short-term time frame (i.e., 2-5 years).

Longer-term measure of success, roughly after a decade or two, would be to examine the evolving composition of the stand and whether or not non-maritime species are invading.

In conjunction with short- and long-term measures, assess of avian visitation rates at the sites should be made and compared to mature maritime forests in the area (Sandy Hook, Fire Island).

Development or enhancement of other ecological services expected from restoration effort of maritime forests need to be assessed, e.g., erosion control, habitat for other species.

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XI. PUBLIC ACCESS

Target Ecosystem Characteristic

> ***One new public access site and one access improvement or upgrade of an existing access site in each of the eight study areas.***

This initial target should be achieved by 2012. Types of access are described Table 11-1. Beginning in 2013, the rate of increased public access should be established and maintained to achieve the following long-term target:

> ***Waters of the Hudson-Raritan Estuary (HRE) and tributary rivers are accessible to all residents within a short (approximately twenty minute) walk or public transit trip.***

This long-term target should be achieved by 2050 and remain indefinitely.

Background

Public access to the Hudson-Raritan Estuary (HRE) is important from cultural, historical, and restoration perspectives. With European settlement and industrialization, transportation facilities including roads, railroads, and ports were built where it was easiest to do so, along the waterfront. In the 19th century and the first half of the 20th, rivers and shorelines were perceived as places to dump waste and as locations to be used for transportation and industries that needed water and access to water. Yet while industry reigned, recreational use of the waterways was widespread, with yacht, boating, and swimming clubs dotting the shore, and excursion boats being a seasonal activity in which many residents of the region engaged.

Attitudes about rivers and shorelines as important for recreation and scenic beauty began to change, albeit slowly, in the late nineteenth century with the work of Frederick Law Olmsted and other pioneers in park and landscape planning. Olmsted believed that land planted with pleasing vegetation served medical, social, and psychological functions for the public, and he thought much the same for bodies of water and their shorelines (Beveridge 2006). The value and importance of public access to waterways and their shorelines is reviewed widely, in many classic books, and well as many technical non-governmental and governmental reports (see Bibliography below).

As a result of water quality and other improvements, a great number of federal, state, regional, municipal and private organizations are promoting increased public access in the estuary. The HRE project, in fact, has emerged out of this heightened interest in restoration and renewal of the region's waterways. Access is critical to the success of the Hudson-Raritan Estuary (HRE) agenda and human benefits are an integral element of the restoration plan. Public access to our waterways will enhance the public's understanding of the natural systems we aim to improve, which in turn helps develop the necessary financial and technical resources. Improved access to the waterfront and the water will foster better understanding, appreciation and stewardship for the estuary.

Target Justification

Technical Merit

Over the years, our region has not adequately prioritized maintaining or improving public access to our waterways. Manufacturing and waterborne transportation uses have effectively eliminated access to the majority of the waterways of the HRE and in so doing have masked the potential public benefits gained from providing this access. Recent public access improvement projects have demonstrated that direct and measurable benefits to the health and well-being of residents are possible. Given this tremendous potential, our approach is to implicitly incorporate public access into our ecosystem restoration approach.

Table 11-1. Types of Public Access

Type*	Description	Example
Direct access	Direct water contact possible; site can be used for accessing estuary waters	Boat launching or swimming area
Indirect access	Open space on the shore but not configured to allow water contact	Waterfront promenade
Vista	View of shoreline and water from a distance	Scenic overlook
Upland access routes	Public space for reaching coastal sites and other access types	Pedestrian route, transit connection, or bike path that leads to the waterfront

* Education can and should be incorporated into each type above.

The public access TEC focuses on 4 categories of access (Table 11-1). The initial target focuses on public access sites in each of the eight HRE study areas. This target was chosen as a mechanism to geographically distribute new and improved access sites throughout the HRE. The long-term target recognizes that population densities and numbers and quality of existing access points must be know to accurately site and prioritize where access improvements should be located. This requires understanding how residents are served, now and in future, by existing public access points including an analysis of the proximity to access sites, information on travel distances and transportation efficiencies.

As a general rule, future development, redevelopment, restoration, or rehabilitation of shoreline areas should include public access into their designs. In theory, there is no upper bound to the number of access points; but transportation of fuel oil or sewage sludge, for instance, may preclude public access in some places or the secure arrival and departure of container and cruise ships may make some areas wholly inaccessible or inaccessible at times. Still, there are places where public access and maritime and industrial activity can and do coexist, such as the Hackensack Meadowlands, Newtown Creek and the Bronx River. Indirect access (visual access) in maritime districts like Port Jersey or along Newark Bay is also desired, and can provide important passive recreation and education opportunities. The opportunity for education is embedded in every aspect of the HRE plan, and therefore access and restoration can actually be complementary rather than competing approaches to the same area. Of course there are some areas such as nesting grounds where limited access is needed to protect the resources; but these are limited and generally understandable to the public.

In general, access and restoration can work in concert to help integrate environmental improvements and public benefits. Wherever practicable the public access targets should be coupled with the other HRE ecosystem targets in this report. For example a location where wetlands are going to be improved could be an excellent location for new public access point. The result could both enhance wetland habitats, provide educational and recreational opportunities to the public (which in turn support the efforts to advance project goals) and lead to the ultimate improved stewardship of the site and the estuary. Another example is efforts to restore fish, crabs and lobster habitat which is driven by both ecological and economic goals. Making these efforts more accessible and understandable to a wider section of the public who may already engage in recreational fishing can help rebuild and strengthen the connection between the estuary and the human community which surrounds it.

Policy and Management Relevance

Today, the public benefits of proximity and access to waterways and their shorelines are well-known and well-established. However, in highly urbanized and industrialized areas, relatively little has been done to correct the practices of the past, in part due to dated public perceptions that pollution still abounds. Increased public access is more than desirable; it serves as a safety valve for urban residents, helping them to get away from the negative aspects of city life and to make contact with a more natural environment. Contact with aquatic ecosystems is educational and valuable as a way for residents to begin to understand the importance of these ecosystems. The population of the New York/New Jersey metropolitan area is at an all-time high, and families constitute a higher proportion of the total than they have in many decades. Better planning for the waterfront and the region’s waterways can help fulfill the growing demand for recreation, both active and passive.

Protecting and improving public access to urban waterfronts was established as a national policy in the Federal Coastal Zone Management Act (CZMA) of 1972. As a result, coastal states and municipalities were required to develop special management plans to help address and advance CZMA goals. New York State published its first waterfront revitalization plan in 1982, and in 1984 the State of New Jersey passed a law to ensure the creation of a Hudson River Waterfront Walkway through the 11 municipalities in Hudson and Bergen Counties between the George Washington and Bayonne Bridges. On the local level, the City of New York (1993) and many other municipalities have developed special zoning rules to help guide waterfront redevelopment, including requirements for public access in many areas.

There have also been goals set for improvement in public access in and around the HRE. The NY-NJ Harbor Estuary Program has a goal of access for all citizens within 30 minutes of home, and a target to increase access points 10% from 2003 to 2009 (NY-NJ Harbor Estuary Program 2006). For vistas, the Hudson River Estuary Program of the New York State Department of Environmental Conservation (NYDEC) seeks to designate 1000 scenic views of the Hudson, including the conservation of 25 of the scenes painted by Hudson River School artists. The Hudson River Estuary Action Agenda 2005—2009 of the NYDEC (Dunwell, 2005) proposes the establishment of "a regional system of access points and linkages so that every community along the Hudson has at least one new or upgraded access point to the river for fishing, boating, swimming, hunting, hiking, education, or river watching." All of these discrete and yet disparate initiatives have timeframes to achieve their goals. They illustrate the tremendous interest in improving public access as well as the need to look at the whole Hudson-Raritan Estuary more comprehensively in order to see where synergies can be created and economies of scale potentially realized.

Necessary Implementation Information

A obvious first step toward implementing the Public Access TEC is to assemble detailed information on numbers and quality of existing access points. Some of the necessary information is readily available from existing regional programs. For instance, the New York-New Jersey Harbor Estuary Program's manages a GIS database of access points. The Metropolitan Waterfront Alliance has their own database of access points in and around New York City and the NY-NJ Baykeeper is approaching completion of public access database covering the NJ area of the Hudson Raritan.

In additional to understanding the location and quality of existing access points, implementing the TEC will require an assessment of public use and need for access and specific access types. Information such as population densities, community specific access needs, proximity to existing and proposed sites, and required travel distances are all required. The HEP Access Working Group is in the early stage of initiating a number of steps that will advance the public access targets, including:

> 1) GIS Analysis of the data set of existing access points in order to identify areas where there is more than ½ mile between access points; areas where higher

concentrations of young people, lower-income people, and non-native English speaking people live
2) Research and publication of a list of "model" access points that can stand as case studies or Best Design/ Management Practices
3) A list of potential access points around which stakeholders can focus energy and resources.

Measures of Performance

The initial target focused on 2012 provides a simple means to assess progress: new and improved sites in each of the eight study areas. For the long-term, progress can be assessed and reported by calculating the number of residents with and without the identified access types (Table 11-1.) within the travel specifications. Finally, success of a specific access point should be tested by professional public polling as well as by direct measures of the number of people utilizing a location in a year. In general, public access sites are so visible that progress is also readily visible.

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5. Discussion

The goal we developed to guide HRE restoration planning is aimed at ecosystem elements or habitats that promote human and natural benefits. Three fundamental properties of the HRE set our direction. First, the HRE is a human dominated ecosystem and a world center of culture, and we believe it is necessary to have public benefits central to any ecosystem management plan. Second, the state of the ecosystem is currently far from its original condition in almost every way, and we do not regard returning the original ecosystem condition realistic or desirable. Third, we did not want to shape restoration planning around a fixed system state as we regard the HRE as a dynamic, changed, and changing ecosystem. Despite these constraints, we concluded that restoration projects can provide clear and valuable benefits for the biota and people. Also, our approach is consistent with the HRE restoration vision of the management agencies: a "functioning ecosystem and a strong vibrant port providing benefits to everyone".

The use of quantitative targets to organize restoration planning was not adopted easily, and target statements developed at the October 2005 workshop lacked numeric descriptors. Participants succeeded in developing many (23) and varied ecosystem targets that were mostly practical for implementation. However, the workshop did not produce ecosystem targets defined in quantitative terms. Many participants believed it was unrealistic to pose quantitative targets in a large group setting. Later it was learned that a small team, working at a pace that allows compilation and synthesis of technical and biological information, could effectively develop specific quantitative targets. In general, identifying a limited set of restoration ideas is difficult and stating them in numeric form is even more challenging.

The mix of TEC statements from the workshop was indicative of the diverse thinking by scientists and Harbor Estuary managers. Creating and protecting habitat in the estuary was the most common rationale used by participants in choosing TECs. Workshop participants seemed to apply two different perspectives in forming TEC ideas: physicochemical and biological properties of the ecosystem or "place based" thinking versus biotic features of the ecosystem or "species conservation" thinking. The diversity of thinking was helpful because it generated a wide range of targets.

A thorough search of past ecosystem plans and strategy documents yielded a comprehensive set of 97 goals, objectives, and aims for potential restoration. Combined with the workshop products, the interests and plans of the Harbor Estuary community were thought to be thoroughly canvassed. When organized into themes, the grand list of planning elements provided a good context for the project team to choose a practical set of ecosystem targets. Therefore, the recommended TEC list reflects broad interests and focuses on items repeatedly raised in past planning efforts.

The goal of promoting a mosaic of new and enhanced habitats will diversify the physical complexity of the ecosystem. It is also a goal that follows the renaturing approach to environmental restoration. Each of the recommended TECs, when implemented, will provide benefits to the biota and estuary environment, and contribute to the establishment of this mosaic. It is anticipated that diversifying physical habitat will diversify the biota of the ecosystem, and the increased biotic diversity should have positive benefits for ecosystem functioning (review in Cardinale et al. 2006). However, the individual TECs were not developed to change ecosystem- scale functions and processes, and therefore ecosystem-scale processes are not recommended as measures of program performance for any of the TECs.

The set of ecosystem targets was also selected to provide public benefits, and the policy and management sections in the TEC descriptions detail public relevance. TECs were designed to increase the visibility of the Harbor Estuary to the public, provide access and education opportunities, and allow more opportunity for people to experience the estuary environment. The public access target is directly relevant to people. Major habitat features such as the shoreline and shallows target provide highly visible sites that can be visited, appreciated as a complex combination of conditions, and experienced as a contrast to the built shorelines. Islands for waterbirds are habitats with visible biota, unique features in the ecosystem, and contrasting appearance to the typical estuary settings. Finally, some targets have public appeal despite not being readily experienced. Oyster reefs are the focus of many public interest groups, and restoration of these habitats has already begun through grassroots interest and hard work. Although each TEC has a different blend of natural and human benefits, the project team worked to address both purposes in our selections and definitions.

The practice of providing restoration objectives in the form of precisely stated and quantified targets was the project team's central method for developing TECs. A similar method was used in the Everglades ecosystem restoration plan to define elements for performance reporting (termed essential ecosystem component; Harwell et al. 1999). Use of a precise terminology and consistent language helped the project team understand how to proceed on difficult and complex problems. This practice also helped get the team working together in a coordinated manner despite initially varying views on how to address restoration on an ecosystem scale. Consistent terminology and language has benefited internal communication and coordination in other large scale environmental efforts as well (Haug et al. 1984a). It also helps identify the relative value of different options, define progress through time, and transfer the most important information to decision-makers (Haug et al. 1984b). The project team's restoration planning proceeded quickly once the team adopted the concept and practice of defining ecosystem targets as its primary task.

While this effort attempts to build upon the past experiences of others conducting large-scale restoration planning, the approach described in this report presents three new concepts that should greatly enhance the comprehensive restoration plan for the Harbor Estuary. First, the TECs focus on relations between habitats, dependent biota, public use and appreciation, and feasibility. The range of considerations in formulating TECs is important because a borad set of benefits are anticipated from the restoration program. This holistic and broad approach was possible because the project team was not driven by a government agency or a consortium of agencies. Discussions were not encumbered by the bounds of agency mandates and authorities and were free to focus on initiatives that made the most sense for the estuary and its public.

Second, the TECs elevate the importance of the public's connection to the estuary, as compared to most restoration discussions. All advocates for the environment appreciate the importance of public involvement and public support. In most cases, public support is limited to constituency building through a variety of outreach activities. The TECs go further by making safe, abundant public access a target characteristic of the ecosystem. The Harbor Estuary ecosystem will not flourish if the people that live here do not benefit from the proposed ecosystem enhancements, or do not perceive these benefits as worthwhile and important. Reestablishing access to the Harbor Estuary will lead to a stronger sense of place and ownership in the estuary's resources, leading to stronger advocates for land and other resource use that is compatible with the ecosystem services wanted by the community.

Third, the TECs are forward looking. Many estuary-level restoration efforts in the U.S. become bogged down by expending too much effort to extract habitat goals from the past state of the estuarine watershed. Uncertainty is the strongest reason for using conditions at a previous date as the basis for establishing restoration goals for the future. Stakeholders often presume an estuary was "healthier" in the past, so they accept restoring the physical appearance of the estuary to something that resembled that which was present during those healthier times as practicable, especially when the underlying causal relationships are not known. But as many have noted, turning back the clock is not always feasible, nor necessarily desired, especially in urban settings. Focusing on the future using knowledge of what can be done and what current science knows about the functional relationships within ecosystems is in our view the most prudent way to proceed.

The renaturing approach to restoration planning, combined with quantitative ecosystem target statements, succeeds in presenting a clear and powerful agenda for the HRE. A product of both natural and human considerations, it is an agenda that will need to be reconsidered and revised through time. Public interests tend to shift and the ecosystem changes as well. Restoration actions and projects should proceed and the project team is confident that achieving the targets will improve the Harbor Estuary. Nevertheless, there are other projects and objectives that would be beneficial, and in the future more targets could be integrated into the *mosaic*. The project team hopes that this ecosystem restoration agenda meets current program needs, acts as a "blueprint" to improve the Harbor Estuary environment, and sets a stage for new restoration targets based on advancements in science and public understanding.

6. Recommendations

Maintain Technical Advisory Capability – The study team felt it is important to state that the current TECs should not be viewed as an endpoint for restoration planning. We considered the HRE ecosystem as dynamic and public interests and issues will vary over time as well. Thus we expect adjustments, refinements, and different TECs will be desired with restoration experience and new ecosystem conditions. While we provide a substantial set of restoration targets, we worked with limited time and data that constrained the resolution and specificity of our TECs. Also, with implementation we expect there will be new technical issues and restoration planning needs. Therefore, some arrangement to maintain a standing technical advisory group would likely be valuable and efficient through time.

Foster Shared Responsibility for Restoration – Government and non-government organizations should play prominent roles in restoring the HRE and doing so will expand the traditional mission of many organizations. The legal authorities of agencies should be viewed as definitions of their base responsibility and not the limits of their knowledge or potential value to the effort. Likewise, environmental groups must work as true partners with the agencies, assuming the same risks and holding equal responsibility for supporting and implementing the projects. This sense of shared responsibility is critical to restoring the HRE and communication is the cornerstone to building the restoration community.

Monitor and Maintain Restoration Sites – Full long term success of restoration will depend on maintenance of site conditions, control of debris, and monitoring of undesirable change. For decades local communities, NGOs, and various levels of government have supported or implemented stream, river bank, and beach cleanups. Similar programs to safeguard restoration sites could be undertaken by volunteers, students, and community groups.

Information Assets be Openly Available – Tapping the value and knowledge of agencies, scientists, and conservationists will depend on common access to the relevant information. By 2010, all government agencies and private groups working on the HRE should have access to an information management and distribution system. Synergy results from multiple uses and users of information and leads to a more thorough understanding of complex systems, more effective communications, and more trust among stakeholders.

Monitor the Changing Estuary Ecosystem – Monitoring programs are needed to characterize change in HRE over time so restoration plans and projects can be adapted to current conditions. Change will come from both development pressures and natural forces, such as sea level rise. By 2010, these monitoring programs should be underway and supported by a sustainable funding source. The program should be designed by a interagency science advisory panel that regularly reports to the public.

Public Impact will be Greater if Projects are Linked – The study team recognized great potential for public recognition, education, and societal benefit when restoration projects are bundled for a larger presence and linked to access, outreach efforts, and educational materials. For example, ecotourism is likely possible for some restoration sites and current tour business may benefit from knowing where and why sites were restored. While TECs were depicted as independent restoration objectives, there are additional benefits from a programmatic approach to showing, marketing, and informing people and government about the overall effort and its efforts in the environment.

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